Effects of Urbanization on Climate of Nairobi City

Victor, Ongoma Nzioka J. Muthama, and John K. Ng'ang'a

Department of Meteorology, University of Nairobi

CORRESPONDING AUTHOR
Victor Ongoma
University of Nairobi
P.O. Box 30197 00100, Nairobi
Email: victor.ongoma@gmail.com

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ABSTRACT

Nairobi, Kenya's capital city, is one of the fastest growing cities in the world. There is necessity to investigate the effects of urbanization on the climate of the city. This study looked into the long-term urban modification of annual weather conditions by studying the relation between the weather elements and urbanization indicators.

The results showed that Nairobi city is growing at a high rate as evidenced by a population growth of about 6.9% annually. The temperature was found to have been modified by urbanization such that there is a warming trend; the stations that were more urban recorded a high rate of temperature increase as compared to the less urban stations revealing the formation of an urban heat island. Rainfall trend was similarly found to be increasing with time; however, the change in humidity was found to be insignificant. It further revealed that some of the long term changes in climate over the city were due to changes in surface and atmospheric characteristics of the city such as surface roughness, smoke and destruction of vegetation cover, as a consequence of urbanization.

The environmental implications such as urban surface temperature modification on human comfort are significant. It was suggested that in order to control these trends and to obtain more favourable and healthy climatic conditions, the acreage of green areas must be increased. Incorporation of the findings in the future planning of the city is hence recommended.

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1. INTRODUCTION

Given the large and ever-increasing number of urban dwellers globally, and the profound effects of cities and their inhabitants on the atmosphere, both within and beyond urban limits, ever-increasing attention is being directed to the study of urban climates.

Urban climates are highly modified local climates and are often characterized by higher temperature, lower humidity and rainfall, and weaker winds than surrounding rural areas. These differences in climate parameters vary depending on the factors such as the presence of industrial areas emitting excessive heat or air pollutants, urban density, the orientation of streets, topography and population of cities, amount and type of green areas, form and heat capacity of buildings.

Urbanization is the process by which an

increasing proportion of the population comes to live in urban centres (Hardoy and Satterthwaite, 1989). Densely populated human settlements imply an increased use of fuels for various kinds of application and the result is increased release of heat and pollutants into the environment. Industries and factories release heat and pollutants into the urban boundary layer. In addition, an increase in motor vehicles result in a high consumption of fossil fuel resulting in an increase in heat and air pollutants emission into the urban boundary layer (Ng'ang'a, 2003). This causes the local climate to be substantially warmer than the surrounding, a phenomenon known as the Urban Heat Island (UHI) (figure 1). Precipitation and humidity patterns are also greatly modified depending on the area.

An understanding of the urban climate is therefore important in the planning and design of urban settlements for the comfort of the urban dwellers.

The overall objective of this study was to investigate the impacts of urbanization on the climate of Nairobi city in Kenya. The specific objectives were to examine the effects of urbanization on mean temperature fields, annual rainfall and relative humidity patterns.

Nairobi has experienced some of the highest growth rates of any city in Africa. Since its foundation in 1899, Nairobi has grown to become the largest city in East Africa, despite being the youngest large city in the region. According to GoK (1999) the growth rate of Nairobi is currently at 6.9% per annum and is projected to reach 5 million by the year 2015 (Figure 3).

Studies have shown that, urbanization effects are noticed even for settings of populations as small as 10,000 (Karl et al., 1988) and the magnitude of the urban heat island effect is linearly correlated with the logarithms of the population (Oke, 1973).

According to Shepherd (2005), urban areas with rapid land cover and land use changes suffer significantly from human activities. Understanding the human impacts on nature especially vegetation cover is a central component of global change studies and simulation of urban environments in a climate model framework is a practical research approach.

There are no adequate recent studies that have been done to observe the effect of Nairobi's

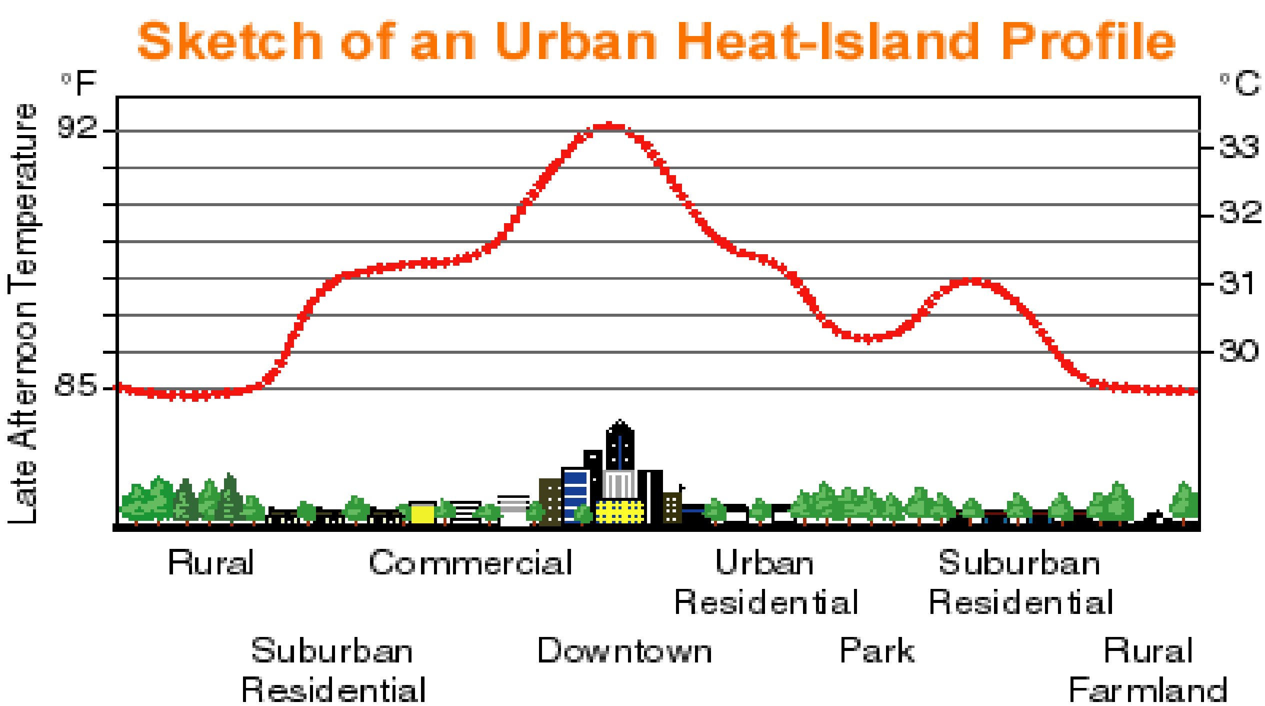

Figure 1: Urban heat island profile

urbanization and its impact on the local climate and further proposed adaptation to the likely climate change-related dangers over the next few decades to fit well within a local development agenda and thus the justification of this research. There is therefore need to study local climatic changes due to urbanization and future expectations in order to support decision making towards better urban planning presently and for the future.

