THE UNIVERSITY OF NAIROBI

INFLUENCE OF URBANIZATON ON MINIMUM AND MAXIMUM TEMPERATURE CHARACTERISTICS OVER MOMBASA CITY

BY

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DECLARATION

This research report is my original work and has not been presented in any other learning institution for an academic award.

Signature………………… Date……………..

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This project has been submitted for examination with our approval as University Supervisors.

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DEDICATION

I dedicate this research project report to my compassionate Mum and Dad for their constant monitoring and reminder not to lose focus. The study is also dedicated to the entire Department of Meteorology as it continues to mould young researchers.

ACKNOWLEDGEMENT

This project report would not have come to its rational end without the contribution, support and collaboration of a number of individuals, who in several ways guided me towards my definitive goal. I would like to extend my sincere gratitude to my supervisors Dr. Franklin Opijah and Dr. Christopher Oludhe, Department of Meteorology; University of Nairobi for their invaluable and tireless guidance. The greatest intellectual liability is to their dedication at every phase of this research project. Moreover, critic for me to shed light on my ideas further drove me to the edges of my analytical thoughts. I desire to also recognize KMD and KNBS for their assistance and kindness which made it feasible for me to gather important data to this research project. Above of all, I continue to be everlastingly thankful to the almighty God for His loads of grace and compassion during the whole study period.

ACRONYMS

KMD - Kenya Meteorological Department

KNBS - Kenya National Bureau of Statistics

UHI- Urban Heat Island

USA - United States of America

CRA- Commission on Revenue Allocation

WMO- World Meteorological Organization

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ABSTRACT

The constant development of waterproof non-natural surfaces in urban areas due to population stress has considerably influenced the thermal environment of urban centres. This research project examined the influence of urbanization (as measured by population density) on maximum and minimum temperature over Mombasa city. The above was achieved by examining monthly maximum and minimum temperature data obtained from Kenya Meteorological Department (KMD) for the period 1989 to 2009 and population census data from Kenya National Bureau of Standards (KNBS) for 1979, 1989, 1999 and 2009 census periods. The city experienced drastic development changes due to augmented population during this period.

For data quality control, single mass curve was used while trend analysis and coefficient of variability were used to realize the specific objectives of the study. Seasonal analysis of temperature revealed two seasons; hot season (December to April) and cold season (May to November). Nevertheless, inter-annual variability of both maximum and minimum temperature demonstrated a positive significant trend from the year 1989 to 2009. This was attributable to urbanization associated with demographic pressure. Moreover, the urban-rural comparison of maximum and minimum temperature between Mombasa (highly urbanized) and Voi area (suburban) revealed that Mombasa experiences higher minimum temperature during cold season.

Correlation analyses indicated that the urban temperature in Mombasa was significantly positively correlated with population density. For the entire period of study, minimum temperature increased by 0.48 ^{o}c per decade and maximum temperature by 0.50 ^{o}c per decade. The end results showed a strong confirmation of the influences of urbanization as measured by population density on the urban air temperature of Mombasa city.

CHAPTER ONE: INTRODUCTION

1.0. INTRODUCTION

Considering the background of rapid urbanization, the population living in urban centres is projected to be around 5 billion by the year 2030 (Ash *et al,* 2008). Numerous alteration of land surface will arise as the increasing number of people travel into urban centres. Modification of land will generate climate change in urban areas. There is a remarkable experience with climates in urban that the air temperature of urban area in comparison with their neighbouring rural areas is dissimilar. The difference in temperature is referred to as the urban heat island (Oke, 1982). Urban Heat Island can considerably influence the living forms of humans and also amplify atmospheric effluence as well as the consumption of energy. The increased rate of urbanization, for instance population density and increased impermeable surfaces, would enhance the UHI.

Several studies have been focused on the implication of the urban structure on the urban climate. Urban structure, an expression which refers to the design and plan if a built-up area which affects the ecological and the quality of an environment through fragmentation and composition of patterns of land, water use as well as consumption of energy and the flow of air (Liu *et al,* 2012). Oke 1973 determined that the size of an urban is one of the main aspects in the development of Urban Heat. Reduction in inertia of thermal energy and the index of vegetation as a result of land invasion hampers evaporation subsequently lessening the loss of latent heat into the atmosphere (Kondoh, 2000). The reduction of wind flow velocity coupled with the sky view parameters, more anthropogenic release of heat, enhanced energy utilization and clogging of transport networks as a result of urban growth will help aggravate the effects of UHI.

Nevertheless, the urban swelling is an unavoidable trend in regard to the rural people moving into metropolitan regions. "High-quality urban structure" would help mitigate the worsening environment in metropolitan areas (Breheny, 1992). The enhanced urban size in consideration to their land usage and the density of population has increased adverse impact on the environment. For the last two decades, fast changes in technology and the migration of rural population to urban areas have brought about the transformation of local natural environment beyond recognition and hence global natural environment is at a threat. The majority of people argue that the location and drastic changes in commercial activities more specifically in megacities have created one of the most visual effects in urban environment (Tamagno *et al*, 1990).

For several third world countries, urban areas are in the verge of growth and higher chunk of land is being transformed to cater for urban utilization, swapping farmlands, grasslands and woodlands. As a consequence, unique and more often unlikeable climatic states are experienced by several urban dwellers on earth presently (Shaharuddin, 1997). The urban settlements provide one of the best visualisations of perceptions and human activities. Residential areas are constantly undergoing modification and developments into area that were to be officially occupied by natural vegetation and agriculture. Residential land was reclaimed or will be reclaimed from water if human need for land usage is high enough. By the year 1950, about 30 percent of global population resided in built-up areas (Streuker, 2003). That figure is currently approaching 50 percent as the existing population in urban areas is roughly at 3 billion persons (Streuker, 2003). In the year 2030, the population in the world is anticipated to increase to around 2 billion and is anticipated to take place in urban regions (Streuker, 2003)

The increased capacity of humans to acquire settlement results in adverse changes in environment on global scale, an event in which population in urban makes a vital contribution. The modification of the atmosphere due to urban growth has been on several occasions been illustrated. Sham,1987 stated that climatically, single apparent effect urban growth is the creation of urban heat island. Streuker, 2003 centred on one prime cause of urban growth on climate as well as weather conditions, the UHI; his study also established that urban air temperature is anchored on the density of population.

Numerous parameters result in temperature variation between built-up and rural regions, ranging from topography alteration to variations in the heat properties of upper materials of the surface and human activities in urban areas. Large urban areas have been revealed to modify physically their climates to forms of enhanced temperatures in relation to the neighbouring rural areas (Brian, 2001). The temperature effect of an urban area is not restricted to the horizontal but also to the vertical with severe implications. Several studies have revealed that the influence on thermal heat of a large urban area ordinarily goes beyond 200m (Sham, 1993).

Urbanization level is shown in different countries varies and may be visualized according to specific ways which may comprise some or any of the following criteria (Sham, 1993).

a) The size of the concentration of people

b) The practice of people migrating to cities merges into urban life

c) The practice in which the civilization spread to rural areas

d) The major form of an economic growth

e) Expansion of urban regions and urban features like facilities and other specified services

f) The practice of population residing in an area increasing

Of the above definitions, last one is the most preferable. Hence, for the restrictions and rationale of this research, last definition was utilized in measuring and determining the intensity of urban development. Therefore, urbanization level mainly depends on the population density.

1.2. PROBLEM STATEMENT

The rapid urban growth leads to accumulated negative impacts in form of pollutants, waste heat generation, diseases and strain on water. Amplified urban temperature can influence human health and energy utilization, and may also lead to more severe problems in the perspective of global warming. Hence, it is important for urban planners and designers to master the nature of the climate difference trends in urban areas to furnish them in planning comfortable and sustainable urban areas thus reducing the unfavourable effects. This research project was aimed at “assessing the influence of urbanization on mean monthly minimum and maximum temperature in Mombasa city.

1.3. OBJECTIVES

The general objective of this research was to assess the influence of urbanization on maximum and minimum temperature over Mombasa city.

To assist in realizing the above overall objective, the following specific objectives were undertaken

I. Examine the level of urbanization in terms of population density.

II. Determine the trend of mean monthly maximum and minimum temperature over Mombasa city for the period 1989-2009.

III. Assess the influence of urbanization on urban micro-climate of Mombasa city.

1.4. SIGNIFICANCE OF THE STUDY

Mombasa city plays an important a significant role in the economic development of the coast region and for the entire East Africa especially as the main entry port for imported goods. Hence, the city attracts lots of people who in turn increase the rate of urbanization. The alteration of the natural surface, release of artificial energy and pollutants into the atmosphere over the city alters the energy equilibrium and radiation. This as a result produces an unusual local climate referred to as the urban heat island. For the rationale of exhaustively understanding the impact of urban micro-climate on environment, decision making and human beings, it is crucial to systematically learn the spatial-temporal tendency of urban environment. Therefore, this research work will be fundamental to urban designers and planners in easing urban heat by employing urban planning strategies that will be aimed at steering land use changes and assigning new areas for commercial, residential and recovery of vegetation. Therefore, an evaluation of urban planning mechanics with regard to the implications of urban thermal environment regulation is valuable to further incorporate them into spatial planning.

