EFFECTS OF URBANIZATION ON RAINFALL AND TEMPERATURE OVER THE CITY OF NAIROBI, KENYA

BY

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DECLARATION

This Thesis is my original work and has never been presented in any other University for the award of degree of Doctor of Philosophy (PhD) in Climatology

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ABSTRACT

Urban areas depending on their size: Surface areas, population, industrial activities, building density, alter the microclimate and impede greening of any city, Nairobi included. The problems associated with urbanization in the city of Nairobi are poorly documented. This formed the basis of the current study. The main objective of this study was to determine the influence of the urbanization on the urban canopy layer and microclimate of Nairobi City. Monthly rainfall and temperature data for the period 1961 to 2008 were obtained from four Kenya Meteorological department's ground stations located within Nairobi City namely; Dagoretti, Wilson Airport, Jomo Kenyatta International Airport (JKIA) and Moi Airbase. Data on population census conducted at stipulated intervals within the study period were obtained from Kenya National Bureau of Statistics. Satellite data on Normalised Difference Vegetation Index (NDVI) was also obtained from NASA satellite. Spatial analysis of temperature across the city pointed out that the most representative station in studying the urban canopy characteristics of the city of Nairobi is Moi Airbase.

The minimum temperature across the city showed a significant positive trend. This may be attributed to urbanization effect leading Urban Heat Island (UHI) which is manifested at night by elevated temperature characteristics. Of the four stations, only Dagoretti exhibited a significant positive trend of maximum temperature. The microclimate of the city of Nairobi exhibited spatial variability, with the wettest part being to the west where Dagoretti Meteorological station is situated and the driest being to the south east where JKIA Meteorological station is located. Time series analysis on rainfall data revealed that the most frequent monthly rainfall distribution over Nairobi was between 49.0 mm and 99.0 mm with rainfall being experienced in all the months of the year. The short rains season is ideally received in November and December (ND), contrary to previous studies which have reported the season as October, November and December (OND). The correlation between rainfall anomalies with NDVI anomalies at time lag of one month was significant, $r = 0.75$ with 56.3% of the variation in NDVI anomaly being explained by rainfall anomaly. The greenness of the city, therefore, was deemed to be driven by rainfall. Further, analysis of NDVI data revealed that irrigated greening measures were not statistically significant.

The study therefore recommended the utilization of prevalent storm water for greening the city of Nairobi. Comparative analyses of temperature and rainfall across the city of Nairobi depicted heterogeneity among the four weather stations, with Moi Airbase being the hottest. Dagoretti, being located at a higher altitude and in a peri-urban setting of the city was the coldest. On the other hand, Dagoretti received the highest annual rainfall amount with JKIA receiving the lowest of the same. A similar rainfall pattern exists during the MAM rainfall season. Therefore the microclimate of Nairobi is not homogeneous.

Minimum temperature in all stations is significantly and positively correlated with population. This is attributed to the Urban Heat Island (UHI) phenomenon. Urbanization is impacting on minimum temperature over the city of Nairobi through heat generation by the urban population. The results suggest that the UHI may cover a region beyond the analysed stations. Further investigations on the influence of urbanization upon the microclimate of the city of Nairobi in future are recommended once more weather stations in and around the city of Nairobi are established.

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LIST OF ABBREVIATIONS AND ACRONYMS

ANOVA	-	Analysis of Variance
Ann	-	Annual
CBD	-	Central Business District
CCN	-	City Council of Nairobi
CO_2	-	Carbon dioxide
ERC	-	Energy Regulatory Commission
GHGs	-	Greenhouse gases
GOK	-	Government of Kenya
ITCZ	-	Inter-Tropical Convergence Zone
JF	-	January, February
JJA	-	June, July and August
JKIA	-	Jomo Kenyatta International Airport
DKM	-	Kenya Meteorological Department
KIPPRA	-	Kenya Institute for Public Policy Research and Analysis
KNBS	-	Kenya National Bureau of Statistics
KUR	-	Kenya-Uganda Railway
LUCC	-	Land Use and Cover Changes
LULCC	-	Land Use Land Cover Change
MAM	-	March, April and May
METROMEX	-	Metropolitan Meteorological Experiment
MDGs	-	Millennium Development Goals
ND	-	November and December
NDVI	-	Normalized Difference Vegetation Index
OND	-	October, November and December
RF	-	Radiative Forcing
SOND	-	September, October, November and December
SDGs	-	Sustainable Development Goals
UHI	-	Urban Heat Island
UNFPA	-	United Nation Fund for Population Activities
UN	-	United Nations

CHAPTER ONE

1.0. INTRODUCTION

This chapter presents the background, problem statement and objectives of the study. The justification, scope and limitation of the study are also elaborated in the following sections.

1.1. Background of the Study

Tropical urban climatology has not received much attention as in the mid-latitude regions of the world. This is partly due to the fact that climatic factors in most cities in tropical developing countries are not considered to be of importance as far as urban planning and design are concerned (Roth, 2007). In Africa, tropical urban climatology has not been taken seriously because there are no climatic extremes like hurricanes or heat waves in the continent. Peterson (1984) estimated the global population to reach 6.1 billion by 2000, 8.2 billion by 2025 and 10.2 billion in 2100. It is expected that 50% of the global population will congregate in urban areas. Increase of urban population leads to dramatic increase of urbanization in the less developed tropical parts of the world including Africa (Oke, 1984 and Cui *et al.,* 2012; Garcia Cueto *et al*., 2009) estimated that about 70% of the World's population would be urbanized by 2050. At the moment, there are over 400 cities in the world that have populations of over one million people.

Urbanization is a population shift from rural to urban areas. This is considered as an increase in the proportion of people living in towns and cities. Urbanization according to Oke (1987) implies an increase in urban population and consequently an increase in size of the urban area. In Africa, urbanization started before industrialization due to colonization (Obudho and Aduwo, 1992). In recent times however, industrialization in urban areas has led to increased population migration from rural to urban centres resulting in various supply problems such as housing, food, energy, sanitation, transport and water (Omwenga, 2011). Massive unemployment, social breakdown and degraded physical environment are some of the problems associated with urbanization in Africa (Jauregui, 1984). Increased urbanization entails modification of urban surface cover due to vegetation removal to create space for buildings, water bodies and bare surface and these have been shown in various studies in urban centres to create distinctive climatic environments (Adebayo, 1985; Ongoma *et al*., 2015).

In Nairobi, increased urbanization has led to various problems such as flooding, inadequate water supply, health challenges, inadequate housing and increased unplanned settlements in the river valleys, all of which have modified the micro-climatic conditions of the city (Ongoma *et al.*, 2015). It is for this reason that there is increasing need to include climate information in urban planning and design. This study focused on rainfall and temperature characteristics within the city of Nairobi by investigating how urbanization may have influenced changes in these climate parameters.

Most observations of climatic variables are made away from cities and even then, local influences are not usually considered by the weather forecasters since they infer the large-scale weather patterns as well as some of the stronger meso-scale circulations. The physical environment of the urban surfaces which are deemed to modify the urban climate are (Oke, 2006; Argueso *et al.*, 2014)*:*

a) The regular arrays of buildings creating wind channels
b) Dense surface materials with high values of thermal conductivity and heat capacity
c) Low soil moisture content due to rapid run-off and impervious surface materials
d) Internal sources of heat, water vapour and pollutants, and
e) Moving vehicles acting as turbulence generators

The above aspects which are found in most urban areas were considered in this study to impact on temperature, convective processes and wind flows which would eventually influence rainfall amount and distribution over the city of Nairobi. Urban climate studies in temperate regions mainly standardize synoptic effects and maximize urban effects by giving results for calm clear conditions but for tropical regions, it is the rainfall and temperature conditions that tend to affect human activities in urban areas and it is on this basis that this study was conducted (IPCC, 2013).

1.2. Statement of the Problem

Urbanization has a negative effect on the local urban climate due to anthropogenic activities that go on in urban conurbations. Urbanization contributes to climate modification in various ways including Greenhouse Gas (GHG) emissions that lead to warming of the atmosphere. Urban areas depending on their size: surface area, population, industrial activities, building density, transport infrastructure such as rail and road network together with vehicular traffic density modify their local climate. All these determine the effective urban micro-climate (IPCC, 2013; Zong et al., 2017). The city of Nairobi has experienced rapid expansion in relation to population growth, booming construction of commercial and residential buildings, an influx of vehicles and an intensified industrialization process (Omwenga, 2011; Ottichilo, 2010). In view of the above, the micro-climate of Nairobi is deemed to have been modified due to removal of vegetation cover, increased area of impermeable surfaces, enhanced GHG emissions from industries and traffic together with waste heat deposition due to energy consumption.

Climatic variables that are mainly influenced by urbanization are temperature, wind regimes, atmospheric stability, and precipitation regimes (Oke, 2006; Ng'ang'a, 1992). This study attempted to establish the impacts of urbanization on spatial and temporal rainfall and temperature characteristics over Nairobi.

1.3 Research Questions

a) How is the microclimatic regime in the urban canopy layer varying in space over the city of Nairobi?
b) How is the microclimatic regimes in the urban canopy layer varying over time in the city of Nairobi?
c) How is urbanization impacting on temperature and rainfall over Nairobi?

Solutions to the above questions were aimed at meeting some specific objectives as indicated below:-

1.4. Objectives of the Study

The main objective of this study was to examine the influence of the urbanization on microclimate of the city of Nairobi. The specific objectives of this study were:

a) To establish the temporal variability of rainfall and temperature over the city of Nairobi;
b) To determine the trend of rainfall and temperature over Nairobi;
c) To determine the impact of urbanization on rainfall, temperature, energy and vegetative cover over Nairobi.

In order to achieve the above specific objectives, accurate and reliable data had to be collected at regular intervals provided by the database at Kenya Meteorological Department (KMD).

1.5 Justification and Significance of the Study

Investigation of the influence of urbanization on climate and the incorporation of climate information in the operations of urban areas in Kenya are of paramount importance. This is especially crucial for Nairobi because of its rapid expansion in population, increased density of built-up area with many high-rise buildings dotting the skyline and sharp increase in vehicular traffic. These factors contribute to several physical, climatological, environmental and human health challenges.

The Nairobi City County had just joined the "100 Resilient Cities" in May 2016 which is associated with *shocks and stresses* for urban areas. This aims at helping the cities become more resilient to the physical, social and economic challenges that are a growing part of the 21st century. Out of the listed shocks and stresses, this study picked *flooding* as one of the stresses that bedevil the city during some rain seasons (UN, 2015).

This study addressed some of the Sustainable Development Goals (SDGs) formulated by United Nations (UN) and outlined in its General Assembly on 12th August 2015 (Kumar *et al 2*016). There are 17 goals which were built on the success of Millennium Development Goals (MDGs) by the same body. There are two specific goals that this study highlights for national and county governments, non-governmental organizations, private sector, civil society and stakeholder households. The two specific goals are:-

Goal 11: Make cities and human settlements inclusive, safe, resilient, and sustainable and

Goal 13: Take urgent action to combat climate change and its impacts

Therefore, findings from this study contribute useful information for urban planning and design for Nairobi city in line with the Urban Areas and Cities Act of 2011. Urban areas are unique because they create their own microclimates which are basically localized. There is need therefore to make weather observations within the different surfaces of an urban area.

1.6. The Study Area

This section describes the study area in terms of location, area, population, land use and climate.

1.6.1. Introduction

Nairobi is the capital city of Kenya and is one of the largest and fastest growing urban cities in Africa. It is an equatorial city located between 1° 9'S and 1° 28'S latitudes and approximately between longitudes 36°4'E and 37°10'E. It is found on the East African plateau with a mean altitude of 1700m above sea level. Generally, the altitude of Nairobi ranges from 1600m to the east to over 1800m to the west and northwest covering an area of about 700 Km^2 (Ng'ang'a, 1992) as shown in Figure 1.1. Nairobi was established in 1899 as a transportation depot by then Kenya-Uganda Railway (KUR) constructors (Nevanlinna, 1996). The city is the major commercial and industrial centre of the country. It serves as the regional and international headquarter for several commercial and public institutions that include multinational companies and United Nations agencies (Ottichilo, 2010).

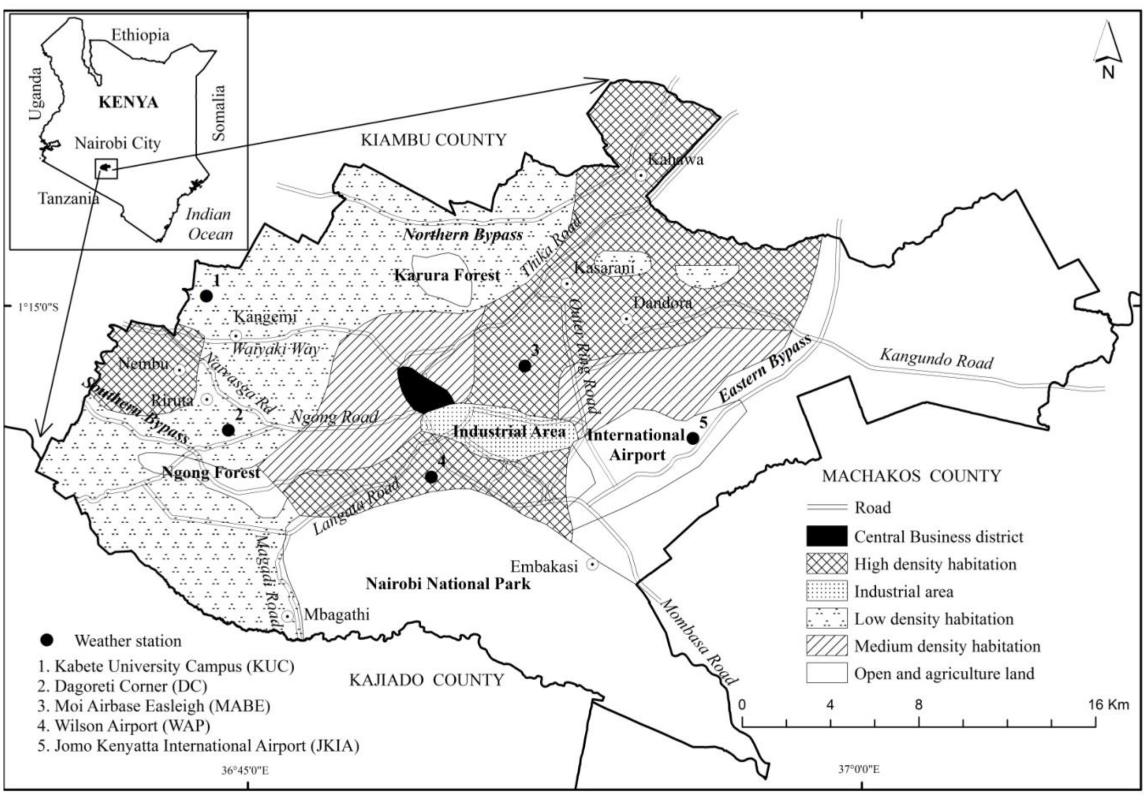

Figure 1 .1 Map of Nairobi County showing Meteorological Stations, Road Network and Landuse patterns (Modified from Makokha and Shisanya, 2010)

1.6.2. Population and Land Use in Nairobi

The population of Nairobi has tripled in size within a period of 18 years. It increased from an estimated population of 267,000 in 1962 to 827,775 in 1980 (Obudho and Aduwo, 1992). The city's population growth has been exponential (Figure 1.2). The population of the city as of 2013 was estimated at 4 million (Figure 2). This rapid population increase has both *"cause and effect"* implications on the physical and climatological aspects of the city. Some of the outcomes of population growth are; increased built-up area which will alter the *albedo* of city surface together with higher emissions of greenhouse gases occasioned by denser industrial activity and more vehicles (Satterthwaite, 2008). It is worth to note that daytime population of the city is higher than the resident population because of people who commute to work and do business from neighbouring counties (Omwenga, 2011).

In addition, Nairobi is a unique city in that the southern part (Figure 1.1) is a National park with a variety of wild animals including Lions, Giraffes, Elephants, Rhinos and others. Effectively, this game park attracts local, regional and international tourists. Nairobi is the capital city of Kenya where all activities that are either administrative, trade, commercial or industrial take place. Owing to this wide range of activities taking place in the city, there are different types of land use with activities such as open spaces being utilized for recreation and urban agriculture along the Nairobi river and its tributaries among others. Land use changes in urban areas are mainly associated with increase of built-up area.

Land use changes have taken place in Nairobi due to urbanization where the built-up areas grew from 3.84 Km^2 in 1910 to 15 Km^2 in 1976 and then increased to 41 Km^2 in 1988. There was a further increase to 62 Km^2 in 2000. It is projected that the built-up area of the city will be increasing at an average annual rate of 1.49 Km^2 per year from 2014 to 2020 (Mundia and Aniya, 2007). This city's Central Business District (CBD) has therefore expanded rapidly which led to a significant loss of forests, such as Karura forest, and other natural vegetation. These changes reveal that there has been a rapid expansion of built-up areas in the city due to increasing urban population coupled with rapid economic developments (Mundia and Aniya, 2006). It should be noted that vegetation density and land use are important in determining urban temperatures because the cooling rate in densely vegetated areas is faster due to utilization of heat for evaporation and evapotranspiration (Jonsson, 2004).

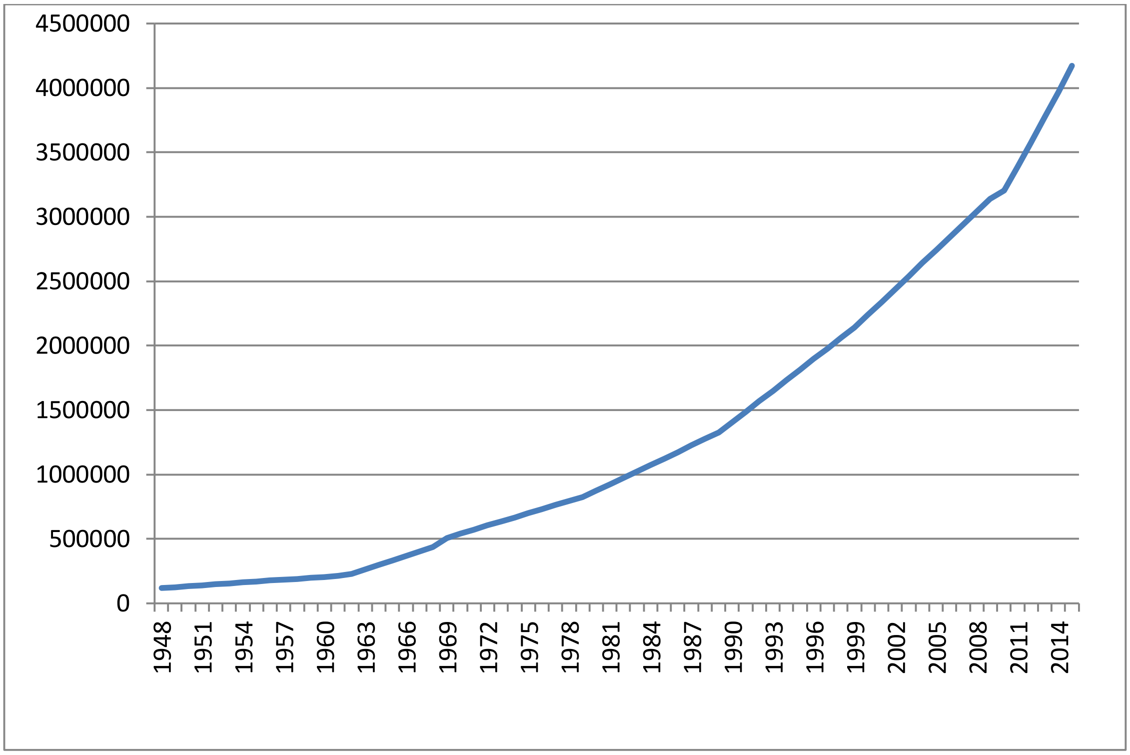

Figure 1.2 Population of Nairobi Projected from 2009 Population Census. (Source, KNBS, 2009)

1.6.3. Climate over Nairobi

The climate of Nairobi is predominantly equatorial and is influenced by the movement of the overhead sun and altitude. Its altitude has an important influence on most of the prevailing meteorological factors. Nairobi has two meteorological stations which make hourly surface observations and these are Dagoretti (1798m above sea level), the National Headquarters of Meteorological Services and Jomo Kenyatta International Airport (1620m above sea level).

This study relied on long-term data averages from four meteorological stations of the city namely Dagoretti, Jomo Kenyatta International Airport (JKIA), Moi Airbase and Wilson Airport as shown in Figure 1.1. The city centre is mainly a commercial district with high rise buildings while the city's suburbs are mainly residential. Physical features of Nairobi are diverse with a rugged topography characterized by different relief aspects which affect the climate and vegetation of the area.

Rainfall and temperature data from these four stations within Nairobi County will be used by this study. The mean daily sunshine period is highest during the months of December to March (8.5 to 9.4 hours) and least in the month of July (about 4.1 hours). The mean annual daily sunshine of the city is about 7 hours (Adebayo, 1991).

Temperature and Relative Humidity: The annual range of temperature in Nairobi is small while the diurnal range is rather large for all the months of the year. This is attributed to the strong insolation during the day resulting in large values of maximum temperature while during the night, the strong radiative cooling results in low minimum temperatures. The warmest period in Nairobi is from December to April with average minimum and maximum temperatures of 11.5°C and 25°C respectively. The coolest period is from June to August with average minimum and maximum temperatures of 11°C and 22°C respectively. The annual average day-time relative humidity of Nairobi is low (about 55%) while the night-time value is high (about 80%). The seasonal variation shows that moisture influx into the city takes place during the wet months of the year (Ng'ang'a, 1992).

Rainfall: Rainfall pattern in Nairobi is bimodal alternating with dry seasons as it is associated with the equatorial low pressure area known as Inter-Tropical Convergence Zone (ITCZ). The ITCZ is connected to the passage of overhead sun and lags by few weeks over the city area twice a year resulting in this pattern of rainfall with so-called "long rains" which are received around April and "short rains" around November (Gitau, *et al*, 2008). EL Nino Southern Oscillation (ENSO) is also associated with rainfall over Nairobi (Indeje *et al*.,) The mean annual rainfall in Nairobi is about 900mm with two maxima, one during April (220mm) and the other during November (160mm).The driest month is July with an average rainfall of about 20mm. The conditions during July characterise the cool season with overcast skies and light rains in the mornings, low temperatures and occasional fog. Rainfall occurs mainly in the night-time because of the strong heating during the day which enhances convection while atmospheric radiative cooling enhances instability inducing further vertical development of clouds. Thunderstorms are experienced in Nairobi especially between November and April. There are year to year variations of rainfall in Nairobi as noted by Ogallo (1977) but studies on rainfall variability in East Africa are hampered by short periods of observations.

Enhanced rainfall amount of Nairobi urban area has been determined by Ng'ang'a (1992). This is one of the specific objectives of this study to ascertain if the same conditions prevail or otherwise.

Wind: The wind flow in Nairobi is affected by two large scale wind regimes. These are the Northeast and Southeast monsoon winds. Northeast monsoons begin in October and end in April. These winds are characterized by a veering and an increase in windspeed as the day becomes warmer followed by a backing and decreasing wind after sunset when temperatures drop. The Southwest/Southeast monsoons last from May to the end of September. These winds are characterised by a backing and a decreasing windspeed after sunset. Winds in Nairobi, however, have a strong easterly component throughout the year (Okoola, 1990).

Other key meso-scale and synoptic weather bearing systems responsible for rainfall over the city Nairobi include Indian Ocean Dipole (IOD), Quasi Biennial Oscillations (QBO), El-Nino Sothern Oscillation (ENSO) and Congo Airmasses (Okoola, 1990; Muthama *et al*., 2008 and Ongoma *et al.* 2015).

1.7 Limitations of the Study

This work focused on the influence of urbanization on rainfall and temperature over the city of Nairobi. Only four stations within the city were considered due limitation in available long data records on rainfall and temperature from other meteorological stations. The city of Nairobi has not had a meteorological station at the Central Business District (CBD). This meant that accurate meteorological data for CBD was not available.

CHAPTER TWO

2.0. LITERATURE REVIEW

This chapter presents synthesis of literature on urbanization, urban energy use, urban climatology and Urban Heat Island. The review beings with an introduction as given in the section below.

2.1. Introduction

Literature review was done for the purpose of determining previous studies done on urban climatology globally, in tropical cities and the temporal changes of climate variables in urban areas. The review also showed the study gaps that this study seeks to address. Urban areas are the regions surrounding cities. An urban area is a location characterized by high human population density and high concentration of built environment features. Urban areas may be cities, towns or conurbations. The world's urban population in 1950s was 746 million and rose to 3.42 billion in 2009. The world has become more urbanized such that urban population will grow to 6.4 billion by 2050 (Omogbai, 2011).

2. 2. Urban areas and Urbanization

Urban areas are the regions surrounding cities. An urban area is a location characterized by high human population density and high concentration of built environment features. Urban areas may be cities, towns or suburbs (Loughner, 2012). Urban areas are highly developed with high density of human structures such as residential houses, commercial buildings roads, bridges and railways. Urbanization produces radical changes in the nature of surface and atmospheric properties of a region due to removal of vegetation which is replaced by metal, asphalt and concrete. This replacement transforms the radiative, thermal, moisture and aerodynamic characteristics of the urban environment (Garcia Cueto, *et al.*, 2009). Vegetation in urban areas, otherwise known as greening, improves air quality by lowering of air temperatures and increasing atmospheric pollutant removal rate.

Greening also affects urban hydrological cycle through changes in runoff, evapotranspiration and precipitation (Loughner, 2012).Urbanization occasions a general increase in minimum temperatures of urban areas which in turn reduces the diurnal temperature range (Cai, *et al*, 2003).

There are several indicators of urbanization, namely: population density, energy use, land use land cover change (LULCC), air quality, among others. Energy use is composed of several elements which include petroleum use, CO_2 emissions, waster energy quantity, biomass and electricity use, among others. According to the Kenya National Energy Policy whose overall objective is to ensure sustainable, adequate, affordable, competitive, secure and reliable supply of energy to meet national and county needs at lower costs while at the same time protecting and conserving the environment (GOK, 2014). Nairobi's energy sources include biomass, fossil fuels, hydro and geothermal. These sources provide the energy used by households, commerce and industry but are highly dependent on price, income levels, availability and acquisition of relevant appliances. Biomass is the highest energy source in Nairobi with about 91,250 tonnes of charcoal being consumed per year (CCN, 2007).

2.2.1. Urban Energy Consumption

Urbanization entails an increase in population and more economic activities which may lead to enhanced income and lifestyles of urbanites. These lead to increased energy consumption. Energy consumption demands in Nairobi are on the rise due to rapid population growth of the city, booming construction activities and the increase of road transport vehicles (GoK, 2014). Most of the energy used in Nairobi is mainly sourced from fossil fuels such as petroleum and diesel.

Anthropogenic activities have altered composition of the atmosphere, especially urban atmosphere and urban surface albedo by increasing the concentrations of long-lived greenhouse gases mainly carbon dioxide (CO_2) with others such as methane (CH_4), nitrous oxide (N_2O) and halocarbons, and medium- to short-lived gases, such as tropospheric Ozone, and black carbon aerosols (Skeie *et al*., 2011). Once in the atmosphere, these gases perturb the energy budget of the Earth exerting a radiative forcing (RF) of the climate system by various mechanisms, namely greenhouse gas and ozone absorption of long-wave radiation, and ozone absorption and aerosol–radiation interactions) in the short-wave spectrum (Zhong *et al*., 2017). Radiative forcing is thus a major contributor to the development of Urban Heat Island (UHI).

2.3 Urban Climatology

Urban climatology is a field of climatology that is concerned with interactions between urban areas and the atmosphere. It investigates the effects that urban areas have on the atmosphere above and vice versa. Urban climate studies can be tackled mainly from *micro-scale* to *local-scale* spatially. The process of urbanization creates distinct urban surface and urban atmosphere (Oke, 2006; Chandler, 1976; Chandler, 1965). This has both physical and social implications. The urban atmosphere has two layers namely; the urban boundary and the urban canopy layers as shown in Figure 2.1.

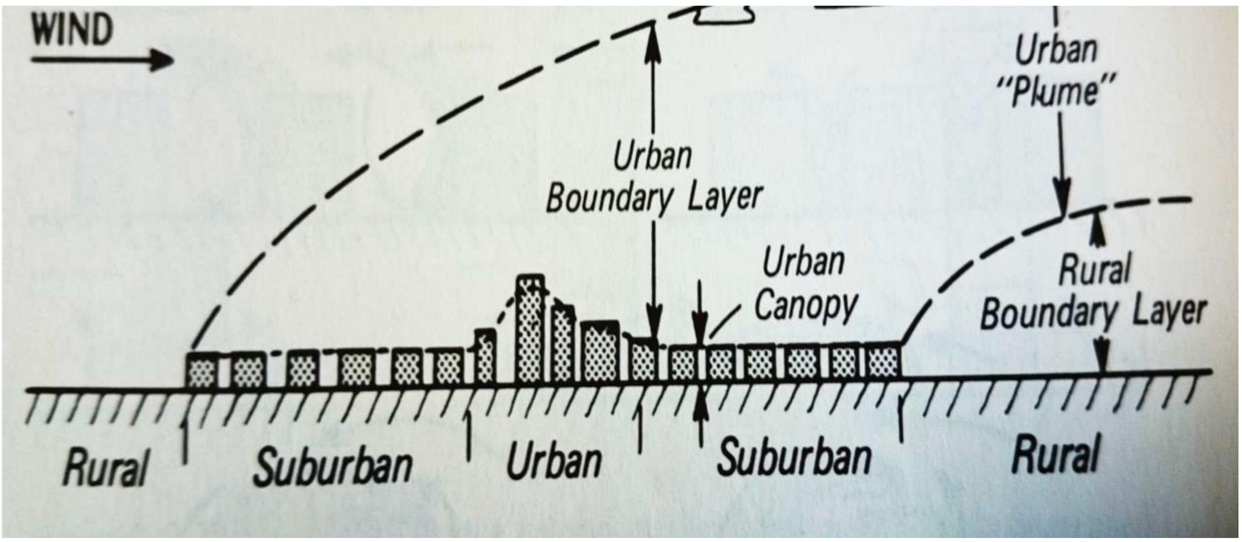

Figure 2.1: Schematic representation of the urban atmosphere illustrating a two-layer classification of urban modification (Oke, 1990)

Urban boundary layer over a city is formed due to spatially integrated heat and moisture exchanges between the city and its overlying air. The urban canopy layer on the other hand is the surface of the city where fluxes across this plane comprise those from roofs, canyon tops, trees, lawns and roads (Arnfield, 2003; Bornstein, 1983).

Among the physical implications are:

- high density of building which modifies energy exchange, wind speeds and direction
- release of anthropogenic heat to the atmosphere from buildings, chimneys, industries and automobiles.

Social implications are:

- health of urban dwellers deteriorates due to pollution, sanitation and lack of recreational activities
- development of infrastructure and increase in the number of motor vehicles

The field of urban climatology has had its first study taken less than two centuries ago (Arnfield, 2003). Urban climate deals with temporal and spatial scales. The field on part of spatial dimension has two main scales according to Oke (2006) which are:

a) *Micro* from 0.1-1.0km
b) *Local* from 0.8km to 5 km

Temporal scales extend from a second to centuries depending on the climate variables under investigation. This study utilized the *local* scale in its data collection together with monthly and annual data on temperature and rainfall.