Kenya is situated on the Eastern coast of Africa, and lies astride the equator. It lies between latitudes 5.5° north and 5° south and between longitudes 34° and 42° east. Nairobi city; Kenya's capital city is located at 1^{0} 17'S 36^{0} 49'E and has a land area of 684 km^{2}.

The urban heat island has become a growing concern; for more than 100 years. In rural areas, a large part of the incoming solar energy is used to evaporate water from vegetation and soil. In cities, where less vegetation and exposed soil exists, the majority of the sun's energy is absorbed by urban structures and asphalt. Hence, during warm daylight hours, less evaporative cooling in cities allows surface temperatures to Addition city heat is given off by vehicle and factories, as well as by industrial and domestic heating and cooling units. This effect causes the city to become (1 to 6^{o}C) warmer than surrounding landscapes. The impacts also include reducing soil moisture.

Every settlement is capable of generating an UHI, regardless of its size (Mills, 2006). Observations for UHI studies display common characteristics, the urban–rural difference reveal itself as a pool of warm air with largest values closest to the urban centre. At the urban edges, temperature changes are rapid and thereafter increase more slowly. However in the vicinity of green parks, lower temperatures are observed. The strength of the UHI is referred to by the maximum urban – rural difference recorded. Its magnitude is greatest at night, under clear skies and with little wind. Under such conditions, surface cooling is associated with radiation exchange. While exposed rural sites cool rapidly after sunset, urban sites cool more slowly .The difference between urban and rural sites grows with time after sunset and reaches a maximum difference after about 4 hours. The maximum UHI value recorded is usually found in the centre of the settlement which is generally larger for bigger settlements (Karl, *et al*., 1988).

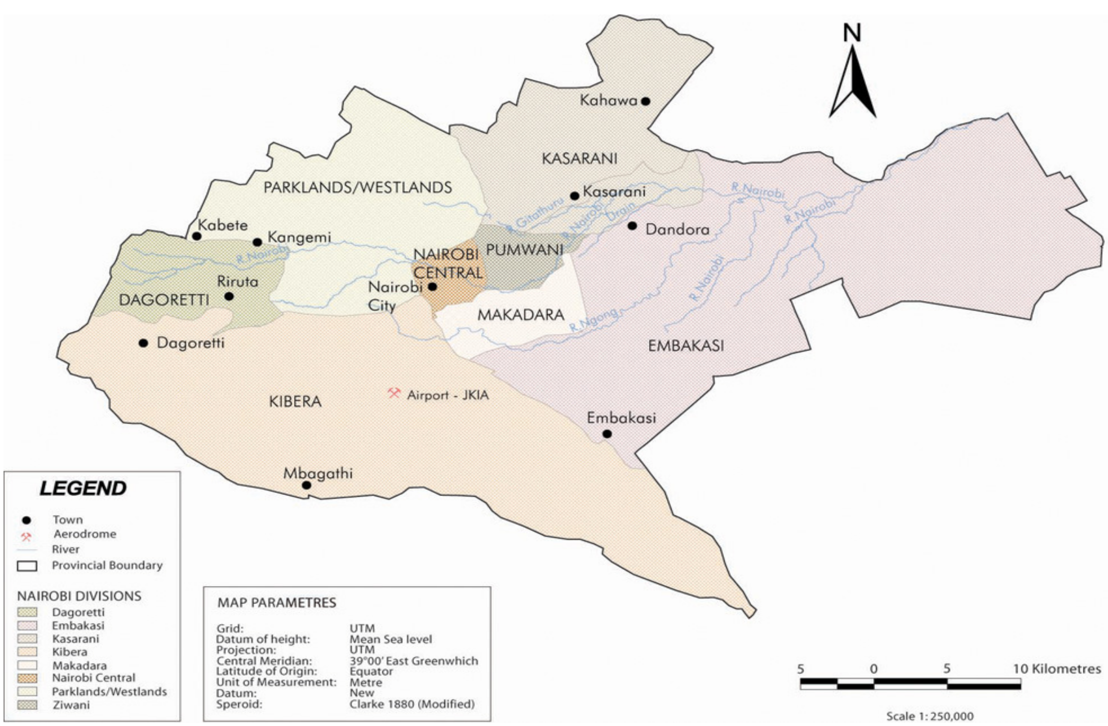

Figure 2: The area of study
Source: www.unep.org/.../Images/nairobi_map.jpg

Studies on urban-rural climatic differences have long been carried out since Howard (1833) , who reported that night was 3.7 ^{0}c warmer and day was 0.34 ^{0}c cooler in the London city than the countryside in early 1800s. In recent studies, Karl, et al. (1988) stated that in the US, annual mean temperature at stations in populated area of 10 000 people or more were 0.1 ^{0}c warmer than the nearby stations located in rural areas with a population of less than 2000.

Rainfall enhancement in urban areas has been attributed to higher condensation nuclei concentrations over the urban areas, the thermal and frictional effects of the area (Changnon, 1996; Vogel and Huff, 1978).Rainfall may be enhanced by air pollution that increases the number of condensation nuclei through the atmospheric addition of smoke and dust particles. Also, the additional generation of heat within the city increases the number of convection currents over that surface, the convection is key in the development of thunderstorms.

Urbanization is strongly correlated with increment in greenhouse gases emission, according to IPCC (2008), theoretical and climate model studies suggest that in climate that is warming due to increasing greenhouse gases; a greater increase is expected in extreme precipitation as compared to the mean. Hence, anthropogenic influence may be easier to detect in extreme precipitation than in the mean. This is because extreme precipitation is controlled by the availability of water vapour, while mean precipitation is controlled by the ability of the atmosphere to radiate long –wave energy to space, and the latter is restricted by increasing greenhouse gases.

Urban effect has been found to be associated with stimulation of rain output in ongoing storms as opposed to an increase in frequency of storms (Huff and Vogel, 1978).

Generally, rural areas are more humid than the urban ones almost throughout the year with the exception of the wettest period of the year. Unkasevic et al. (2001) compared the urban –rural/sub urban water vapour pressure and relative humidity is drier than surrounding areas in the afternoon throughout the year. Similarly, in the study of Robaa (2003) in Cairo, it was found that on the basis of relative humidity, urban atmosphere is drier than its surrounding areas throughout the year. Fortuniak et al. (2006) analyzed data from two automatic stations in Poland (one rural and one urban) for the period 1997-2007, he found out that relative humidity is lower in town, sometimes by more than 40%.

2. DATA AND METHODOLOGY

2.1 Data

The data used in the study comprised of two categories:

(i) The climate data which comprised of monthly rainfall, humidity and temperature elements of Nairobi City for about forty years to date. The meteorological stations are Muguga Forest Station, Moi Air Base, Muguga KARI, Dagoretti Corner, Kabete Agrometeorological Station, and Nairobi Wilson Airport.