1.5. JUSTIFICATION

Considering increased anthropogenic activities linked to human population in urban areas, an environmental crisis of high temperature has been on the rise. This has resulted into variation of land surface, energy use and consequent creation of waste heat. Hence, this attests to be untenable factor that leads to unwarranted energy use for cooling and leaves the urban dwellers at a bigger risk of increased mortality. In accordance to the above perspective and in view that rapid and massive population growth is anticipated in future, it becomes progressively more significant to apply appropriate urban temperature alleviation strategies in bid to reduce energy utilization and improve the quality of life in urban areas. Therefore, this research project report about urbanization influence on maximum and minimum temperature could be vital in alleviating urban thermal environment and planning that focuses on use of land by assigning new areas for commercial and residential as well as recovery of vegetation. The land utilization changes will inescapably redesign urban structure which will in turn modify urban thermal setting. Consequently an assessment of urban planning ways with regard to implications on urban thermal environment is useful when incorporated further into spatial planning.

CHAPTER TWO: LITERATURE REVIEW

2.0. LITERATURE

Most of the megacities are basis of pollution; waste heat and thermal constitution of the atmosphere above. An UHI can be superlatively visualised as an enclosed space of dormant warm atmosphere above major cities (Emmanuel, 2005). Latent heat absorbed at daytime by roads as well as concrete constructions in urban areas is irradiated at sundown, generating high contrast in temperature between the urban and its neighbouring rural areas (Asimakopoulos *et al, 2001*). The exact range and structure of this occurrence differ in temporal and special form due to the local, urban and weather features (Oke, 1987). Hence the morphology of UHI can be significantly influenced as a result of exclusive features of each urban and land use.

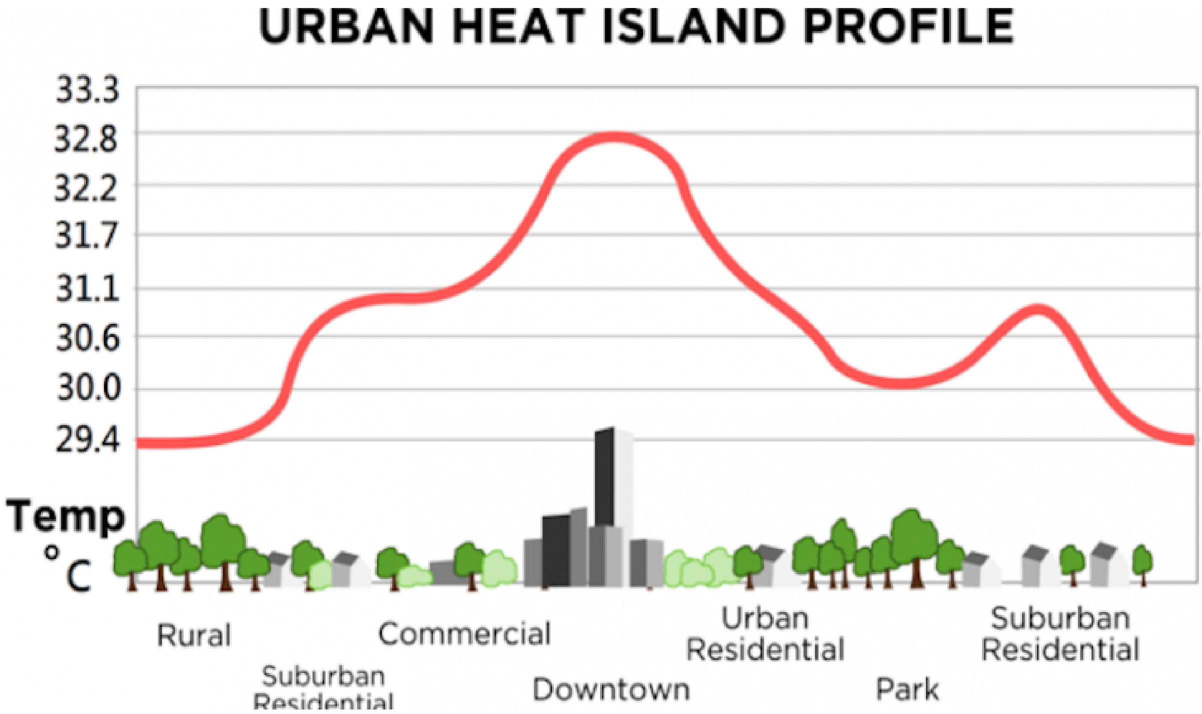

Figure 1: Urban Heat Island Profile (World Atlas, 2009)

Oke, 1987 stated from figure 1 that for big cities with clear sky and slow winds immediately at sunset, boundaries between the urban and the adjacent rural area displays a sharp difference in temperature while the rest of the urban appears to be warmer with stable but less horizontal difference in temperature as you move close to the middle of the city. The intensity of UHI is mainly determined by thermal equilibrium in the urban and could create variation in temperature of about 10 degrees

(Asimakopoulos *et al, 2001)*. The UHI occurrence may transpire during the night time or during the day time.

At present, several megacities are approximately 2 degrees warmer compared to their neighbouring rural areas while dense residential and commercial areas are 5 to 7 degrees hotter (Bonan, 2002). Several key factors influence rise in temperature of cities and contributes a lot to development of urban heat. UHI is caused by several different parameters which ca be grouped into two categories; (1) parameters of meteorological in nature .i.e. humidity, cloud cover and flow of wind; (2) factors related to urban structure .i.e. geometry of the surface, ventilation, heat properties if fabrics and water surface proofing and many more. According to the study by Landesberg, 1981, UHI materializes in each city and town as well as being one of the apparent visualization of urban growth. It is clear that urban temperature badly affects electricity usage for cooling in premises and also enhances generation of smog and increase release of effluents from industries including carbon monoxide, oxides of nitrogen and sulphur (IV) oxide.

The study by Karl *et al,* 1988 showed the association between climate and urbanization inferring that urbanization has affected climate documentations in USA in small towns. The study employed two methods its analysis utilizing mean monthly minimum, maximum as well as 1219 meteorological stations. Historical urbanization climatology network for the 20th century revealed that night time occurrence was predominant and was insignificant for the maxima temperature but noteworthy for the daily minima, mean and the range, totalling to 0.06 degrees (mean), 0.13 degrees (minima) and -0.14 degrees (daily). The study by Chen *et al* 2003 focused on the monthly temperature for 16 meteorological stations in Shanghai for the period 1961 to 1997 in the urban and neighbouring regions.

The outcome of the study showed that the region experiences features of heat island and as having temperature variations between the urban and the surrounding rural stations increasing steadily during summer by 0.7 degrees for two decade from 1975. Shanghai may be considered to be a large heat island in comparison to the neighbouring rural areas with a 0.6 degrees difference in temperature. The UHI impact was relatively weak for the period of 1968-1977 and amplified speedily for the period 1978 to 1987. The phenomenon was very strong during the period 1988 to 1997 a 1 degree excess air temperature. UHI could be linked to increased utilization of energy economic expansion of the city as a result of population growth.

The study by Mohan *et al* 2013 employed micro-meteorological stations in examining the UHI of Delhi for a one month period in 2013. The findings of the study showed that UHI could be categorised into three ways based on land surface cover; high UHI which is primarily within crowded as well as commercial areas; medium UHI exhibited in medium and less crowded urban regions and low UHI noticed in open green areas. Crowded and highly commercialised areas showed elevated UH at hourly maxima of 10.7 degrees with an average of about 8.3 degrees daily, figures that are comparable with maxima and mean UH degrees of megacities like London and New York.

Goldreich, 1992 examined UHI in Johannesburg with data sourced using exhaustive movable unit capable of measuring dry bulb as well as wet temperature at midday and close to sunrise for the period 1966 to 1967. The findings revealed humidity and UHI was strong during high inversion cod nights at the middle of the city. They illustrated that urbanization has impacted the UHI for Johannesburg for the period 1960 to 1990 and the current warming trend may be attributed to the development of the city and not prevalent regional rise in temperature.

Shisanya and Makokha scrutinized UHI in the city of Nairobi. Their results showed that warm conditions were noticed at daytime while cooling was experienced at night. Furthermore, warming rate and cooling rate were linked to the yearly seasons and the prevailing conditions around the weather stations. The rate of cooling was prevalent one hour before to three hours after sundown while warming was high for5-9 hours before nightfall. The prevalent warming rate and cooling rate were more pronounced for the dry hot period of February to March while the lowest was during July to August cool dry period. For the hot and dry period, elevated warming and cooling were linked to the growth of severe UHI in Nairobi.

Opijah *et al. 2008* examined the contribution of anthropogenic heat to the heat budget for the city of Nairobi. The study measured the waste heat discharged from artificial supplies consisting of industrial, road transport, commercial, metabolic heating activities and domestic. The study also considered the energy degree of a given activity and the intensity of the activity, considering bio-fuels, human metabolism and electrical energy consumption.

The study established that development and growth of Nairobi city with respect to the economic, demographic, industrial, built environment and infrastructural structures, favoured an enhanced demand for anthropogenic energy resources, which in turn amplify the waste heat released into the atmosphere. The established implication was that this heat would considerably alter the heat stability of the study locale in future particularly during the "cool-dry" season. Anthropogenic heating is also likely to exacerbate the temperature increase over the city due to global warming in future.