The incorporation of climate information in urban planning and design is an important aspect which has to be considered. This will reduce chance of losses associated with some climatic hazards in urbanized areas as well as the health of urban residents (Page, 1976). Urban climatology has received tremendous attention in temperate and subtropical regions while insignificant research was undertaken in the tropics (Munn, 1968; Oke and Hannel, 1968 and Jauregui, 1984; Chow, 1984). This could be attributed to the fact that there are few incidences of climate extremes in tropical regions especially temperatures such that urban climate studies have been ignored in planning and design of urban areas. (Adebayo, 1991 and Stull, 1991).

Tropical urban climatology is a relatively new area of research and this could be attributed to the fact that in the tropics, there are few incidences of climatic extremes which has made planners and designers to ignore climate considerations in city planning. In the tropics, the first attempts in urban climatology studies were to search for similarities or differences in urban climates of tropical cities compared to those of mid-latitude cities. The structure of the atmosphere in terms of wind and temperature profiles over cities differs significantly from that over adjacent rural areas due to the heat island effect (UHI) created by cities which according to McElroy (1972) is the main cause of thermal differences between urban and rural surfaces. Oke (1984) indicated that the macro-scale atmospheric processes are the main controls of climatic conditions in urban areas with the urban area modifying the micro-scale atmospheric processes.

Monthly or annual long-term averages of climate data in urban areas according to Jauregui (1984) show urban influences on diurnal amplitude of temperature, air pollution concentrations, visibility, sunshine, and monthly rainfall. The modification of climate by urbanization is mainly evidenced by the heat island effect. Heat fluxes in urban areas are due to varying thermal characteristics of the urban surface and the production of the anthropogenic heat (Oke, 1974). Landsberg (1982) noted that the heat island is a result of, among others, the heat added by combustion processes, metabolism of living beings and the reduction of wind speed inside an urban area which reduces the exchange of air with the outside.

The urban heat island is defined by Oke (1990) as the difference between rural and urban temperatures. Its development is influenced by the change in the radiation balance of cities. The urban heat island is the most documented example of human-induced climate change and it is found in every city. The urban heat island, according to Arnfield (2003), is best developed during clear calm nights with strong radiative cooling. He recommended that the heat island studies are best conducted during anti-cyclonic weather conditions with clear skies and weak regional winds.

Oke (1974) classified the urban atmosphere into two layers namely; the urban canopy layer and the urban boundary layer as shown in Figure 2.1. Urban canopy layer extends from the ground to the roof level of urban buildings, the forcing functions and controlling parameters of climate are different from those of the urban boundary layer. This study concentrates on the urban canopy layer. Within the urban canopy layer, the variations of climatic elements such as temperature, wind speed, and humidity are strongly related to urban land use patterns and urban morphology. Radiation conditions at the ground level are very strongly influenced by the detailed geometry of the nearest surroundings such as buildings, trees, and topography (Taesler, 1984; Clarke and McElroy, 1968).

Much of the literature on urban precipitation has been primarily concerned with establishing whether the urban area has any effect on the precipitation distribution. Climatological analyses of the urban effect on precipitation are often hampered by lack of sufficiently detailed data in and around cities (Changnon, 1972).Three main factors may be the cause of urban-induced changes in precipitation. According to Pooler (1963), these are; additional condensation nuclei of a particular type, increased tropical convergence and thermal convection resulting from higher temperatures. These factors are thought to increase precipitation in urban areas (Ng'ang'a, 1992). Measurement of urban effects on precipitation requires vertical sampling using an aircraft and sophisticated equipment which are expensive and not readily available for this study.

2.4 Urban Heat Island (UHI)

Urban Heat Island (UHI) is a term that was first introduced in the 1940's (Roth, 2007). It refers to the atmospheric warmth of a city compared to its countryside. This is the most investigated aspect of urban climate. The structure of urban atmosphere differs significantly from that of adjacent rural areas due release of chemicals from anthropogenic activities in the city. Urban Heat Island studies show that sometimes, urban –rural temperature differences of upto12^{o}C have been recorded during clear and calm nights (Eliasson and Svensson, 2003). Urban heat Island development is well correlated with the thermal characteristics of the materials in the city.

There are several causes of urban heat island effect according to Oke (1982) and these are:-

a) Greater absorption of solar radiation due to multiple reflection and radiation trappings by building walls and vertical surfaces in the city
b) Greater retention of infrared radiation in street canyons due to limited sky view caused by tall and compact buildings.
c) Greater uptake and delayed release of heat by building and paved surfaces in the city
d) More portion of absorbed solar radiation is converted to sensible heat rather than latent heat due to replacement of moist soils and plants with waterproof surfaces resulting in decline of surface evaporation
e) Greater release of sensible and latent heat from the combustion of fuels for urban transport, industrial processing and domestic space heating/cooling.

The above mentioned factors are characteristic of urban areas.

Extra warmth in cities has general practical implications depending upon the microclimate of the city. Cities located in cold climates that experience cold weather benefit from urban heat island in terms of cheaper house heating costs, improved outdoor comfort, fewer road weather hazards and conducive conditions for plant growth and animal habitat. To the contrary, cities in hot climates experience increased discomfort which could aggravate the threat of heat stress and mortality, and high cost of air conditioning (Stewart and Oke, 2012 and Ongoma, *et al*, 2016). Urban Heat Island phenomenon also impacts on energy consumption. For instance, warmer nights reduce the demand for heating. Urban energy is used mainly for two purposes: a) to directly meet the energy needs of resident households and b) to produce, deliver and dispose of goods and services.

Nairobi's households, commerce and industry use several types of fuels for energy availability depending on price, income levels and appliances that will be used. Sources of energy in Nairobi include biomass, fossil fuels, hydro and geothermal (CCN, 2007).

2.5 Precipitation

Precipitation in urban areas is influenced by geographical location of the urban area which determines the macro/global precipitation regime. The local precipitation regime for an urban area is modified by changes in wind and convection patterns. The contributing factors are urban heat island, increased surface roughness and aerosol concentration acting as condensation nuclei (Han, 2014). A study done on the influence of urbanization on rainfall in Kuala Lumpur showed that yearly average rainfall displayed on upward trend (Shaharuddin *et. al.*2011).

The above finding agrees with earlier studies done by Metropolitan Meteorological Experiment (METROMEX) in 1970's in the US to investigate modification of meso-scale convective rainfall by major cities (Huff, 1986). Results from METROMEX have shown that urban effects lead to enhanced precipitation during summer months by about 5% to25%. Later investigations done by Tropical Rainfall Measuring Mission (TRMM) in some American cities found that there was rainfall enhancement downwind of an urban setting between 1998 and 2000. The rainfall enhancement in these cities was upto 28% to a distance of between 30 and 60 km downwind of the cities (Shepherd *et al*, 2002).

It is now a known fact that urbanization enhances rainfall because of enhanced convection over urban areas which could be attributed to:-

a) Increased surface to atmosphere transfer of water vapour due to evaporation
b) Increased convergence due to urban roughness or,
c) Greater concentration of urban aerosols serving as condensation nuclei.

Efe and Eyefia (2014) attempted to ascertain the differences between urban and rural precipitation of Benin City in Nigeria. They used data generated from direct field measurements of precipitation for one year. Their results showed that there was a 43% increase of precipitation in the urban area over the country side. They also revealed that precipitation in the city is strong and heavy**.**

2.6 Mid-Latitude Urban Regions

Extensive specific climatological studies have been carried out in temperate cities. In their studies of urban heat island in Hamilton, Ontario, Oke and Hannel (1968) noted that Hamilton presents an extremely complex situation where under given synoptic conditions, there are three sets of climatic controls. These climatic controls are the topography of the city, the urban morphology, and the city's proximity to a large lake. They noted that the controls operate on different space and time scales. They divided the city into four land use types (Heavy Industrial, Commercial, Central Business District, and Residential).

Air temperature data was gathered by means of traverses conducted simultaneously using six automobiles equipped with Assman psychrometers (Oke and Hannel, 1968; Roth, 2007). The city was divided into six sectors and data was obtained from about 200 points providing an observation density of about two points per km^2. The standard meteorological data were obtained from two stations in the city. From the analysis of the heat island data, it became clear that the complexity of the situation of Hamilton made it impossible to make immediate generalization. Their results showed that under clear nights with winds less than 2 m/sec, there was a well-developed heat island of about 5 to 6°C. Under conditions with wind speeds greater than 6 to 8m/sec, the heat island was reduced to less than 1°C. It is worth noting that this study was conducted for two days which is a short period for one to draw concrete conclusion about the heat island development in the city.

Ludwig (1968) conducted temperature measurements in the summer of 1967 in Dallas and Fort Worth, Texas. The two cities during summer have no interference of temperature by topography as they are relatively flat with no large water bodies and have few summer time storms. They are both large cities with well- defined downtown sections composed of many tall densely packed buildings. To determine temperature in different parts of the city, instruments mounted on vehicles were used. Wet and dry bulb temperatures were measured at 2m above the ground surface with aspirated linear-response composite thermistor sensors. The sensors were protected from radiation errors with white shields. The accuracy of the dry bulb reading was ±0.25°C and the wet bulb about ±0.5°C.

On the 18th of July 1967, with overcast and rainy conditions, the temperature in Dallas changed much less both with time and space than on a clear sunny day. However, the heat island was evident at the time of minimum temperature. In Fort Worth, the results showed a pronounced heat island at the time of minimum temperature while at the time of maximum temperature, the city centre was cooler than the commercial areas on either side. Analyses for two other days showed the same phenomenon. Analyses of the heat island from two cities indicated evidence of the night time heat island and the data relating the urban-rural temperature difference yielded a correlation coefficient of - 0.79 (Ludwig, 1968).

The evidence from the work of Ludwig (1968) was not conclusive that the temperature field observed in Dallas should be generalized to other cities. This is because the temperature fields in cities without tall compact central business districts are likely to be different from those of a city with such an extensive central business district. On a smaller scale, Landsberg (1968) made temperature observations in a setting where an isolated building complex was contrasted to a relatively undisturbed rural type environment. Temperature measurements were done using the Barnes Infrared thermometers placed in three different environments that is: a courtyard, a lawn area and a woodgrove.

Two series of measurements were made and they showed the heat island development in a small complex of buildings. The observations were made in mid- summer when no heating took place and from the time of daily maximum temperature through sunset to about 2 hours after sunset. In the first case, there were only few mostly high clouds when the courtyard was exposed to bright sunshine all day (Landsberg, 1968).

Noon global radiation was 836Wm^2. In the afternoon, the air temperatures over the grass and in the courtyard were at 30.6°C and the woodgrove was 30°C. With an afternoon light thunderstorm, rapid cooling was experienced with a drop of 4°C in 45 minutes. Low surface temperatures were observed in the grass and woodland surface (2°C below air temperature) caused by the evaporative cooling.

These observations indicated a heat island effect after sunset at the isolated building complex. Generalisation over a whole urban area, however, cannot be done but instead several sites over the urban area need to be established for a comprehensive explanation of the heat island effect. Influence of urbanization on precipitation has been investigated on the basis of increased condensation nuclei and the heat island effect. Landsberg (1982) analysed rainfall records of eight cities in USA and the results showed increases in rain and convective storm activity in six of the eight cities. The thunder and hail frequencies were found to require a critical size of urban area and population (> 0.9 million people). He found that the increases were at night when rural areas are expected to show minimum convective activity. The effect of population on precipitation is mainly by introduction of condensation nuclei in the urban atmosphere.

Lawrence (1971) reviewed previous information in the UK concerning the relationship between day of the week and rainfall. He found that weekdays were wetter than weekends while the weekly cycle linked local rainfall anomalies in urban areas to man-induced influences rather than physiographic or water influences.

2.7. Tropical Urban Regions

Tropical urban climates have not been extensively studied. The few studies done in the tropics are based on data from standard meteorological stations which are rarely ideal to monitor the urban climate systems. Most of these stations are located away from the city centres and their data cannot be ideal to represent the urban climate. There is little information concerning the state of the urban atmosphere above roof level and there is almost no work on the underlying atmospheric processes due to lack of facilities like instruments, qualified personnel and funds (Oke, 1984 and Roth, 2007).Research findings from mid-latitude urban areas cannot be transferred to tropical cities however similar they are because of the unique topography of a city (Pamanabhamurty and Bahl, 1981).

Urban areas in the tropics are increasing their industrial production with little control or reduction of emission of gases and particulates. Consequently, the increasing amount of pollutants in tropical urban areas leads to greater absorption, scattering and reflection of incoming solar radiation. This reduces the amount of energy reaching the urban surface. This reduction can be at least 10% compared with rural surroundings (Emmanuel, 2016).

An example of above is the study of Ibadan (Adebayo, 1985) where the total incoming radiation in the city was analysed. Temperature was found to decrease by between 12.5% to 22% from the rural area and the city centre, the mean values were ranging from 0.3 Ly/min in the rural area to 0.25 Ly/min in the city centre during early hours of the day. In the afternoon, the difference dropped to about 10%. He ascribed this to increased atmospheric pollutants towards the city centre. The distribution of net radiation in Ibadan showed values between 0.086 to 0.12 Ly/min in the rural suburbs and between 0.126 and 0.166 Ly/min in the city centre (an increase of about 20-30%) which he attributed to absorptive effects of atmospheric pollutants for long wave radiation.

Traverses made to measure temperature and relative humidity in the city revealed that the urban heat island was most marked in the dry season (March) with a range of 5-7.5°C in the city centre. Relative humidity was about 7% lower in the city centre than in the rural suburbs. Early morning observation revealed an urban heat island of 0.8°C in the city centre. This study did not indicate clearly whether the observed heat island was for maximum and minimum temperature which is very essential in urban climate studies.

In a similar study made in Lagos (Ojo, 1981), the day time net radiation was highest at 1000hrs and 1500hrs local time. The highest value of 0.28 Ly/min was recorded in areas of high traffic and building densities in mainland Lagos and around the International Airport at Ikeja. The high radiation values were attributed to the greenhouse effects of atmospheric pollutants ejected into the atmosphere from industries, aircrafts and automobiles from the high traffic density areas. Domestic and industrial pollutants were also cited as reasons for the high values recorded in the high density areas of Mushin and the Apapa Industrial Complex, respectively. The highest value (over 0.138 Ly/min) was recorded at noon outside the densely built-up areas to the west and north of the city because greater amount of incoming solar radiation was able to reach the surface.

In the less densely built-up areas, net radiation values were relatively lower. In the late afternoon when traffic density was very high, net radiation values were very high. It should be noted that Lagos is a coastal city where marine influence of the Atlantic Ocean is dominant. This should be taken into account in its microclimatic studies.

In New Delhi, a tropical city in India, Padmanabhamurty and Mandal (1982) found that the urban-rural incoming shortwave radiation differences during winter were considerable. The urban area received less radiation and this was attributed to comparatively higher pollution levels in the urban area. It was also noted that there were occasions when rural solar radiation was less than that received in the urban area and this could have been due to change of wind direction resulting in transport of pollutants from the urban location to rural location as was the case of net radiation after 1400hrs local time in New Delhi.

In a previous study in New Delhi, Padmanabhamurty and Bahl (1981) found that when winds were light, the near surface speeds are greater in the built-up area than in the outskirts of the city. With winds less than 4m/s, there was 20% increase in speed over the city. The greatest increase according to their findings occurred with winds less than 1.3m/s. Due to heat island effect and change in surface roughness, the urban wind field becomes complex. Chow and Chang (1982) indicated that due to rapid development of urbanization in Shanghai, China, the increasing built-up area had caused a change in the surface roughness which lowered wind speeds in the city.

In a later study of the urban climate of Shanghai, Chow (1984) noted that Shanghai is the most rapidly growing city in China and its climate has a strong monsoonal character making it a humid sub-tropical city. He investigated the urban heat island on a clear calm night on 13th December 1979 at 20hrs and observed the warmest temperature of 8.5°C at the high density urban dwelling area while the nearby rural stations recorded air temperature of 2-3°C.The average records of annual temperature showed that the urban heat island was pronounced at the mean minimum temperature more than the mean maximum temperature. Diurnal and seasonal variations of heat island intensities were evident. He noted that the heat island did not develop during the day time but from 15 to 17hrs and the urban rural temperature difference increased rapidly remaining between 2 to 4.5°C from dusk until sunrise under clear calm synoptic conditions.

Urban influences on climate in Shanghai were found to be very pronounced in temperature, wind, humidity and precipitation by Chow and Chang (1984). They found that long-term trend of temperature was towards greater warmth, winds became weaker and humidity decreased. Under calm and clear conditions, the urban area appeared as a heat island and dry island on summer nights.

The high humidity in the city exhibited a moisture island and during the rainy season, the urban area and its lee became a rainy island. They called these the "four island effects" of Shanghai urban climate.

In his study of the urban heat island effect in Nairobi, Nakamura (1967) used climatological data from three meteorological stations namely; Dagoretti Corner representing the western sub-urban area, Eastleigh (now Moi Airbase) representing the CBD and Jomo Kenyatta International Airport (JKIA) representing the eastern sub-urban area. In addition, he measured air temperature at 120 temporary stations and his results showed that the city temperature was higher than that of sub-urban areas.

The difference between Moi Airbase and Jomo Kenyatta International Airport was 1.3°C for the minimum temperature. As for the maximum temperature, there was a very small difference between the city and the suburbs which meant that the city had small diurnal range of temperatures. Dagoretti was cooler than Jomo Kenyatta International Airport by 2.2°C for maximum temperature and by 1.3°C for the minimum temperature which he attributed to altitude-temperature change (Nakamura, 1967). He found that it was warmer near the city than the suburbs but the warmest part was the Nairobi Railway station. However, he did not investigate temperatures within the densely built-up areas of the city.

It is noted that the city has grown extensively since 1967. Okoola (1980) investigated the urban heat island in Nairobi and established that the heat island effect is stronger for the minimum temperature than for maximum temperature. The highest monthly value of minimum temperature between Eastleigh (currently Moi Airbase) and Embakasi (currently JKIA) was 2.5°C during January and February. During the same months, he observed that the city was cooler than its suburbs by 0.5°C at the maximum temperature.

From the two studies on heat island effect in Nairobi, it is clear that more investigation of temperature differences in Nairobi need to be carried out. The need and significance of urban precipitation studies in the tropics arise due to the fact that water balance conditions in urban areas depend on the characteristics of precipitation like its intensity, duration and frequency.

Knowledge of such characteristics will be of use in monitoring the urban hydrologic system which will be handy in the designing of urban drainage networks and systems (Mabongunje, 1968). The intensity of tropical rainfall with a duration of 15 minutes is often two to four times higher than that of the similar duration in Western Europe. Oyebande (1990) compared two-year rainfall intensities of five West African cities and four European cities for different durations and found that the values for African cities were much higher than those of their European counterparts.

Rainfall in the city of Ibadan according to Adebayo (1993) varied considerably between 1961 and 1981 with the mean annual rainfall reducing significantly between 1970 and 1976. However throughout the period, the northern end of the city was wetter than the southern end. Previous studies, however, carried out by Oguntala and Oguntoyinbo (1982) in Ibadan show that the occurrence of floods in the city has been increasing since 1950. They attributed this to the increase in rainfall and also increase of impervious surfaces in the city. From the literature reviewed, it can be appreciated that there has been no comprehensive study of the microclimate of Nairobi city separating the urban influences on climate from the meso-scale climate. It is also clearly indicated in the literature that transferability of results from other urban areas is not advisable.

2.8. Radiative Forcing and Urbanization in Kenya

The concept of radiative forcing is explained by the following equation:

$\Delta T_s = \lambda RF$ ……………………………………………………………………(2)

Where ΔT_s is the global mean equilibrium temperature change at the surface, λ is the climate sensitivity parameter and RF is radiative forcing.

Therefore, radiative forcing manifests a linear relationship with the global mean equilibrium temperature change at the surface. Radiative forcing represents a linear view of its contribution to global mean temperature change between two distinct equilibrium climate states (IPCC, 2007) as illustrated in Figure 2.2 below.

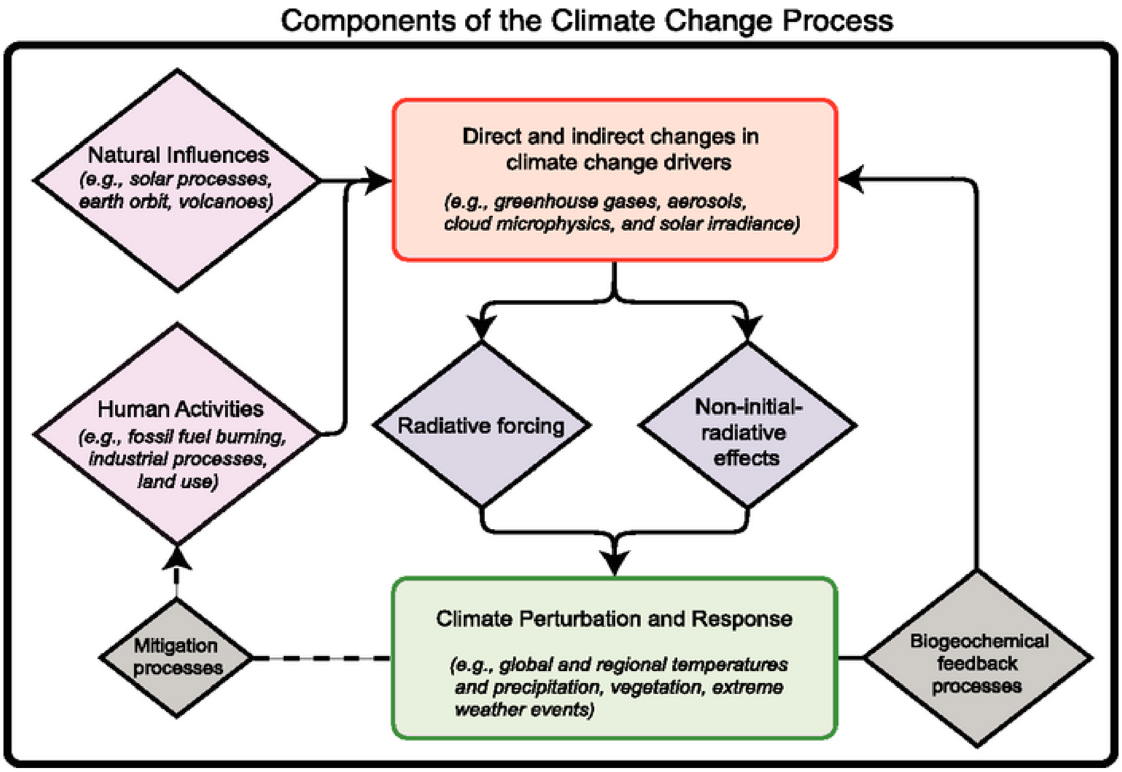

Figure 2.2 Diagram illustrating how RF is linked to other aspects of climate change assessed by IPCC, 2007.

This concept encompasses both natural influences and anthropogenic activities (Figure 2.2). Human activities in urban areas, Nairobi included, contribute to RF in a unique way given the variety of sources of greenhouse gases in urban areas which are termed as RF agents. In the context of RF there are anthropogenic and natural RF agents (Figure 2.3). Anthropogenic forcing agents include well mixed GHGs, Ozone, Stratospheric water vapour from CH_4, Surface albedo, Contrails, Aerosol-Radiation Interaction and Aerosol-Cloud Interaction. Carbon dioxide (CO_2) and other well-mixed GHGs are the most prominent radiative forcing agents which exert the highest positive radiative forcing. The natural forcing agent is solar radiation.

A few studies have been done to investigate the characcteristics and dynaimcs of RF over Kenya. For instance, Makokha *et al*., (2010) derived radiative characteristics of the atmosphere over Nairobi, Mbita and Malindi. Radiative forcing due to atmospheric aerosols was estimated during the period 2006 to 2008, and found to remain relatively constant at 0.46 for all the three sites despite the observed differences in the various aerosol particle properties, namely: physical, mode of generation, chemical and number densities dominating the sites. This value was slightly lower as compared to the combined global anthropogenic radiative forcing estimated to be +1.6 [-1.0, +0.8] W/m^2.

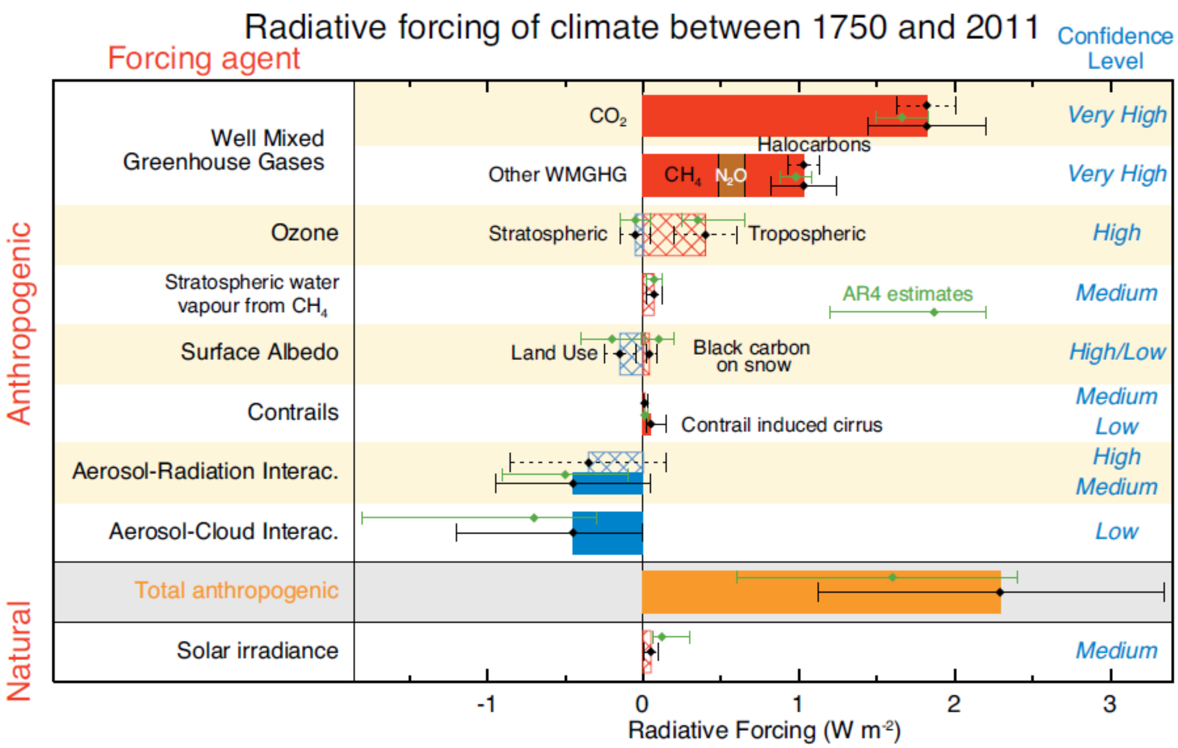

Figure 2.3 Radiative forcing agents (IPCC, 2013)

In the context of radiative forcing agents, negative radiative forcing is critical in slowing down or reversing global warming. Therefore, land use change – especially afforestation, aerosol radiative interaction and aerosol-cloud interaction are important (Figure 2.3). Only a few studies have been done over Kenya and East Africa in general. One of the pioneering studies was by Muthama, *et al*. (2008) who estimated cloud cover using satellite derived reflectivity by considering Nairobi and Mombasa for Kenya, Dar-es-Salaam and Kilimanjaro for Tanzania, and

Kampala, Makerere and Kasese for Uganda. The remotely sensed data were obtained from one channel of the Total Ozone Mapping Spectrum (TOMS) satellite. Correlation analysis indicated that there is a significant relationship between ground-based cloud cover and satellite-derived reflectivity, influenced by the prevailing mesoscale conditions.

The study inferred that satellite-derived reflectivity could represent the observed cloud cover, and consequently study radiative forcing even in locations deficient of ground-based cloud observations. Increased cloud cover represents negative radiative forcing as was shown in Figure 2.2. An imposed negative radiative forcing on the Earth-atmosphere system represents an energy deficit and hence reversal of global warming. More studies are need in this context over Nairobi.

2.9. Theoretical Basis and Framework

The theoretical basis of this study is founded on three theories which are deemed to be fundamental pillars of the research, namely: Inadvertent weather modification theory (Haggard, 1990); Malthusian theory of population growth and the Second Law of Thermodynamics. Inadvertent weather modification theory relates urbanization to climate variables as shown in Figure 2.4.There has been a dramatic and rapid urbanization around the world and this has brought about weather modifications in urban areas. These weather modifications are directly attributed to anthropogenic activities such as removal of vegetation cover and replacement of the same with buildings and some impervious surfaces like tarmac roads, addition of pollutants to the urban atmosphere from industries and vehicles together with addition of condensation nuclei.

This in turn alters radiation exchange, temperatures and precipitation characteristics of the urban boundary and urban canopy layers (Haggard, 1990). It is projected that 80% of the world's population will be urbanized by the year 2025 (UNFPA, 2007).

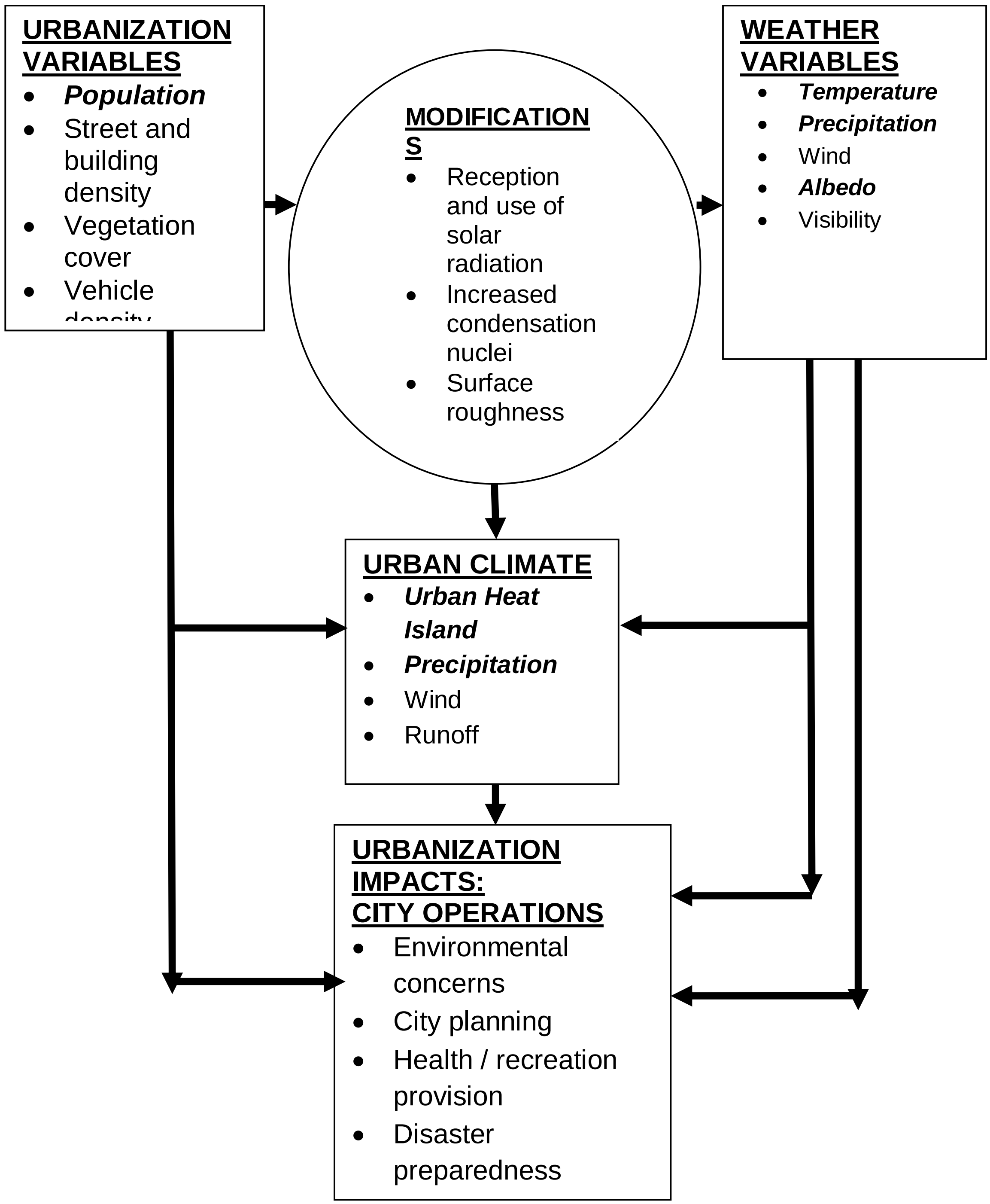

Figure 2.4: Theoretical Model of Urbanization and Climate (Source: Researcher)

Malthusian theory of population growth states that human populations grow exponentially while food production grows at an arithmetic rate. This theory is applicable to urbanization because of rural-urban migration of agriculturally productive people which in turn reduces food production. Urban population growth in Africa is exacerbated by migration from rural to urban areas coupled with increased life expectancy of urban dwellers. Rapid urban population growth implies modification of the urban environment mainly Land Use and Cover Changes (LUCC) one of them being creation of a distinct micro-climate of the specific urban area (Deng *et al.*, 2013).