(ii) Urbanization indicator: Nairobi City population that was obtained from the Kenya National Bureau of Statistics for about twenty years (GoK, 2007).

2.2 Methodology

The Single mass curve technique was used to test data homogeneity while Graphical Methods were used in trend detection.

Correlation analysis was used to determine the relation of urbanization indicator (population) to climatological parameters.

3. RESULTS AND DISCUSSION

3.1 Estimation of Missing Data

Spatial correlation and Arithmetic Mean methods were used to estimate missing data. Rainfall data of all the stations used was available except that for Dagoretti Corner for the year 1988 that was estimated.

3.2 Urbanization indicators

3.2.1 Population

Nairobi's population is growing with time (figure 3).

There are wide varieties of standards of living in Nairobi. Most wealthy Kenyans live in Nairobi City but the majority of Nairobi population is poor. Half of the population has been estimated to live in slums which cover just 5% of the city area. The growth of these slums is as a result of urbanization following increase in rural to urban migration in search of employment and education. The growth of slums is also due to poor town planning.

3.2.2 Energy Sales to Nairobi

The consumption of energy in Nairobi has generally been increasing with time; 1996 to 2005 (figure 4). There was however a significant decline in energy sales from 1999 to the year 2001 with the lowest in the latter; 2001.

Energy consumption increase is a good indicator of urbanization in the sensethat energy drives all forms of livelihood in which economy is included. Urbanization goes hand in hand with increase in the number of industries, rise in household and increase in fuel consumption by the transport sector.

Increase in fuel consumption in Nairobi can be attributed to domestic and industrial fuel consumption as well as rise in the number of vehicles. The rise in fuel consumption is strongly correlated with an increment in Green House Gases emission causing warming effect to the city.

The mean of the first data set was 24.33 while the second set had 24.47. This clearly indicates a positive trend (i.e., an increase in the mean maximum temperature with time). The urban air temperature is therefore gradually rising in Nairobi city as is the case in other cities of the world. One of the possible