Ndolo *et al,* 2018 considered the influence of urbanization on minimum as well as maximum temperature feature over Nairobi city. Mean monthly and maximum records from 4 land-based weather stations (Wilson Airport, Dagoretti Corner, Jomo Kenyatta International Airport and Moi Air Base) from 1961 to 2007 were utilized. Spatial analysis of temperature across the city showed a significant positive trend which was ascribed to urbanization influence. The analyses also established that increasing minimum temperature patterns in the city was non-uniform due to the different rates of population dynamics and local urbanization.

In summary, the tendency of increasing temperatures requires serious contemplations in planning of climate responsive urban services for hastily expanding cities. Increasing temperatures may not necessarily be due global scale climate warming, but could be an expression of the local scale signal of micro-climate warming due to increased urbanization and the associated increase in energy utilization, changes in land cover and land use mainly attributed with removal of vegetation and its replacement with impervious constructions. Therefore, there is a need to exhaustively carry out intense analysis of urban heat implications on temperatures as a result of urbanization.

CHAPTER THREE: DATA AND METHODOLOGY

3.0. STUDY AREA

The county of Mombasa is amongst the 47 counties of Kenya. The county has a population of about 939,370 people (Census, 2009). Previously it was one of the former districts of Kenya but in the year 2013 it upgraded into county status, based on the previous district boundaries. It is considered the least county in Kenya, having approximate area coverage of 219km^2 exclusive of 65 square kilometres of water mass. Mombasa is located in the south eastern of the former province of the coast. The county neighbours Kilifi to the north, the Indian Ocean to the east and the county of Kwale to the south west. Based on local boundaries, the county is alienated into 7 divisions, 18 locations and 30 sub-locations. Mombasa has an elevation of 50m above mean see level and lies between latitudes 3^o 56'and 4^o 10' south of equator and longitudes 39^{o}34' and 39^{o}46' east.

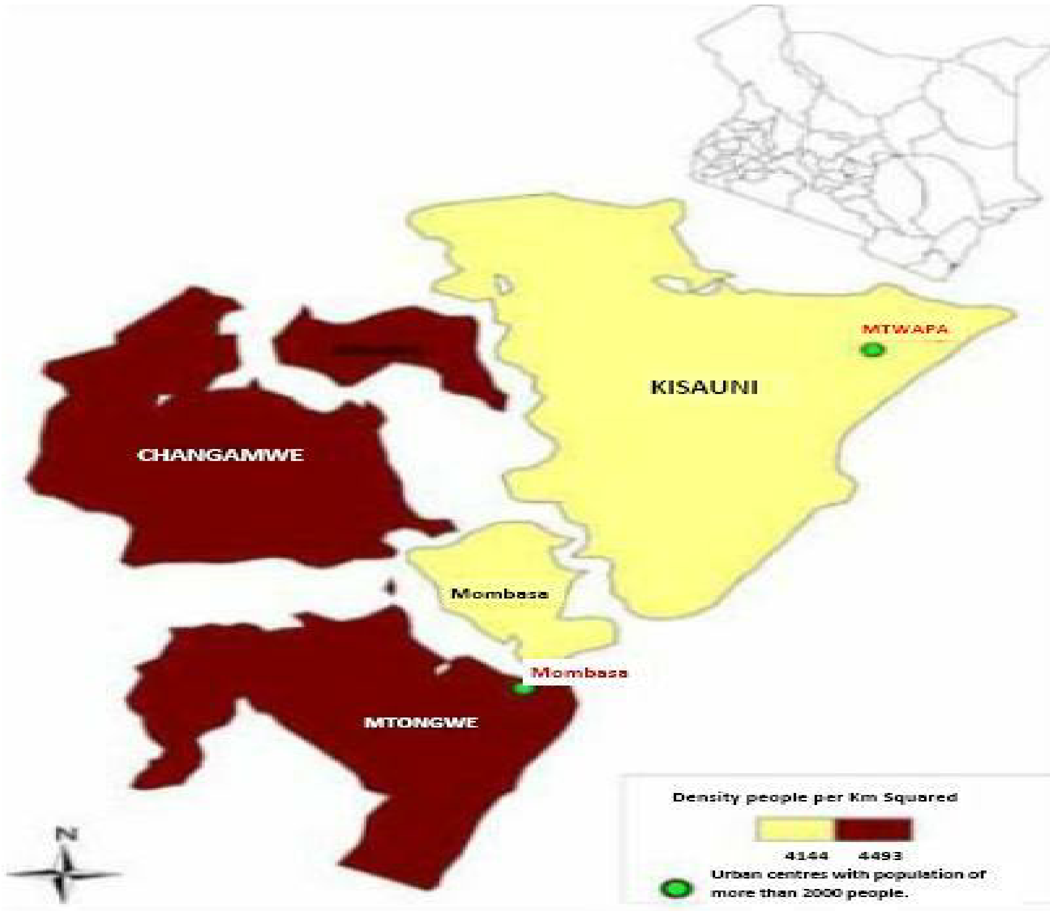

Figure 2: Mombasa County map latitudes 3°56' and 4°10' south of equator and longitudes 39°34' and 39°46' east (CRA, 2011)

3.1. DATA

The data for population density for the city of Mombasa was sourced from Kenyan government resources more specifically, the Kenya National Bureau of Statistics. *In situ* mean monthly minimum and maximum temperature data were obtained from Kenya Meteorological Department for the period 1989 to 2009 for two weather stations; Moi International Airport and Mtwapa Agro meteorological.

3.1.1. Estimation of missing data

Missing mean monthly maximum and minimum temperature data were approximated using the Arithmetic mean method represented by equation 1.

$$\mathbf{T_A = \frac{1}{n}\sum_{i=1}^{n} X_i} \qquad \textbf{Equation 1}$$

Where, T_A is mean temperature in a month; n = the number of days in a month; X_i is daily values of temperature recorded at the station and i is 1, 2, 3, 4 ...n

3.1.2. Data Quality Control

Quality control is imperative in order to identify any discontinuities in the data that may have arose from man-made influences like changes in methods and observational schedules and methods, shifting of station sites, instrumental changes, and other human related processes (WMO, 1996). In a bid to ensure that quality data has been used for the study, some analysis was done on it to ascertain that it was homogeneous and consistent.

3.1.3. Homogeneity Test

The suggested test for homogeneity of the data comprise the single and double mass curve, though the single mass curve was employed in this study. Here, accumulated temperature data were plotted against time, and where a straight line was obtained, it was an indication that the data was consistent and inclusive.

3.2. METHODOLOGY

1. 3.2.1. Time series analysis to examine the level of urbanization

Time series involves array of statistical data in a sequential order e.g. in order with its time of happening. Time series analysis is really an attempt to assess the behaviour of a given weather parameter with time. These components consist of cyclical variation, trend analysis, seasonal and random variations. The compilation of data during the investigation is taken at a specified times and those times must be the same e.g. in this study the data involved monthly means of temperature data.

3.2.2. Trend analysis of monthly mean maximum and minimum temperature

The trend is considered long term parameter the show the decline or development in time over a given period of time. The trend in time series in this research project report was analyzed by means of the graphical method.

1. 3.2.3. Regression and correlation analyses between population and temperature

Regression and correlation analyses were performed to assess the strength of linear association between population density and minimum and maximum temperatures for Mtwapa and Moi Airport stations. Linear regression model was applied with the aim of establishing the correlation between temperature and population density. If ***Y*** is a linear function of ***x***, then the regression equation is given by;

$$Y = a + bx + \varepsilon \qquad \text{Equation 2}$$

Where ***a*** is a constant of proportionality, ***ε*** is the random error and ***b*** a coefficient of ***x***

Correlation coefficient was determined using the relation;

$$r_{xy} = \frac{\sum_i^n (x_i - x)(y_i - y)}{\sum_i^n (x_i - x)^2 \sum_i^n (y_i - y)^2} \qquad \text{Equation 3}$$

Where r_{xy} is the computed value of correlation coefficient, x_i and y_i are the dependent and independent variables respectively.

The student t-test was used to investigate the level of significance of the values.

CHAPTER FOUR: RESULTS AND DISCUSSION

This chapter consists of results and discussion based on the analysis done in the study.

4.0. POPULATION

It is evident that population density in Mombasa (table 1) has been increasing significantly over the past years and the trend is expected to continue. Population trend depicts urban growth and is thus expected that the impacts of urbanization on urban climate will be pronounced.

Table 1: Population census and Population density for Mombasa city for the period 1979 to 2009

Name	Status	Pop. Census 1979	Pop. Census 1989	Pop. Census 1999	Pop. Census 2009
Mombasa	County	341,148	461,753	665,018	939,370
Density per km^2		1,622	2,108	3,036	4,289

Population growth results to growth of urban areas and it involves land-use changes that are due to human activities. These processes of urban development lead to the construction of roads, buildings, and increase in traffic that generates micro-climate of its own.

4.1. Trend of Mean Monthly Maximum and Minimum Temperature over Mombasa for the period 1989 To 2009

3. 4.1.1. Missing data

The few missing data in the station were filled using the Long Term Mean which is based on the arithmetic mean method.

1. 4.1.2. Test for data homogeneity

To test if the data is homogeneous, single mass curves were plotted. This required plotting cumulative temperature records against time. A straight line graph indicates that data is homogeneous while non-homogeneous is indicated by significant departures of some data points from the straight line. It was observed from the single mass curves (Figures 3 and 4) that the stations had homogeneous temperature data.