This therefore brings into focus the Second Law of Thermodynamics (also known as Law of Increased Entropy) in terms of temperature, precipitation, wind, albedo and the overall energy balance scenarios. Urban areas are known to contribute to weather and climate modification due to increased emission of various greenhouse gases (GHGs) to the urban atmosphere coupled with significant land use changes. These changes trigger modifications of surface properties and topography which eventually create urban barrier effects that alter regional airflow.

When climate variables are modified due to urbanization, they create a distinct urban climate by propagating urban heat island phenomenon, an urban precipitation regime that could be different from rural precipitation, an urban air flow modified by urban surface characteristics and enhanced runoff due to impervious surfaces associated with urbanization. These changes affect surface fluxes of heat, water vapour and momentum to the atmosphere and thus modifying local and regional atmospheric circulations (Grimmond, 2007).

Urban climatology studies are useful in guiding city operations about environmental concerns such as floods during rainy seasons and on the best ways to deal with weather and climate related disasters like water-borne diseases prevention. Urban planning should also involve a design of effective drainage system of runoff by knowledge of the spatial and temporal quantities that are expected combined with consideration of urban population dynamics.

2.10 Synthesis of Research Gap

This study notes that transfer of findings from studies done in other urban areas is not appropriate because each specific urban area has its unique climatic zone, topography, design, altitude, location, industrial activities and population dynamics. That is why it is necessary to study the microclimate of Nairobi as a single entity with the intention of bridging the gap between urban climatology and its applications to urban operations in Kenya. The findings from this study will contribute to choice of best planning options for; runoff water management, greening of the Nairobi and the well-being of the residents in line with Kenya's Vision 2030. Limited studies have documented the influence of urbanization on the micro climate of equatorial cities. (Ongoma *et al*., 2012; Ongoma *et al.,* 2015; Opijah *et al*., 2008),

CHAPTER THREE

3.0 DATA AND METHODOLOGY

This chapter discusses the data and methodology that were used to carry out this study.

3.1 Introduction

This study was based on the premise that urbanization is a good example of human modification of climate in terms of energy balance, water balance, wind flow characteristics and atmospheric modifications among other climate impacts. It is in terms of energy and water balances that immediate climate modifications are most likely to be exemplified and this study surveyed temperature and rainfall as contributing elements in the energy-water balances of an urban area, which in this case was Nairobi. The temperature and rainfall characteristics were considered in terms of amounts, averages and variances over time thus generating time series modules for accurate descriptions of the maximum and minimum temperature trends, rainfall anomalies and frequencies.

3.2. The Data Types and Sources

Four types of data were sourced as follows:

3.2.1 Meteorological Data

This study obtained monthly climatic data from Kenya Meteorological Department data base from 1961 to 2008 from four stations located within Nairobi City namely; Dagoretti Corner, Wilson Airport, Jomo Kenyatta International Airport (JKIA) and Moi Airbase. The data used in this study were total monthly rainfall (see Appendix 1) and mean monthly temperature from Dagoretti Meteorological Station representing the southern relatively cooler part of Nairobi, Moi Airbase representing the densely populated part of Nairobi to the north east, Jomo Kenyatta International Airport representing the eastern relatively dry part of Nairobi and Wilson Airport representing the transitional zone between urban and peri-urban zones of the city. Temperature data were deemed necessary in this study because urbanization alters city's microclimate through energy consumption (KIPPRA, 2010) and emissions from both industrial and domestic activities as well as modification of land surface thermal and aerodynamic characteristics.

Air pollution which is prevalent in industrialized cities has also been given as one of the key factors that contribute to modification of global energy balance. The study also gathered minimum and maximum temperature data from the aforementioned stations.

3.2.2 Population Data

The population data of the city of Nairobi was obtained from Kenya National Bureau of Statistics population census from 1948 to 2009. An exponential estimation was then done for the subsequent years up to the year 2013. Thus an estimated population of 4 million people was obtained for the year 2013 (See Figure 1.2).

3.2.3 Normalized Difference Vegetation Index

Data on Normalized Difference Vegetation Index (NDVI) were retrieved from the National Aeronautics and Space Administration (NASA) – Giovanni site containing satellite data from NASA. Analyses and visualizations used in this study were produced with the Giovanni online data system, developed and maintained by the NASA GES DISC. Giovanni is an online (Web) environment for the display and analysis of geophysical parameters in which the provenance (data lineage) can easily be accessed. (Acker and Leptoukh, 2007).

3.2.4 Energy Consumption data

Data on vehicles in Nairobi were obtained from ERC (2015). They were used to compute energy consumption values over the city, namely CO_2 emissions in gCO_2/km as a function of the number of vehicles. This was based on a technique by Omwenga (2011) who estimated motor vehicles population in Nairobi as being 30% of the national figures and established the rate of increase in number of vehicles in Nairobi as 11.3% per year.

3.3. Methodology

This section describes some statistical methods that were used to analyse the various datasets which were collected for this study. The data were subjected to quality control procedures to examine their homogeneity and consistency.

3.3.1 Data Quality Control

Homogeneity tests were applied to climate data to check for consistency and continuity in these data sets. Inconsistency in the climate records may arise because of several reasons among them being change of measuring instrument, change of site, growth of trees and buildings among others. Rainfall and temperature data were subjected to single mass curve analysis for verification of homogeneity to confirm that the data were free from artificial trends or changes. This was done by cumulating monthly values and then plotting them against the progressive years.

3.3.1.1 Single Mass Curves

The single mass curve is among the methods that have been used to test the quality of climate records to check for inconsistencies (heterogeneity records) and also provide a correction factor to these records. The single mass curve analysis involves plotting cumulative records for a given location against time. A straight line would signify consistency in the records while a change in slope lasting for more than five continuous points would indicate heterogeneity in data sets. The single mass curve was used in this study to check for the consistency in rainfall and temperature data sets.

3.3.1.2 Estimation of Missing Data (Rainfall/Temperature)

There are several methods that can be used for estimating missing meteorological data. Some of these methods include the arithmetic mean method, the isohyetal linear interpolation and isopleths methods, the Thiessen weighted method, correlation and weighted arithmetic mean method among many others. This study adopted the arithmetic mean method and where necessary, missing data was replaced by using the median or the mode. The section below describes the arithmetic mean method.

3.3.1.2.1 Arithmetic mean method

This is one of the simplest method of estimating missing meteorological data. In this case, one needs to determine the long-term mean of the variable given by the equation below:

$$\overline{X} = \frac{1}{\mathrm{N}}\sum_{i=1}^{n} X_i \quad for \quad i = 1,2,3,4,\ldots\ldots\ldots, n \qquad \ldots\ldots\ldots\ldots \quad (1)$$

Where

$\overline{X}$ is the Long term mean, N is the total number of observations, X_i is the climate variable and *n* is the total length of the data records.

3.3.2 Time Series Analysis

A time series is a collection of observation taken at specified times, usually at equal intervals. This could be hourly, daily, weekly, monthly, seasonally or annual series of meteorological elements such as precipitation, temperature, and humidity among others. Many time series show certain characteristics or variations in their temporal behaviour and the analysis of such movements can be used to forecast the future movements of the time series.

The characteristic movement of a time series (called components) can be classified into four major types, namely:

- Trend(Long term fluctuations or movements)
- Seasonality (Seasonal fluctuations with periods less than one year)
- Cyclical patterns (Periodic and Quasi-periodic movements)
- Systematic pattern and random noise (Unpredictable or irregular patterns)

There are two techniques that can be used to identify trend components in a given time series data. These are graphical and statistical approaches. In the graphical approach, a plot of the series is done on a graph paper and then smoothened off. Personal judgment can then be used to describe the trend. This method is however very subjective. The statistical approach is a more objective approach for determining the trends of rainfall and temperature. The technique used here is the Analysis of Variance (ANOVA) where the whole series was divided into two sets (groups) and then the *t*-test and the *F*-tests were used to test the significance of the difference between means of the two groups of data from the same series.

3.3.3 Statistical Analysis

This section provides the statistical methods used to analyse the different data sets that were used in this study.

3.3.3.1 Correlation Analysis of Rainfall and Temperature

The formula for determining the relationship between rainfall and temperature as given by the correlation coefficient is shown below:

$$r_{xy} = \frac{\sum_{i=1}^{n} x_i y_i - \frac{\left(\sum_{i=1}^{n} x_i\right)\left(\sum_{i=1}^{n} y_i\right)}{n}}{\sqrt{\left[\sum_{i=1}^{n} x_i^2 - \frac{\left(\sum_{i=1}^{n} x_i\right)^2}{n}\right]\left[\sum_{i=1}^{n} y_i^2 - \frac{\left(\sum_{i=1}^{n} y_i\right)^2}{n}\right]}} \quad \text{............} \quad (2)$$

Where r_{xy} is the computed correlation coefficient, X and y are the different climate variables respectively. In the end, the data records were divided into two equal samples sizes which were then tested for the significance of the difference between the two means to check on the significance of trend.

The Student t-test was used to test the significance of the computed correlation coefficients. The Student t-test depends on the sample size i.e. degrees of freedom. Equation 3 gives the expression used for t–test.

$$t = \frac{(\overline{X}_1 - \overline{X}_2)}{S\sqrt{\left(\frac{1}{n_1} - \frac{1}{n_2}\right)}} \quad \ldots\ldots\ldots\ldots \quad (3)$$

Where *t* is the calculated value of statistic *t* then $\overline{X}_1$ and $\overline{X}_2$ are the means of the first and second set of values, n_1 and n_2= number of items in set 1 and set 2 respectively while S is the standard deviation. The computed value of *t* is compared to the critical value at $n_1 + n_2 - 2$ degrees of freedom to ascertain whether the means are significantly different or otherwise

Tests of Significance of Correlation

Testing the significance of a correlation can be achieved using the parametric Student's t test below:

$$t_{n-2} = r\sqrt{\frac{n-2}{1-r^2}} = \sqrt{\frac{r^2(n-2)}{1-r^2}} \quad \ldots\ldots\ldots\ldots \quad (4)$$

Where t_{n-2} is the t statistic with (n-2) degrees of freedom, *r* is the correlation coefficient and *n* is the number of observations.

3.3.3.2 Regression Analysis between Climate Variables

In fitting the simple linear regression model equation, you hypothesize a model of the form: $Y = a_0 + a_1X + \varepsilon$ which contains the deterministic part, $a_0 + a_1X$ and the error term, ε. a_0 and a_1 are the regression constants to be determined from the sample data. To determine the regression coefficients a_0 and a_1 , there is need to minimize the sum of the squared deviation errors given by:

$$\sum_{i=1}^{n} \varepsilon_i^{\ 2} = \sum_{i=1}^{n} (y_i - \hat{y})^2 \qquad \text{or} \qquad \sum_{i=1}^{n} \varepsilon_i^{\ 2} = \sum_{i=1}^{n} [y_i - (a_0 + a_1 x_i)]^2 \quad \text{...... (5)}$$

The minimum is found by differentiating the above equation and equating to zero. The solutions to the above equations are determined from the following simultaneous equations:

$$\frac{\partial \sum_{i=1}^{n} \varepsilon_i^{\ 2}}{\partial a_0} = -2 \sum_{i=1}^{n} [y_i - (a_0 + a_1 x_i)] \qquad \text{and}$$

$$\text{............} \qquad (6)$$

$$\frac{\partial \sum_{i=1}^{n} \varepsilon_i^{\ 2}}{\partial a_1} = -2 \sum_{i=1}^{n} [x_i y_i - x_i (a_0 + a_1 x_i)]$$

Solving the above simultaneous equations after equating to zero gives:

$$\sum_{i=1}^{n} y_i = n a_0 + a_1 \sum_{i=1}^{n} x_i \qquad \text{and} \qquad \sum_{i=1}^{n} x_i y_i = a_0 \sum_{i=1}^{n} x_i + a_1 \sum_{i=1}^{n} x_i^{\ 2}$$

Yielding $a_0 = \bar{y} + a_1 \bar{x}$

$$\text{............} \qquad (7)$$

and $$a_1 = \frac{\sum_{i=1}^{n} [(x_i - \bar{x})(y - \bar{y})]}{\sum_{i=1}^{n} (x_i - \bar{x}_i)^2} \qquad \text{or} \qquad a_1 = \frac{n \sum_{i=1}^{n} x_i y_i - \sum_{i=1}^{n} x_i \sum_{i=1}^{n} y_i}{n \sum_{i=1}^{n} x_i^{\ 2} - \left(\sum_{i=1}^{n} x_i \right)^2}$$

The sample data are then used to estimate the values of a_0 and a_1

3.4 Energy Consumption Analysis

The energy consumption patterns in Nairobi were based on motor vehicle emissions of carbon dioxide per distance travelled. The study adopted the technique by Omwenga (2011) of estimating motor vehicular population in Nairobi as being 30% of the national figures and established the rate of increase in number of vehicles in Nairobi as 11.3% per year. The subsequent CO_2 emissions in gCO_2/km were estimated as a proxy of the number of vehicles.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter discusses the results of data analysis based on the four specific objectives. Data quality analysis was however performed to ensure reliable results for valid conclusions and recommendations. It is the subject of the following sub-section. Other four sections, representing each specific objective, are also discussed.

4.2 Results from Homogeneity Tests

Weather data from four weather stations (Figures 4.1 to 4.4) were subjected to single mass curve analysis. Fig. 4.1 below illustrates the results of the single mass curve analysis for rainfall over Dagoretti corner. Evidence of slight discontinuity is visible around 1978 and 1998. However, these breaks are not visually significant. The rainfall data were therefore declared of good quality.

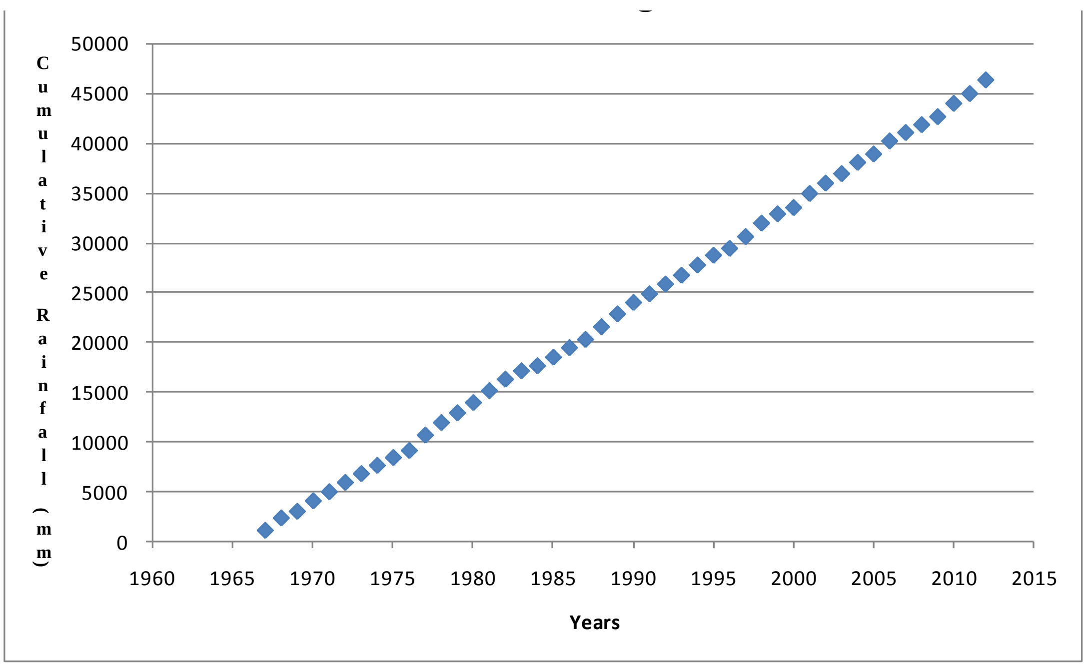

Figure 4.1. Single mass curve of rainfall over Dagoretti Corner station

Figure 4.2 shows the results of maximum temperature data quality control and it depicts homogeneity in the data sets. The data were therefore deemed to be of good quality. It may be observed that the discontinuities observed from Figure 4.1 compared to Figure 4.2, maybe due to rainfall instrumentation since temperature values are not affected in the same way.

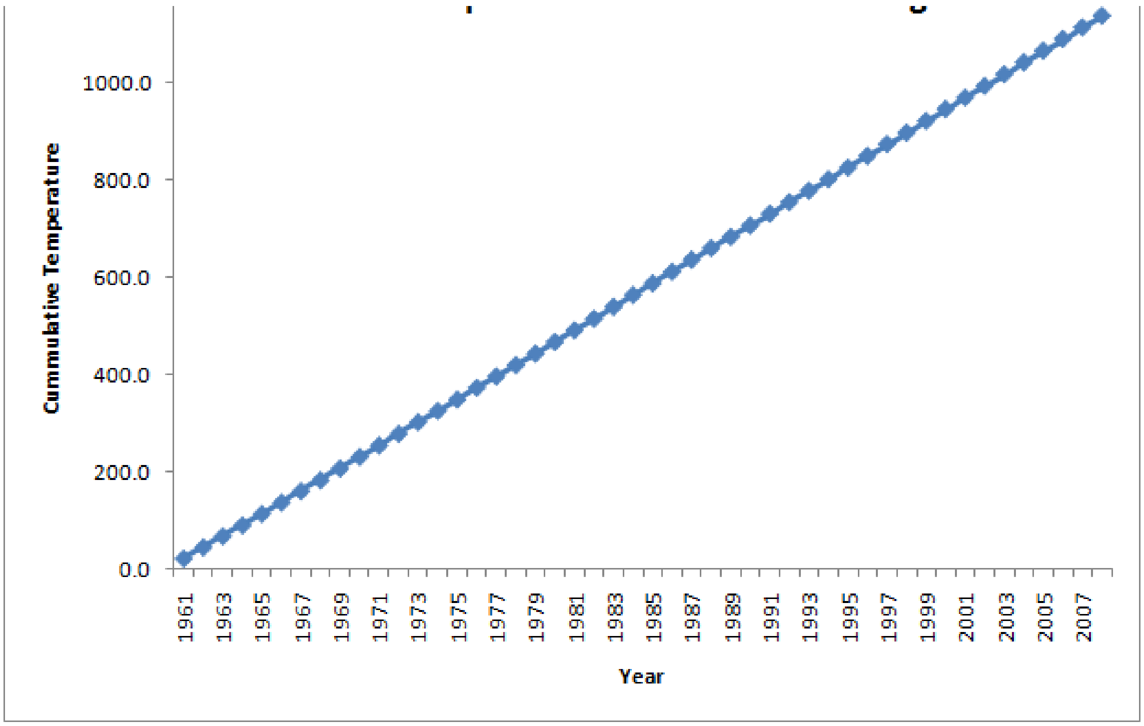

Figure 4.2 Single mass curve of maximum temperature over Dagoretti

Figure 4.3 is a graph of minimum temperature data quality. It depicts the same pattern as Figure 4.2. The data were therefore of good quality.

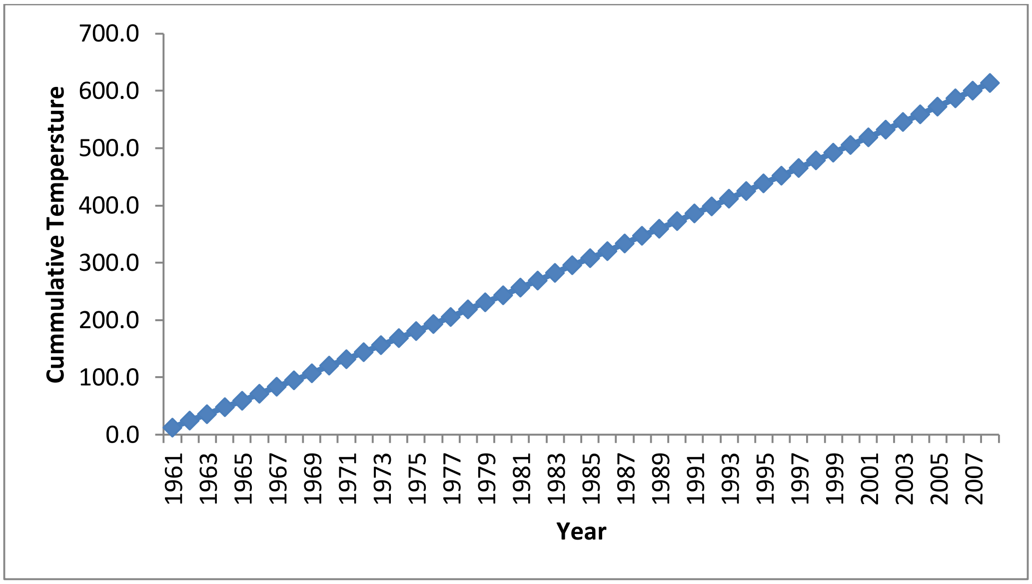

Figure 4.3 Single mass curve of minimum temperature over Dagoretti

At Wilson Airport station (Figure 4.4), the rainfall single mass curve plot shows two discontinuities in 1976 and 1997. However, they are insignificant. Therefore the data were considered useful for further analysis.

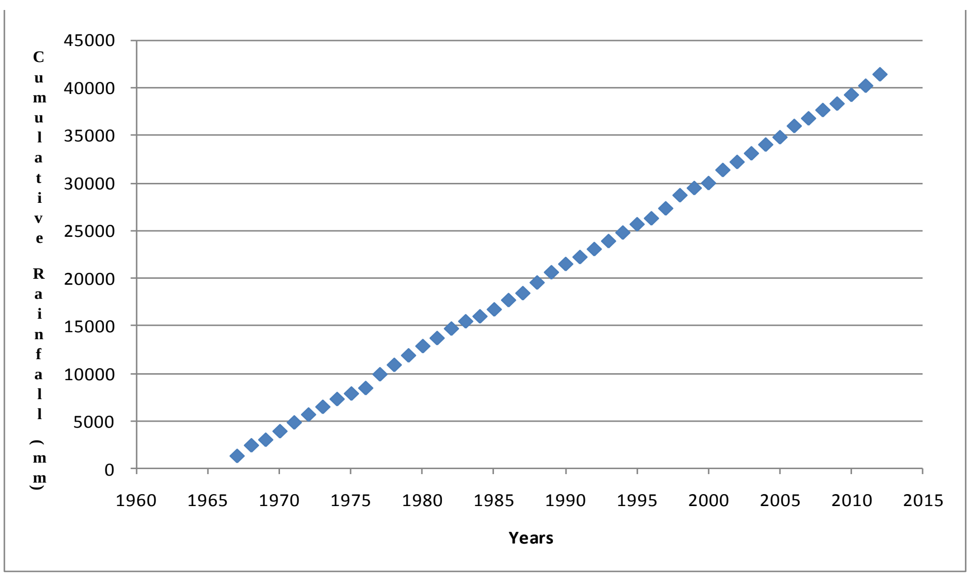

Figure 4.4 Single mass curve of annual rainfall at Wilson

The maximum temperature data are declared to be of good quality based on the single mass curve analysis (Figure 4.5) which shows a continuous straight line without any discontinuity. Same is case with the minimum temperature single mass curve analysis (Figure 4.6).

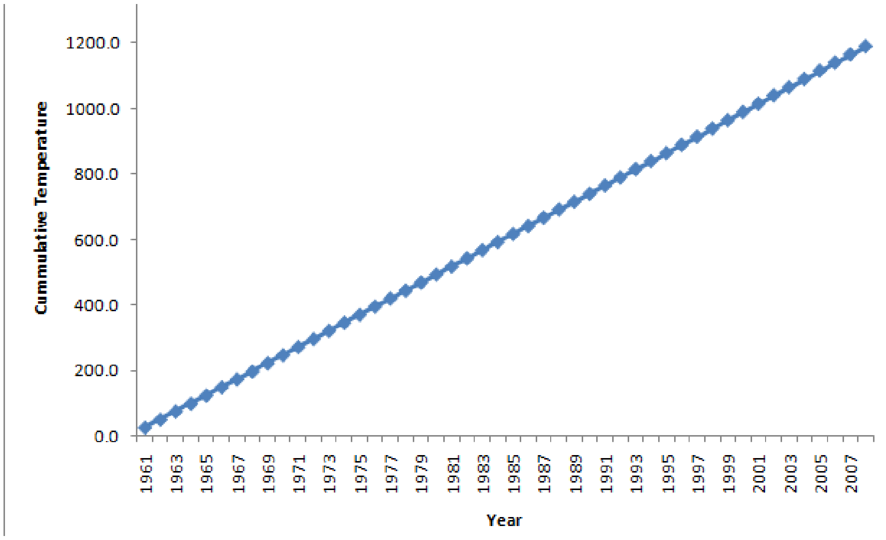

Figure 4.5 Single mass curve for maximum temperature for Wilson

This indicates that the instruments used for maximum and minimum temperatures were harmonious, together with the entire observational procedure at Wilson airport.

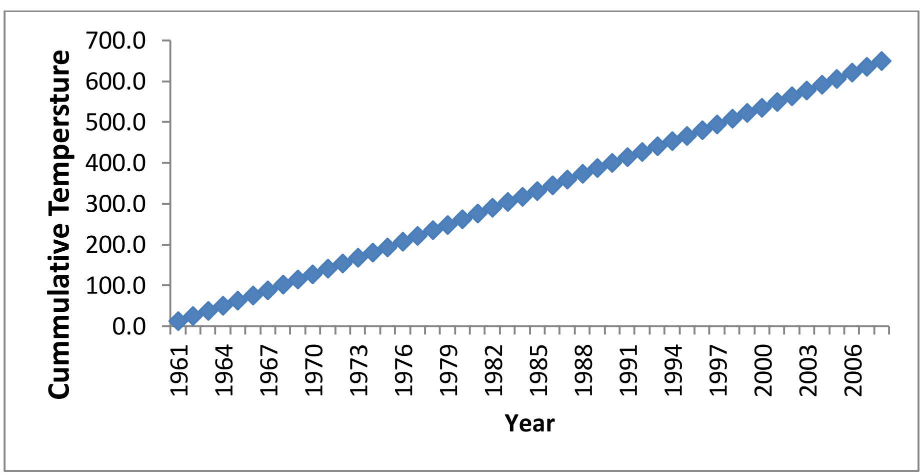

Figure 4.6: Single mass curve for minimum temperature for Wilson

The single mass curve analysis of monthly rainfall records at Moi Air base station (Figure 4.7) depicts an almost straight line with two distinct discontinuities in 1976 and 1997. However these discontinuities are considered insignificant. Thus the data were deemed to be of good quality.

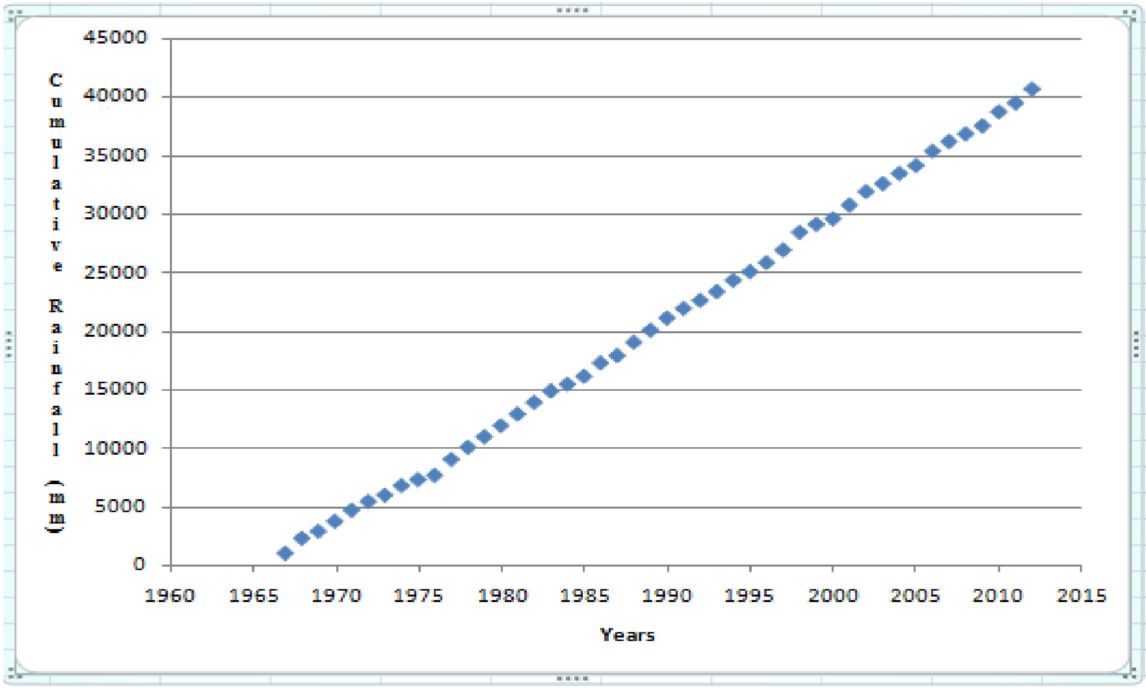

Figure 4.7 Single mass curve of rainfall at Moi Air Base

The maximum and minimum temperatures at the Moi Air base were also found to be of good quality on the basis of their single mass curve analysis.

The rainfall data over Jomo Kenyatta International Airport (JKIA) depicted two discontinuities in 1976 and 1997, similar to the other three stations (Figure 4.8). However, these discontinuities were also deemed insignificant and as such the data were considered to be of good quality for subsequent analyses.