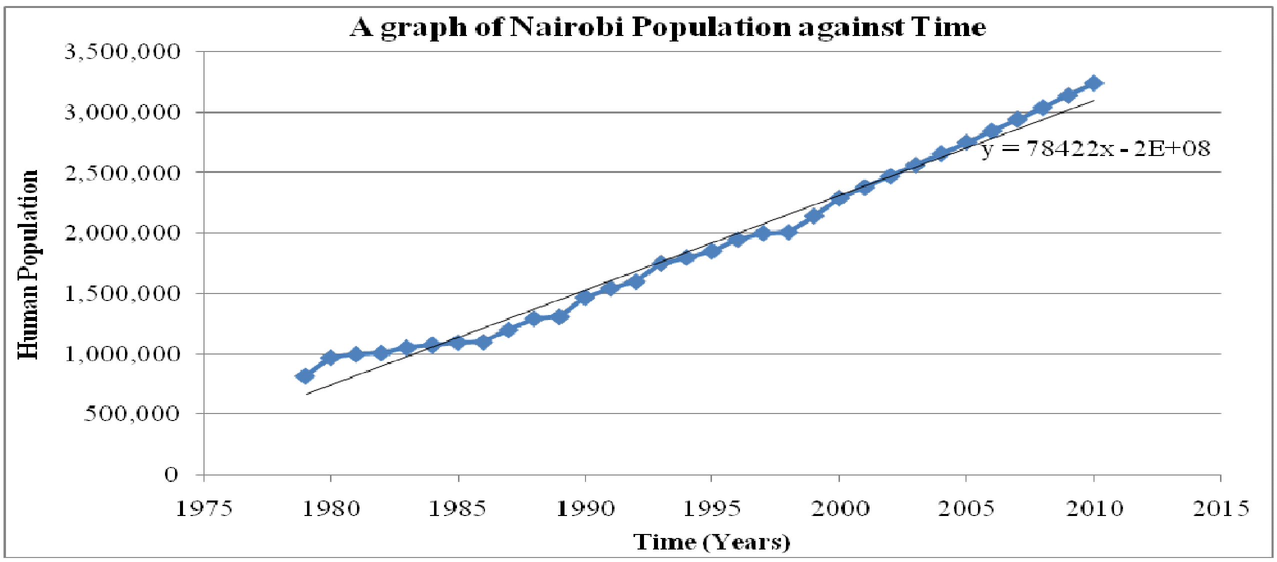

Figure 3: Time series of population for Nairobi city

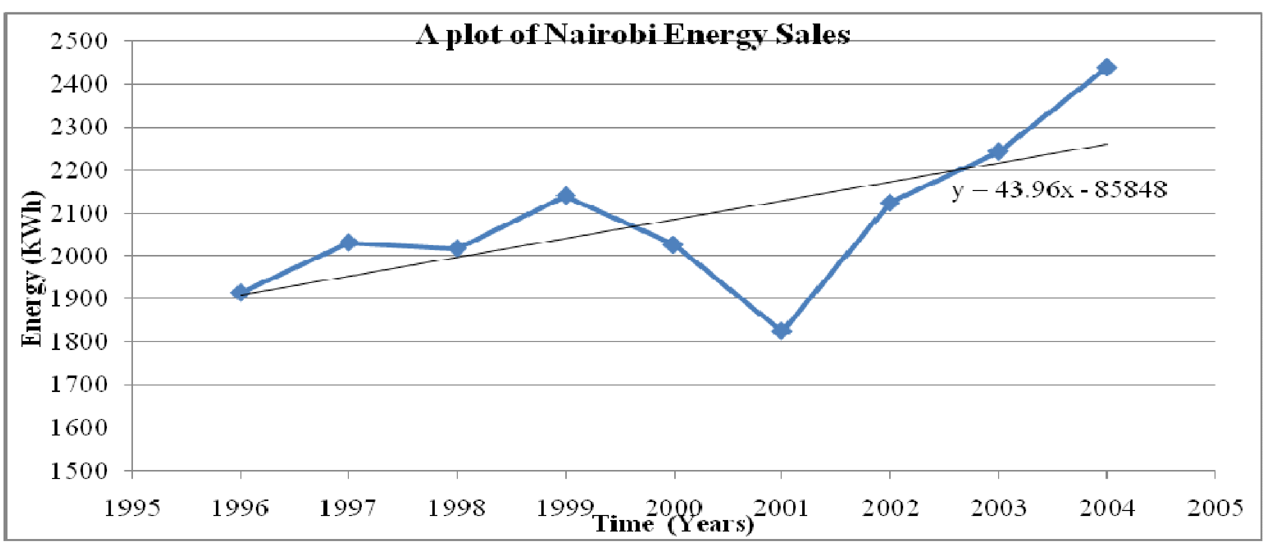

Figure 4: Time series of fuel sales in Nairobi

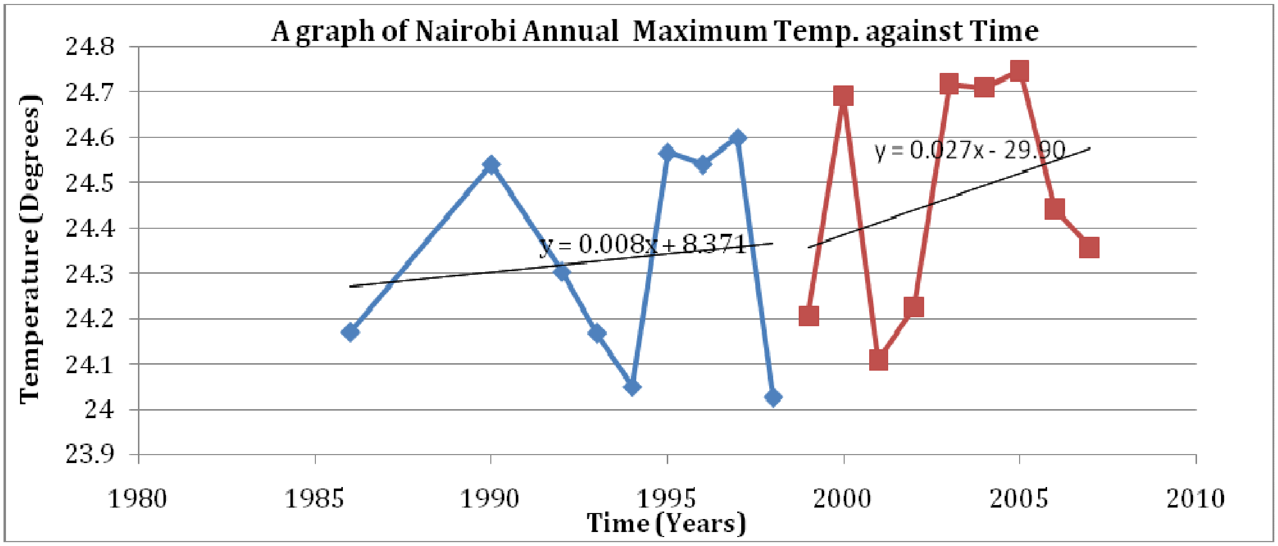

Figure 5 : Maximum temperature trend for Nairobi

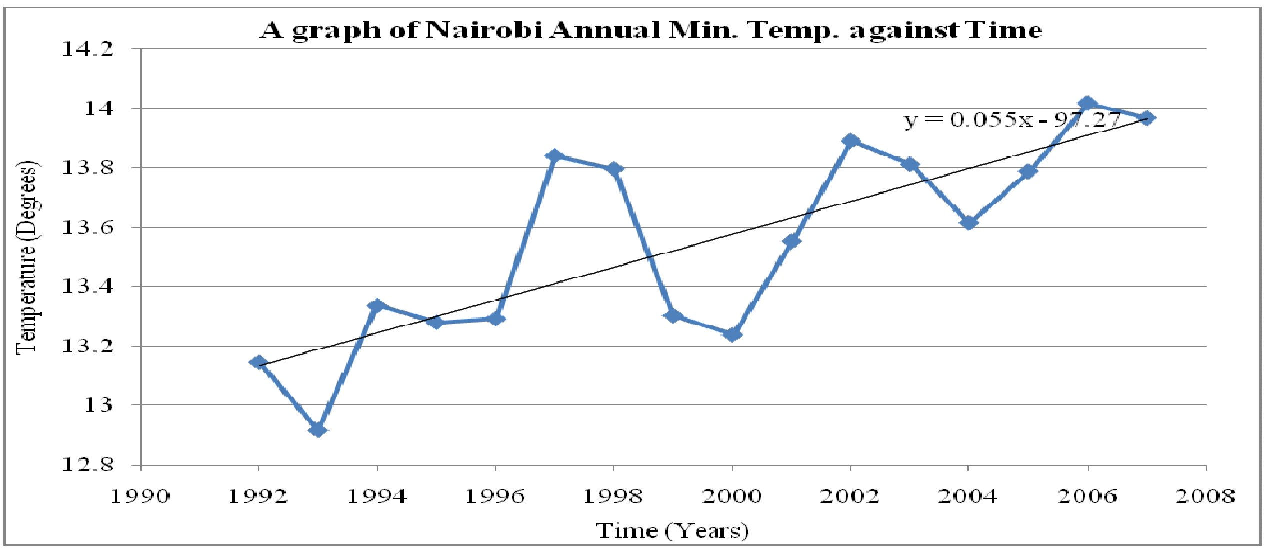

Figure 6 : Minimum temperature trend for Nairobi

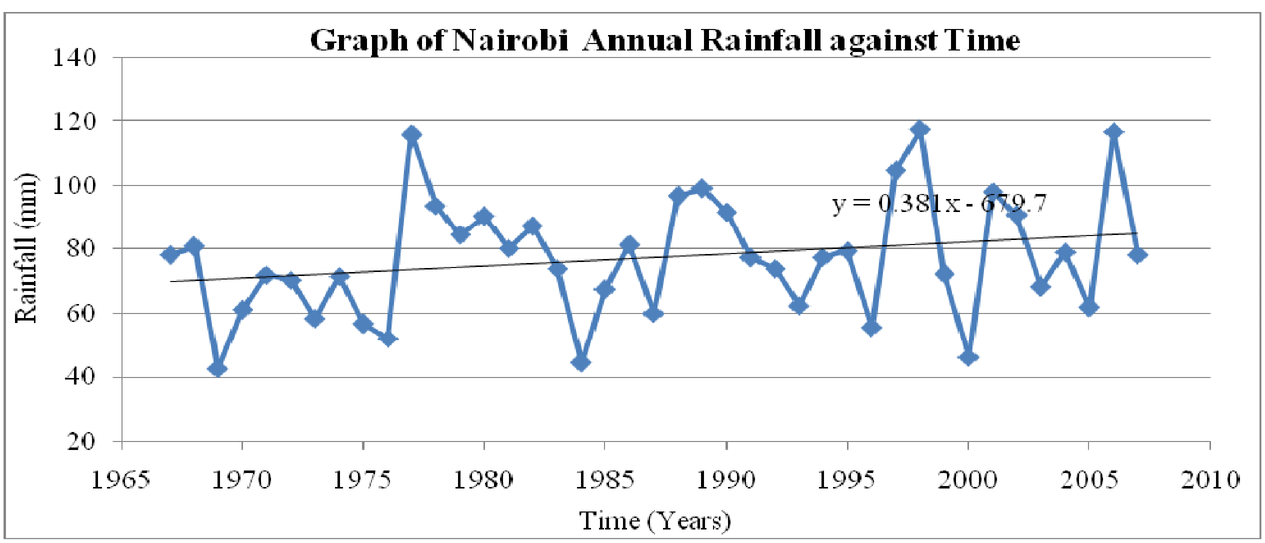

Figure 7 : Rainfall Trend for Nairobi

causes may be the drastic reduction in the area nder vegetation in cities, implying that land use planning becomes critical in determining the environmental quality.