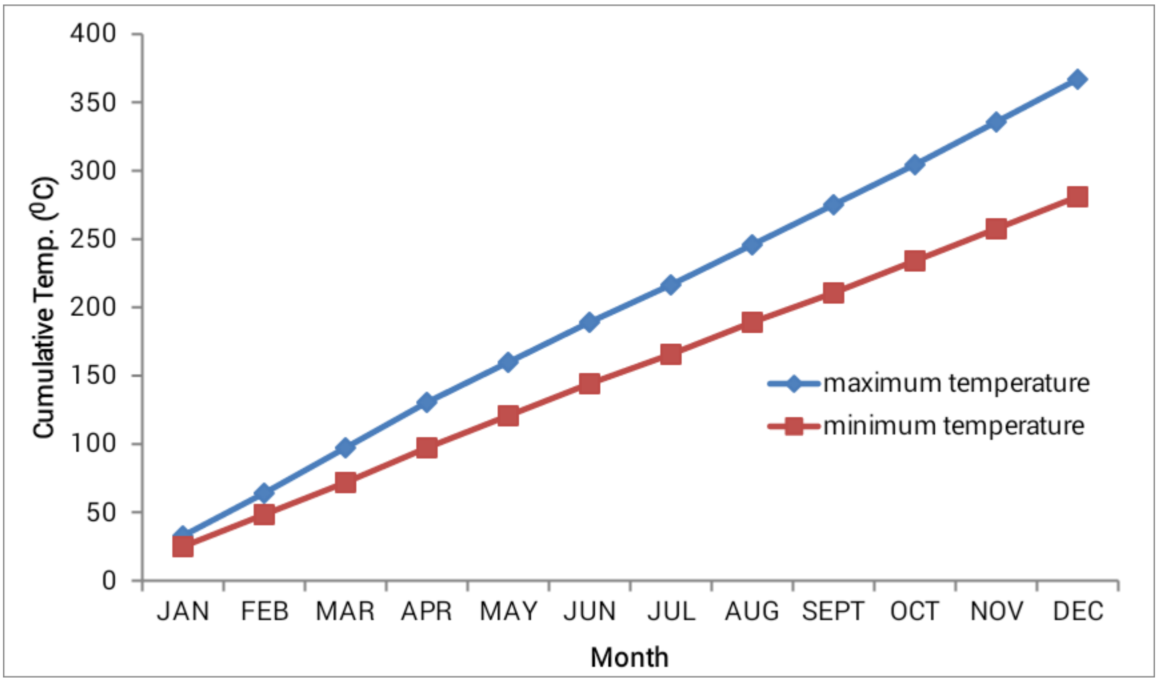

Figure 3: Maximum and minimum temperature (°c) homogeneity test for Mtwapa station

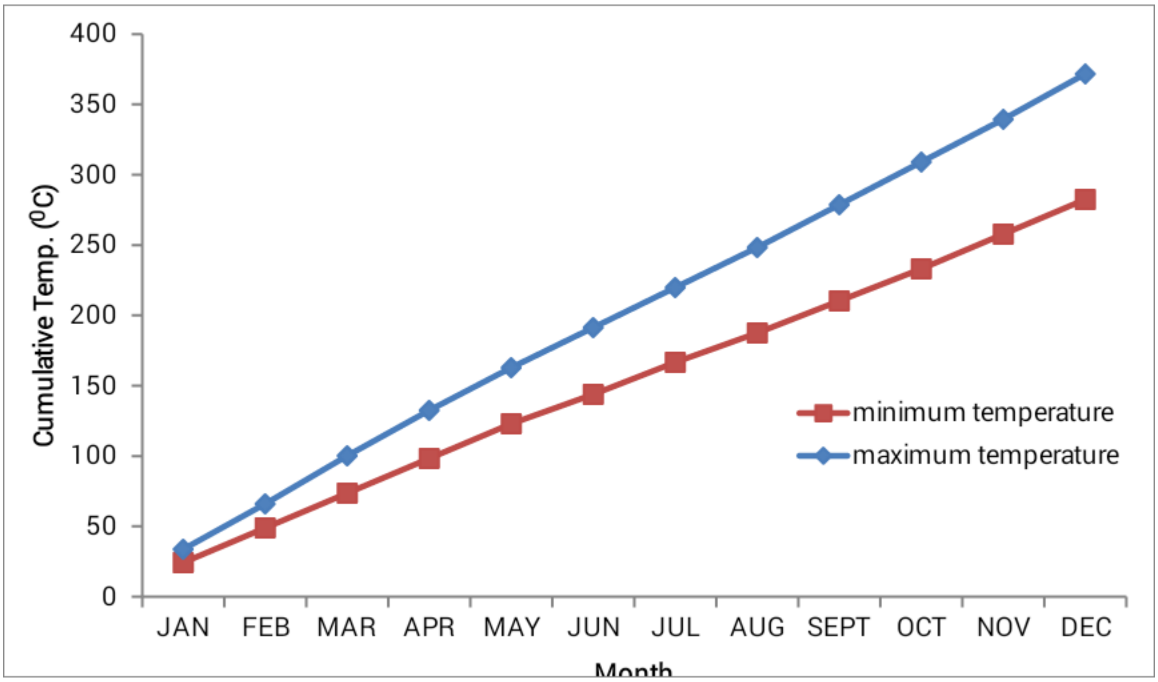

Figure 4: Minimum and maximum temperature (°c) homogeneity test for Moi Airport station

4.1.3. Analysis of mean monthly maximum and minimum temperature (°c) over Mombasa

From figures 5 and 6, the seasonal analysis of temperature reveals that two seasons are evident in Mombasa area; one relatively hot (December to April) and one relatively cold season (May to November).

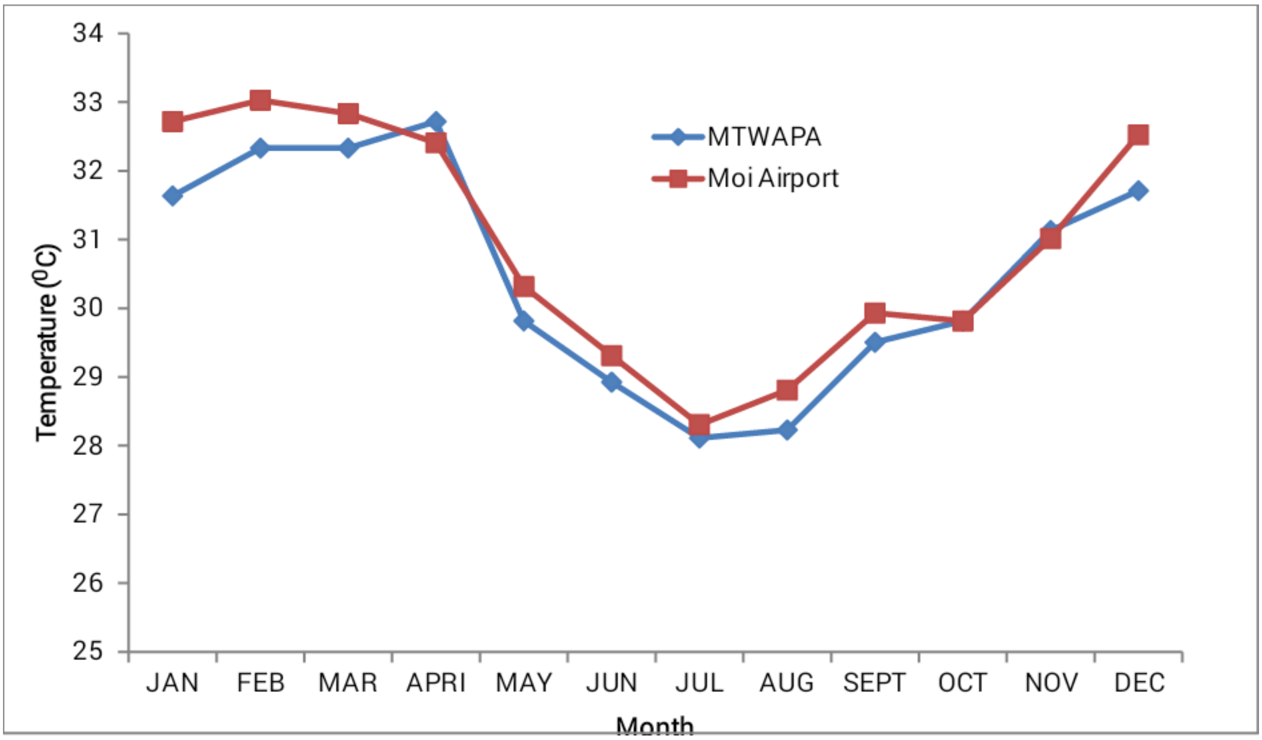

Figure 5: Seasonal mean monthly temperature (^{o}c) patterns for Moi Airport and Mtwapa stations

However, the region experiences Long Hot Season which is observed during December to April and relatively Short Cold Season during July to August. Moreover, there is apparent difference in the lengths of these seasons from the two stations which may be ascribed to the varying micro-climatic conditions across various regions of the city and its surroundings.