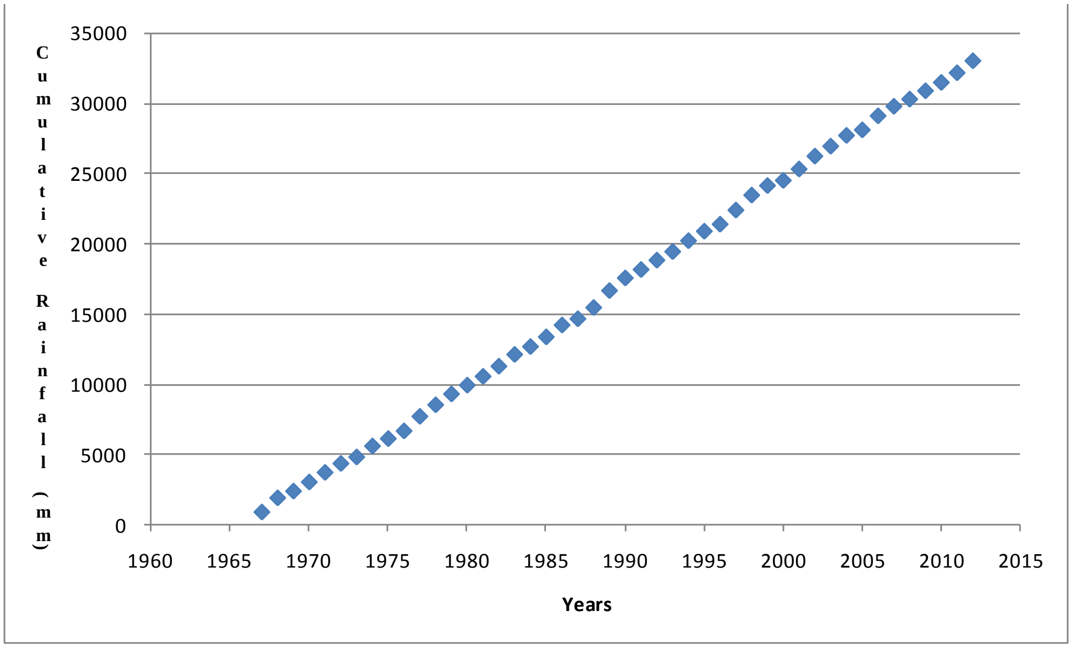

Figure 4.8: Single mass curve of rainfall at JKIA

The single mass curve analysis results for maximum and minimum temperatures over JKIA (Figures 4.9 and 4.10) are similar to the other three stations. Straight lines are evident from the graphs. The data were therefore incorporated for subsequent analyses. It was noted that the mass curves for Moi and JKIA rainfall were inconsistent in their rainfall records which may have been caused by the prevailing synoptic conditions affecting all the stations. The 1997 -1998 El-Nino episode might have contributed to this inconsistency.

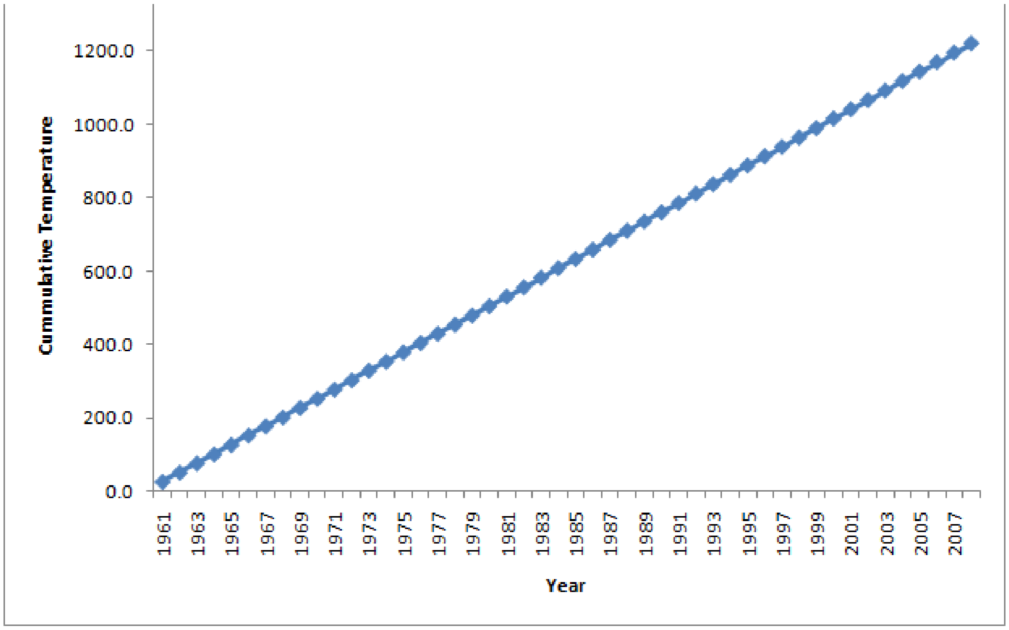

Figure 4.9 Single Mass Curve for Maximum Temperature at JKIA

The maximum and minimum temperature data over JKIA were found to be consistent as indicated by the single mass curves shown in Figures 4.9 and 4.10.

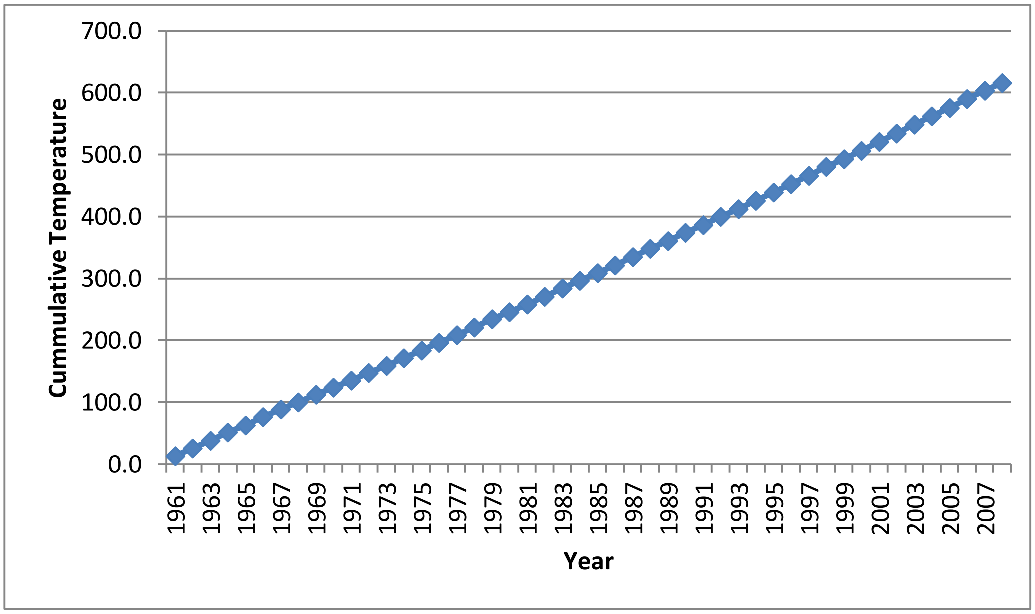

Figure 4.10 Single Mass Curve for Minimum Temperature at JKIA

4.3 Results from Rainfall and Temperature Time Series Analysis

Rainfall data for all the four stations were subjected to temporal and trend analyses. Monthly means were obtained for the period 1967 to 2012, a total of 46 years. The results are discussed in the section below:

4.3.1 Temporal Variability of Rainfall and Temperature

The 46 years of monthly rainfall data were subjected to seasonality analysis (Figure 4.11). Two seasons were observed, namely: the March-April-May (MAM), or long rains season, and November- December (ND), the short rains season. Many previous studies have observed OND instead of ND (Opijah *et al.*, 2008 and Ongoma *et al.*,2015). It is noted from Figure 4.11 that there is no adequate justification for terming the monthly duration of short rains as OND season. This is the case for all the four stations.

Spatial analysis shows that Dagoretti Corner station is the wettest of the four while JKIA station is the driest. Therefore the west of Nairobi city is the wettest while the south eastern part is the driest. This may be due topography considering that much of the rainfall experienced in Nairobi city is of convective nature (Opijah, *et al*., 2008)

It observed that it rains all the year round in Nairobi. However, the amount varies from month to month. Hence the establishment of the rainy seasons due to enhanced amounts, with the MAM season receiving the longest and highest with a peak in April and ND season with a peak in November

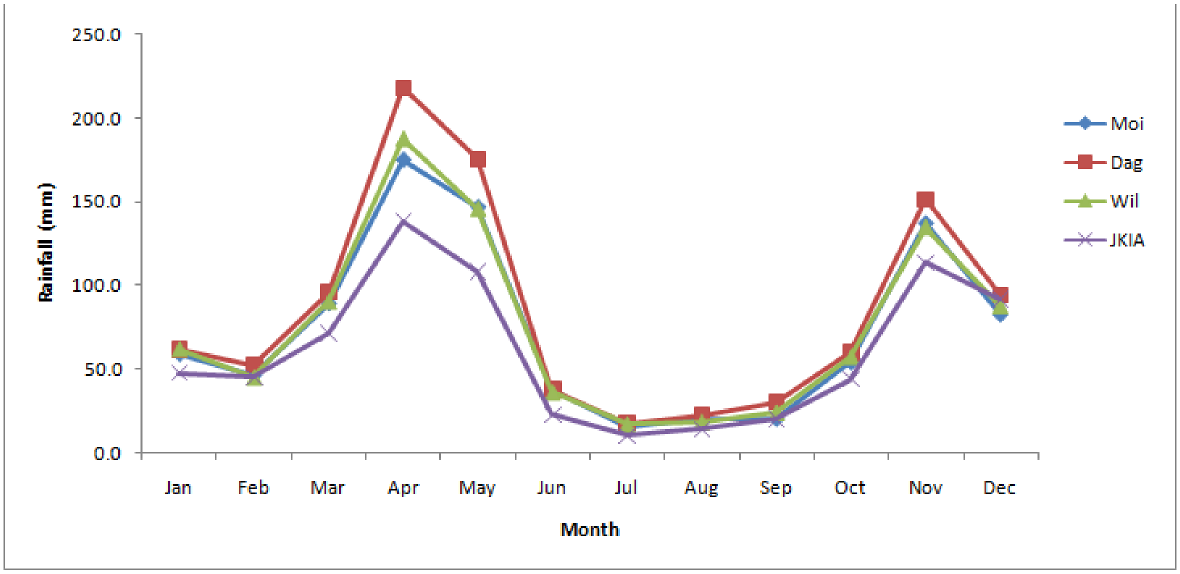

Figure 4.11: Seasonal distribution of rainfall over the Four Stations in Nairobi

Operational definition of hot season adopted in this study is monthly mean temperature exceeding 25ºC. As such two hot seasons are evident from Figure 4.12. However, there is apparent difference in the lengths of these seasons from station to station. This may point at varying microclimatic conditions across the city. Dagoretti corner station experiences cooler microclimate, with a hot season observed during January to March, hereby termed as the long hot season, and a short hot season in October. Wilson airport station is characterised by warmer microclimate compared to Dagoretti corner, such that the long hot season is observed during December to March, and a short hot season in September to October. The microclimate of JKIA area is the warmest, with the long hot season experienced from September to March. Effectively, there is no short hot season in this area.

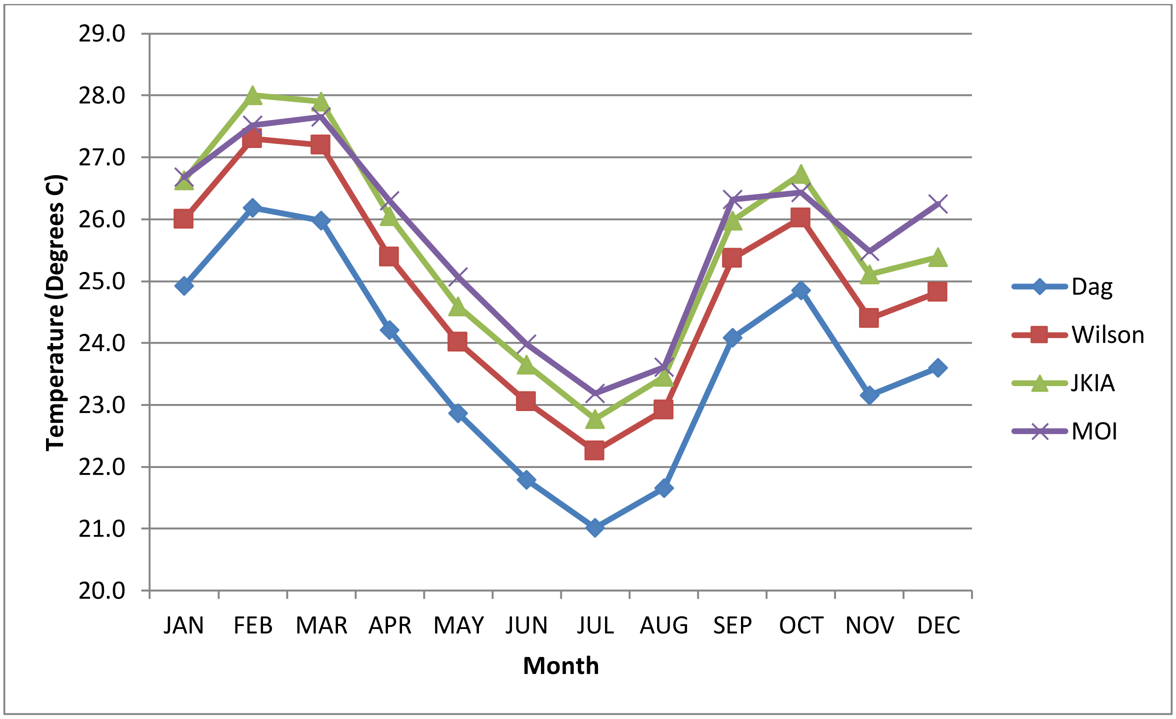

Figure 4.12: Variation of Maximum Temperature over the Four Stations in Nairobi

Two distinct patterns of minimum temperature are observed across the city (Figure 4.13). Wilson airport area experiences higher minimum temperature than Dagoretti and JKIA areas. Moi airbase has the highest minimum temperatures which is characteristic of stations located at the core of urban areas (CBDs).

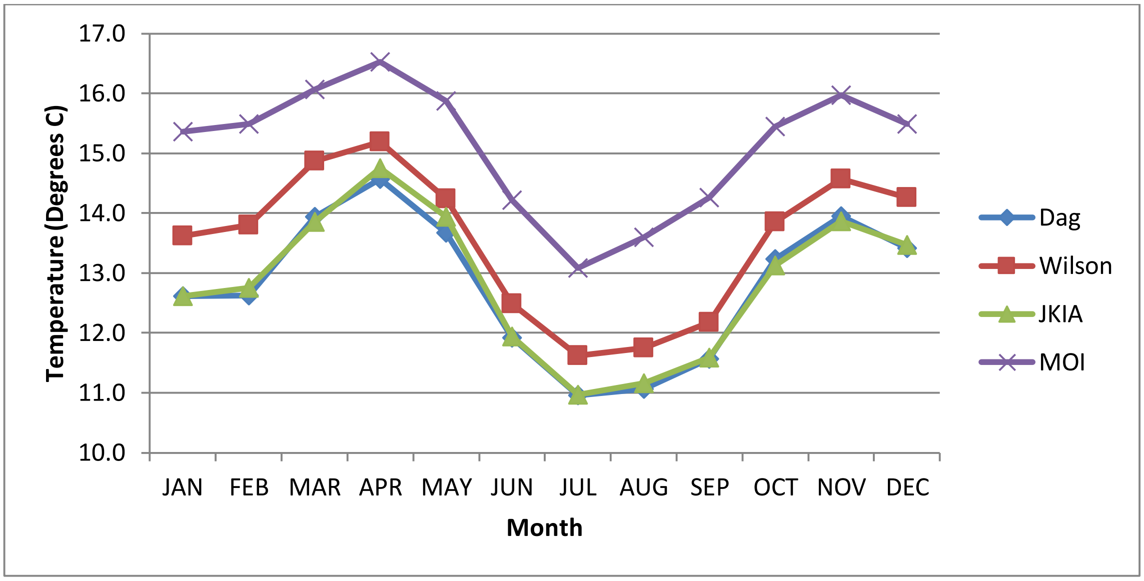

Figure 4.13: Variation of Minimum Temperature over the Four Stations in Nairobi

Monthly rainfall frequency distribution on the wettest part of Nairobi city (Figure 4.14) shows positive skewness with the peak at 50mm and very few months at more than 350 mm. Floods in the city of Nairobi are therefore ideally expected to rare occurrence, assuming proper drainage design and maintenance.

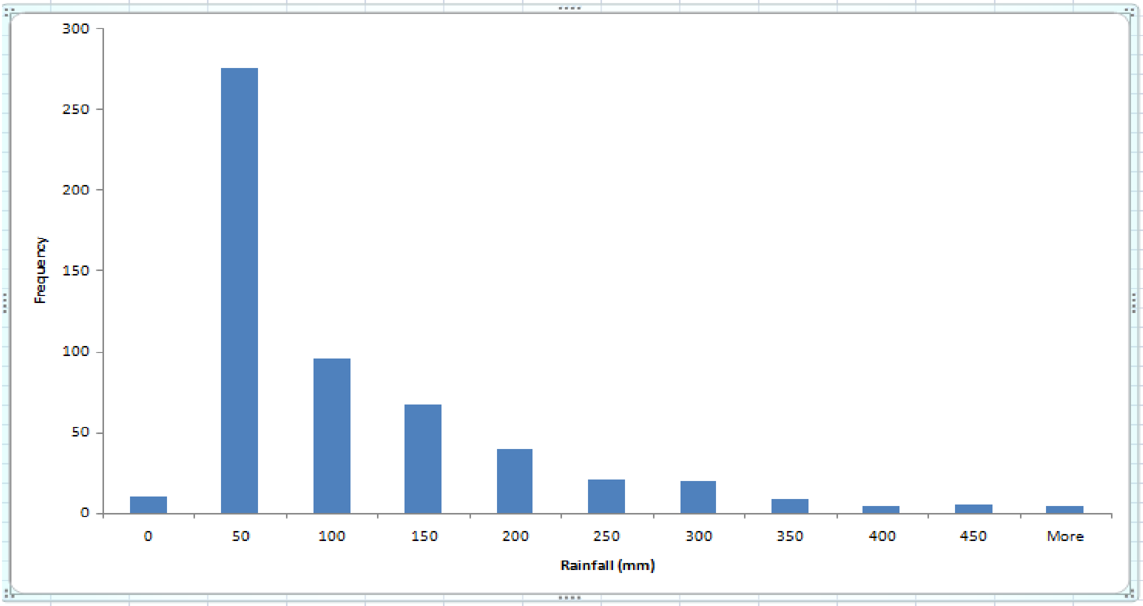

Figure 4.14: Frequency Distribution of Rainfall over Dagoretti Corner station

Monthly rainfall frequency distributing over the driest part of city of Nairobi (Figure 4.15) depicts positive skewness with the peak at 50mm and very few months at more than300 mm. Flooding risk is very low in this part of the city although on some heavy rainy seasons, floods have been reported with some international flights being diverted to drier airports of the country.

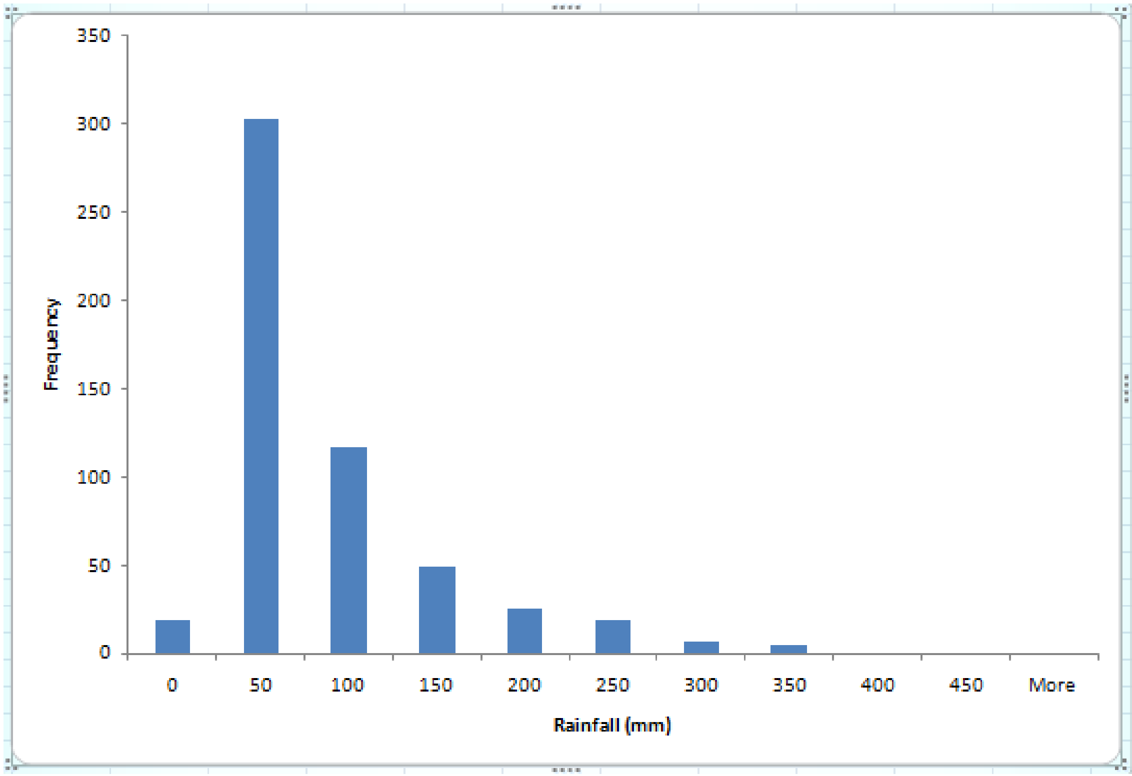

Figure 4.15: Frequency distribution of rainfall over JKIA station

Comparing Figure 4.14 and 4.15, both frequency distributions are similar. This suggests that the two stations seem to belong to the same urban canopy. However, there seems to be a slight difference in the microclimates.

There is evident annual rainfall variability over Dagoretti corner, with pronounced peaks in 1977, 1989, 1998, 2000 and 2011 (Figure 4.18). All these peaks coincide with years that experienced excessive rainfall such as the El-Nino of 1998.There were several years characterised by relatively dry conditions:1969, 1984 and 2000. These are associated with the prevailing weather systems such as the La-Nina of 2000.The trend line depicts an increasing trend which was not significant (See Table 4.1).

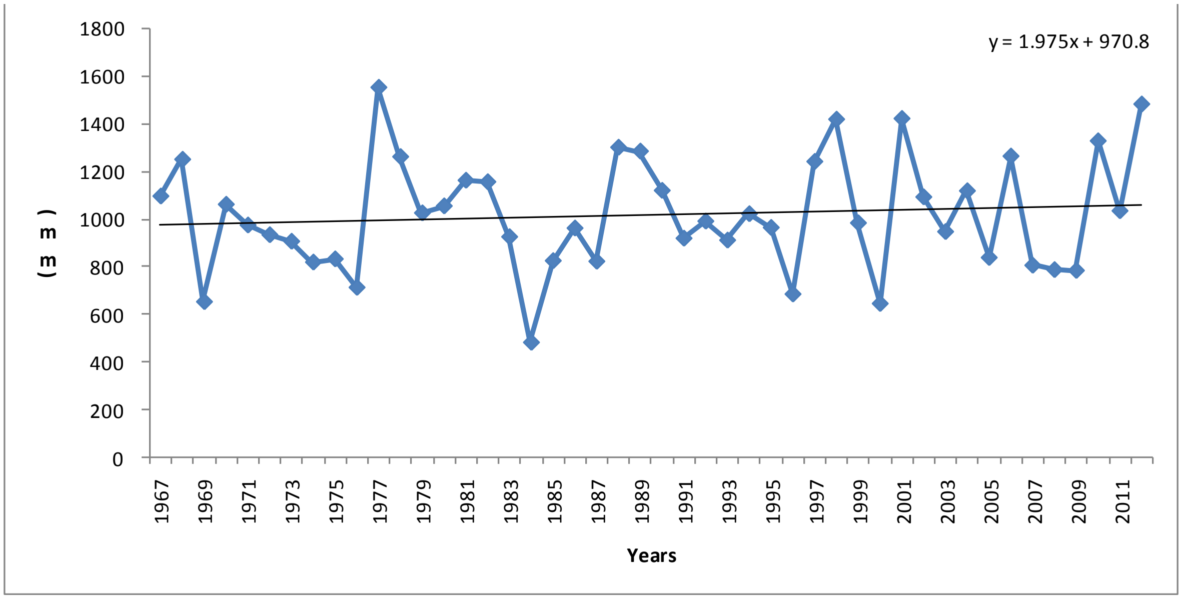

Figure 4.16: Variation of Annual Rainfall and Trend over Dagoretti

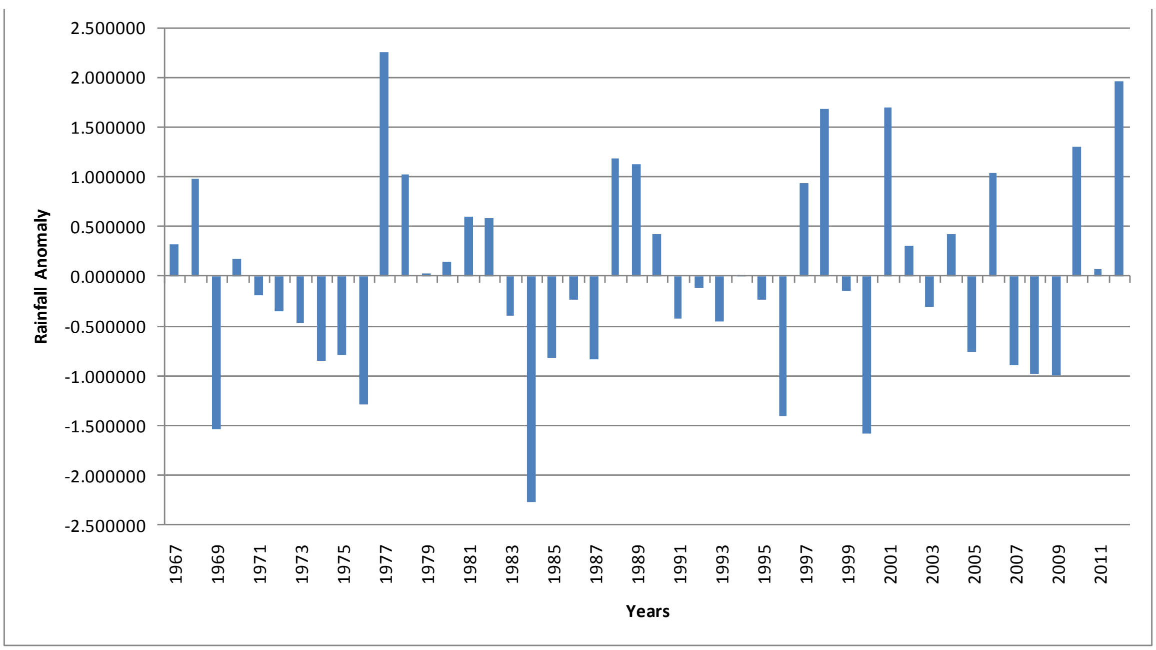

Figure 4.17: Variation of Annual Rainfall Anomalies for Dagoretti

Rainfall data was subject to time series analysis using standardized or normalized data (Figure 4.17). It may be observed from the Figure 4.17 that more recent years have more frequent above normal rainfall occurrences. There are fewer below normal occurrences which confirm the increasing rainfall trend.

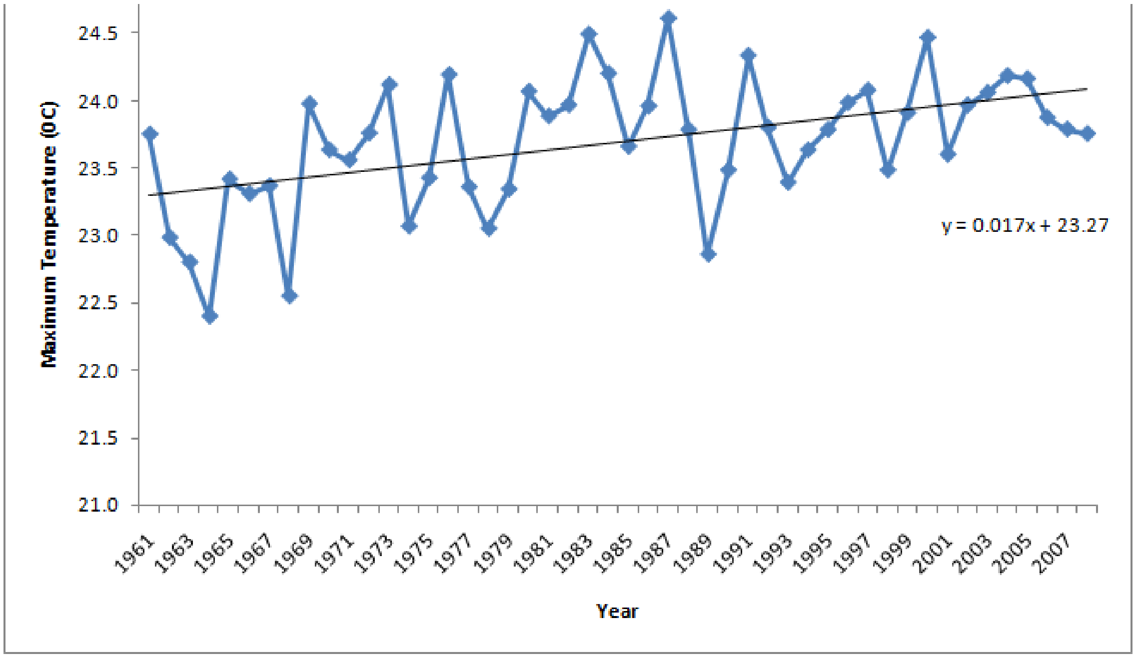

Figure 4.18: Inter-annual Variability of Maximum Temperature over Dagoretti

There is an apparent year to year variability of maximum temperature over Dagoretti corner station. The latter years seem to be characterised by less variability (Figure 4.18). This could be associated with a transformed urban microclimate possibly as a consequence of increase in building density.

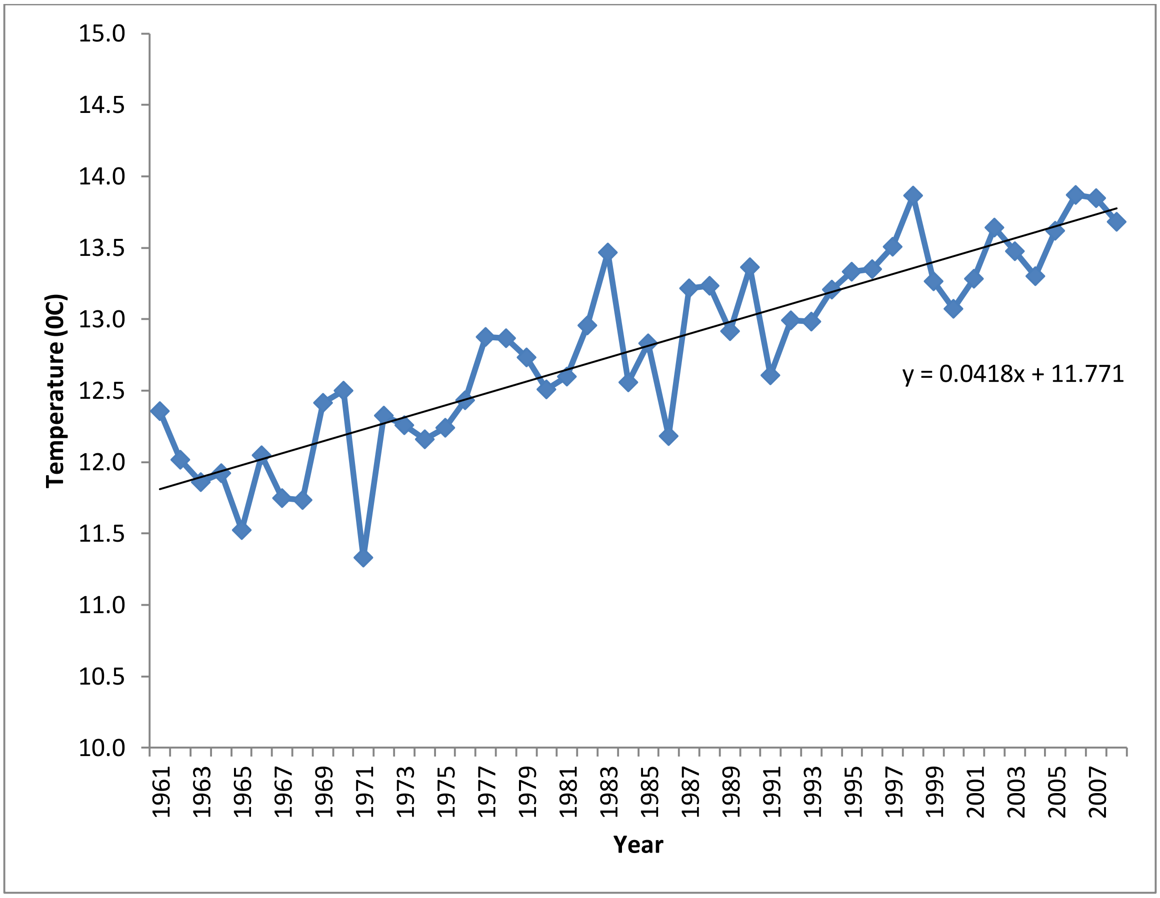

Figure 4.19: Inter-annual Variability of Minimum Temperature over Dagoretti

The variability in minimum temperature over Dagoretti corner seems less pronounced as compared to the maximum temperature variability. However, there are few spikes in the years 1971, 1981, 1987 and 1997 (Figure 4.19).They may be associated with the 10 year solar cycle. It is evident that there is a gradual increase in mean minimum temperature.

