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Influence of Urbanisation on Minimum and Maximum Temperature characteristics over Nairobi City

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ABSTRACT

Urban Heat Island being the most investigated aspect of urban climate is not prominently investigated in tropical African urban areas. This paper seeks to address the influence of urbanization on outdoor temperature characteristics in the city of Nairobi. Monthly minimum and maximum temperature data from four ground-based weather stations namely, Dagoretti Corner (DC), Wilson Airport (WA), Jomo Kenyatta International Airport (JKIA) and Moi Air Base (MAB) stations over a 47-year period from 1961 to 2007 were used. The data were subjected to time series analysis. Station to station correlation analysis was performed as an indicator of the linear association of station records and also to understand spatial variability. 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 MAB. The minimum temperature across the city shows a significant positive trend. This may be attributed to urbanization effect. Among all the four stations, only DC exhibited a significant positive trend of maximum temperature. Trend analysis revealed that there was significant minimum temperature increase of 0.43^0C with a significant maximum temperature increase of 0.11^0C per decade during the 47-year period. This is a strong evidence of temperature modification due to urbanization. Comparative analysis of temperatures across the city of Nairobi depict heterogeneity among the four weather stations, with MAB being the hottest while DC is the coldest. Therefore, the microclimate of Nairobi is not homogeneous and implications of urbanization on planning of climate sensitive structures and services should be area specific. Further analysis to establish Urban Heat Island (UHI) characteristics of the city in future is recommended especially with availability of more weather stations around the city of Nairobi and adjacent rural areas.

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Introduction

Urbanization is a population shift from rural to urban areas. This implies that urban population is increasing rapidly especially in developing countries where people migrate to urban areas for employment, education and better living conditions. 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. Nairobi has experienced a high urbanization rate with the city's population growing from 267,000 in 1962 to over 4 million currently (Omwenga, 2011). Increased urbanization entails modification of urban surface due to removal of vegetation cover to create space for buildings, water bodies, open spaces and the establishment of impervious surfaces. These have been shown in various studies of urban centres to create distinctive climatic environments (Adebayo, 1985 and Ongoma *et al*., 2013).

Urbanization modifies the local climate due to anthropogenic activities that go on in urban conurbations in various ways including Greenhouse Gas (GHG) emissions that lead to establishment of greenhouse effect. 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 local climate. All these determine the effective urban microclimate. In particular, the city of Nairobi has notable waste heat deposition due to energy consumption attributable to these urban characteristics (KIPPRA, 2010).

Nairobi is the capital city of Kenya. It is an equatorial city located at the latitude 1°17'S and longitude 37°'10'E. It is found on the East African plateau with a mean altitude of 1700m above sea level. The altitude of Nairobi ranges from 1600m to the east to over 1800m to the west and northwest covering an area of about 700 square kilometers (Ng'ang'a, 1992, Kinguyu *et al*., 2000, Ongoma, *et al.*, 2014), see Figure 1.

The city is the major commercial and industrial hub of not only the country but is also the regional and international headquarter for several commercial and public institutions that include multinational companies and United Nations agencies (Ottichilo, 2010).

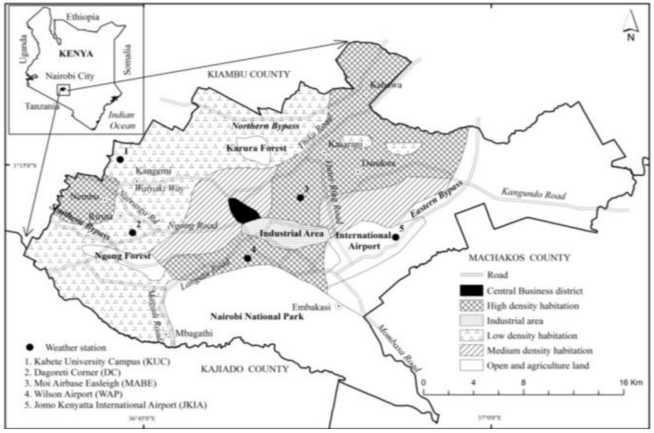

Figure 1. *Map of Nairobi County showing Meteorological Stations, Road Network and Land use patterns*

This study was based on the premise that urbanization is a good example of human impact on local climate, namely the modification of climate in terms of energy balance, water balance, wind flow characteristics and change in atmospheric composition 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 as one of the major weather variables contributing to the energy balance of an urban area, which in this case is Nairobi (Figure 2).