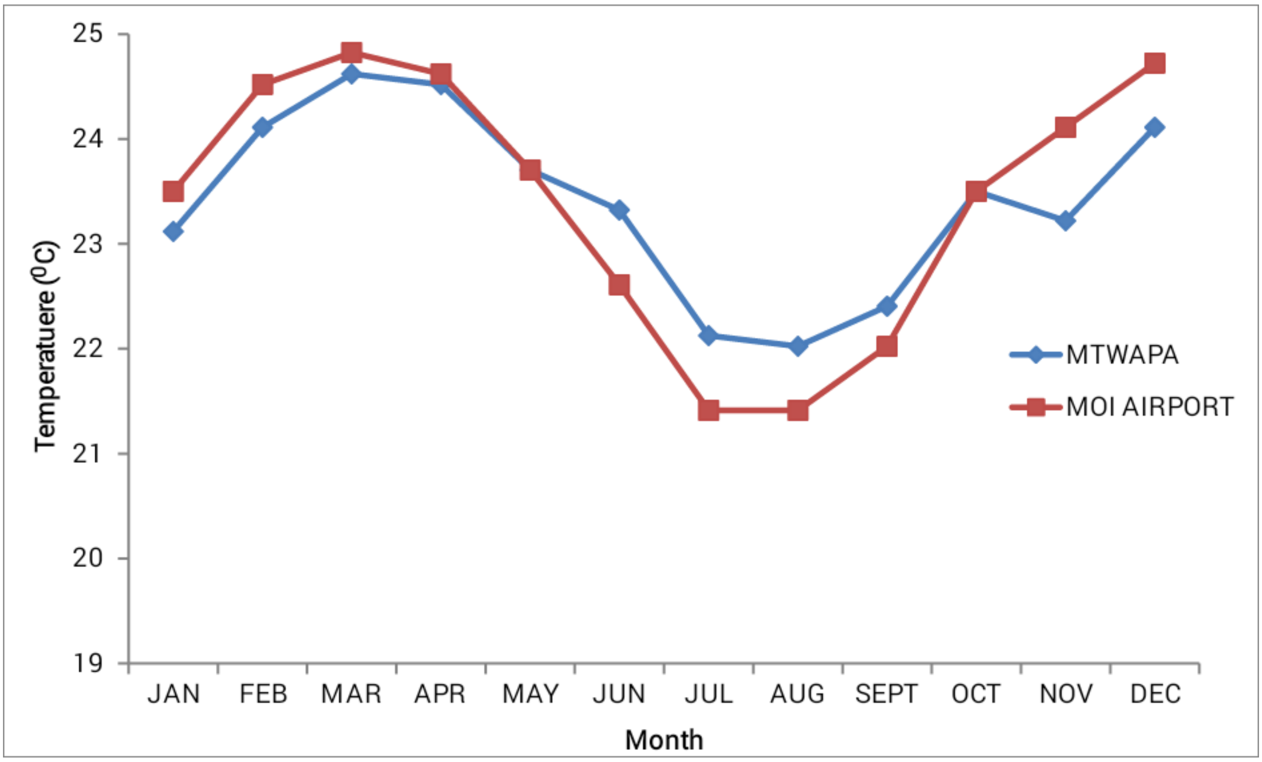

Figure 6: Seasonal mean monthly minimum temperature (°c) patterns for Mtwapa and Moi Airport stations

Moi Airport area experiences lower minimum temperature than Mtwapa areas during the months of July and August (Figure 6). The two areas are surrounded by varying channels of ocean water which act as a huge thermal storage, altering the minimum temperature here. During the heating mode this water body absorbs a huge amount of heat resulting in a lower minimum temperature, due to specific heat capacity of water which is higher than that of dry soil. Evaporation from the upper layer of water will remove part of the heat from adjacent air and thus increase the cooling mode. The more latent heat of vaporization of water as well as the high heat capacity of moist air also may increase the cooling form further.

4.2. INTER-ANNUAL VARIABILITY OF MAXIMUM TEMPERATURE OVER MOMBASA METRO AREA

From figures 7 and 8, temporal variability of mean monthly maximum and minimum temperature for Moi Airport and Mtwapa stations shows significant positive trend. This significant increase in decadal temperature (1989, 1999 and 2009) in the region is associated with changes in land use/land cover and anthropogenic heat release related to urbanization effects as a result of increased population in area.

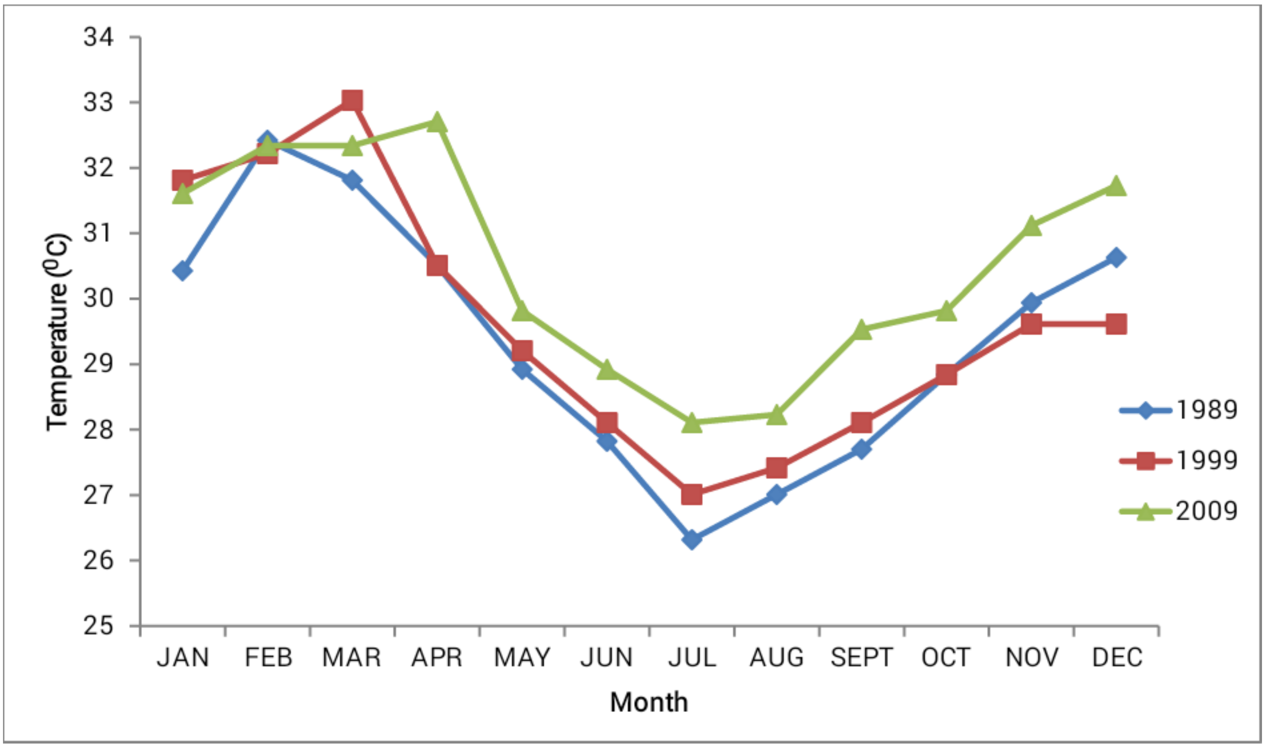

Figure 7: Annual variability of mean monthly maximum temperature for Mtwapa station (1989, 1999 and 2009 decadal periods)

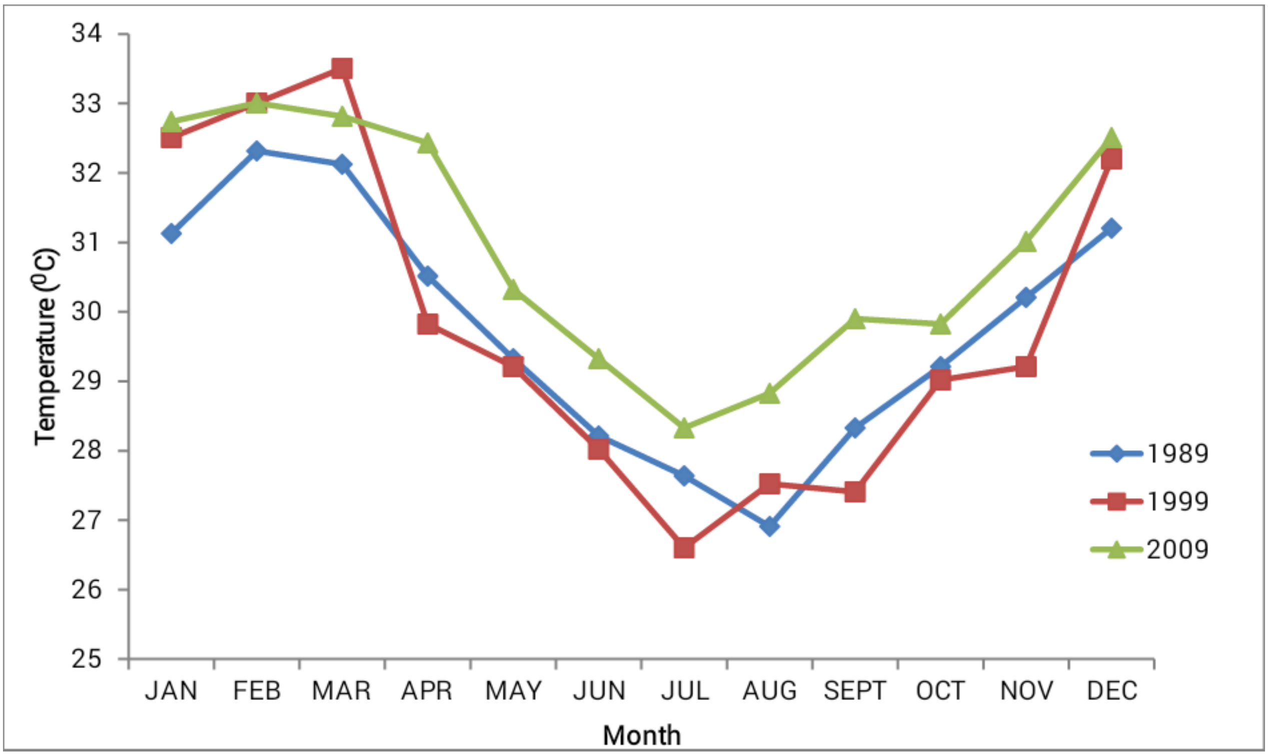

Figure 8: Mean monthly maximum temperature (°c) for Moi Airport station (1989, 1999 and 2009 decadal periods)