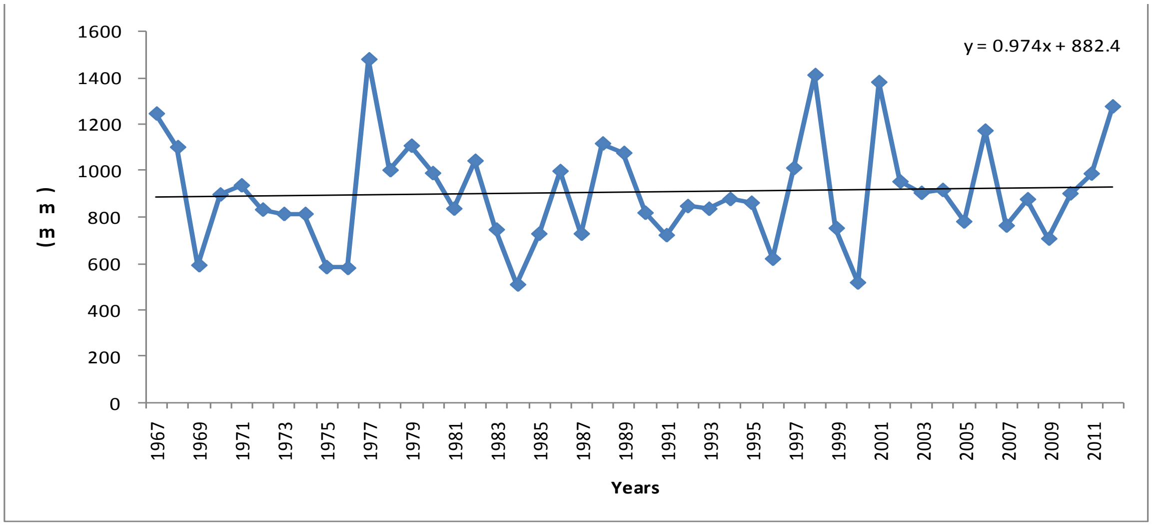

Figure 4.20: Variation of Total Annual Rainfall and Trend for Wilson

Rainfall variability over Wilson Airport station shows notable fluctuations (Figure 4.20). A few year exhibit pronounced variability, including 1967, 1977, 1998, 2001 and 2005. These fluctuations are almost similar those of Dagoretti corner station. This suggests that similar rainfall generating systems generally influence the two stations.

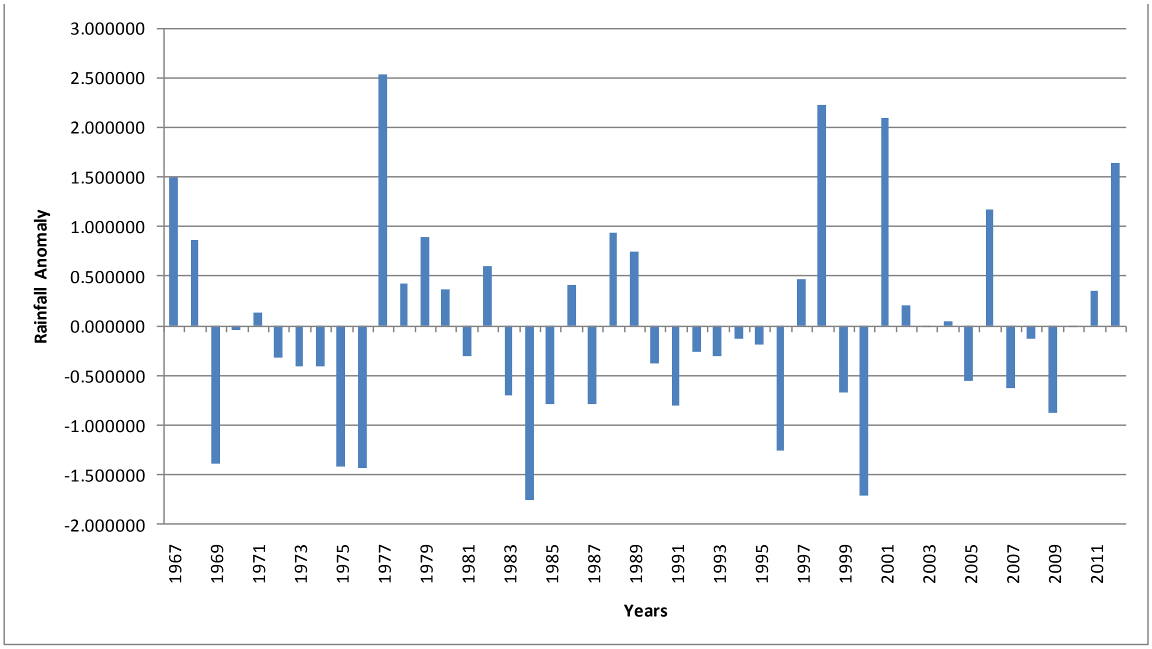

Figure 4.21: Variation of Annual Rainfall Anomalies for Wilson

Figure 4.21 shows existence of extreme rainfall occurrences after every 4 to5 years. In the latter years there are more positive anomalies than the former years. A striking anomaly in 1977 is notable. Wilson Station had the highest anomaly compared to all the other three stations.

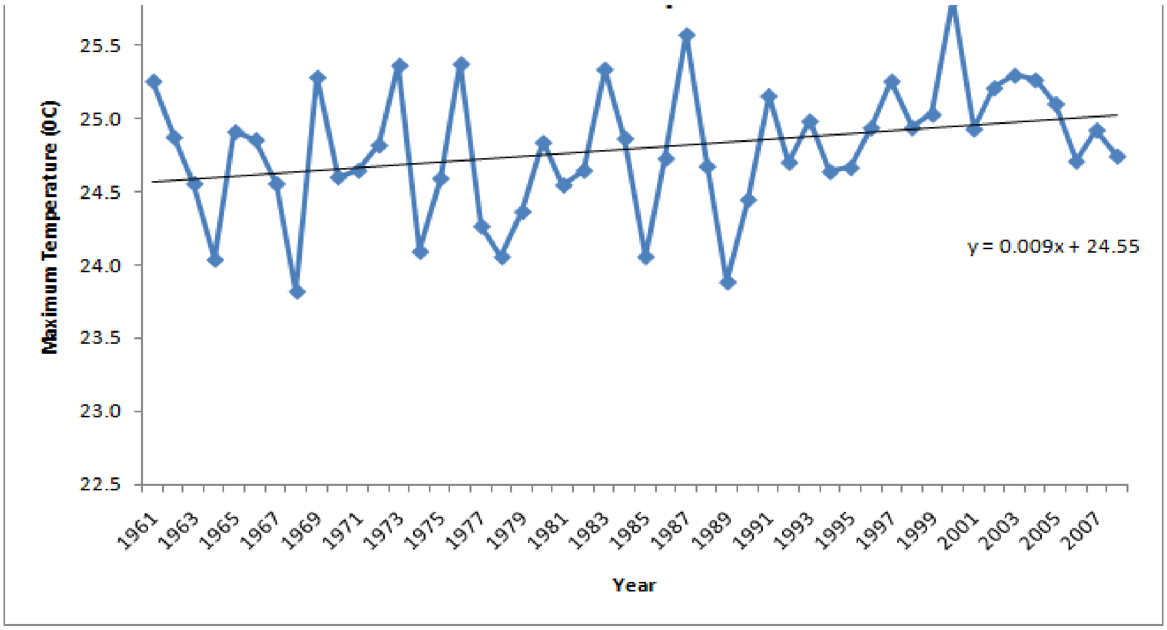

Figure 4.22: Variation of Mean Annual Maximum Temperature for Wilson

Maximum temperature variability over Wilson Airport station is observed, with the later years being less pronounced (Figure 4.22). This observed variability cuts across all the four stations.

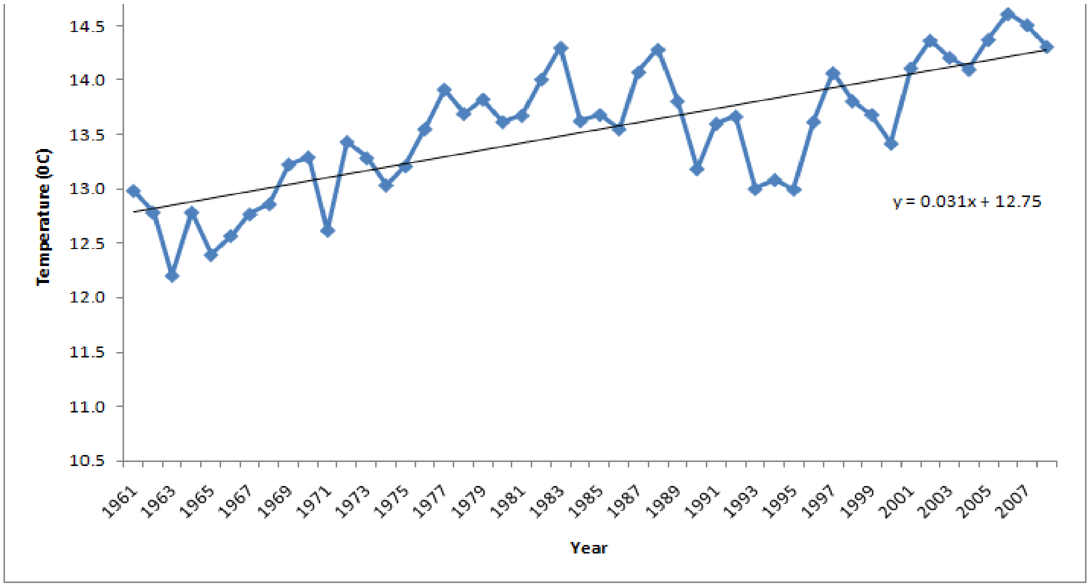

Figure 4.23: Variation of Mean Annual Minimum Temperature for Wilson

The minimum temperature over Wilson Airport station shows year to year variability (Figure 4.23). There is also evidence of steeper increase of minimum temperature than the corresponding maximum temperature.

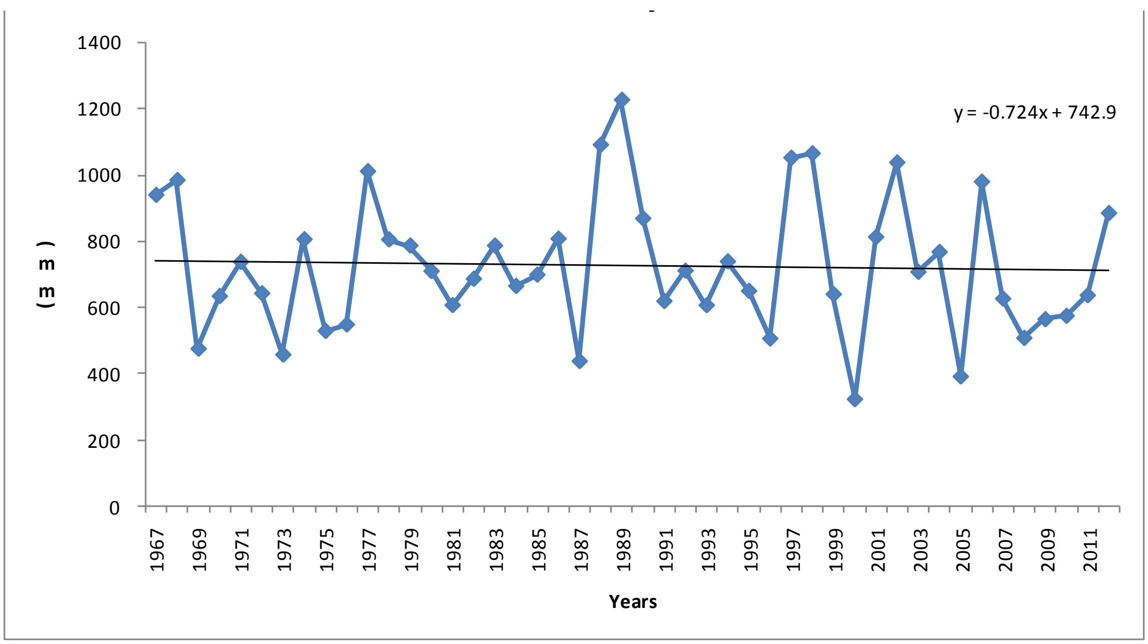

Figure 4.24: Inter- annual Rainfall Variability over JKIA

The rainfall variability over JKIA station shows year to year fluctuations (Figure 4.24). However, since 1986, the fluctuations seem to be more pronounced. 1988 was the year with largest variability as corroborated by Figure 4.25. The general annual trend of rainfall for this area shows that it was decreasing.

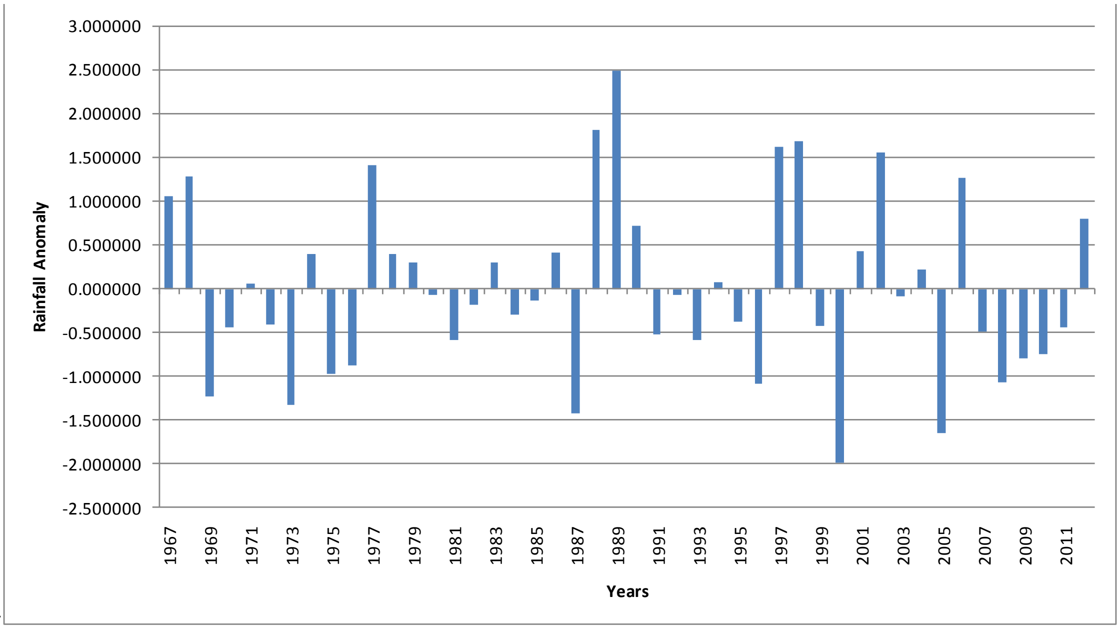

Figure 4.25: Variation of Annual Rainfall Anomalies for JKIA

Rainfall anomalies over JKIA indicate that in the period around 2006 to 2010, there were consecutive years with persistent below normal rainfall occurrences. This is the only period with such an extreme pattern. The amplitudes of the negative and positive anomalies are relatively similar, apart from 1988 which had an anomaly of +2.5 standard deviations which is indicative of possible flooding at the airport.

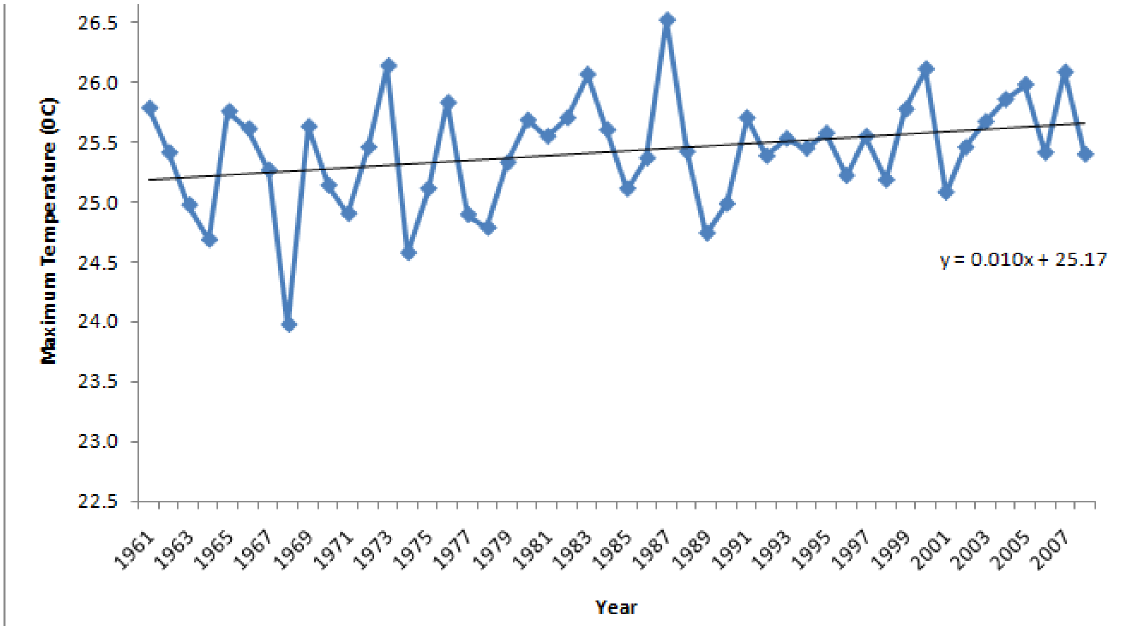

Figure 4.26: Inter- annual Variability of Maximum Temperature over JKIA

Year to year fluctuations are observed in the inter-annual maximum temperature patterns over JKIA. The last decade shows less variability than previous ones (Figure 4.26).

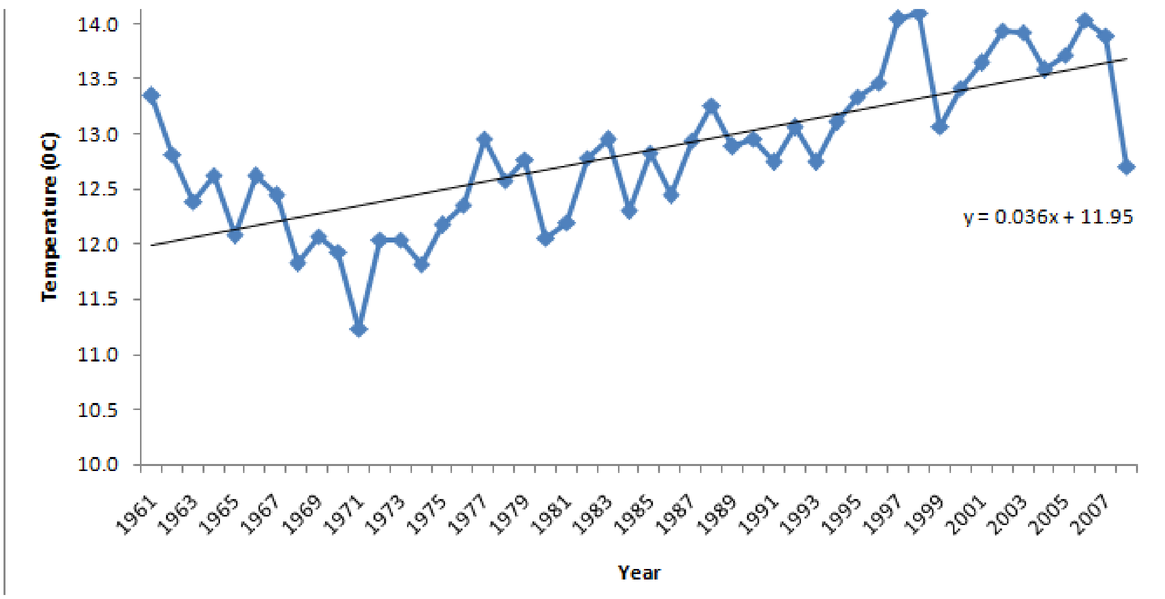

Figure 4.27: Inter- annual variability of Minimum Temperature over JKIA

Inter-annual minimum temperature over JKIA shows low variability (Figure 4.27). However, the period 1961 to 1971 portray a curios pattern of general decrease in temperature. This pattern is unique compared to the other three stations. This may be associated to some microclimatic influence over the area. Further studies may shed more light to this observation.

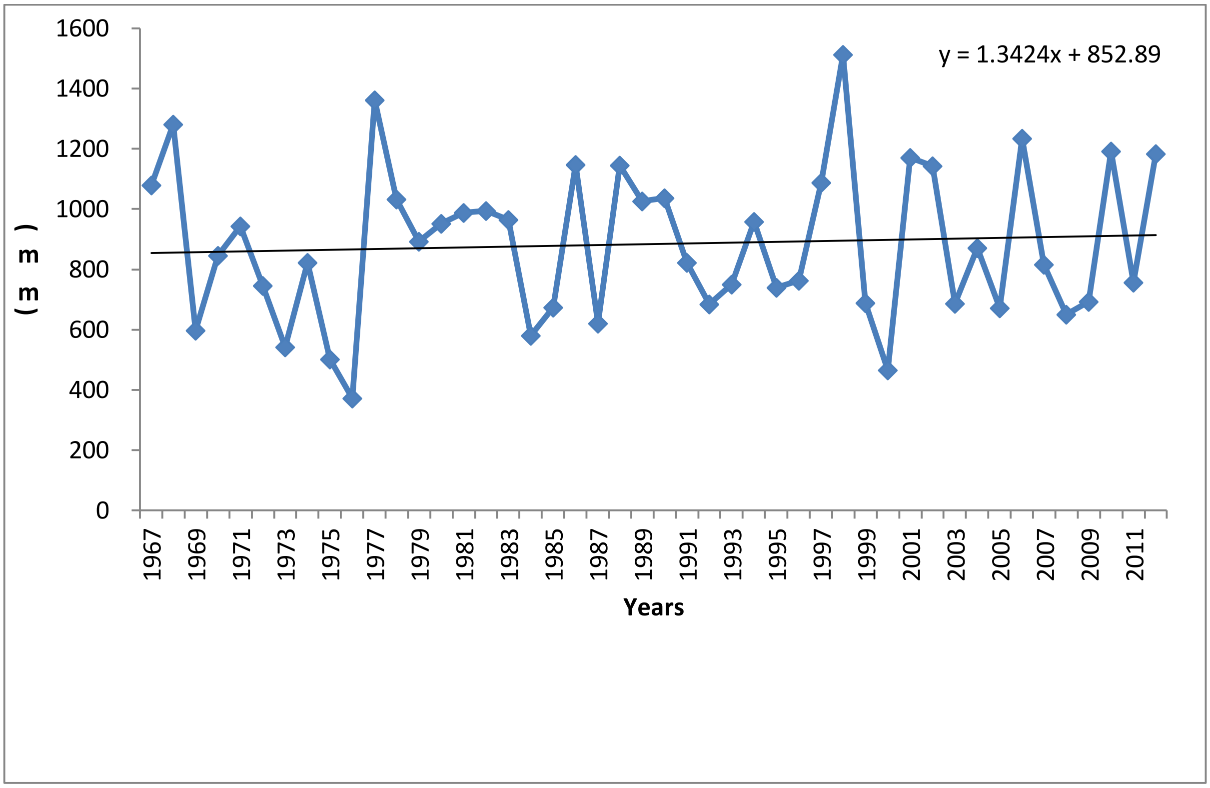

Figure 4.28: Inter -Annual Rainfall Variability over Moi Airbase

Year to year annual rainfall variability is evident (Figure 4.28). However, the period 1979 to 1983 showed virtually no variability. This seems to be unique for Moi Airbase station.

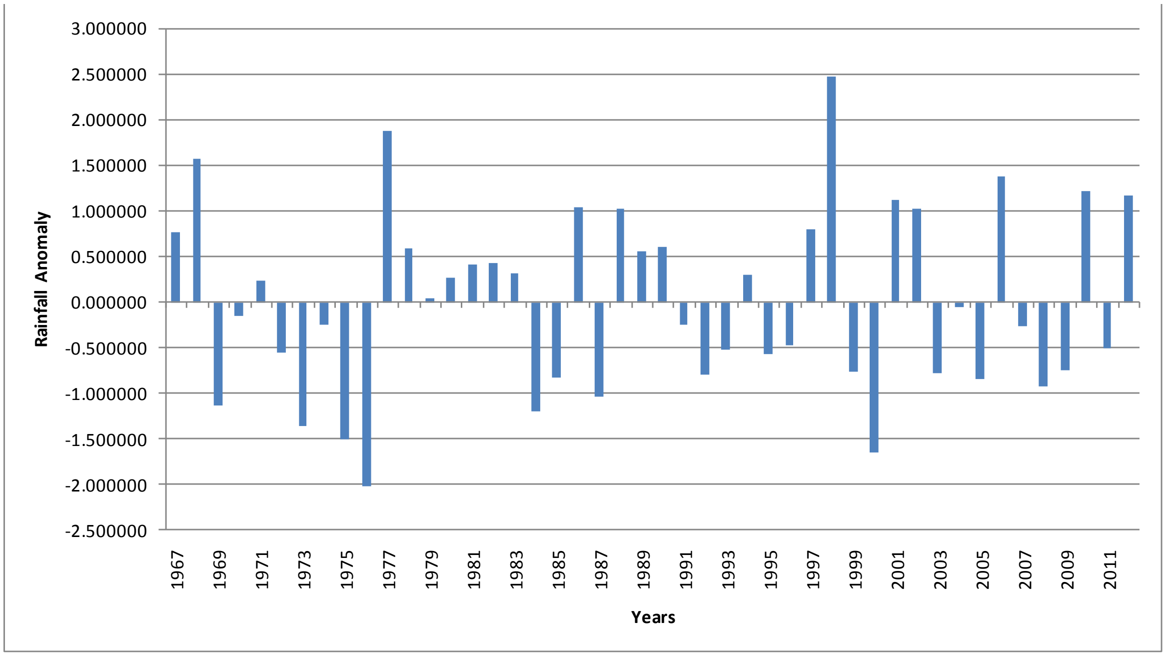

Figure 4.29: Rainfall anomaly over Moi Airbase

Rainfall anomalies over Moi Airbase as shown in Figure 4.29 are indicative of below normal period, from 1969 to 1976, apart from 1971 . From 1977 to 1982 the rainfall was above normal. Subsequent years do not show that pattern. This points out that there has been a shift in the inter-annual rainfall pattern. This may suggest increasing influence of the changing high density of built- up area around the station, thus altering the rainfall pattern.

4.3.2 Rainfall and temperature trend analysis

Analysis of rainfall across the four stations reveals no significant trend. Visual comparison of the trend lines for the four stations indicates a general increasing pattern, although with the gradient of the slopes being positive and rather gradual (Table 4.1). However, JKIA shows a gradual negative gradient, but all the same insignificant. Therefore the microclimate of Nairobi may not be inferred on the basis of annual rainfall trends.

Table 4.1 Significance of Trend analysis

Station	Climate Parameter	Regression equation	Test of Significance of Trend
Dagoretti Corner	Rainfall	Y = 970.8+1.98X	Not Significant
	Maximum Temperature	Y = 23.3+0.02X	**Significant**
	Minimum Temperature	Y = 11.8+0.04X	**Significant**
Wilson Airport	Rainfall	Y = 882.4+0.97X	Not Significant
	Maximum Temperature	Y = 24.6+0.01X	Not Significant
	Minimum Temperature	Y = 12.8+0.03X	**Significant**
JKIA	Rainfall	Y= 742.9-0.72X	Not Significant
	Maximum Temperature	Y= 25.2+0.01X	Not Significant
	Minimum Temperature	Y = 12+0.04X	**Significant**
Moi Airbase	Rainfall	Y = 852.8+1.34X	Not Significant
	Maximum Temperature	No sufficient Data	N/A
	Minimum Temperature	No sufficient Data	N/A

Minimum temperature across the city of Nairobi shows a significant increase (Table 4.1). All the stations depict this pattern. The results mean that urbanization strongly affects minimum for Nairobi. The slope terms of all the stations are comparable. This may suggest an enhanced Urban Heat Island effect probably due to increased heat capacity of urban structures together with reduced evaporation in the city environment (Ongoma, *et al.*, 2012 and Argueso, *et al*, 2014). However, there is a significant increase in maximum temperature over Dagoretti alone. This is a further evidence of the existence of a unique microclimate over Dagoretti as compared to the other stations.

4.3.3 Results from Statistical Analysis of Urbanization impact on Microclimate

The influence of urbanization on rainfall, maximum and minimum temperature and vegetative cover was computed using correlation and regression analyses (Table 4.2a).

Table 4.2a: Correlation of Population with Minimum Temperature

Station	**Season**	**Correlation Coefficient (r)**
Dagoretti Corner	JF	**0.595**
	MAM	**0.701**
	JJA	**0.63**
	SOND	**0.803**
	Ann	**0.828**
Wilson Airport	JF	**0.551**
	MAM	**0.474**
	JJA	**0.506**
	SOND	**0.488**
	Ann	**0.634**
JKIA	JF	**0.666**
	MAM	**0.656**
	JJA	**0.55**
	SOND	**0.82**
	Ann	**0.826**

Minimum temperature in all stations is significantly and positively correlated with population (Appendix 4 and Table 4.2a). This is true for not only the annual mean but also in all the four seasons. This could be connected to the Urban Heat Island (UHI) phenomenon. Urbanization is impacting on minimum temperature over the city of Nairobi. The results suggest that the UHI may cover a region beyond the analysed stations. Inclusion of neighbouring stations to the city in a future study would shed more light on this finding and also elucidate on the phenomenon of climate change.

Table 4.2b: Correlation of Population with Maximum Temperature

Station	Season	Correlation Coefficient (r)
Dagoretti Corner	JF	0.074
	MAM	0.110
	JJA	**0.424**
	SOND	0.129
	Ann	**0.307**
Wilson Airport	JF	0.097
	MAM	0.211
	JJA	**0.444**
	SOND	0.099
	Ann	**0.355**
JKIA	JF	0.076
	MAM	0.179
	JJA	**0.389**
	SOND	0.096
	Ann	**0.311**

Population and maximum temperature correlations are mostly insignificant except for JJA seasons and annual averages, with all the stations exhibiting positive correlation. This alludes to reduction of UHI during the day due to incoming solar radiation. In addition, waste heat emission by the urban population during the cold season is enhanced with respect to the maximum temperature.