Since Nairobi does not have a large evenly distributed industrial areas that could emit excessive heat and smoke except in a small location, the main reason for climate change especially in temperature may be modified surfaces and atmospheric features in urban areas. Urban environments mainly consist of impervious surfaces which have lower albedo than rural surfaces.

3.3 Trend Analysis

3.3.1 Trend Analysis of minimum Temperature

The graphical method clearly suggests an increasing trend of minimum temperature (figure 6) further supported the view of a warming urban environment.

3.3.2 Trend analysis of Rainfall

Rainfall trend is observed to be increasing (figure 7)

This can be attributed to a collection of aerosols with a typical size between 0.01 and 10 micrometer that reside in the atmosphere for at least several hours, affecting the climate directly through scattering and absorbing radiation and through acting as cloud condensation nuclei.

The increase of heat in Nairobi city leads to increase in the rate of convection over the city. Increase in convection leads to increment in rainfall frequency as well as the amounts.

3.3.3 Humidity Trend Analysis

A plot of humidity against the respective time in years indicates negative humidity trend (figure 8).

It is the reduction of humidity with time that shows the city is becoming drier as an effect of urbanization. Due to urbanization, the extent of water seepage into the earth surface is generally low thus reducing the amount of water available for evaporation. Similarly, the amount vegetation cover is low thus leaving the earth surface exposed to intense heating and definitely end up being dry.

3.4 Correlation Analysis

The correlation coefficient was found to be 0.7587 between population and minimum temperature. A coefficient of 0.3578 was realized for the relation of maximum temperatures and population. The coefficient of correlation between population and humidity was 0.0282 and 0.0879 for rainfall.

In all cases, correlation was positive. Urbanization was found to be highly correlated with minimum temperature and least correlated with rainfall. One parameter (minimum temperature) can therefore be used to estimate or predict urbanisation given the high correlation coefficient of 0.7587. Rainfall on other hand was found to be not strongly correlated to population and can therefore not be used as an index of urbanisation.

3.5 Regression Analysis Minimum Temperature and Population

From the plot of population and minimum temperature (figure 9), it was evident that there was a direct positive relationship between the two.

The value of coefficient of determination is 0.575, was about 58% of the variability in minimum temperature that can be explained by population growth. The remaining percentage; of about 42% of the variability in minimum temperature can not be explained by human population.

3.6 Comparison Rainfall Trends within and outside the city centre

Comparing the trends (figure 10), Moi Air Base has a positive slope of 0.132 while Muguga Forest Station has a weak negative slope of 0.108. The rainfall trend in the more urban setting; Moi Air Base, increases at a low rate compared to the station in the rural setting that shows a slightly decreasing trend.

3.7 Minimum temperature

Owing to the incompleteness of Muguga Forest Station and Moi Air Base minimum temperature data, NWA and KAS stations were used as a representation of more urban and more rural setting respectively.

The rate of change of minimum temperature over a station in a more urban setting like NWA is more warmer than the station in a rural setting like Kabete Agrometeorological Station (Figure 11).