The temperature characteristics were considered in terms of magnitudes, averages and variation over time thus generating time series modules for informative depiction and descriptions of the maximum and minimum temperature trends. The conceptual framework of urbanization and its impacts on local climate which was also the guiding principle in this study is summarized in Figure 2 below.

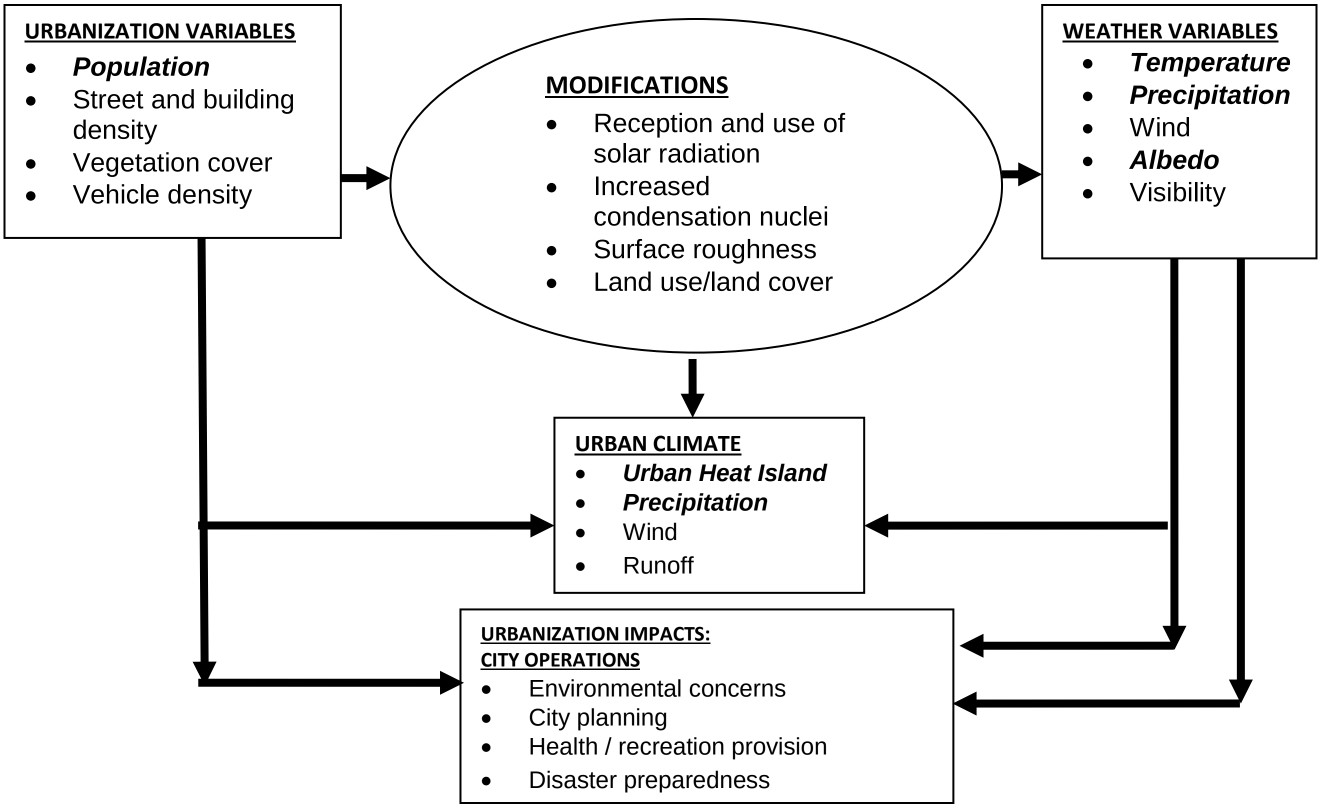

Figure 2*: Theoretical Framework of Urbanization and Local Climate impacts that guided this study*

Monthly minimum and maximum temperature data were obtained from Kenya Meteorological Department data base from 1961 to 2007 from four stations located within Nairobi City namely; DC, MAB and WA. DC Station represents the southern relatively cooler part of Nairobi, MAB represents the densely populated part of Nairobi to the north east, JKIA represents the eastern relatively hotter part of Nairobi and WA represents the transitional zone between urban and peri-urban zones of the city.