Table 4.2c: Correlation of Population with Rainfall

Station	Season	Correlation Coefficient (r)
Dagoretti Corner	JF	0.113
	MAM	-0.116
	JJA	-0.055
	SOND	0.152
	Ann	0.004
Wilson Airport	JF	0.094
	MAM	-0.150
	JJA	-0.029
	SOND	0.181
	Ann	0.025
JKIA	JF	0.020
	MAM	-0.125
	JJA	-0.155
	SOND	0.080
	Ann	-0.033

Analysis of the relationship between seasonal and annual rainfall versus population reveals a non-significant correlation (see Appendix 4). Influence of urbanization on rainfall has been the subject of many studies around the world.

4.3.4 Results of analysis of microclimatic zones

Analysis of Mean Monthly rainfall totals (Figure 4.11) shows the existence of four unique microclimatic zones, each station representing one zone. Table 4.3 below confirms this observation. Correlation analysis among the four different stations illustrates these unique patterns.

Table 4.3 Correlation coefficients and coefficient of determination for the four stations.

	Dagoretti		**Wilson**		**JKIA**		**Moi Air Base**	
	r	R^2	r	R^2	r	R^2	r	R^2
Dagoretti								
Wilson	0.899	0.808						
JKIA	0.763	0.582	0.735	0.540				
Moi Air Base	0.854	0.729	0.857	0.734	0.827	0.684		

On the basis of the four stations, four unique microclimates are delineated. The exact spatial delimitation would be attainable with a higher density network of stations within the city of Nairobi. Maximum temperature across the city of Nairobi is characterised by microclimatic variability, with four zones being discernible (Figure 4.12). Minimum temperature shows two maxima and a minimum (Figure 4.13).

4.3.5 Energy Consumption Patterns over Nairobi

This section discusses the energy consumption patterns in Nairobi based on motor vehicle emissions of carbon dioxide per distance travelled. Omwenga (2011) estimated the motor vehicle population in Nairobi to be 30% that of the national figures and established the rate of increase in number of vehicles in Nairobi as 11.3% (Table 4.4).

Table 4.4: Cumulative number of registered vehicles in Nairobi

Year	Cumulative number of registered vehicles in Nairobi
2008	389256
2009	436275
2010	495377
2011	554973
2012	606887
2013	675465
2014	751792
2015	836745
2016	931297

After ERC (2015)

Table 4.5 presents the average CO_2 emissions in gCO_2/km between 2010 and 2012. It is noted that the average CO_2 emissions have been on the increase within this period indicating increase in energy consumption within the city. Albeit the very short data length for conclusive determination of causal relationships, there is some evidence that energy conversions drive urbanization in Nairobi.

Table 4.5: Average CO_2 emissions

Year	Average
2010	57.02
2011	57.54
2012	58.14

After ERC (2015)

4.3.6 Results of Rainfall Anomalies against NDVI Anomalies

There is a significant correlation of 0.75 between Rainfall anomalies with NDVI anomalies at time lag of one month (see Appendix 5 and Figure 4.32). Therefore, the variance explained is 0.563. This implies that the greenness of the city is driven mainly by rainfall. Seasonal vegetation is dominant over perennial trees. In addition, no irrigated greening intervention can be discerned from the NDVI analysis. Greening improves air quality by decreasing day time air temperature as well as increasing the removal rate of air pollutants from the urban atmosphere (Loughner, 2012). Greening also affects urban hydrological cycle through changes in runoff, evapo-transpiration and precipitation. Strategies to utilise storm water for greening the city as well as urban agriculture are recommended.

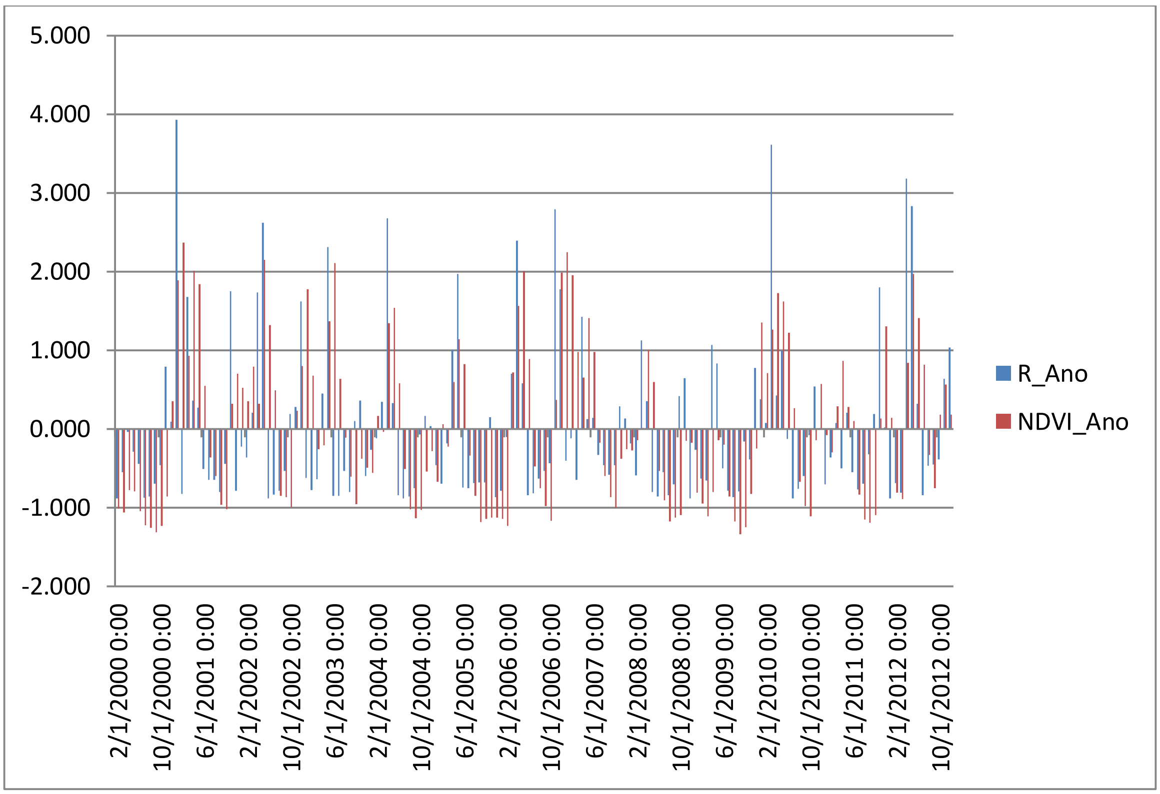

Figure 4.30: Monthly NDVI anomalies versus Rainfall anomalies over Nairobi

Note: R_Ano signifies Rainfall Anomalies while NDVI_Ano is for NDVI Anomalies

4.3.7 Results of NDVI and Rainfall over Nairobi County

The annual anomalies attest to the observed monthly pattern (Figure 4.31). However, in 2003 and 2007, an inverse relationship was observed contrary to expectation. This may be connected to the OND rainfall seasons of the previous years. That is, there was enough moisture for the vegetation to have grown even though with a corresponding negative rainfall anomaly (see appendix 5).

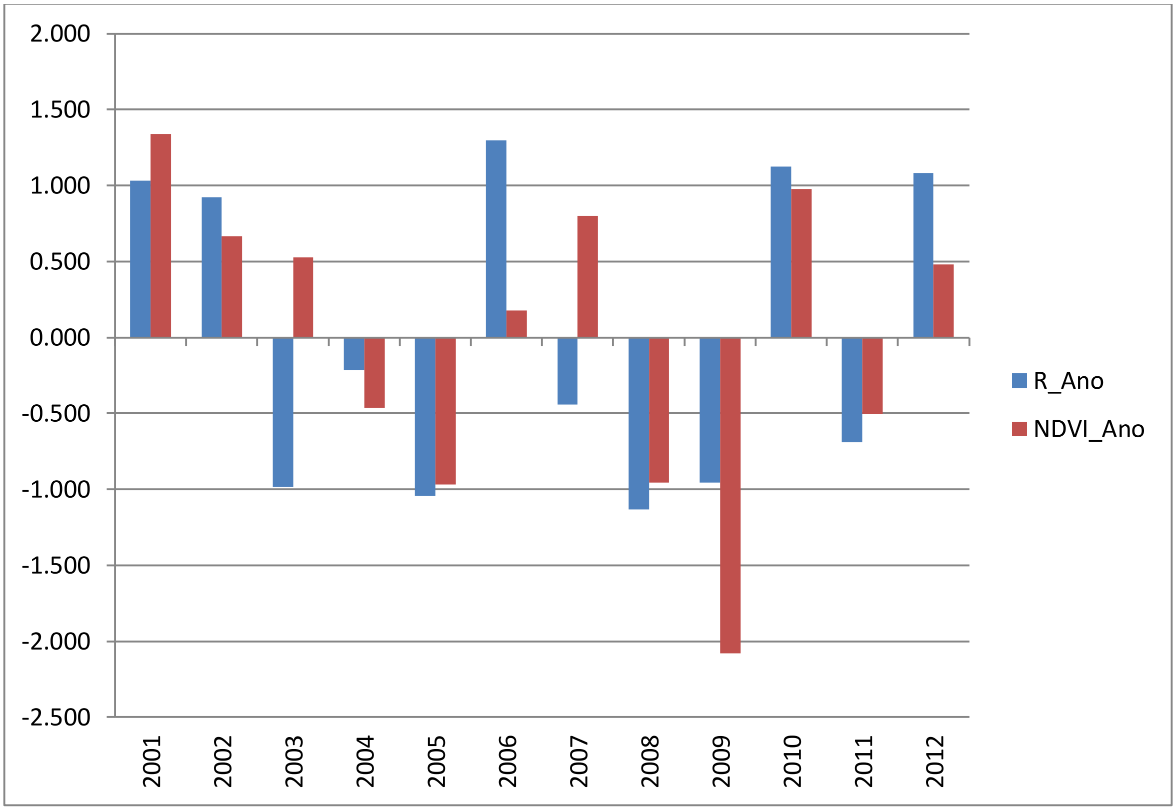

Figure 4.31: Annual NDVI anomalies versus Rainfall over Nairobi

Note: R_ Ano and NDVI _ Ano are as described in Figure 4.30

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

This chapter gives some conclusions and recommendations from this study.

5.1 Conclusions

The study found that temporal patterns of rainfall over the city of Nairobi depict no discernible influence due to urbanization. This may be attributed to the nature of rainfall formation mechanisms which include local convective systems, meso-scale and large scale weather systems. However, it is observed that it rains every month in the city of Nairobi and the most frequent monthly rainfall distribution is between 49.0 mm and 99.0mm, with the most frequent amount being 50mm. The short rains season is ideally ND, even though previous studies have adopted OND. No justification based on the spatial and temporal analyses the 46 years of monthly rainfall data support the OND concept.

There is an increasing trend in minimum temperature across all the four stations in the city attributable to urbanization effect. However, there is significant positive trend in maximum temperature over Dagoretti station as compared to the other stations. This could be attributed to the fact that this meteorological station is located uphill, downwind of CBD and gets UHI influence on maximum temperature characteristics. Despite this, further research will help elucidate the phenomenon especially in the light of climate change.

Population and maximum temperature for JJA seasons and annual averages in all station are significantly and positively correlated. This may be associated with reduction of UHI during the day due to incoming solar radiation. In addition, waste heat emission by the urban population during the cold season is expected to be relatively elevated with respect to the maximum temperature.

The most representative station in studying the urban canopy characteristics of the city of Nairobi is Moi Airbase. The microclimate of the city varies from station to station, with the wettest part being to the west, where Dagoretti station is located and the driest being to the south east where JKIA is located.

5.2 Recommendations and Suggestions for Further Research

Further research on the impacts of the most frequent monthly rainfall amounts of about 50mm on the city's environment and operation will bring to light the most prudent mechanisms critical for use as intervention measures such greening and control of surface runoff in the city. Further analysis of the micro-climate of Nairobi city in future is recommended especially with availability of more weather stations around the city of Nairobi. There is need to monitor and continuously document energy dynamics in domestic and industrial activities within the city of Nairobi.

It would be interesting for Kenya Meteorological Department and the County Government to investigate further the impacts of 50mm of monthly rainfall, which is most frequent in Nairobi, on the urban surfaces in terms of greening of the city, flood mitigation and rainwater harvesting.

Further investigation on the influence of population on maximum JJA temperatures will clarify the role of population dynamics and waste heat emission in the city of Nairobi. As regards minimum temperature, it is noted that UHI may cover a region beyond the analysed stations and as such, inclusion of neighbouring stations to the city in a future study would shed more light on this finding.

Studies on urban energy dynamics and time series are required, especially as pertains to energy consumption and emissions, including waste heat. These studies should be iniated by ERC and academic researchers in line with Energy Regulations 2018 .This will help explain the UHI's influence on minimum and maximum temperature.

Enhanced greening of the city by the County Government of Nairobi and other stakeholders is recommended. Strategies to plant trees and increase vegetative cover will go a long way in increasing the CO_2 sink and hence contributing to ambient temperature reduction. Further, strategic use of rain water harvesting from rainfall runoff across the city will contribute to the enhanced greening. This may be achieved by construction of storage systems such as water tanks or dams by Nairobi Water and Sewerage Company to store storm water. This will reduce flooding of city streets together with the risk of emergence of attendant water-borne diseases.

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APPENDICES

Appendix 1: Rainfall Raw Data

TOTAL MONTHLY RAINFALL FOR SYNOPTIC STATIONS IN NAIROBI

MOI AIR-BASE

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1967	0.0	1.8	39.4	180.4	542.5	42.7	15.2	43.0	22.3	98.9	70.5	23.1
1968	0.0	209.9	280.3	278.0	61.7	60.2	2.1	3.0	1.8	59.3	250.9	74.8
1969	62.6	62.5	49.0	24.6	170.6	5.8	1.4	27.6	0.0	20.0	156.2	17.6
1970	113.8	70.0	192.9	156.8	101.2	39.3	1.9	5.3	0.0	40.0	89.1	34.7
1971	84.4	0.0	21.5	261.2	305.3	16.9	21.0	47.0	14.8	15.0	50.2	106.6
1972	11.2	54.3	39.8	14.8	121.2	156.8	7.1	5.4	35.9	152.0	128.7	17.6
1973	96.3	82.2	11.0	126.2	69.6	15.3	5.8	5.2	35.8	12.5	62.9	18.1
1974	5.2	8.4	105.6	320.3	38.4	66.6	70.4	22.1	15.8	27.0	99.2	43.8
1975	7.5	3.9	26.4	42.1	81.6	8.3	36.5	0.4	82.2	48.1	130.8	32.9
1976	6.1	31.5	25.2	9.1	18.5	19.1	10.4	4.4	55.9	9.6	86.6	94.9
1977	15.5	65.1	32.2	341.0	322.9	81.0	31.1	95.6	9.4	36.8	233.8	98.2
1978	148.4	79.7	177.7	217.9	28.0	5.7	12.3	22.2	3.6	86.8	117.9	132.5
1979	105.7	157.1	97.9	116.1	147.0	21.6	12.3	3.9	6.0	16.5	190.9	18.0
1980	96.0	8.6	51.4	100.1	339.2	53.9	0.6	15.4	3.4	28.6	238.9	16.3
1981	5.8	2.4	115.1	277.9	316.0	2.0	7.7	20.2	75.5	58.1	38.4	69.9
1982	3.5	15.0	33.0	173.6	162.4	54.9	8.8	3.5	13.7	178.2	201.6	145.5
1983	0.3	150.2	68.3	239.1	33.6	53.6	38.3	42.3	1.9	67.9	23.5	245.6
1984	17.8	2.9	6.8	45.5	0.0	1.8	10.5	16.5	18.6	154.7	210.2	95.9
1985	0.3	77.0	77.3	180.5	53.9	12.8	43.4	1.7	29.1	32.1	57.6	106.9
1986	20.4	0.0	69.8	348.3	334.8	22.5	1.8	0.5	13.9	34.9	174.3	125.3
1987	38.0	16.6	17.1	219.1	92.6	41.0	39.8	22.6	8.2	0.0	98.8	26.5
1988	91.5	9.8	166.7	391.3	104.2	71.5	5.7	9.7	42.8	24.8	98.1	128.5
1989	114.1	22.6	101.5	164.1	145.5	7.4	40.2	35.0	29.5	52.7	108.0	206.6
1990	66.6	33.1	216.9	199.8	104.2	20.2	5.0	44.1	21.2	57.3	148.4	120.2
1991	34.9	5.7	176.0	119.3	151.6	29.6	7.6	38.0	3.4	28.1	152.8	75.2
1992	9.1	0.0	16.3	262.3	61.7	23.5	27.2	22.8	6.0	80.2	87.5	87.0
1993	268.1	77.8	15.8	27.4	79.5	52.9	1.6	22.7	0.0	21.6	97.9	84.7
1994	9.3	81.4	44.5	212.9	65.1	44.4	15.2	26.4	0.0	111.1	281.0	67.1
1995	52.6	62.4	162.5	110.0	61.8	58.1	7.2	21.8	7.6	55.1	84.6	55.8
1996	5.8	62.7	139.8	160.4	67.4	64.8	13.5	35.2	26.1	0.0	185.2	2.7
1997	0.0	0.0	20.8	314.9	128.9	45.5	32.8	33.2	0.0	69.1	308.6	134.9
1998	375.1	225.5	59.8	110.2	472.8	107.5	13.7	16.9	50.7	16.6	57.1	6.4
1999	1.6	2.4	128.8	126.4	4.5	3.4	10.2	21.8	30.7	24.2	204.1	130.3

2000	1.1	0.0	28.4	71.1	49.7	36.7	1.1	2.3	15.7	36.0	140.4	82.2
2001	403.4	5.2	215.0	104.7	97.2	31.4	19.9	20.1	7.0	36.8	220.9	8.6
2002	55.5	43.6	91.5	220.0	293.9	0.0	4.2	8.4	29.3	90.1	97.5	210.0
2003	22.0	8.9	20.4	112.0	268.2	3.2	3.1	29.8	6.9	82.7	104.5	23.9
2004	51.9	64.4	102.9	298.7	102.0	3.8	0.0	2.0	11.2	68.6	88.3	77.2
2005	35.9	15.9	58.8	158.4	239.7	11.6	11.1	16.7	17.4	17.5	87.1	1.5
2006	8.2	65.5	133.0	274.7	122.8	3.6	6.0	21.5	29.3	37.6	308.3	223.2
2007	40.7	64.3	20.1	194.1	84.4	85.9	46.4	35.5	25.7	35.4	98.7	85.1
2008	58.8	24.7	168.9	103.9	7.3	2.1	28.1	3.7	15.4	109.1	128	0.2
2009	52.3	21.2	19.3	163.7	144.3	32.3	8.5	1.3	7.6	61.2	41.7	139
2010	105.8	80.8	377.4	109.9	157.8	63.7	0.5	10.4	24.1	67.4	119.8	74.9
2011	15.0	43.8	80.5	32.5	91.6	28.1	10.1	16.1	47.0	90.4	225.4	75.7
2012	0.0	16.4	6.1	341.0	311.6	101.0	3.9	35.2	36.5	42.0	127.5	161.2

DAGORETTI

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1967	0.0	17.2	30.9	221.7	477.8	46.0	22.7	46.7	33.5	77.4	93.7	26.8
1968	0.0	172.2	192.7	293.4	127.2	42.1	4.9	3.0	14.4	35.0	284.0	79.3
1969	94.9	77.8	86.7	20.1	196.9	4.0	1.5	28.4	4.3	27.9	102.3	7.9
1970	92.6	12.9	148.4	347.8	224.8	24.2	14.6	4.6	4.5	28.4	113.0	44.2
1971	51.5	6.6	19.4	233.2	322.3	23.1	13.2	9.6	51.3	9.1	66.7	167.3
1972	18.5	76.4	37.2	19.6	228.6	141.3	16.5	4.6	55.7	195.9	125.3	13.0
1973	139.8	97.3	14.9	326.7	61.3	18.4	6.5	4.2	101.8	22.2	68.6	43.6
1974	7.4	9.9	140.4	255.1	49.9	96.6	69.1	9.6	18.2	28.8	98.3	34.9
1975	11.9	1.6	43.7	173.2	188.2	10.4	24.9	2.9	137.6	61.1	100.3	75.8
1976	22.7	42.3	31.0	98.7	85.9	46.3	18.0	18.3	61.1	13.3	177.6	97.4
1977	30.2	75.0	37.5	498.5	312.9	42.4	51.7	50.7	23.5	45.3	268.1	113.5
1978	143.5	34.2	298.9	257.7	36.8	8.5	11.0	64.9	15.4	133.6	125.9	128.9
1979	70.8	165.8	143.6	129.3	184.0	28.5	43.6	10.8	51.4	20.1	107.4	68.8
1980	91.9	13.0	37.9	105.9	418.5	27.2	2.1	17.3	25.2	30.1	250.6	33.5
1981	14.6	6.0	138.7	568.6	232.7	11.3	10.5	38.9	38.7	44.5	18.0	38.0
1982	0.0	19.4	61.7	214.3	217.9	35.9	27.0	8.5	34.1	151.8	220.0	163.7
1983	5.6	182.1	67.6	172.9	39.2	13.1	16.1	29.2	2.8	52.9	24.9	317.9
1984	4.4	1.0	6.3	78.5	3.1	6.3	7.8	7.6	30.6	123.2	140.3	73.6
1985	0.1	92.7	131.9	232.0	72.7	21.6	27.6	5.9	16.1	33.6	111.7	78.3
1986	12.5	0.0	80.1	239.1	259.1	26.2	1.1	3.7	0.2	25.3	192.5	120.8
1987	44.5	11.8	50.7	327.5	94.3	75.7	1.0	10.0	15.1	1.5	157.4	32.1
1988	76.0	25.3	163.8	388.5	241.8	90.6	13.6	30.0	14.8	25.5	82.9	145.8
1989	110.2	47.4	80.2	264.7	257.8	28.3	37.9	23.6	52.4	60.4	114.9	204.6
1990	52.7	27.6	215.8	247.3	219.4	9.7	15.7	8.6	24.8	63.5	140.0	92.9
1991	12.3	0.0	94.0	148.4	253.0	23.2	2.8	40.2	3.9	31.6	182.9	125.8

1992	8.0	73.6	30.2	419.6	94.4	28.3	40.1	5.3	5.6	51.2	134.9	98.4
1993	274.8	151.8	49.1	25.1	95.2	46.6	1.4	11.9	0.0	45.4	101.2	107.6
1994	9.9	92.8	59.1	247.0	114.3	19.8	19.3	53.9	3.4	87.8	245.5	67.7
1995	15.1	116.8	168.2	109.7	210.3	31.3	11.8	25.8	29.2	116.5	95.2	33.2
1996	18.2	45.5	121.4	112.8	89.4	58.3	19.5	28.4	21.9	1.5	167.8	0.0
1997	1.3	0.0	35.0	427.8	13.8	4.9	5.0	15.3	0.5	155.7	383.8	196.1
1998	361.5	144.2	73.9	111.8	412.7	86.4	41.0	25.3	26.0	7.9	56.2	68.9
1999	17.6	0.5	185.0	174.1	25.8	4.4	4.9	61.2	15.9	22.4	286.7	183.7
2000	2.7	0.0	39.5	107.7	120.3	24.1	4.6	9.2	38.6	25.7	174.7	98.0
2001	449.5	31.7	294.5	145	108.9	106.9	25.9	17.6	28.6	38.3	159	13.3
2002	43.0	55.4	89.9	205.2	142.1	0.6	22.5	6.4	26.2	75.2	161.5	262.8
2003	52.0	15.7	28.6	232.9	262.9	38.0	2.2	11.3	44.2	70.4	167.4	20.2
2004	133.9	31.7	85.8	322.1	199.2	9.4	0.4	10.1	21.2	72.2	167.9	62.6
2005	102.8	39.2	62.9	162.8	243.2	16.5	16.6	12.1	21.0	45.7	114.4	0.2
2006	8.1	10.8	156.2	307.9	146.7	10.2	4.5	45.1	45.0	36.6	310.1	180.4
2007	28.3	107.3	31.2	199.6	110.0	47.7	46.2	36.7	51.5	38.4	68.9	39.2
2008	45	22.4	133.2	100.3	32.6	3.6	55.1	8.6	89.4	123.8	172	0.5
2009	64.5	20.1	37.9	79.3	158.1	101.5	13.2	3.6	9.1	98.4	76.5	121.1
2010	76.0	107.3	252.0	157.3	353.6	37.7	2.5	35.3	28.9	99.2	110.5	65.1
2011	14.2	125.8	128.5	49.4	79.1	125.8	8.7	41.8	31.8	132.6	166.0	129.2
2012	0.0	9.9	5.5	469.1	255.3	26.2	8.6	85.6	9.7	62.8	278.3	268.3

WILSON

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1967	0.0	62.0	28.2	239.4	577.1	31.9	17.2	31.9	21.6	94.6	120.8	18.7
1968	0.0	112.3	153.0	324.7	124.5	27.8	1.7	3.1	4.6	37.8	253.3	57.0
1969	81.8	40.4	65.3	19.2	167.7	2.7	1.4	29.3	0.2	30.3	130.2	26.0
1970	110.9	18.4	188.8	220.9	168.2	27.7	6.0	1.3	1.2	51.2	69.0	33.5
1971	64.0	1.2	14.0	285.3	335.7	12.7	8.0	20.6	20.6	17.8	36.6	119.8
1972	9.9	71.2	39.8	10.9	116.7	137.0	24.5	4.1	82.2	204.4	112.7	19.0
1973	183.7	86.0	13.9	249.6	75.0	14.4	4.9	2.8	87.4	15.8	60.9	19.4
1974	15.8	11.5	145.0	248.7	56.0	88.9	53.3	10.2	22.2	22.3	102.9	37.1
1975	5.5	0.8	27.4	134.2	95.5	8.6	12.4	1.0	99.7	64.4	96.5	40.3
1976	3.5	17.5	27.3	112.3	74.2	38.5	13.6	11.7	53.4	18.2	114.1	98.3
1977	22.6	47.9	38.4	450.5	308.7	69.5	34.2	89.4	18.1	26.4	244.4	125.4
1978	140.4	36.1	218.2	221.8	31.3	6.6	7.9	27.4	7.8	66.9	93.9	143.1
1979	35.7	346.2	124.4	112.8	130.6	34.9	28.1	10.6	42.2	27.0	87.8	125.5
1980	90.5	8.6	51.7	105.3	454.1	19.1	1.7	8.8	5.9	18.2	197.2	27.6
1981	3.7	2.0	106.3	323.4	144.9	30.7	9.6	30.4	43.9	41.7	40.2	59.9
1982	2.4	14.1	31.2	192.9	164.4	8.4	13.5	3.1	15.9	186.4	220.1	188.9
1983	1.8	128.0	43.4	137.1	38.0	31.0	22.5	29.8	3.6	63.6	22.4	225.7

1984	7.6	1.6	5.3	87.3	1.6	5.0	12.8	22.4	13.9	144.8	123.9	85.6
1985	0.0	91.2	88.0	188.8	59.7	32.4	50.2	3.1	22.5	20.6	67.5	105.0
1986	17.1	0.0	65.2	284.5	300.1	3.7	0.5	1.6	1.0	22.8	157.3	143.5
1987	40.6	13.6	23.9	278.7	109.0	71.2	15.7	8.4	15.2	1.9	125.3	25.8
1988	78.5	28.4	181.2	322.7	151.1	103.6	7.3	13.1	30.2	9.0	66.7	123.5
1989	95.7	25.1	65.1	277.4	168.3	2.8	59.2	19.5	11.1	45.8	103.5	201.4
1990	46.2	28.8	271.0	171.9	76.1	1.7	3.3	11.1	6.2	34.7	98.4	69.5
1991	28.9	2.4	151.9	114.2	144.2	30.6	2.6	1.0	4.0	28.6	149.6	65.2
1992	1.5	15.1	27.4	414.6	56.8	16.6	88.1	8.7	4.9	37.5	80.1	96.2
1993	272.2	104.0	9.2	9.6	122.9	49.4	0.0	12.8	0.0	49.7	128.1	78.2
1994	12.0	52.4	54.5	172.3	109.9	73.6	10.2	40.0	2.3	69.4	230.9	50.3
1995	39.6	59.6	136.5	80.2	122.3	85.1	18.1	17.8	22.2	118.2	122.3	39.8
1996	6.9	39.6	135.5	95.3	60.1	77.0	13.2	24.0	3.8	5.3	161.5	0.0
1997	0.0	0.0	15.8	324.5	130.7	6.9	7.4	27.9	0.0	102.1	295.3	100.1
1998	436.8	112.2	75.0	84.5	460.2	63.4	62.9	15.2	11.0	0.0	56.6	30.4
1999	3.0	0.0	126.6	156.3	10.6	1.5	4.2	31.9	17.8	33.2	242.3	125.7
2000	9.8	0.0	32.7	85.4	52.7	45.9	3	4.2	23.5	43.9	140.3	78.9
2001	466.3	6.3	283.9	111.5	86.9	66.1	35	16.7	15.9	67.7	211.5	10.1
2002	63.2	13.1	82.2	141.1	117.6	0.0	6.0	3.3	25.6	75.5	109.3	315.4
2003	31.5	4.2	26.6	194.7	364.2	8.5	0.3	60.3	33.7	52.1	106.9	21.2
2004	123.8	62.8	88.2	295.3	79.8	6.0	0.0	0.0	11.1	58.0	117.4	74.1
2005	49.2	14.5	126.5	157.1	285.2	6.6	14.9	5.8	15.8	27.5	73.6	4.7
2006	9.2	42.3	143.2	249.8	89.2	9.2	3.9	29.0	67.5	26.3	293.0	207.7
2007	53.3	104.9	21.6	176.1	60.3	75.4	19.0	21.9	63.5	29.7	87.3	51.0
2008	51.6	24.7	171.4	95.1	19.1	21.4	39.2	6.9	64.7	133.3	248.3	1
2009	59.4	15.3	19.4	83.1	111.5	52	11.4	0	6.9	84.6	91	173.6
2010	65.3	116.6	255.6	82.9	57.6	16.9	1.0	23.9	34.8	117.2	79.0	50.6
2011	10.4	74.8	144.6	46.8	45.4	102.2	10.7	71.0	32.3	145.0	202.3	101
2012	0.0	15.1	3.1	443.3	180.7	33.1	30.0	35.3	19.3	60.7	219.2	234.2