4.3. INTER-ANNUAL VARIABILITY OF MINIMUM TEMPERATURE OVER MOMBASA METRO AREA

Figures 9 and 10 show the result of the climatic series for the mean monthly minimum temperature for Mtwapa and Moi Airport stations in Mombasa. Minimum temperature trends have significant values from the late 1989 to 2009 for all the stations indicating a warming trend. This can be attributed to the fast expansion of the city associated with urbanization effects. Due to this urban expansion, urban variation of air temperature began to be manifested in Mombasa.

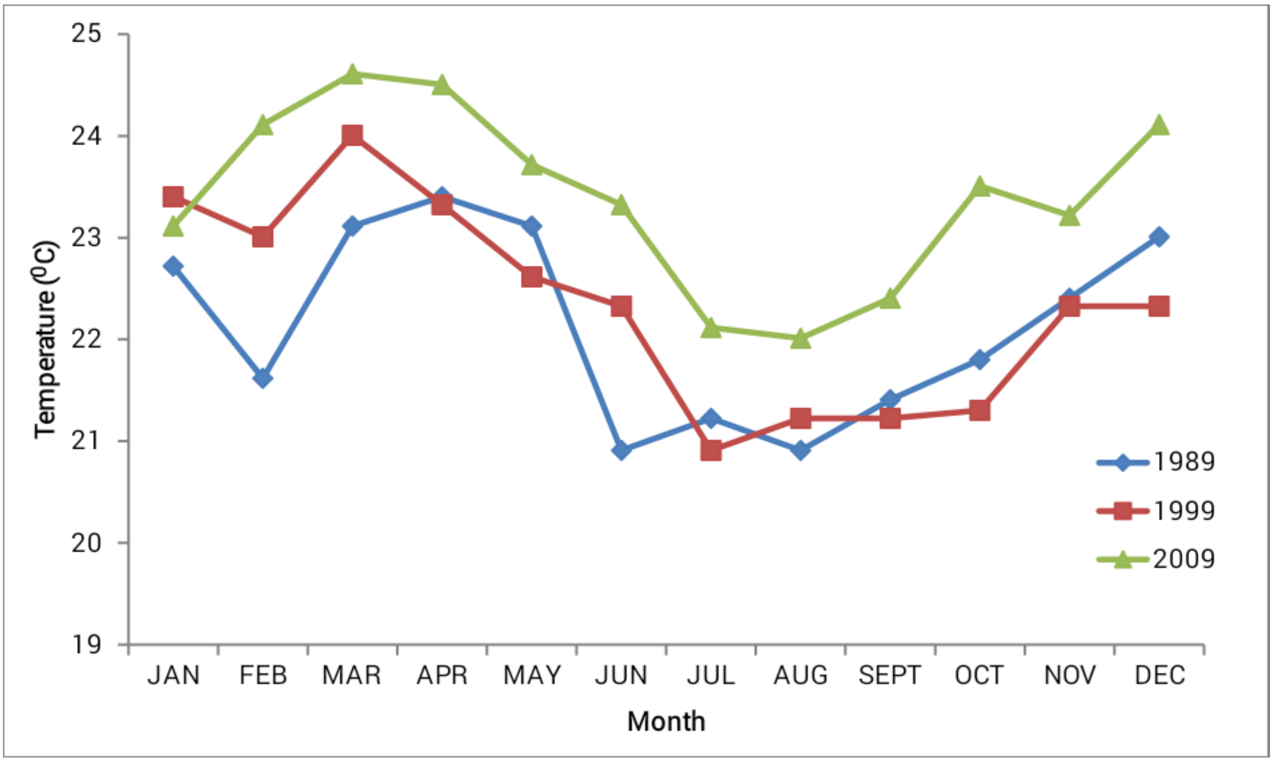

Figure 9: Mean monthly minimum temperature (°c) for Mtwapa station (1989, 1999 and 2009 decadal periods)

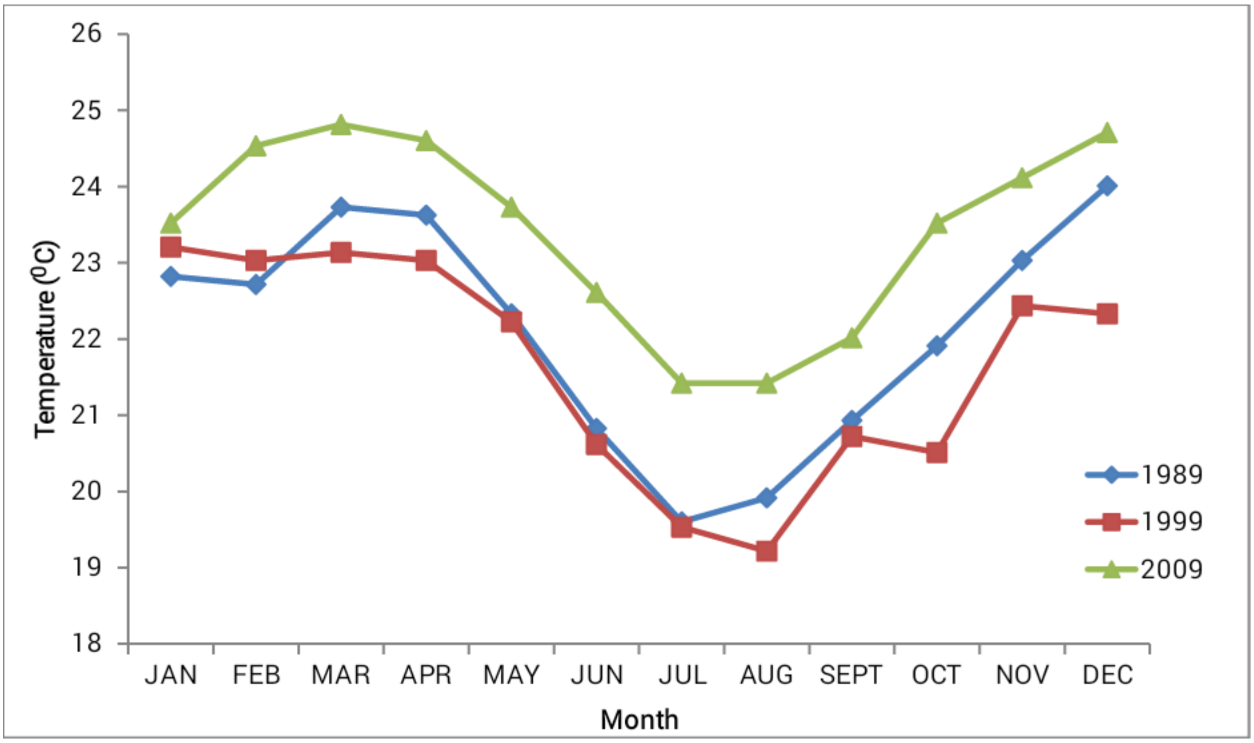

Figure 10: Mean monthly minimum temperature (°c) for Moi Airport station (1989, 1999 and 2009 decadal periods)

Mombasa city is getting more urbanized and this is indicated by population density changes. In the process of urbanization (associated population pressure),natural land cover removal and replacement with urban materials like asphalt, metal, concrete, stone and bricks has significant impact to the surrounding environment, including enhanced surface water run-off, reduced evaporation,, high transfer and storage of heat and deterioration of water and air quality in the urban area. The implication of these modifications is that it can have significant impacts on the local climate and weather (Landsberg, 1981). Considerable amount of temperature variance increase in urban areas is well explained as a function of population growth (Mitchell, 1961). Hence, the urbanization effects on land surface cover, water and vegetation in Mombasa metro area have implications on the urban temperature at different scales and all of these parameters point to population increment.