Several studies have characterised temperature seasons on the basis of agricultural productivity potential, human health and also indoor-outdoor heat energy balance (Domroes and El-Tantawi, 2005, Garcia *et al*., 2009, and IPCC, 2013). Characterization of temperature seasons in this study was performed in the context of human comfort.

Time series and correlation analyses were employed in this paper. In fitting the simple linear regression model equation, a model of the form:

$$Y = a_0 + a_1 X + \varepsilon \ldots\ldots\ldots\ldots (1)$$

This equation contains the deterministic part, $a_0 + a_1 X$ and the error termε. Then$a_0 \wedge a_1$ are the regression constants to be determined by Least Squares Method from the sample data sets. Correlation analysis was performed to measure the strength of linear association between population and maximum and also minimum temperatures for the four stations. The formula for determining the correlation coefficient is given by equation (2) below:

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

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

3. Results and Discussions

Seasonal temperature analysis reveals that two hot and one relatively cold seasons are evident in Nairobi region as a whole. This is evident in Figure 3 from which two maxima can be noticed, one centred in February and a second one in October, while July is the coldest month. However, there is apparent difference in the lengths of these seasons from station to station. This may point at varying microclimatic conditions across various areas of the city. DC station experiences cooler microclimate, with a hot season observed during January to March, hereby termed as the Long Hot Season (LHS), and a Short Hot Season (SHS) in October. WA station is characterised by warmer microclimate compared to DC, such that the LHS is observed during December to March, and a short hot season from September to October. The microclimate of JKIA area is the warmest, with the LHS experienced from September to March without any SHS.

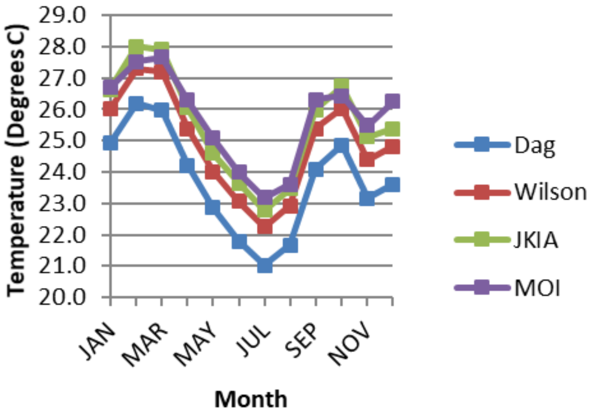

Figure 3: *Seasonal maximum temperature patterns of stations in Nairobi*

Two distinct patterns of minimum temperature are observed across the city (Figure 4). WA area experiences higher minimum temperature than DC and JKIA areas. DC station experiences a more prolonged Cold Season (CS) observed during the 3-months June to August. All the other three stations are characterised by warmer cold season compared to DC, such that the CS is observed only in July. The microclimate of JKIA area is the warmest, with the LHS experienced from September to March without any SHS.

Many studies have reported hot and cold seasons over Nairobi and indeed in East African region (King'uyu *et al*., 2000).

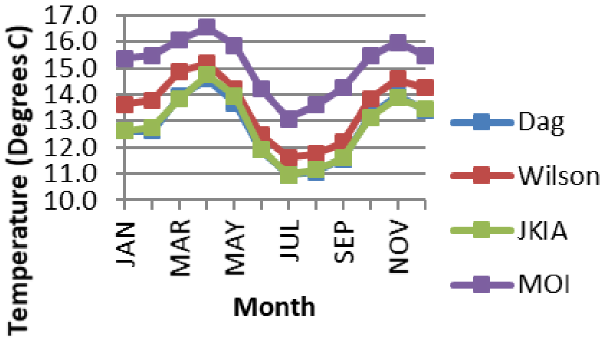

Figure 4: *The annual cycle of minimum temperature at various stations in Nairobi*

Characterization of the seasons, however, still remains inadequately quantified. This paper proposes hot (HS) and cold (CS) seasons in Nairobi to be characterised by the temperature range:

$24^{o}C \geq HS \leq 28^{o}C$ and $11^{o}C \geq CS \leq 23^{o}C$, respectively (Figures 3 and 4).