JKIA

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1967	0.5	34.6	37.8	214.2	372.5	37.4	8.4	32.1	9.3	66.6	86.4	40.3
1968	0.0	141.0	138.3	251.4	61.9	20.7	1.9	1.9	0.0	34.5	278.6	54.6
1969	76.6	41.0	41.8	8.7	138.2	2.4	0.6	13.5	1.4	27.9	111.3	13.6
1970	126.0	3.2	111.4	190.1	93.5	9.7	10.3	1.4	0.6	32.1	34.0	23.1
1971	33.9	1.6	5.1	270.6	165.0	12.0	8.1	38.1	11.7	2.6	26.5	163.2
1972	11.9	53.1	28.0	0.7	80.1	120.6	8.6	2.4	54.7	161.5	97.4	24.8
1973	106.1	33.7	1.4	54.5	61.4	21.8	0.9	3.0	62.7	14.5	80.3	18.8
1974	25.3	60.7	136.6	201.4	86.6	48.1	43.6	18.6	32.9	10.9	70.9	71.0
1975	9.4	0.1	31.4	123.8	90.7	11.4	25.0	0.2	78.0	31.1	92.4	37.1
1976	2.8	24.5	50.5	132.6	33.1	21.0	28.5	4.1	40.4	4.6	111.1	96.8
1977	12.9	50.3	30.8	348.4	144.2	17.9	19.2	51.7	12.8	16.9	231.1	75.2
1978	76.8	57.7	202.9	128.1	36.1	3.1	20.8	3.9	6.9	24.3	126.6	118.8
1979	78.4	288.5	67.9	99.9	94.0	17.4	14.4	5.2	0.7	6.3	80.4	34.6
1980	56.7	10.6	78.0	93.9	307.0	16.5	0.0	14.4	0.3	25.0	6.4	101.9
1981	2.0	0.8	80.5	196.7	185.2	0.0	3.5	3.4	21.1	30.7	32.8	51.6
1982	1.8	4.6	11.6	120.5	91.4	8.1	8.1	13.3	17.9	147.8	149.4	113.1
1983	1.0	160.3	38.7	208.3	29.2	68.8	6.2	17.4	0.9	29.2	31.8	195.9
1984	7.8	0.0	17.6	64.7	3.4	0.7	6.4	5.5	####	134.1	104.5	203.7
1985	12.3	141.2	59.3	189.5	54.3	16.7	8.2	1.3	17.0	35.1	46.1	118.9
1986	34.7	0.0	112.1	245.2	167.8	11.1	0.1	2.2	1.5	3.0	140.4	90.1
1987	21.5	8.5	7.0	120.0	92.8	78.6	0.6	16.5	9.0	0.0	63.6	21.6
1988	1.6	146.7	223.6	52.5	23.0	5.0	4.4	20.5	46.2	57.4	87.5	422.8
1989	108.3	30.2	70.8	217.7	192.3	0.8	34.3	16.3	59.3	105.4	165.0	226.0
1990	27.1	34.9	178.9	167.2	54.9	3.2	5.3	56.0	17.6	60.6	168.8	94.7
1991	9.6	6.0	98.5	54.7	209.3	15.6	1.8	6.9	2.4	35.2	84.6	95.9
1992	3.4	10.2	8.7	227.3	155.0	12.7	35.7	9.7	0.4	37.7	78.5	132.6
1993	210.9	51.7	17.0	8.3	51.4	43.2	0.0	4.1	0.0	69.7	68.6	83.2
1994	0.6	97.2	47.6	163.0	58.0	35.7	3.1	23.7	0.0	73.1	203.4	34.5
1995	59.1	79.4	133.3	70.7	86.4	46.9	18.1	17.5	32.3	45.6	29.5	32.4
1996	36.9	69.4	55.8	61.2	55.8	58.6	16.3	12.1	2.0	0.0	129.0	10.6
1997	0.0	0.0	35.0	235.6	163.1	8.6	14.7	22.4	0.0	80.4	307.7	184.6
1998	293.7	111.1	53.1	110.4	326.7	69.9	1.0	6.2	18.1	0.0	68.7	6.4
1999	0.9	1.3	123.5	88.6	3.0	1.9	3.8	33.2	0.0	37.9	251.1	95.9
2000	13.4	0.0	18.5	74.8	18.7	26.9	1.0	1.4	8.0	11.6	113.4	37.4
2001	275.4	10.7	122.1	67.8	38.6	13.7	19.9	14.3	3.7	33.6	197.7	15.9
2002	57.6	15.1	99.1	151.9	158.9	1.6	0.2	3.9	54.5	48.7	115.1	331.2
2003	16.9	9.5	22.1	154.6	234.8	6.8	1.6	47.8	17.8	52.3	119.8	24.3
2004	95.3	76.2	93.3	137.6	57.9	10.7	0.0	0.6	26.5	65.3	123.5	81.4

2005	36.7	1.4	46.3	130.2	89.5	3.6		3.4	9.1	6.6	65.5	1.2
2006	6.3	38.0	124.5	222.9	98.6	0.2	0.0	27.8	5.5	19.2	232.6	204.2
2007	83.4	18.2	35.8	195.7	52.8	27.2	28.0	12.0	19.6	23.7	95.0	36.4
2008	40.5	2.8	134.6	81	4.7	0.5	27.2	3.2	32.2	100	82.6	0.1
2009	52.4	1.9	27.1	84.5	140.0	33.7	5	0.6	2.3	60.4	45.5	112.5
2010	54.0	71.2	133.1	37.2	73.0	23.1	1.3	6.6	8.0	34.9	77.9	55.7
2011	1.8	53.6	91.1	17.8	45.0	29.6	2.9	42.2	27.8	47.4	249.6	29.1
2012	0.0	3.4	4.2	281.7	195.6	32.2	13.4	4.1	36.8	60.9	58.6	194.5

APPENDIX 2: DAGORETTI AVERAGE MONTHLY MAXIMUM TEMPERATURE

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1960	24.5	26.0	24.7	23.0	22.8	22.6	21.1	22.3	23.7	24.2	23.7	23.8
1961	26.4	27.1	26.5	24.2	24.1	23.3	22.2	21.4	22.2	23.4	21.3	22.9
1962	22.9	25.1	25.7	24.8	21.9	21.4	19.9	21.3	23.0	24.0	22.8	23.0
1963	22.7	24.3	24.9	23.3	21.8	20.7	21.0	21.1	23.2	25.7	23.3	21.6
1964	23.2	25.5	24.6	23.0	22.1	21.7	18.8	20.1	22.2	22.5	23.3	21.8
1965	23.3	26.6	26.5	24.1	22.5	22.1	20.4	21.2	24.6	24.0	22.2	23.5
1966	24.7	25.1	24.3	22.7	22.6	21.2	21.1	22.6	23.6	25.0	22.5	24.3
1967	26.1	27.2	27.6	24.5	21.7	20.1	20.1	20.6	23.1	23.2	22.3	23.9
1968	26.7	24.8	23.3	22.1	21.1	20.4	19.1	19.5	24.3	24.8	21.5	23.0
1969	24.7	23.4	24.0	25.5	23.3	22.5	21.3	22.0	25.3	26.5	24.3	24.9
1970	24.4	27.3	26.4	23.4	22.4	21.2	20.1	20.2	24.2	25.7	23.8	24.5
1971	25.2	27.2	26.8	24.7	21.9	19.9	19.6	21.2	23.7	24.8	24.3	23.4
1972	23.6	24.1	25.9	26.6	23.1	22.1	21.0	22.3	25.4	24.4	22.8	23.8
1973	24.4	26.0	27.0	26.0	23.4	21.9	21.9	21.5	24.5	24.7	23.8	24.3
1974	25.7	26.5	24.5	23.3	22.6	20.5	19.7	20.6	22.0	24.7	22.5	24.2
1975	25.9	27.2	27.5	24.5	22.6	21.1	21.1	19.9	22.5	22.3	23.0	23.5
1976	25.1	26.1	27.1	24.4	23.6	22.7	22.1	22.6	23.8	25.8	23.9	23.1
1977	24.2	26.1	25.1	23.7	22.9	21.4	20.3	22.0	23.7	26.0	22.5	22.4
1978	23.4	24.7	24.0	23.4	22.4	21.7	20.9	21.7	24.4	24.3	22.9	22.8
1979	22.9	24.4	24.9	23.6	22.3	21.1	20.7	21.7	24.3	25.8	23.9	24.5
1980	26.2	25.8	27.2	25.9	23.3	21.2	20.6	21.0	24.8	26.0	23.2	23.6
1981	25.4	27.2	26.0	23.1	22.4	22.2	20.4	22.3	23.9	24.9	24.6	24.2
1982	26.5	28.0	28.0	24.0	22.3	22.8	22.1	21.0	23.9	22.8	23.2	23.0
1983	25.4	25.9	26.7	25.0	23.4	23.2	21.3	23.7	24.8	25.2	25.3	24.0
1984	25.3	27.1	26.8	26.1	24.7	22.6	21.5	22.2	25.3	23.3	22.5	23.0
1985	28.0	25.2	25.4	23.3	22.1	21.5	21.3	21.1	24.1	24.8	23.4	23.7
1986	25.7	28.0	26.3	23.6	22.2	20.9	21.6	22.6	24.1	26.0	23.1	23.4
1987	24.4	26.6	27.6	25.0	23.6	22.2	21.9	22.2	25.6	26.7	24.2	25.3
1988	26.0	26.9	26.6	24.0	22.7	21.8	21.4	21.5	23.1	25.4	23.0	23.0
1989	23.8	24.4	25.9	22.7	22.6	20.4	20.4	20.7	23.3	23.9	22.7	23.5
1990	23.7	25.7	24.2	23.4	23.6	22.2	22.1	21.2	24.6	25.2	22.8	23.1
1991	26.5	27.7	27.2	24.7	23.1	22.7	20.7	22.3	24.8	26.0	23.1	23.2
1992	24.9	27.2	26.7	25.2	23.3	22.2	21.1	20.6	23.6	24.8	22.9	23.1
1993	21.8	23.6	25.4	25.1	24.4	21.9	21.4	22.2	24.8	25.6	21.1	23.4
1994	26.0	26.9	26.5	22.8	22.1	21.7	21.2	21.5	23.9	25.0	22.9	23.1
1995	25.3	26.2	24.1	24.0	23.2	23.3	21.1	22.3	24.4	24.5	23.7	23.3
1996	25.7	26.8	26.0	24.4	23.0	21.2	20.8	21.6	24.7	25.9	22.8	24.9
1997	26.5	28.1	27.2	23.8	22.6	21.9	21.8	23.1	25.5	23.4	22.3	22.7
1998	23.1	25.5	25.2	24.8	23.3	22.3	19.6	20.3	23.7	25.6	23.5	24.9
1999	25.9	27.4	26.1	23.5	23.2	22.6	21.6	21.9	24.1	25.4	22.9	22.3
2000	24.7	27.2	27.1	25.4	23.8	22.4	22.2	22.8	24.5	25.9	23.8	23.8
2001	22.6	25.4	24.9	23.5	23.1	21.8	20.8	23.2	25.2	26.3	22.8	23.6
2002	25.5	26.9	25.2	24.4	23.2	21.9	22.7	21.4	24.3	25.0	23.6	23.5
2003	25.1	27.4	27.1	25.9	22.8	21.6	21.2	22.0	23.9	23.4	23.8	24.5
2004	25.2	25.4	26.3	24.3	23.3	21.9	23.3	23.0	25.4	24.6	23.4	24.1

2005	26.2	26.8	26.6	25.1	23.4	21.3	20.7	21.6	23.9	25.2	23.7	25.4
2006	25.9	26.8	25.9	23.2	22.7	22.6	20.7	23.2	23.3	25.8	22.8	23.6
2007	24.2	26.1	26.1	24.8	23.1	22.9	21.3	21.5	23.5	24.2	23.5	24.1
2008	25.2	25.7	25.9	23.4	22.8	21.7	20.8	22.2	24.9	24.3	24.1	24.1
2009	25.6	25.6	27.4	25.5	23.6	23.3	21.7	22.1	25.8	24.4	24.1	24.3
2010	24.5	25.5	24.5	24.3	23.4	21.7	21.6	22.1	24.2	25.4	22.9	24.3
2011	25.8	26.8	26.0	24.9	23.9	23.6	23.5	21.7	23.9	24.1	23.6	23.8
2012	26.2	27.0	28.0	24.5								

DAGORETTI

AVERAGE MONTHLY MINIMUM TEMPERATURE

	JAN	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
1960	11.2	11.0	13.2	14.0	11.6	10.3	9.5	9.3	10.6	12.5	13.4	12.2
1961	10.6	11.2	13.6	14.0	13.7	10.9	10.6	11.6	12.1	13.1	13.4	13.5
1962	12.1	10.0	13.1	14.0	13.4	11.1	9.6	10.5	11.6	13.2	12.5	13.1
1963	11.7	11.2	12.9	13.8	13.6	10.8	8.6	9.4	9.7	13.3	14.0	13.3
1964	11.3	12.4	13.5	14.6	13.3	10.9	9.4	10.1	9.9	12.0	13.4	12.3
1965	10.5	8.8	12.5	13.8	13.0	8.9	9.8	10.1	11.4	12.6	13.8	13.1
1966	11.5	13.5	14.1	13.8	12.6	11.4	10.5	9.7	11.3	12.3	13.0	10.9
1967	9.4	10.8	12.8	14.4	13.7	11.1	10.8	9.8	10.2	12.3	13.4	12.3
1968	9.3	12.3	13.0	13.5	13.0	11.4	9.9	10.2	9.3	13.0	13.0	12.9
1969	12.0	13.3	14.3	14.2	13.1	10.9	10.2	10.1	11.2	13.1	13.8	12.8
1970	13.7	12.7	14.5	14.3	13.5	11.7	10.3	11.1	10.7	12.8	13.1	11.6
1971	11.1	9.5	11.7	13.8	13.3	10.7	10.4	9.9	9.2	11.6	12.6	12.2
1972	11.5	11.7	12.2	14.3	13.6	11.6	10.7	10.7	11.3	14.0	13.0	13.3
1973	12.3	13.5	12.7	14.6	13.2	11.6	9.5	10.9	11.1	12.5	13.9	11.3
1974	11.2	11.8	13.5	14.3	12.8	12.5	11.5	11.1	10.1	12.0	12.9	12.2
1975	11.5	11.9	14.1	14.2	13.3	12.1	11.5	10.6	11.5	12.1	12.3	11.8
1976	11.2	12.9	13.2	14.1	13.4	11.5	10.5	10.4	11.6	12.8	13.9	13.7
1977	13.2	13.0	14.7	14.7	13.7	11.9	11.4	10.7	11.1	12.6	13.8	13.7
1978	12.3	13.0	14.5	14.3	12.7	12.1	11.3	11.2	11.7	13.5	13.6	14.2
1979	13.9	13.7	12.6	14.7	13.7	11.4	10.7	11.1	11.0	13.0	13.3	13.7
1980	11.8	13.1	13.7	14.6	13.8	10.6	10.3	10.6	11.6	13.0	14.0	13.0
1981	12.3	12.3	14.3	14.0	13.9	11.6	10.3	11.2	11.6	12.8	13.5	13.4
1982	12.7	12.6	13.2	14.2	14.1	11.9	11.6	11.8	12.1	13.4	14.2	13.7
1983	13.2	13.4	15.3	15.2	14.3	13.2	12.3	11.6	11.2	13.6	14.5	13.8
1984	11.6	10.8	13.9	15.0	13.0	11.3	12.0	10.9	11.6	13.4	14.0	13.2
1985	14.4	13.8	12.6	14.3	13.6	11.4	10.4	10.9	12.1	13.0	14.0	13.5
1986	13.0	12.6	13.8	14.7	8.4	11.2	9.7	9.5	11.4	13.9	14.2	13.8
1987	13.4	12.7	14.4	14.5	14.1	12.5	11.1	11.9	12.4	13.5	14.5	13.6
1988	13.5	13.9	14.8	14.9	13.9	12.5	11.4	11.9	12.4	12.4	13.9	13.3
1989	13.3	11.8	13.6	14.0	13.6	12.3	11.2	11.3	12.3	13.4	13.9	14.3
1990	12.9	14.2	14.6	14.9	14.1	11.5	13.6	11.6	11.4	13.8	14.1	13.7
1991	12.7	12.7	13.6	14.3	14.5	12.9	11.5	10.2	10.3	11.3	13.8	13.5
1992	12.8	12.6	14.4	15.0	13.3	12.8	11.5	10.7	11.6	13.1	14.0	14.1

1993	13.7	12.7	13.1	14.9	14.3	13.2	10.4	11.2	10.8	13.5	14.4	13.6
1994	13.0	12.5	14.4	14.0	14.0	12.0	11.7	12.0	12.3	14.3	14.5	13.8
1995	12.7	13.0	14.0	15.1	14.6	12.4	11.5	11.4	12.3	14.3	14.6	14.1
1996	13.3	14.0	15.1	14.7	14.4	13.3	11.4	10.4	12.3	13.5	14.4	13.4
1997	13.3	12.0	15.0	14.7	14.1	13.2	11.5	11.6	12.5	14.2	15.0	15.0
1998	15.4	14.9	15.4	16.0	15.0	13.0	11.8	12.1	12.7	12.5	14.1	13.5
1999	13.2	13.0	14.7	14.7	13.4	12.1	11.9	12.3	11.8	13.5	14.3	14.3
2000	12.6	11.1	14.5	14.7	13.5	12.5	11.4	12.0	11.8	13.8	14.7	14.3
2001	13.6	14.0	13.8	15.0	14.1	12.2	11.0	11.2	12.5	13.7	14.3	14.0
2002	13.6	13.3	14.7	15.5	14.5	12.3	11.0	12.2	12.3	14.2	15.2	14.9
2003	13.3	12.9	14.5	15.5	14.8	13.2	11.4	11.3	12.9	13.9	14.6	13.4
2004	14.1	14.2	14.7	15.1	14.0	11.2	9.4	10.7	12.6	14.1	14.9	14.6
2005	13.7	13.8	15.3	15.2	14.9	13.1	11.3	11.9	12.6	13.5	14.7	13.5
2006	13.7	13.8	15.3	15.3	14.9	12.6	12.1	12.0	12.6	14.2	14.7	15.3
2007	14.7	13.7	14.2	15.3	14.8	13.0	12.3	12.8	12.4	14.3	15.0	13.9
2008	13.7	13.3	14.9	14.8	14.0	12.3	12.0	12.5	12.7	15.0	15.0	13.9
2009	13.4	14.3	15.0	15.7	15.0	13.4	10.9	12.3	13.3	14.5	15.0	14.9
2010	14.2	15.8	15.3	15.8	15.0	13.2	11.6	12.4	12.2	14.2	14.9	14.0
2011	13.2	13.3	14.9	15.8	15.0	13.6	11.4	12.7	13.6	14.8	15.0	14.5
2012	11.6	13.5	14.5	15.5								

APPENDIX 3: AVERAGE MONTHLY MINIMUM TEMPERATURE

DAGORETTI

AVERAGE MONTHLY MINIMUM TEMPERATURE

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1960	11.2	11.0	13.2	14.0	11.6	10.3	9.5	9.3	10.6	12.5	13.4	12.2
1961	10.6	11.2	13.6	14.0	13.7	10.9	10.6	11.6	12.1	13.1	13.4	13.5
1962	12.1	10.0	13.1	14.0	13.4	11.1	9.6	10.5	11.6	13.2	12.5	13.1
1963	11.7	11.2	12.9	13.8	13.6	10.8	8.6	9.4	9.7	13.3	14.0	13.3
1964	11.3	12.4	13.5	14.6	13.3	10.9	9.4	10.1	9.9	12.0	13.4	12.3
1965	10.5	8.8	12.5	13.8	13.0	8.9	9.8	10.1	11.4	12.6	13.8	13.1
1966	11.5	13.5	14.1	13.8	12.6	11.4	10.5	9.7	11.3	12.3	13.0	10.9
1967	9.4	10.8	12.8	14.4	13.7	11.1	10.8	9.8	10.2	12.3	13.4	12.3
1968	9.3	12.3	13.0	13.5	13.0	11.4	9.9	10.2	9.3	13.0	13.0	12.9
1969	12.0	13.3	14.3	14.2	13.1	10.9	10.2	10.1	11.2	13.1	13.8	12.8
1970	13.7	12.7	14.5	14.3	13.5	11.7	10.3	11.1	10.7	12.8	13.1	11.6
1971	11.1	9.5	11.7	13.8	13.3	10.7	10.4	9.9	9.2	11.6	12.6	12.2
1972	11.5	11.7	12.2	14.3	13.6	11.6	10.7	10.7	11.3	14.0	13.0	13.3
1973	12.3	13.5	12.7	14.6	13.2	11.6	9.5	10.9	11.1	12.5	13.9	11.3
1974	11.2	11.8	13.5	14.3	12.8	12.5	11.5	11.1	10.1	12.0	12.9	12.2
1975	11.5	11.9	14.1	14.2	13.3	12.1	11.5	10.6	11.5	12.1	12.3	11.8
1976	11.2	12.9	13.2	14.1	13.4	11.5	10.5	10.4	11.6	12.8	13.9	13.7
1977	13.2	13.0	14.7	14.7	13.7	11.9	11.4	10.7	11.1	12.6	13.8	13.7
1978	12.3	13.0	14.5	14.3	12.7	12.1	11.3	11.2	11.7	13.5	13.6	14.2
1979	13.9	13.7	12.6	14.7	13.7	11.4	10.7	11.1	11.0	13.0	13.3	13.7
1980	11.8	13.1	13.7	14.6	13.8	10.6	10.3	10.6	11.6	13.0	14.0	13.0
1981	12.3	12.3	14.3	14.0	13.9	11.6	10.3	11.2	11.6	12.8	13.5	13.4
1982	12.7	12.6	13.2	14.2	14.1	11.9	11.6	11.8	12.1	13.4	14.2	13.7
1983	13.2	13.4	15.3	15.2	14.3	13.2	12.3	11.6	11.2	13.6	14.5	13.8
1984	11.6	10.8	13.9	15.0	13.0	11.3	12.0	10.9	11.6	13.4	14.0	13.2
1985	14.4	13.8	12.6	14.3	13.6	11.4	10.4	10.9	12.1	13.0	14.0	13.5
1986	13.0	12.6	13.8	14.7	8.4	11.2	9.7	9.5	11.4	13.9	14.2	13.8
1987	13.4	12.7	14.4	14.5	14.1	12.5	11.1	11.9	12.4	13.5	14.5	13.6
1988	13.5	13.9	14.8	14.9	13.9	12.5	11.4	11.9	12.4	12.4	13.9	13.3
1989	13.3	11.8	13.6	14.0	13.6	12.3	11.2	11.3	12.3	13.4	13.9	14.3
1990	12.9	14.2	14.6	14.9	14.1	11.5	13.6	11.6	11.4	13.8	14.1	13.7
1991	12.7	12.7	13.6	14.3	14.5	12.9	11.5	10.2	10.3	11.3	13.8	13.5
1992	12.8	12.6	14.4	15.0	13.3	12.8	11.5	10.7	11.6	13.1	14.0	14.1
1993	13.7	12.7	13.1	14.9	14.3	13.2	10.4	11.2	10.8	13.5	14.4	13.6
1994	13.0	12.5	14.4	14.0	14.0	12.0	11.7	12.0	12.3	14.3	14.5	13.8
1995	12.7	13.0	14.0	15.1	14.6	12.4	11.5	11.4	12.3	14.3	14.6	14.1
1996	13.3	14.0	15.1	14.7	14.4	13.3	11.4	10.4	12.3	13.5	14.4	13.4
1997	13.3	12.0	15.0	14.7	14.1	13.2	11.5	11.6	12.5	14.2	15.0	15.0
1998	15.4	14.9	15.4	16.0	15.0	13.0	11.8	12.1	12.7	12.5	14.1	13.5
1999	13.2	13.0	14.7	14.7	13.4	12.1	11.9	12.3	11.8	13.5	14.3	14.3
2000	12.6	11.1	14.5	14.7	13.5	12.5	11.4	12.0	11.8	13.8	14.7	14.3

2001	13.6	14.0	13.8	15.0	14.1	12.2	11.0	11.2	12.5	13.7	14.3	14.0
2002	13.6	13.3	14.7	15.5	14.5	12.3	11.0	12.2	12.3	14.2	15.2	14.9
2003	13.3	12.9	14.5	15.5	14.8	13.2	11.4	11.3	12.9	13.9	14.6	13.4
2004	14.1	14.2	14.7	15.1	14.0	11.2	9.4	10.7	12.6	14.1	14.9	14.6
2005	13.7	13.8	15.3	15.2	14.9	13.1	11.3	11.9	12.6	13.5	14.7	13.5
2006	13.7	13.8	15.3	15.3	14.9	12.6	12.1	12.0	12.6	14.2	14.7	15.3
2007	14.7	13.7	14.2	15.3	14.8	13.0	12.3	12.8	12.4	14.3	15.0	13.9
2008	13.7	13.3	14.9	14.8	14.0	12.3	12.0	12.5	12.7	15.0	15.0	13.9
2009	13.4	14.3	15.0	15.7	15.0	13.4	10.9	12.3	13.3	14.5	15.0	14.9
2010	14.2	15.8	15.3	15.8	15.0	13.2	11.6	12.4	12.2	14.2	14.9	14.0
2011	13.2	13.3	14.9	15.8	15.0	13.6	11.4	12.7	13.6	14.8	15.0	14.5
2012	11.6	13.5	14.5	15.5								

Appendix4: Correlation analysis between Population with Rainfall and Temperature

	Pop	*Moi_JF*	*Moi_MAM*	*Moi_JJA*	*Moi_SOND*	*Moi_Ann*	*Dag_JF*	*Dag_MAM*	*Dag_JJA*	*Dag_SOND*	*Dag_Ann*
Pop	1										
Moi_JF	0.062	1.000									
Moi_MAM	-0.043	0.081	1.000								
Moi_JJA	-0.150	0.111	0.139	1.000							
Moi_SOND	0.102	-0.265	0.050	-0.051	1.000						
Moi_Ann	0.017	**0.428**	**0.808**	0.312	0.354	1.000					
Dag_JF	0.113	**0.945**	-0.023	0.115	-0.332	0.298	1.000				
Dag_MAM	-0.166	0.046	**0.844**	0.077	0.002	**0.646**	-0.039	1.000			
Dag_JJA	-0.055	0.284	0.145	**0.732**	-0.145	0.307	0.282	0.149	1.000		
Dag_SOND	0.152	-0.283	-0.010	-0.051	**0.863**	0.240	-0.335	-0.067	-0.240	1.000	
Dag_Ann	0.004	0.420	0.673	0.224	0.290	**0.854**	0.351	**0.756**	0.311	0.294	1.000
Wils_JF	0.094	**0.951**	0.023	0.088	-0.339	0.326	**0.953**	0.005	0.302	-0.347	0.358
Wils_MAM	-0.150	0.061	**0.884**	0.139	-0.083	**0.654**	-0.010	**0.882**	0.168	-0.078	0.675
Wils_JJA	-0.029	0.185	0.032	**0.790**	-0.162	0.182	0.221	0.079	**0.864**	-0.243	0.198
Wils_SOND	0.181	-0.240	-0.040	-0.067	**0.871**	0.239	-0.277	-0.118	-0.092	**0.887**	0.247
Wils_Ann	0.025	**0.488**	**0.689**	0.285	0.175	**0.857**	0.421	**0.645**	0.429	0.166	0.899
JKIA_JF	0.020	**0.906**	0.058	0.126	-0.312	0.349	**0.881**	0.019	0.322	-0.359	0.329
JKIA_MAM	-0.125	-0.022	**0.847**	0.166	0.108	**0.680**	-0.142	**0.760**	0.094	0.103	0.599
JKIA_JJA	-0.155	0.049	-0.074	**0.824**	-0.157	0.049	0.069	-0.095	**0.681**	-0.107	0.025
JKIA_SOND	0.080	-0.207	0.070	-0.043	**0.800**	0.306	-0.229	0.031	-0.072	0.735	0.308
JKIA_Ann	-0.033	0.263	**0.623**	0.256	0.459	**0.827**	0.164	**0.516**	0.258	0.397	0.763
Dag_MinT_JF	**0.595**	0.445	0.037	-0.021	-0.109	0.183	0.457	0.046	0.089	-0.117	0.224
Dag_MinT_MAM	**0.701**	0.202	0.021	0.107	0.020	0.138	0.208	0.010	0.071	0.049	0.157
Dag_MinT_JJA	**0.630**	0.053	-0.160	0.271	0.207	0.052	0.038	-0.173	0.230	0.212	0.045
Dag_MinT_SOND	**0.803**	-0.005	-0.104	-0.143	0.361	0.059	0.054	-0.183	-0.101	0.363	0.071
Dag_MinT_Ann	**0.828**	0.192	-0.067	0.040	0.168	0.125	0.215	-0.100	0.067	0.175	0.144
Wils_MinT_JF	**0.551**	0.270	0.087	-0.076	-0.037	0.159	0.301	0.111	-0.017	-0.067	0.203

Wils_MinT_MAM	**0.474**	-0.092	0.277	-0.033	0.056	0.176	-0.118	0.212	-0.051	0.109	0.158
Wils_MinT_JJA	**0.506**	0.043	-0.019	0.267	0.245	0.166	0.048	-0.004	0.337	0.240	0.219
Wils_MinT_SOND	**0.488**	-0.126	-0.084	-0.174	0.413	0.034	-0.063	-0.181	-0.016	0.414	0.056
Wils_MinT_Ann	**0.634**	0.005	0.065	-0.043	0.247	0.153	0.035	0.014	0.055	0.254	0.182
JKIA_MinT_JF	**0.666**	**0.463**	0.172	0.055	-0.108	0.302	0.501	0.142	0.171	-0.101	0.346
JKIA_MinT_MAM	**0.656**	0.096	0.335	0.054	0.133	0.356	0.079	0.250	0.072	0.154	0.337
JKIA_MinT_JJA	**0.550**	0.021	-0.061	0.300	0.170	0.097	0.041	-0.133	0.256	0.169	0.059
JKIA_MinT_SOND	**0.820**	0.009	-0.055	-0.135	0.358	0.101	0.069	-0.150	-0.102	0.399	0.125
JKIA_MinT_Ann	**0.826**	0.164	0.092	0.045	0.192	0.238	0.201	0.006	0.086	0.216	0.247
Dag_MaxT_JF	0.074	**-0.678**	0.242	-0.146	0.271	-0.048	**-0.730**	0.159	-0.282	0.299	-0.137
Dag_MaxT_MAM	0.110	-0.244	**-0.449**	-0.027	-0.167	-0.519	-0.133	-0.439	-0.184	-0.054	-0.479
Dag_MaxT_JJA	**0.424**	-0.157	**-0.393**	-0.203	0.230	-0.291	-0.051	-0.383	-0.250	0.258	-0.227
Dag_MaxT_SOND	0.129	0.235	-0.082	-0.129	-0.482	-0.189	0.255	-0.141	-0.123	-0.449	-0.254
Dag_MaxT_Ann	**0.307**	**-0.349**	-0.287	-0.210	-0.068	-0.440	-0.272	-0.338	-0.349	0.017	-0.461
Wils_MaxT_JF	0.097	**-0.616**	0.291	-0.127	0.125	-0.046	**-0.647**	0.221	-0.217	0.212	-0.082
Wils_MaxT_MAM	0.211	-0.159	**-0.506**	-0.024	-0.158	-0.515	-0.027	-0.538	-0.148	-0.041	-0.487
Wils_MaxT_JJA	**0.444**	-0.083	**-0.396**	-0.267	0.342	-0.220	0.017	-0.437	-0.290	0.410	-0.156
Wils_MaxT_SOND	0.099	0.293	-0.043	-0.101	**-0.649**	-0.204	0.311	-0.144	-0.124	-0.494	-0.254
Wils_MaxT_Ann	**0.355**	-0.211	-0.299	-0.210	-0.169	-0.429	-0.114	-0.400	-0.320	0.012	-0.426
JKIA_MaxT_JF	0.076	**-0.689**	0.267	-0.169	0.264	-0.043	**-0.729**	0.216	-0.263	0.280	-0.099
JKIA_MaxT_MAM	0.179	-0.222	**-0.532**	0.023	-0.174	-0.562	-0.084	-0.516	-0.128	-0.103	-0.532
JKIA_MaxT_JJA	**0.389**	-0.193	**-0.350**	-0.177	0.309	-0.236	-0.072	-0.339	-0.174	0.305	-0.164
JKIA_MaxT_SOND	0.096	0.234	-0.102	-0.140	**-0.606**	-0.263	0.276	-0.083	-0.133	-0.470	-0.212
JKIA_MaxT_Ann	**0.311**	**-0.361**	**-0.330**	-0.186	-0.109	-0.491	-0.247	-0.330	-0.291	-0.014	-0.449