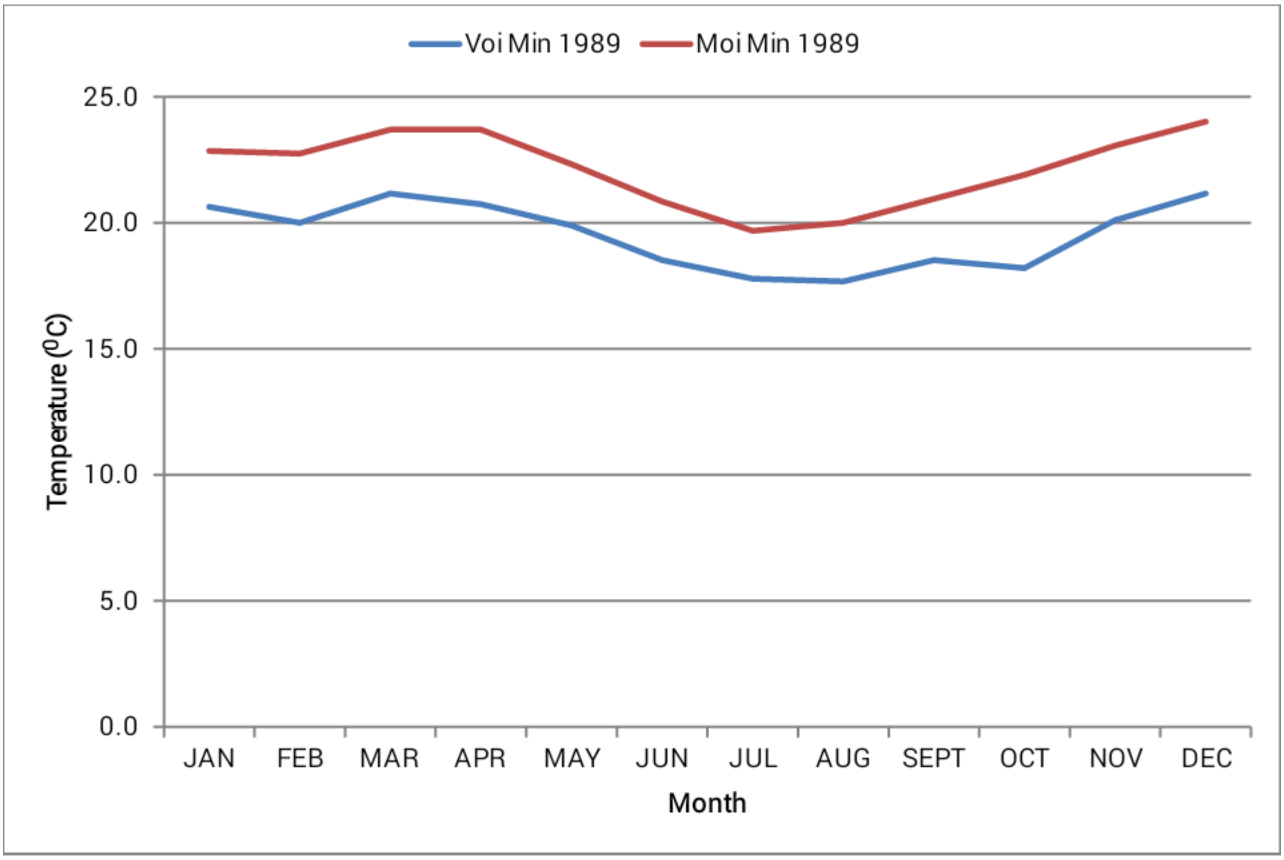

Figure 11: Mean monthly urban-rural minimum temperature (°c) comparison between Voi and Moi Airport stations (1989)

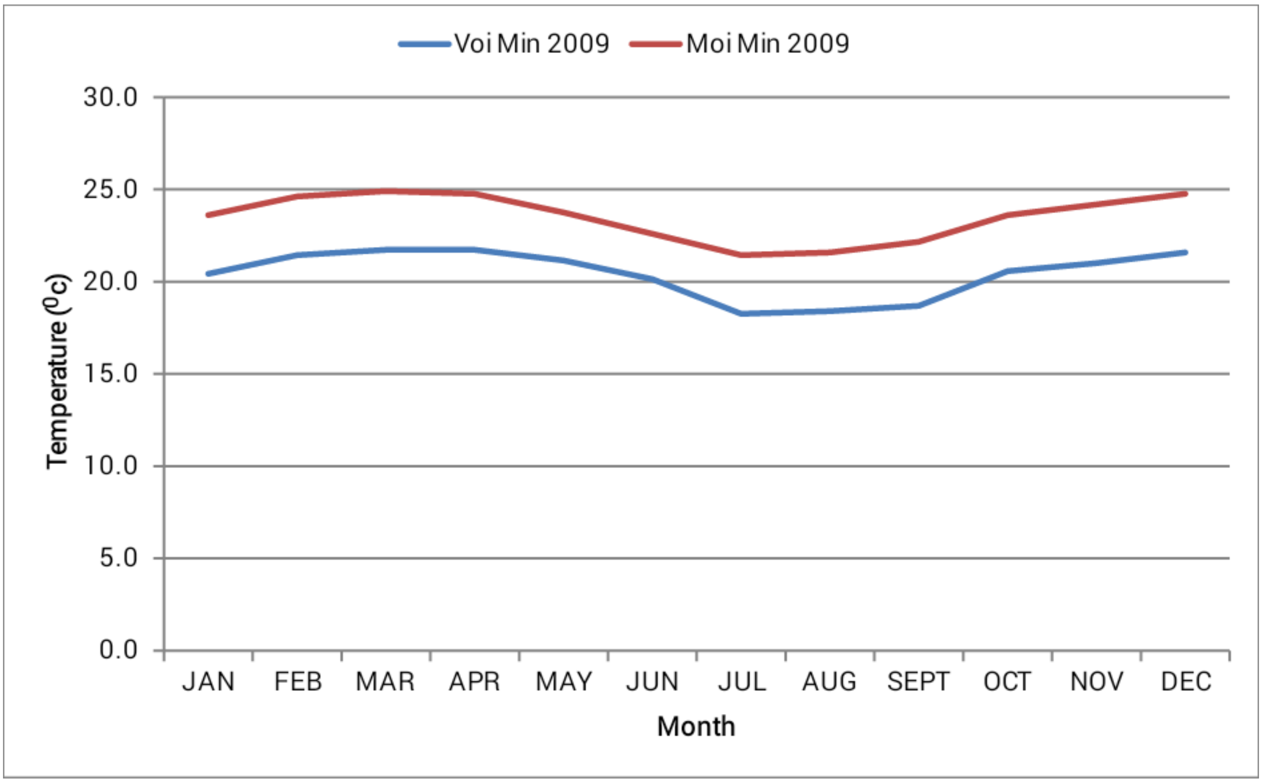

Figure 12: Mean monthly urban-rural minimum temperature (^{o}c) comparison between Voi and Moi Airport stations (2009)

From figures 11 and 12, it is evident that Mombasa experiences high minimum temperature values compared to the rural Voi station. These variations can be attributable to the various fluxes of urban to rural energy budget .i.e. heat storage. The suburban surrounding of the city begins to quickly cool while the urban region maintains higher air temperature. Moreover, Mombasa area has 65km^2 of water mass which has high specific heat capacity thus moderating the heating process and offering a large surface area for the cooling process. Geographically, the proximity to the Indian Ocean can influence local wind whose speed and direction are important in spreading the cooling effects of urban water.

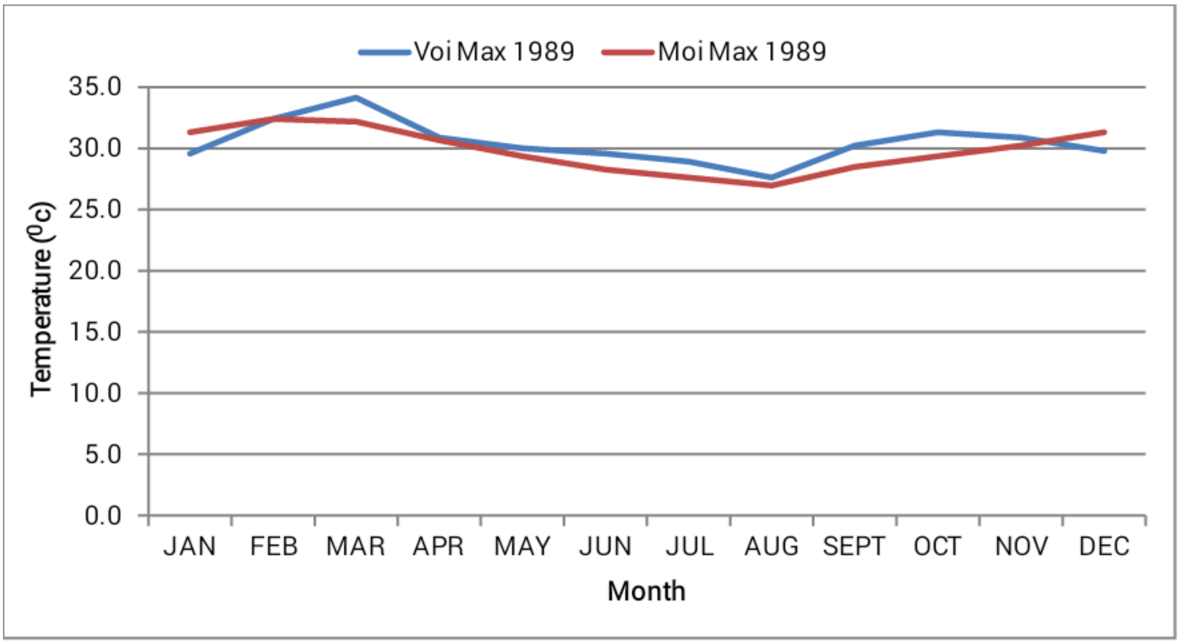

Figure 13: Mean monthly urban-rural maximum temperature (°c) comparison between Voi and Moi Airport stations (1989)