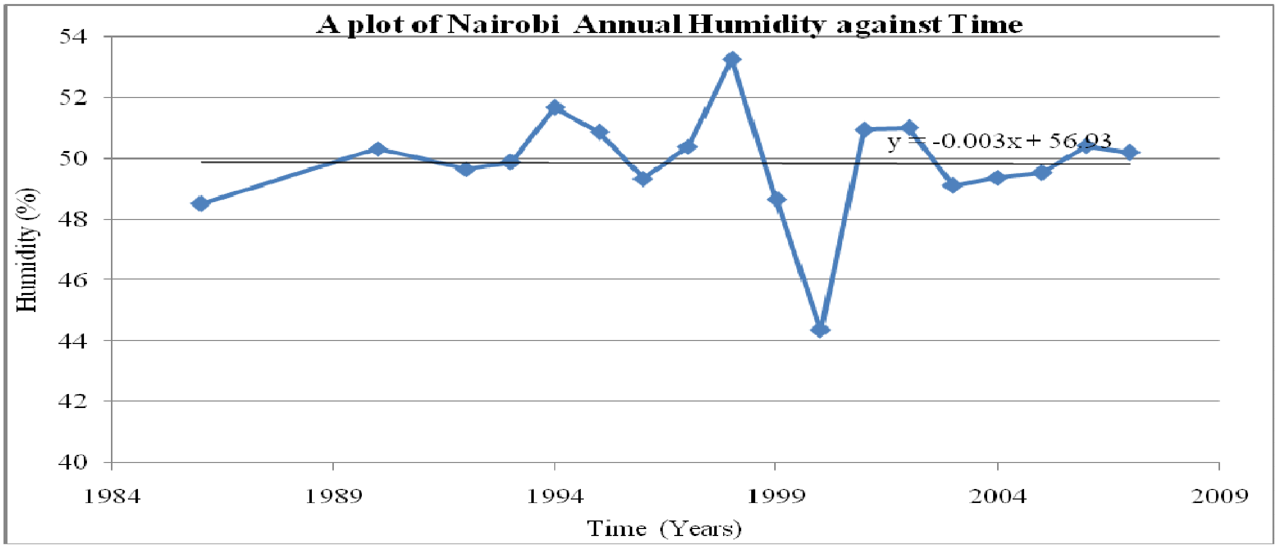

Figure 8 : Humidity Trend for Nairobi

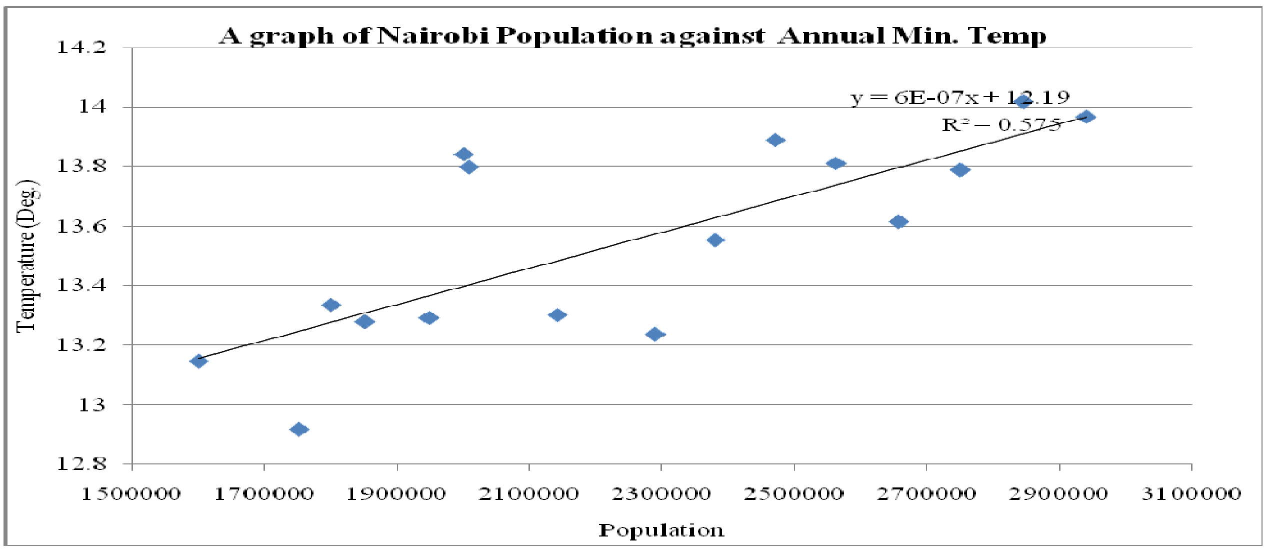

Figure 9 : Nairobi population-minimum temperature regression

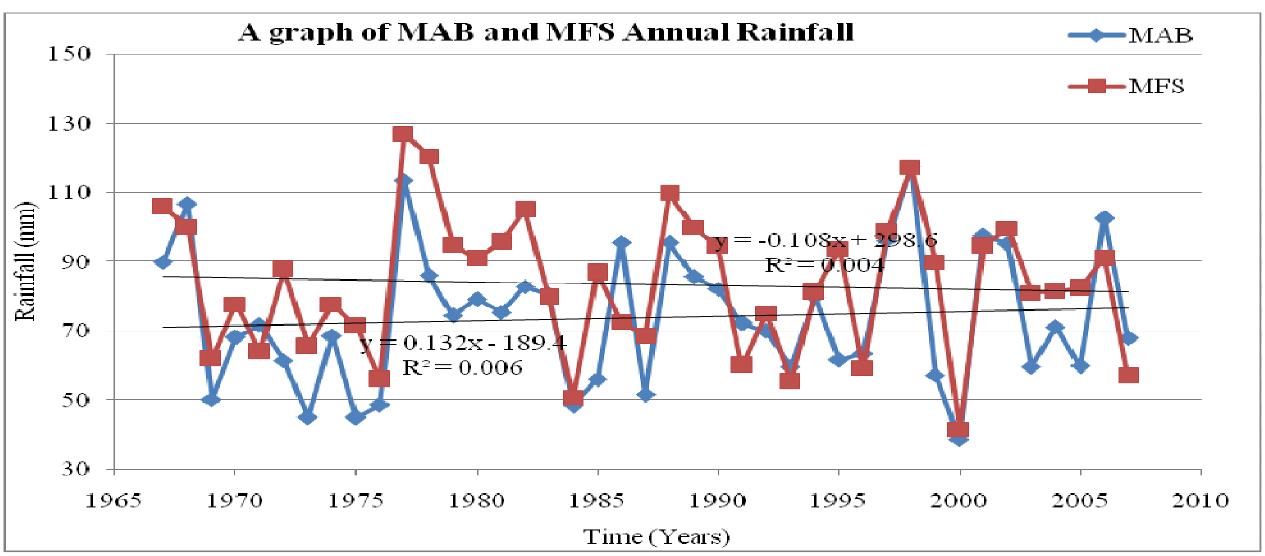

Figure 10 : Rainfall trends of Moi Air Base and Muguga Forest Station

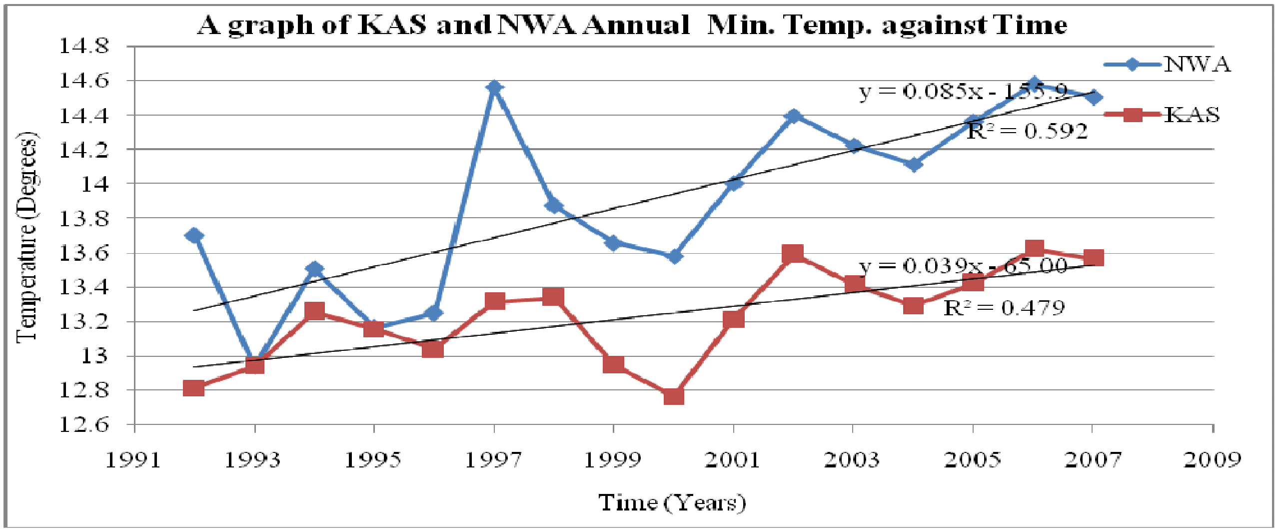

Figure 11 : Nairobi Wilson Airport (NWA) and Kabete Agrometeorological Station (KAS) Minimum Temperature trend

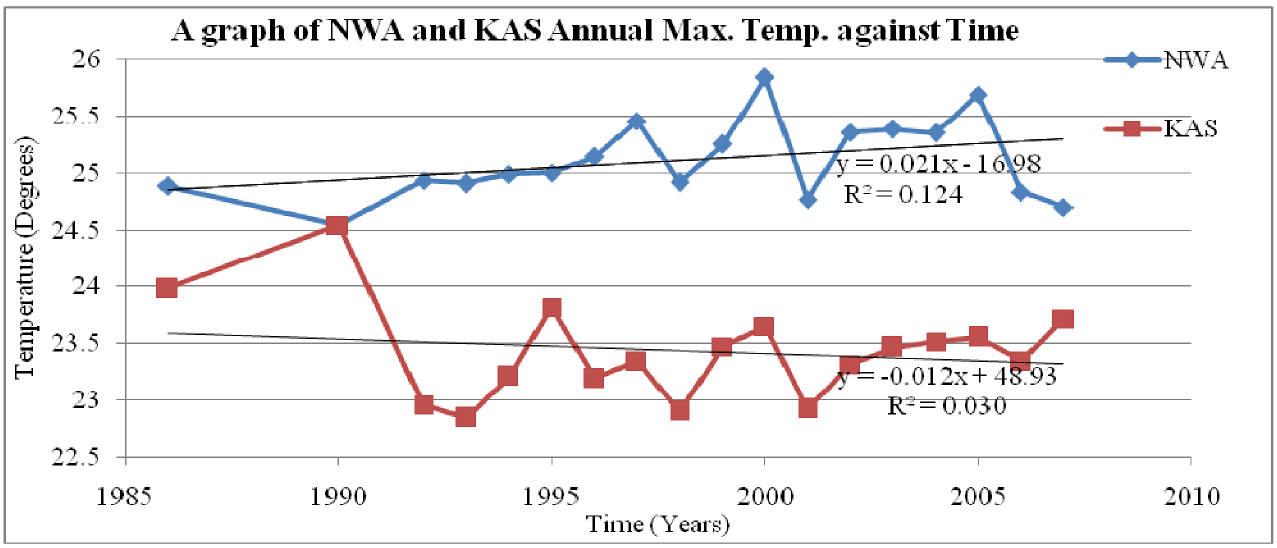

Figure 12 : Nairobi Wilson Airport (NWA) and Kabete Agrometeorological Station Maximum Temperature trend