Wils_JF	*Wils_MAM*	*Wils_JJA*	*Wils_SOND*	*Wils_Ann*	*JKIA_JF*	*JKIA_MAM*	*JKIA_JJA*	*JKIA_SOND*	*JKIA_Ann*	*Dag_MinT_JF*	*Dag_MinT_MAM*	*Dag_MinT_JJA*
1.000												
0.021	1.000											
0.194	0.071	1.000										
-0.266	-0.174	-0.131	1.000									
0.472	0.715	0.301	0.219	1.000								
0.932	0.006	0.269	-0.279	0.430	1.000							
-0.107	0.850	0.023	-0.007	0.606	-0.070	1.000						
0.048	-0.029	0.756	-0.107	0.103	0.094	0.013	1.000					
-0.254	-0.033	-0.099	0.688	0.178	-0.217	0.059	-0.160	1.000				
0.187	0.538	0.177	0.328	0.735	0.275	0.667	0.081	0.611	1.000			
0.471	-0.060	0.110	-0.093	0.189	0.495	-0.116	-0.112	-0.098	0.070	1.000		
0.168	-0.048	0.159	0.011	0.095	0.140	-0.046	0.061	0.035	0.075	0.629	1.000	
0.007	-0.239	0.270	0.184	-0.029	-0.006	-0.153	0.242	0.184	0.066	0.468	0.756	1.000
0.007	-0.238	0.004	0.409	0.035	-0.004	-0.163	-0.101	0.278	0.074	0.594	0.595	0.555
0.183	-0.185	0.147	0.183	0.084	0.174	-0.149	0.010	0.137	0.085	0.802	0.870	0.811
0.323	-0.014	0.002	-0.024	0.157	0.332	-0.081	-0.204	0.013	0.084	0.890	0.544	0.400
-0.099	0.213	-0.051	0.072	0.139	-0.132	0.209	-0.154	0.087	0.121	0.449	0.629	0.384
0.046	-0.066	0.305	0.276	0.183	0.024	-0.026	0.121	0.322	0.243	0.457	0.649	0.800
-0.061	-0.167	-0.073	0.499	0.085	-0.113	-0.153	-0.238	0.347	0.059	0.356	0.273	0.242
0.047	-0.031	0.027	0.301	0.168	0.012	-0.035	-0.179	0.260	0.145	0.654	0.618	0.528
0.513	0.095	0.201	-0.083	0.357	0.501	0.006	-0.035	-0.054	0.196	0.898	0.723	0.454
0.071	0.231	0.131	0.085	0.292	0.105	0.251	-0.035	0.148	0.318	0.656	0.759	0.578
0.013	-0.126	0.289	0.083	0.012	0.021	-0.032	0.255	0.187	0.162	0.276	0.622	0.727
0.051	-0.144	-0.045	0.405	0.121	-0.002	-0.100	-0.118	0.314	0.140	0.483	0.594	0.545
0.188	-0.008	0.141	0.187	0.226	0.173	0.013	-0.005	0.197	0.231	0.684	0.791	0.675
-0.711	0.213	-0.249	0.187	-0.181	-0.671	0.266	-0.227	0.180	-0.039	-0.227	0.002	0.045
-0.140	-0.330	-0.104	-0.129	-0.425	-0.304	-0.422	0.056	-0.092	-0.471	-0.051	0.191	0.088
-0.074	-0.532	-0.137	0.290	-0.332	-0.135	-0.503	-0.101	0.176	-0.286	0.373	0.351	0.299

0.261	-0.159	-0.041	-0.403	-0.202	0.248	-0.271	-0.035	-0.537	-0.442	0.395	0.210	-0.073
-0.274	-0.339	-0.221	-0.029	-0.478	-0.357	-0.391	-0.127	-0.120	-0.521	0.205	0.315	0.149
-0.651	0.300	-0.212	0.079	-0.130	-0.648	0.301	-0.131	0.118	-0.034	-0.334	0.058	0.029
-0.061	-0.420	-0.064	-0.119	-0.438	-0.233	-0.497	0.094	-0.078	-0.472	-0.026	0.261	0.176
-0.022	-0.527	-0.204	0.416	-0.246	-0.080	-0.464	-0.139	0.263	-0.180	0.269	0.333	0.263
0.321	-0.076	-0.126	-0.510	-0.177	0.260	-0.204	-0.057	-0.572	-0.421	0.274	0.155	-0.145
-0.143	-0.324	-0.246	-0.078	-0.425	-0.270	-0.389	-0.088	-0.134	-0.484	0.089	0.343	0.134
-0.720	0.257	-0.247	0.159	-0.167	-0.698	0.258	-0.186	0.188	-0.044	-0.258	0.075	0.071
-0.091	-0.429	-0.018	-0.129	-0.458	-0.241	-0.521	0.120	-0.159	-0.544	-0.007	0.223	0.174
-0.082	-0.492	-0.116	0.374	-0.256	-0.124	-0.466	-0.067	0.224	-0.219	0.360	0.310	0.284
0.299	-0.103	-0.100	-0.434	-0.165	0.276	-0.192	-0.142	-0.584	-0.423	0.375	0.131	-0.065
-0.240	-0.341	-0.196	-0.032	-0.458	-0.329	-0.412	-0.104	-0.157	-0.543	0.193	0.315	0.197

Dag_MinT_SOND	*Dag_MinT_Ann*	*Wils_MinT_JF*	*Wils_MinT_MAM*	*Wils_MinT_JJA*	*Wils_MinT_SOND*	*Wils_MinT_Ann*	*JKIA_MinT_JF*	*JKIA_MinT_MAM*	*JKIA_MinT_JJA*	*JKIA_MinT_SOND*	*JKIA_MinT_Ann*	*Dag_MaxT_JF*
1.000												
0.856	1.000											
0.587	0.727	1.000										
0.453	0.568	0.584	1.000									
0.445	0.684	0.500	0.541	1.000								
0.638	0.482	0.460	0.439	0.491	1.000							
0.690	0.753	0.781	0.786	0.761	0.820	1.000						
0.606	0.798	0.810	0.507	0.448	0.361	0.648	1.000					
0.632	0.781	0.585	0.678	0.506	0.292	0.618	0.783	1.000				
0.437	0.603	0.168	0.261	0.582	0.195	0.352	0.393	0.608	1.000			
0.905	0.785	0.476	0.454	0.455	0.582	0.636	0.570	0.664	0.590	1.000		
0.811	0.892	0.613	0.562	0.582	0.464	0.687	0.809	0.892	0.750	0.885	1.000	
-0.009	-0.056	-0.189	0.266	0.096	0.079	0.083	-0.212	0.210	0.173	0.063	0.059	1.000
0.070	0.085	-0.017	0.236	0.128	0.183	0.176	-0.033	-0.040	0.188	0.134	0.083	0.135
0.646	0.525	0.441	0.326	0.211	0.446	0.469	0.344	0.316	0.164	0.567	0.452	-0.006
0.165	0.211	0.394	0.265	-0.112	0.140	0.225	0.333	0.078	-0.216	0.032	0.075	-0.258
0.362	0.319	0.264	0.457	0.133	0.353	0.398	0.181	0.233	0.128	0.330	0.277	0.358
-0.091	-0.107	-0.282	0.288	0.026	-0.058	-0.015	-0.201	0.211	0.188	0.016	0.046	0.867
0.142	0.162	-0.055	0.142	0.117	0.174	0.131	0.048	0.017	0.304	0.232	0.189	0.059
0.656	0.485	0.279	0.190	0.128	0.432	0.357	0.317	0.304	0.217	0.628	0.479	-0.009
-0.022	0.071	0.267	0.217	-0.180	0.031	0.110	0.260	0.022	-0.170	-0.049	0.018	-0.254
0.286	0.260	0.097	0.344	0.036	0.245	0.246	0.187	0.220	0.223	0.344	0.305	0.240
0.024	-0.026	-0.187	0.324	0.096	0.095	0.107	-0.205	0.186	0.155	0.051	0.046	0.918
0.156	0.162	-0.004	0.109	0.150	0.195	0.153	0.023	-0.032	0.303	0.220	0.165	0.080
0.648	0.508	0.400	0.247	0.222	0.471	0.448	0.345	0.297	0.165	0.560	0.445	0.018
0.069	0.150	0.416	0.177	0.019	0.077	0.210	0.284	0.009	-0.250	-0.046	0.003	-0.267
0.370	0.332	0.256	0.355	0.206	0.351	0.382	0.185	0.181	0.168	0.329	0.275	0.302

Dag_MaxT_MAM	*Dag_MaxT_JJA*	*Dag_MaxT_SOND*	*Dag_MaxT_Ann*	*Wils_MaxT_JF*	*Wils_MaxT_MAM*	*Wils_MaxT_JJA*	*Wils_MaxT_SOND*	*Wils_MaxT_Ann*	*JKIA_MaxT_JF*	*JKIA_MaxT_MAM*	*JKIA_MaxT_JJA*	*JKIA_MaxT_SOND*
1.000												
0.424	1.000											
0.212	0.345	1.000										
0.745	0.736	0.549	1.000									
0.116	-0.062	-0.201	0.297	1.000								
0.933	0.456	0.218	0.701	0.112	1.000							
0.314	0.917	0.215	0.599	0.001	0.421	1.000						
0.269	0.154	0.858	0.436	-0.116	0.299	0.070	1.000					
0.713	0.621	0.483	0.862	0.378	0.798	0.627	0.555	1.000				
0.177	0.019	-0.186	0.384	**0.908**	0.120	0.028	-0.207	0.318	1.000			
0.937	0.440	0.236	0.712	0.047	**0.940**	0.355	0.271	0.707	0.117	1.000		
0.344	0.949	0.224	0.640	-0.058	0.387	0.899	0.011	0.522	0.067	0.401	1.000	
0.173	0.220	0.750	0.371	-0.240	0.153	0.080	0.771	0.346	-0.241	0.225	0.140	1.000
0.730	0.687	0.443	**0.905**	0.264	0.716	0.572	0.375	0.820	0.383	0.780	0.675	0.487

Appendix 5: Rainfall and NDVI Data sets

Months	Rainfall	NDVI
2/1/2000 0:00	0	0.262137
3/1/2000 0:00	28.4	0.256233
4/1/2000 0:00	71.1	0.292146
5/1/2000 0:00	49.7	0.28954
6/1/2000 0:00	36.7	0.258749
7/1/2000 0:00	1.1	0.236695
8/1/2000 0:00	2.3	0.232047
9/1/2000 0:00	15.7	0.224826
10/1/2000 0:00	36	0.235352
11/1/2000 0:00	140.4	0.282211
12/1/2000 0:00	82.2	0.432928
1/1/2001 0:00	403.4	0.625192
2/1/2001 0:00	5.2	0.684743
3/1/2001 0:00	215	0.505406
4/1/2001 0:00	104.7	0.640567
5/1/2001 0:00	97.2	0.619358
6/1/2001 0:00	31.4	0.457264
7/1/2001 0:00	19.9	0.34352
8/1/2001 0:00	20.1	0.314794
9/1/2001 0:00	7	0.269068
10/1/2001 0:00	36.8	0.262035
11/1/2001 0:00	220.9	0.429375
12/1/2001 0:00	8.6	0.476538
1/1/2002 0:00	55.5	0.454491
2/1/2002 0:00	43.6	0.433618
3/1/2002 0:00	91.5	0.488367
4/1/2002 0:00	220	0.429021
5/1/2002 0:00	293.9	0.65706
6/1/2002 0:00	0	0.553471
7/1/2002 0:00	4.2	0.450312

8/1/2002 0:00	8.4	0.282647
9/1/2002 0:00	29.3	0.281101
10/1/2002 0:00	90.1	0.264136
11/1/2002 0:00	97.5	0.417416
12/1/2002 0:00	210	0.488988
1/1/2003 0:00	22.0	0.610645
2/1/2003 0:00	8.9	0.474048
3/1/2003 0:00	20.4	0.357301
4/1/2003 0:00	112.0	0.363472
5/1/2003 0:00	268.2	0.560458
6/1/2003 0:00	3.2	0.65193
7/1/2003 0:00	3.1	0.468832
8/1/2003 0:00	29.8	0.375228
9/1/2003 0:00	6.9	0.313278
10/1/2003 0:00	82.7	0.269708
11/1/2003 0:00	104.5	0.34136
12/1/2003 0:00	23.9	0.32719
1/1/2004 0:00	51.9	0.319265
2/1/2004 0:00	64.4	0.409792
3/1/2004 0:00	102.9	0.384608
4/1/2004 0:00	298.7	0.556844
5/1/2004 0:00	102.0	0.581299
6/1/2004 0:00	3.8	0.461221
7/1/2004 0:00	0.0	0.325474
8/1/2004 0:00	2.0	0.261635
9/1/2004 0:00	11.2	0.247647
10/1/2004 0:00	68.6	0.260969
11/1/2004 0:00	88.3	0.321939
12/1/2004 0:00	77.2	0.354234
1/1/2005 0:00	35.9	0.305423
2/1/2005 0:00	15.9	0.396667
3/1/2005 0:00	58.8	0.360813
4/1/2005 0:00	158.4	0.463243

5/1/2005 0:00	239.7	0.531617
6/1/2005 0:00	11.6	0.492109
7/1/2005 0:00	11.1	0.346959
8/1/2005 0:00	16.7	0.282955
9/1/2005 0:00	17.4	0.241008
10/1/2005 0:00	17.5	0.246436
11/1/2005 0:00	87.1	0.248733
12/1/2005 0:00	1.5	0.248757
1/1/2006 0:00	8.2	0.246766
2/1/2006 0:00	65.5	0.235131
3/1/2006 0:00	133.0	0.478561
4/1/2006 0:00	274.7	0.584917
5/1/2006 0:00	122.8	0.639342
6/1/2006 0:00	3.6	0.500152
7/1/2006 0:00	6.0	0.32932
8/1/2006 0:00	21.5	0.294752
9/1/2006 0:00	29.3	0.266532
10/1/2006 0:00	37.6	0.243601
11/1/2006 0:00	308.3	0.435603
12/1/2006 0:00	223.2	0.637155
1/1/2007 0:00	40.7	0.669499
2/1/2007 0:00	64.3	0.633377
3/1/2007 0:00	20.1	0.511387
4/1/2007 0:00	194.1	0.470586
5/1/2007 0:00	84.4	0.565042
6/1/2007 0:00	85.9	0.511228
7/1/2007 0:00	46.4	0.367173
8/1/2007 0:00	35.5	0.313922
9/1/2007 0:00	25.7	0.281359
10/1/2007 0:00	35.4	0.263261
11/1/2007 0:00	98.7	0.341339
12/1/2007 0:00	85.1	0.357083
1/1/2008 0:00	58.8	0.355341

2/1/2008 0:00	24.7	0.370918
3/1/2008 0:00	168.9	0.389914
4/1/2008 0:00	103.9	0.514375
5/1/2008 0:00	7.3	0.463243
6/1/2008 0:00	2.1	0.322343
7/1/2008 0:00	28.1	0.275694
8/1/2008 0:00	3.7	0.242604
9/1/2008 0:00	15.4	0.248515
10/1/2008 0:00	109.1	0.252874
11/1/2008 0:00	128.1	0.369878
12/1/2008 0:00	0.2	0.367114
1/1/2009 0:00	52.3	0.287569
2/1/2009 0:00	21.2	0.270217
3/1/2009 0:00	19.3	0.250511
4/1/2009 0:00	163.7	0.289435
5/1/2009 0:00	144.3	0.371463
6/1/2009 0:00	32.3	0.363943
7/1/2009 0:00	8.5	0.282309
8/1/2009 0:00	1.3	0.242519
9/1/2009 0:00	7.6	0.221926
10/1/2009 0:00	61.2	0.233269
11/1/2009 0:00	41.7	0.286014
12/1/2009 0:00	139	0.358484
1/1/2010 0:00	105.8	0.558232
2/1/2010 0:00	80.8	0.477642
3/1/2010 0:00	377.4	0.546404
4/1/2010 0:00	109.9	0.605165
5/1/2010 0:00	157.8	0.591548
6/1/2010 0:00	63.7	0.542161
7/1/2010 0:00	0.5	0.422358
8/1/2010 0:00	10.4	0.30549
9/1/2010 0:00	24.1	0.266702
10/1/2010 0:00	67.4	0.250541

11/1/2010 0:00	119.8	0.370887
12/1/2010 0:00	74.9	0.460588
1/1/2011 0:00	15.0	0.378935
2/1/2011 0:00	43.8	0.351927
3/1/2011 0:00	80.5	0.425025
4/1/2011 0:00	32.5	0.497242
5/1/2011 0:00	91.6	0.423528
6/1/2011 0:00	28.1	0.401807
7/1/2011 0:00	10.1	0.285236
8/1/2011 0:00	16.1	0.245027
9/1/2011 0:00	47.0	0.240069
10/1/2011 0:00	90.4	0.252035
11/1/2011 0:00	225.4	0.405274
12/1/2011 0:00	75.7	0.552356
1/1/2012 0:00	0.0	0.406404
2/1/2012 0:00	16.4	0.287725
3/1/2012 0:00	6.1	0.278324
4/1/2012 0:00	341.0	0.493692
5/1/2012 0:00	311.6	0.635157
6/1/2012 0:00	101.0	0.565624
7/1/2012 0:00	3.9	0.491073
8/1/2012 0:00	35.2	0.347675
9/1/2012 0:00	36.5	0.294936
10/1/2012 0:00	42.0	0.412068
11/1/2012 0:00	127.5	0.45972
12/1/2012 0:00	161.2	0.411862

APPENDIX 6: MONTHLY MAXIMUM AND MINIMUM TEMPERATURE IN NAIROBI

J.K.I.A Maximum Temperature

year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
1985	26.5	26.2	27.1	24.8	23.3	22.8	23.1	22.9	26.2	26.8	25.5	26.2
1986	27.2	29.5	27.5	25.3	23.4	22.3	23	25.2	25.6	28	25.3	24.8
1987	26.5	28.7	30.3	27.6	25.3	23.6	23.9	24.2	27.7	28.6	26.3	27.8
1988	28.2	29.3	28.6	25.4	24.3	23.2	23.2	23.6	25.2	27.4	24.9	25.2
1989	25.4	26.6	27.9	24.3	24.1	23	22.2	22.5	25.8	26.1	24.6	25.1
1990	25.6	27.7	25.2	25	25	24	23.8	22.8	25.9	26.4	24.4	24.5
1991	26.6	28.9	28.6	26.6	24.1	24.1	22.4	24.1	26.6	27.3	25.2	24.8
1992	26.7	29.4	29.2	26.2	24.7	24	22.6	22.2	25.3	26.7	24.9	24.3
1993	23.8	24.7	27.1	27.4	26.2	23.6	22.9	24.2	26.6	27.2	25.6	
1995	28.1	28.1	26.1	26.1		25.2	22.8	23.9	25.9	26.5	26	25.8
1996	27.7	28.7	28	26.3	24.9	22.8	22.6	24.2	26.5	27.7	24.7	25.9
1997	28.1	29.7	29	25.6	24	23.6	23.4			25.8	23.8	24.4
1998	24.6	27	26.9	26.5	24.7	23.7	21.3	21.7	25.2	27.5		
2000	26.2	28.9			26.4	23.8	23.6	24.3	25.7		25.4	25.6
2001	24.4	26.7	26.7	24.8	24.9							
2003			29.1	28	24.3	23.6	22.4	23.4	25.3	27	25	25.9
2004	27.3	27	27.9	25.6	25.5	23.6	25.1	24.6	27.2	26.9	25.5	
2005	27.6	29	28.6	27.2	25	23.1	22.5	23.6				
2007	25.1	28.1	30	26.3					27.7	26.7	25.7	25.6
2008	26.8	27.1	27.4	24.8	24.5	23.2	22.5	24	26.8	26.4	26.3	28.1
2009	27.8	28.3	29.1	27.4	25.4	25	23.6	23.9	27.3	26.6	25.2	27.7
2010	26.1	27.3	26	25.8	24.9	23.5	23.6	24	26.4	28.2	26.1	27.2
2011	28.4	29	28.3	27.2	26.1	25.4	25.9	23.7	26	26.4	25	25.8
2012	28.3	29	30		24.6	23	23.1	25.1	27.1	27.2	27	
2013					25.1	23.3	24.6	23.5	27.1	28.6		

J.K.I.A Minimum Temperature

1985	12.6	13.8	13.3	14.8	14	11.4	10.4	10.9	11.7	12.5	13.5	13.2
1986		11.7	13.1	15.2	14.5	11.8	9.8	9.3	11.4	13.2	13.8	13.4
1987	12.8	12.4	14	14.8	14.3	12.6	11.1	11.7	12.4	13.2	14.2	13
1988	13.5	13.9	14.5	15.7	14.6	12.4	11.6	11.8	12.3	12.5	13.7	13.2
1989	13.4	11.4	13.3	14.5	13.7	12	11.3	11.9	11.8	13.2	14	14.4
1990	12.2	13.9	14.9	15.2	14.1	11.2	9.9	11.8	10.6	13.7	14.6	13.9
1991	12.2	12	13.8	14.2	15	13.2	11.4	10.2	10.8	13.1	13.7	13.4
1992	12.4	12.7	14.3	15.2	13.5	12.8	11.6	11	11.9	13.6	13.9	13.9
1993	13.1	12.3	12.6	14.3	14	13.4	10.6	11.2	10.8	13.4	13.5	
1995	13.4	12.7	14.4	15.1		12.5	11.5	11.2	12.3	14.5	14.4	14.2
1996	13.2	14.5	15.5	14.7	14.8	14.1	12.2	11	11.7	12.8	14.1	13.5
1997	13.4	12.5	15.1	15.6	14.6	13.5	11.8			15	15.6	15.8
1998	15.8	15.7	15.6	16.2	15.5	13	11.7	12.5	12.5	12.9		
2000	13.3	11.1			14	13	11.8	12.2	12.5		15.3	15.1
2001	14.8	15.1	14.5	15.1	14							
2003			14.7	15.8	15.2	13.1	11.6	11.9	13.4	14.4	15.3	14.1
2004	14.8	14.9	14.6	15.4	14.4	11.4	9.9	11.3	13	14.6	15.1	
2005	13.8	14.2	15.3	15.3	15	13	11.1	12.2				
2007	14.9	13.6	14.7	15.1	14.3	12.6	11.7	13.5	13.2	14.2	14.9	14.3
2008	13.3	13.1	14.4	14.4	13.1						15.2	14.2
2009	13.9	14.1	14.4	15.4	15.2	13.7	10.5	12.6	13.3	14.4	15.1	15.1
2010	14.3	15.5	15	15.5	14.6	12.5	11.1	12	11.3	13.5	15.1	14.7
2011	13.9	13.8	14.5	15.2	15.1	14.3	12	13.3	14.4	15.3	16.3	15.5
2012	12.6	14.1	14.6		15	13.5	12.5	12.1	12.7	14.7	15	
2013					14.1	12.7	11.2	12.7	13.3	14		

MOI AIRBASE Maximum Temperature

2004	26.7	27.2	27.7	25.6	25.2	24.1				26.1	25	25.7
2005					25.2	22.9	22.1	23.1	25.4		25.1	26.5
2007	25.7	27.8	27.8	26.3	24.8	25			26.6	26.3	25.4	25.5
2008	26.4	27	27.5	25.3	24.7	23.4	22.4	23.9	26.9	26.6	26.6	27.7
2009	28.1	27.9	29.1	27.4	25.5	25.1	23.6	23.6	27	26.3	26.2	26.1
2010	25.8	27	25.8	26.4	25.2	23.3	22.9	23.3	25.8	27.2	24.8	26.1
2011	27.5	28.7	27.9	26.7	24.9	24.1	25.2	23.9	26.1	26.2		
2012									26.4			

MOI AIRBASE Minimum Temperature

2004	15.9	15.6	16.3	16.6	15.5	13.4	12.3	12.9	14.3	15.3	15.9	15.9
2005					16.1	14.5	13.1	13.4	14.1		16	15.2
2007	16	15.8	15.9	16.3	15.7	14.5	13.6	14.1	13.9	15.3	15.9	15.3
2008	15.1	15	16.1	15.8	15.3	14	13.5	14.1	14.3	15.9	16.1	15.3
2009	15.1	15.4	16.2	16.8	16.1	14.9	12.7	13.4	14.8	15.4	16.3	16.1
2010	15.5	16.6	16	17.1	16.2	14.6	13.2	13.4	13.8	15.4	15.7	15.3
2011	14.8	15	16	16.5	16.2	13.6	13.2	13.9	14.6	15.5		
2012									14.1			

WILSON AIRPORT Maximum Temperature

1985	25.9	25.8	26.3	24.4	22.8	22.6	22.2	21.6	25.1	25.9	24.4	25.1
1986	26.5	28.6	27.2	24.5	22.8	21.8	22.3	24.4	25.1	26.9	24.1	24.4
1987	25.4	27.6	29	26.1	24.5	23.2	22.8	23.2	26.7	27.9	25.3	26.7
1988	27.2	27.9	27.4	24.7	23.9	23	22.2	22.6	25	26.8	24.2	24.4
1989	24.6	25.8	27.2	23.5	23.6	22.3	21.6	21.7	24.6	25.1	23.6	24.4
1990	25	26.9	25.2	24.6	24.7	23.5	22.7	21.9	25.6	26	24.2	24.2
1991	26.5	28.7	28.3	25.8	24	23.7	21.7	22.8	25.8	27	24.7	24.4
1992	25.9	28.8	28.6	26.1	24.3	23.5	22	21.5	24.7	25.8	23.9	24.1
1993	23.8	24.6	26.9	26.6	25.5	23.1	23.2	23	26	26.6	24.9	24.7
1994	27.1		28	25.8	23.9	23.9	22.7	22.5	25.2	26.2	24.1	24.1
1995	26.4	28	25.6	25.2	24.1	24.7	22.2	23.4	25.7	25.6	24.7	24.4
1996	26.4	27.7	27.3	25.6	24.2	22.6	22	23.7	26	27	23.8	25.4
1997	27.4	29.1	28.4	25.4	24.2	23.7	23.2	24.7	26.9	24.9	23.5	24.1
1998	24.3	26.8	26.9	26.2	24.5	23.6	21.2	21.6	25.2	27.3	24.9	26.5
1999	27.7	28.6	27.6	25.2	24.8	24.2	23	23.2	25.5	25.9	23.7	23.6
2000	26.2	28.4	28.3	26.6	25.5	23.6	23.5	24.2	26	27.4	25.1	25.3
2001	24.6	27	26.3	24.8	24.5	23.1	22.3		26.5	26.7	23.7	24.8
2002	26.3	27.9	26.8	25.9	24.6	23.5	24.2	22.8	26	26.2	25.1	25
2003	26.5	28.7	28.4	27.1	24.1	23.2	22.7	23	24.6	26.1	24.6	25.6
2004	26.5	26.6	27.4	25.2	24.6	23.1	24.4	24	26.6	25.7	24.8	25.3
2005	27	28.1	27.8	26.1	24.4	22.5	21.8	23	24.9	26.5	25	26.4
2007	25.1	27.1	27.2	26	24.3	23.6	21.5		25.1	25.6	24.8	25.1
2008	26	26.6	26.9	24.5	23.9	22.7	22	23.5	26	25.7	25	26.3
2009	26.4	26.7	28.4	26.9	24.7	24.5	23	23.3	26.5	25.5	25.2	25.3
2010	25.4	26.3	25.4	25.2	24.4	22.7	22.6	23.1	25.2	26.6	24.2	25.7

2011	26.9		27.2	25.9	24.9	24.8		22.6	24.9	25.2	24.5	25
2012	27.4	28	28.8	25.4	24	22.5		23.9	26		25.2	
2013	26.2	27.8	26.9	25.3		22.6						24.4
2014						23.7	23	24	24.8			

WILSON AIRPORT Minimum Temperature

1985	14.4	14.8	14.3	15.3	14.3	12.1	11.5	11.7	12.4	13.7	14.8	14.7
1986	14.1	14.1	14.6	15.3	14.5	12	10.9	10.6	12.4	14.6	14.7	14.7
1987	14.6	13.8	15.7	15.4	15	13.2	12	12.4	13.5	14	14.4	14.7
1988	15	15.1	15.9	15.7	14.8	12.9	12.7	12.6	13	13.6	14.6	14.3
1989	14.2	13.5	14.8	14.7	14	14.4	11	11.6	12.7	14.1	14.7	15
1990	14.1	15.2	15.2	15.3	14.8	12	10.9	12	11.2	12.4	12.9	12.7
1991	12.2	14.4	14.8	15.3	15.2	13.6	12.2	11.5	11.4	14.3	14.5	14.6
1992	13.4	14.2	15.5	15.9	14.1	13.2	12	11.2	12.1	13.8	14.6	14.4
1993	13.8	13	12.9	13.8	13.2	11.9	11.2	11.7	11.1	13.4	14.6	14.7
1994	13.9		14.6	14.6	13.8	13.5	11.7	12	12.1	14.8		
1995			14.2					11.6	12.3	13.4	13.3	13.8
1996	15						10.4	9.3				
1997		17.1	17.4	17.5				12.2	13.4	14.8	15.2	15
1998	15.3	13.7	15.7	15.9	15.1	13.2	12.5	12.2	12.2	12.3	14.4	14
1999	13.8	13.6	15.6	14.6	13.4	11.8	12.2	12.7	12.5	13.9	14.9	14.9
2000	14	12.5	15.4	15.3	14.3	13	12.1	12.1	10.5	13.6	15.1	15.1
2001	14.2	15.1	14.6	15.6	14.7	12.8	11.9		13.4	14.7	15	15
2002	14.9	14.7	15.4	16.3	14.9	12.9	12.1	12.5	13.2	14.7	15.7	15.5
2003	14.4	14.3	15.4	15.9	15.3	13.6	12	12.1	13.4	14.7	15.3	14.3
2004	15.4	15.1	15.6	15.9	14.5	12.2	10.8	11.7	13.5	14	15.2	15.5
2005	14.9	14.7	16	15.9	15.4	13.7	11.8	12.6	13.1	14.2	15.3	14.8
2007	16	15.3	15.5	15.4	14.9	13.5	12.6	13.1	12.9	14.7	15.5	14.7
2008	14.4	14.2	15.8	15.9	14.6	12.6	12.3	12.9	13.2	15.3	15.7	15.1
2009	14.6	15	15.7	16.2	15.6	13.9	11.8	12.8	13.9	14.8	15.7	15.6
2010	15	16.2	15.6	16	15.7	13.9	12.4	12.9	13.1	15	15.6	15.1
2011	14.8		16	16.5	15.4	14.3		13.4	14.2	15.3	15.7	15.6
2012	13.6	15	15.7	16.1	15.1	13.6		12.4	13.1		15.8	
2013	15.5	15.3	16.6	16.1		13						15.3
2014						14.3	13.4	13.5	13.6			

Appendix 7: Publications

1. Ndolo, I. J., N. J. Muthama, C. Oludhe, J. K. Ng'ang'a and R. S. Odingo, 2017: Diagnosis of Urbanization and Seasonal Rainfall over the City of Nairobi. *J. Meteorol. Related Sci. Vol. 10. Issue 1, pp25-34*

2. Ndolo, I. J., N. J. Muthama, C. Oludhe, J. K. Ng'ang'a and R. S. Odingo, 2018: Influence of Urbanization on Minimum and Maximum Temperature characteristics over Nairobi City. *J. Clim. Chang. Sustain. Vol. 1 Issue 2, pp73-81*