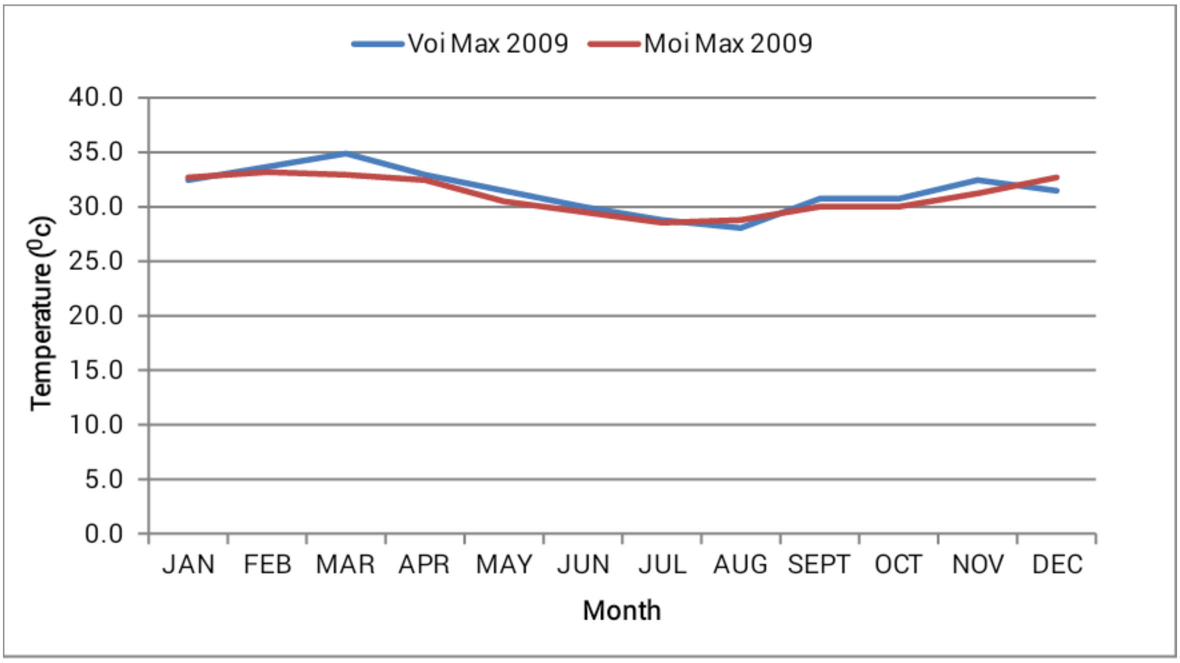

Figure 14: Mean monthly urban-rural maximum temperature (°c) comparison between Voi and Moi Airport stations (2009)

The maximum temperature which is experienced mainly during the day shows a relatively small difference between the two stations (figure 13 and 14). The lower maximum temperature for Mombasa in comparison to the rural Voi station may be attributed to the presence of water body covering the city. Water bodies are likely to create downwind cooling implications. Open water masses offer a good supply of humidity in an order to support the oasis effect during the day, specifically when the area is invaded by drier, larger-scale warmer surroundings (Oke, 1992) of urban environment. Additionally, the direction and speed of wind are also important in spreading the cooling impact of urban water bodies. However, the influence of wind on cooling effect is restricted due to wind obstructing caused by the presence of closely packed buildings hence reducing air velocity. This reduces the effect of convectional cooling.

4.4. ASSESSMENT OF THE INFLUENCE OF URBANIZATION ON MAXIMUM AND MINIMUM TEMPERATURE OVER MOMBASA METRO AREA

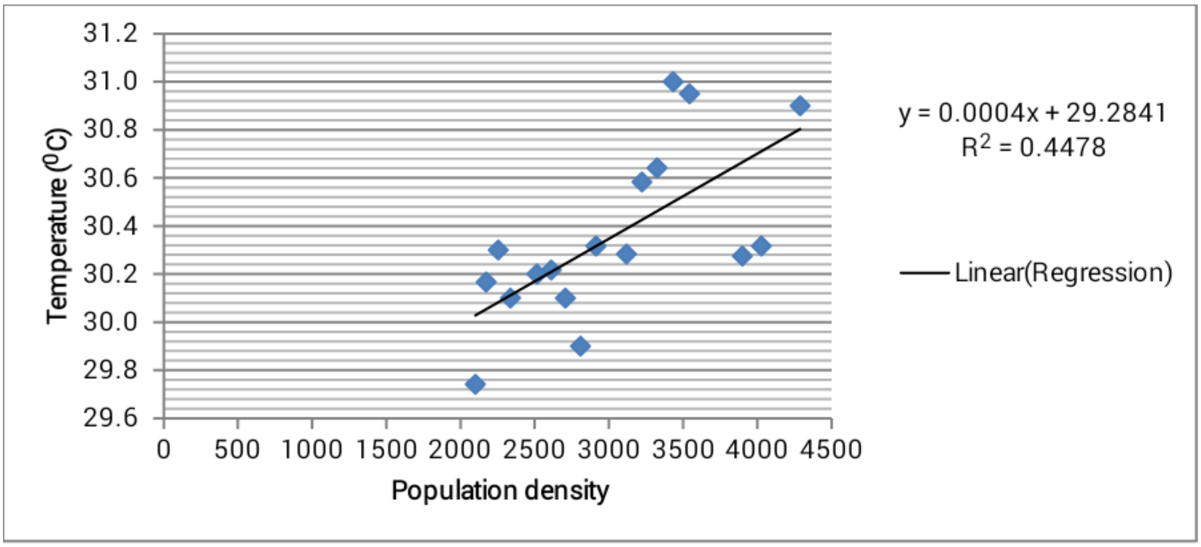

Figure 15: Regression between air temperature (°c) and population density over Mombasa area

Figure 15 shows the regression between air temperature and population density. A moderate positive correlation between the two can be seen. The value of regression coefficient (R^2) is 0.4478. The regression equation between air temperature and population density is;

Y = 0.0004 × Pop-density + 29.284 **Equation 4**

R^2= 0.4478

This simply signifies that with the increase in population density, air temperature also increases. Moreover, it is feasible to predict air temperature on the basis of known population density. The considerable variation of temperature increase in the city could be likely explained as a function of growth in population. The expanding city depicted the highest level of warming and population growth as the main factor contributing to urban temperature modifications.

As urban temperature tends to amplify with increasing population and city size (Hinkel *et al*, 2004), and as cities expand, they increasingly contribute to climate adjustment at levels beyond the local. Oke, 1978 generated a regression model that successfully explained that 97% of the variability in urban temperature is due to a sole predictor variable – the population size. Karl *et al*, 1998 also showed an urban temperature increase of about 1°C per 100,000 people due to urbanization in the USA based on population analysis. The statistical investigation of air temperature with the density of population shows that population expansion tends to add to the rise of urban air temperature and also to the micro-climate of the city of Mombasa.

Table 2: Correlation significance between population density and air temperature (^{o}c) in Mombasa from 1989 to 2009

Station	Climate Parameter	Correlation Coefficient	Significance Trend	Average decadal change of temperature
Moi	Maximum Temperature	0.6692	Significant	0.50 ^{0}C
	Minimum Temperature	0.5756	Significant	0.44 ^{0}C
Mtwapa	Maximum Temperature	0.5905	Significant	0.20 ^{0}C
	Minimum Temperature	0.5777	Significant	0.44 ^{0}C

The influence of urbanization on minimum temperature in the two stations is significant and positive. The results of correlation analysis for both maximum and minimum temperature show that air temperature in all the stations is significantly and positively correlated with population density. This could be linked to the rapid and random urban growth and associated population pressure, which creates changes in urban land cover, land use, loss of vegetation and productive agricultural land; micro-climate change and water, air pollution and anthropogenic heat release.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

This chapter contains the summary of results that were obtained from various analyses carried out in this research project. It also emphasizes conclusions that were drawn from different analyses as well as recommendations to be given to policy makers and future expansions of this study.

5.0. SUMMARY AND CONCLUSION

The alteration in minimum temperature during the study period is higher compared to maximum temperature. Increasing urban temperatures may be associated to the effect of urbanization (demographic pressure) coupled with the global warming owing to speedy urbanization and the accompanying increase in energy utilization, changes in land use and land cover mainly associated with removal of vegetation. These results have revealed that decadal minimum temperatures in Mombasa have been increasing by 0.48 ^{o}c and maximum temperatures by 0.50 ^{o}c during the 20 year period data set studied. The correlation and regression analyses indicated that the air temperature over Mombasa is significantly positively correlated with population in the region. Hence the analysis shows the urban temperature to be likely related to the city size as measured by its population.

5.1. RECOMMENDATIONS

The results of this study have found out that the urban adjustment of minimum temperature in view of warming tendency is on the rise in Mombasa city and is anticipated to reach higher percentages. Environmental implications of such urban temperature variation on the comfort of human beings, design of buildings and orientation, circulation of wind and dispersion of air pollutants should be integrated in the present urban planning and design programmes of the city. There is also need to set up more weather observation stations in Mombasa and its adjacent rural areas for a comprehensive and extensive investigation of urban temperatures in future.

An exhaustive research that takes into account the factors such as humidity, water bodies, wind speed, anthropogenic heat analysis and many other factors need to be carried out in order to extensively quantify urban thermal environment in the study area.

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