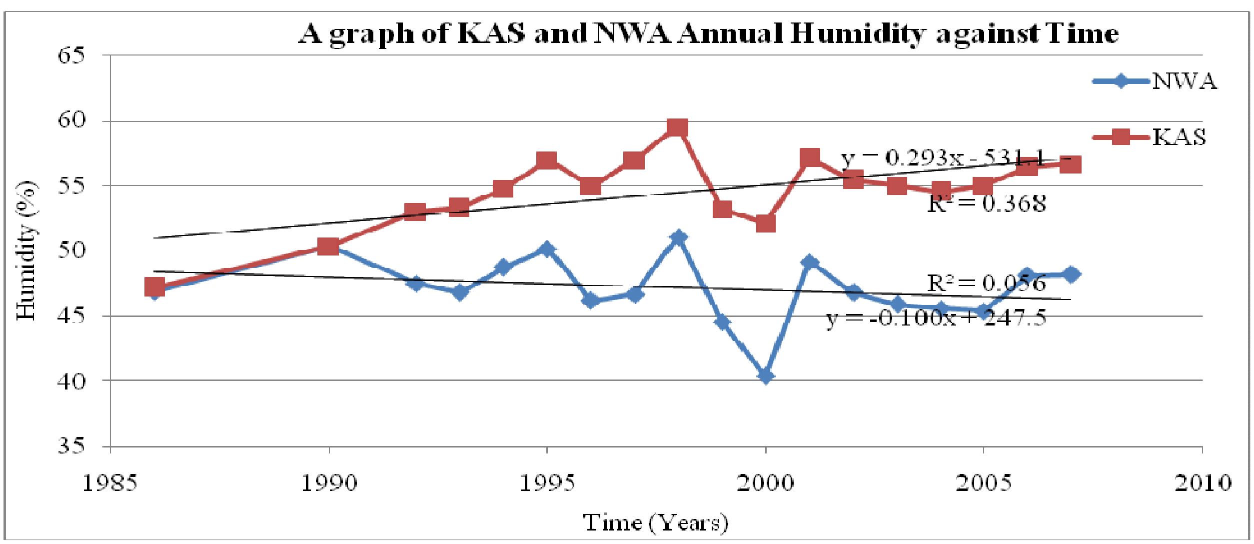

Figure 13 : Kabete Agrometeorological Station (KAS) and Nairobi Wilson Airport (NWA) Humidity trend

This finding indicates a higher modification of population growth on minimum temperature in less urban setting in comparison to a more urban setting.

3.8 Maximum Temperature

The rate of maximum temperature increase at Nairobi Wilson Airport which is more urban is higher than at Kabete Agrometeorological Station (figure 12).

The city is generally getting warmer than the more rural locations. This comes down to a difference between the energy gains and losses of each region. There are a number of factors that contribute to the relative warmth of cities: During the day in rural areas, the solar energy absorbed near the ground evaporates water from the vegetation and soil. Thus, while there is a net solar energy gain, this is compensated to some degree by evaporative cooling. In cities, where there is less vegetation, the buildings, streets and sidewalks absorb the majority of solar energy input. Also, the city has less water and higher runoff rates because the pavements are largely nonporous (except where there are potholes). Thus, evaporative cooling is less which contributes to the higher air temperatures.

Waste heat from city buildings, cars and trains is another factor contributing to the warm cities. Heat generated by these objects eventually makes its way into the atmosphere. This heat contribution can be as much as one-third of that received from solar energy. The thermal properties of buildings also add heat to the air by conduction. Tar, asphalt, brick and concrete are better conductors of heat than the vegetation of the rural area.

The canyon structure that tall buildings create enhances urban warming. During the day, solar energy is trapped by multiple reflections off the buildings while the infrared heat losses are reduced by absorption. However, urban heat island effects can also be reduced by weather phenomena although it is not applicable in the study. The temperature difference between the city and surrounding areas is also a function of the synoptic scale winds. Strong winds reduce the temperature contrast by mixing together the city and rural air.

3.9 Humidity

Humidity in the more rural setting like Kabete Agrometeorological Station (KAS) is showed increasing while in more urban setting like Nairobi Wilson Airport (NWA), is shown to decrease with time (figure 13).

It therefore affirms that the city is becoming drier in comparison to its environs.

4. CONCLUSIONS

The main purpose of this study was to determine the urbanization effect on the climate elements over Nairobi City using historical temperature, relative humidity and rainfall data.

The findings of this study have established that Nairobi City is growing at a high rate of about 6.9%. Population growth is directly proportional to energy use, while an increase of fossil fuel energy implies an increase in emission of heat from domestic use, industries, green house gases and dust particles into the environment. All these have the effect of increasing air temperature.

The trend test results show that there has been a significant warming trend in both the mean maximum and minimum temperature in the urban setting. This was found to be more significant in the surface minimum temperatures as compared to maximum temperatures. In contrast, the maximum temperature at the less urban setting does not show any significant trend. This therefore ascertains that there is an urban induced modification (warming) in the surface temperature.

Trend test for rainfall showed an increase in rainfall amounts, thus, there is modification of rainfall by urbanization at least within the city.

Humidity was tested and found to be insignificantly decreasing with time over the city. A further comparison between the more urban and the less urban station showed that there is a decrease in humidity levels in the more urban setting than in the less urban setting. This implies urban settings are becoming drier as result of urbanization.

The environmental implications of such urban surface temperature modification are very sensitive to human comfort and therefore the findings in this study should be incorporated in the current and future planning programs of the city.

5. RECOMMENDATIONS

Green areas in cities have been considered as potential measure in mitigating the urban heat island effect (Wong and Yu, 2005). Urban forest areas which serve as urban lungs should be enlarged and be well maintained. Related professionals whose work fields are planning and designing, e.g. landscape architects and urban planners, should seek new ways of providing healthy environments for people considering the basic principles of their occupations, e.g. leaving enough vegetated spaces. Another approach for the construction of thermally comfortable environments may be the clustering of newly developing cities by placing large green areas between them and by reducing the size of population and surface areas of the settlements. Since the number of such studies in developing countries like Kenya is insufficient, their quality and quantity should be increased in order to provide local people with more livable urban environments.

Decentralization of resources to minimise rural – urban migration, reduced urban population, reduces pressure on urban resources. This reduces the rate of depletion of natural resources such as clearing of vegetation to create room for settlement and business centres. Reduction in population goes a long way in reducing amount of waste disposal.

Intensification of the network of meteorological stations so as to enhance their coverage of the city and other urban centres should be encouraged because sufficient climate data from the stations will facilitate more accurate research in future.

REFERENCES

Aesawy, A.M and Hasanean, H.M., 1998. Annual and Seasonal Climatic Analysis of Surface Air Temperature Variations at Six Southern Mediterranean Stations. Theoretical and Applied Climatology, 61, 55-68.

Awuor, Cynthia B., Victor A. Orindi and Andrew Adwerah (2008), Climate Change and Coastal Cities: The Case of Mombasa, Kenya, *Environment and Urbanization*, Vol. 20, No. 1.

Bates, B.C., Z.W. Kundzewicz, S. Wu and J.P. Palutikof, Eds., 2008: Climate Change and Water. Technical Paper of the Intergovernmental Panel on Climate Change, IPCC Secretariat, Geneva, 210 pp.

Changnon, S. A., 1996a: Defining the flood: A chronology of key issues. *The Great Flood of 1993,* S. Changnon, Ed., Westview Press, 3–28.

Fortunaik K., K. Klysik and J. Wibig, 2006.*Urban-Rural Contrasts of Meteorological parameters in Lodz*. Theoretical Application in Climatology, 84, 103-116.

Fortuniak K., K. Klysik and J. Wibig, 2006. Urban-rural contrasts of meteorological parameters in Lodz. *Theor. Appli. Clim.* 84, 108 – 116

GOK 1999, National population and housing census. Vol 1. Ministry of Planning and National Development Central Bureau of Statistics.

Hardoy, Jorge E. and Satterthwaite, David (1989). *Squatter Citizen; Life in the Urban Third World*, Earthscan Publications, London.

Houghton J.T and Callander B.A; IPCC, 1992: Climate Change 1992: *The supplementary report to the IPCC scientific assessment.*

Houghton J.T, Callander B.A and Maskell K.; IPCC, 1994: Climate Change 1994: *Radiative forcing of Climate Change and an Evaluation of the IPCC Emission scenarios.*

Howard, L., 1833; Climate of London Deduced from meteorological observations, 3rd ed; in 3 Vols. Harvey and Darton, London.

Huff FA and Changnon SA Jr (1973) Precipitation modification by major urban areas. *Bull Amer. Meteor Soc* **54**:1220-1232

Huff, F. A., and J. L. Vogel, 1978: Urban, topographic, and diurnal effects on rainfall in the St. Louis region. *J. Appl. Meteor., **17**, 565 -577*

IPCC (Intergovernmental Panel on Climate Change), 2007a:*Climate Change 2007:the Physical Science Basis .Contribution of Working Group I to the Fourth Assessment Report of the IPCC*, S. Solomon D. Qin, M. Manning Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller,Eds. Cambridge University Press, Cambridge 996 pp.

Karl T.R., Diaz, H.F and Kukla, G., 1988.Urbanization: Its detection and Effects in the United States Climate record. Journal of Climate, 1, 1099- 1023.

Karl, T. R., H. F. Diaz, and G. Kukla, 1988: Urbani zation: Its detection and effect in the

United States Climate Record, *J. Climate*, *1*, 1099-1123.

Mills, G. 2006: Progress toward sustainable settlements: a role for urban climatology. *Theoretical and Applied Climatology* 84, 69–76, doi: 10.1007/s00704–005–0145–0.

Mitchell, J.M., Dzerdzeevskii, B., Flohn, H., Hommery, W. L., 1996. *Climatic Ch*ange WMO TN-79, WMO No. 195. TP-100, WMO, Geneva, 79 pp.

Ng'ang'a, J. K., 2003. *Use of Weather and Climate Information for Mitigation of Air Pollution Related Disasters (A Case of Nairobi).* Proceedings of the Sixth Kenya Meteorologoical Society (KMS), KMS-KMD, pp 86-92.

Oke, T.R., 1973. *City Size and the Urban Heat Island* .Atmospheric Environment 7: 796- 779.

Oke, T.R. 1979. Review *of Urban Climatology 1973-76.*TN-134, WMO No. 383, WMO, Geneva.

Okoola, R. E., 1980 .*The Nairobi Heat Island.* Kenya Journal of Science and Technology. Series A, Vol 1, No. 2, 53-65.

the Impact of Urbanization on the Microclimate over Nairobi Area, PhD Thesis, University of Nairobi.

Opijah F. J., and Mukabana, J., 2004. On the Influence of Urbanization on the Water Budget in Nairobi City: A Numerical Study. GeoJournal, 61, 121-129.

Robaa, S. M, 2003. Urban - *Suburban/rural differences over Greater Cairo, Egypt. Atmosfera* 16, 157-171.

Shepherd JM (2005) A review of current investigations of urban-induced rainfall and recommendations for the future. *Earth Interactions* **9**: paper 12, 27 pp.

Unkašević M., O. Jovanović and T. Popović, 2001. Urban-suburban/rural vapour pressure and relative humidity differences at fixed hours over the area of Belgrade city. *Theor. Appl. Climatol.* **68**, 67-73.

Vogel, J. L., and F. A., Huff, 1978: Relations between the St. Louis urban precipitation anomaly and synoptic weather factors. *J. Appl. Meteor.,* 1**7,** 247 - 251

Wong N. H. and C. Yu, 2005. Study of green areas and urban heat island in a tropical city. *Habitat Int.* **29**, 547-558.

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*5).****.Appendix.*** Lengthy, mathematical analyses whose details are subordinate to the main theme of the paper should normally appear in an appendix. Each appendix should have a title.

6)..References. References should be arranged alphabetically without numbering. The text citation should consist of the author's name and year of publication, [e.g., "according to Rossby (1945)," or "as shown by an earlier study (Rossby 1945)"]. When there are two or more papers by the same author in the same year, the distinguishing suffix (a,b, etc.) should be added. More information on preparing and arranging references is provided in section 3d of this document.

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Charney, J. G., and A. Eliassen, 1964: On the growth of the hurricane depression. *J. Atmos. Sci.*, **21**, 68–75.

Wallace, J. M., and P. V. Hobbs, 1977: A*tmospheric Science: An Introductory Survey*. Academic Press, 350 pp.

2) FOR A BOOK

Reference must consist of last name and initials of author(s), year of publication of book, title of book (italicized or underlined), publisher's name, and total pages. For example:

Wallace, J. M., and P. V. Hobbs, 1977: Atmospheric Science: An Introductory Survey. Academic Press, 350 pp.

3) FOR A CHAPTER IN A BOOK

For a book or monograph that is a collection of papers written by independent authors, the reference must be made to the authors of a particular

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Anthes, R. A., 1986: The general question of predictability.

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