Investigation of the year to year temperature variation and detection of trend are very important indicators of climate change, for example local scale warming. This was done for each of the stations. Result for DC station is shown in Figure 5 for maximum temperature and Figure 6 for minimum temperature. There is apparent year to year variability of maximum temperature over DC station. The latter years seem to be characterized by less variability (Figure 5).

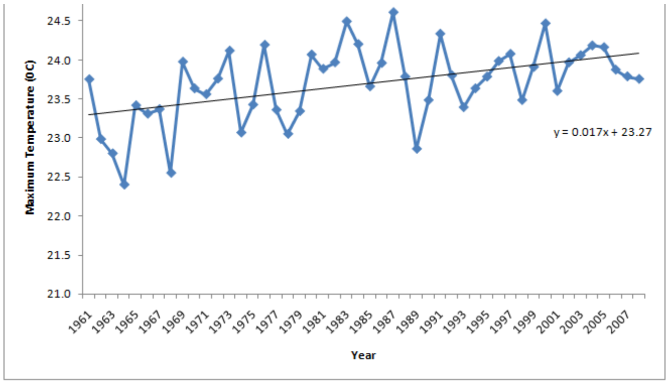

Figure 5: *Inter-annual variability and trend of maximum temperature over Dagoretti.*

This could be associated with a transformed urban microclimate possibly as a consequence of increase in buildings and settlement structures. These include formal building and informal structures in form of slums within the area. The variability in minimum temperature over DC seems less pronounced as compared to the maximum temperature variability. However, there a few spikes in the years 1971, 1981, 1987 and 1997 (Figure 6). These may be associated with the 10-year sunspot cycle.

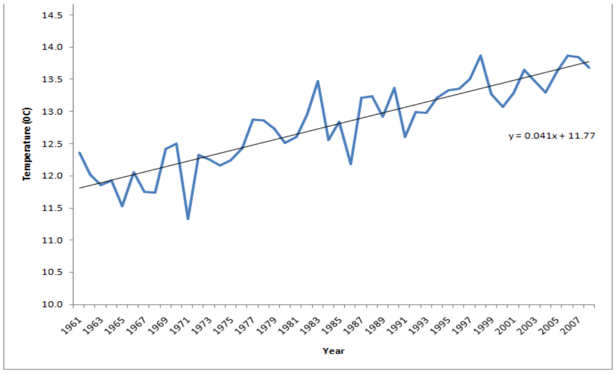

Figure 6: *Inter-annual variability of minimum temperature over Dagoretti*

However, it is evident that there is a gradual increase in mean minimum temperature, the average warming being nearly 0.43^{0}C during the 48 year period.

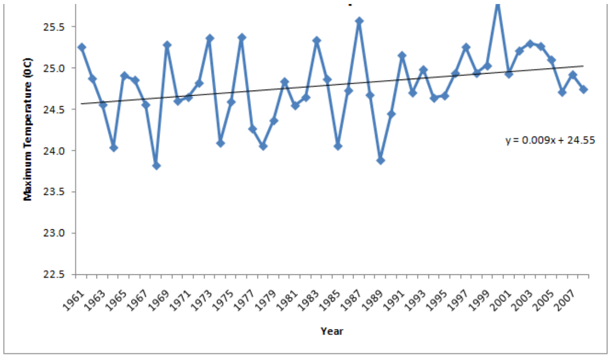

Figure 7: *Variation and trend of mean annual maximum temperatures for Wilson*

Maximum temperature variability over WA station is observed, with the latter years being less pronounced (Figure 7). This observed variability cuts across all the four stations

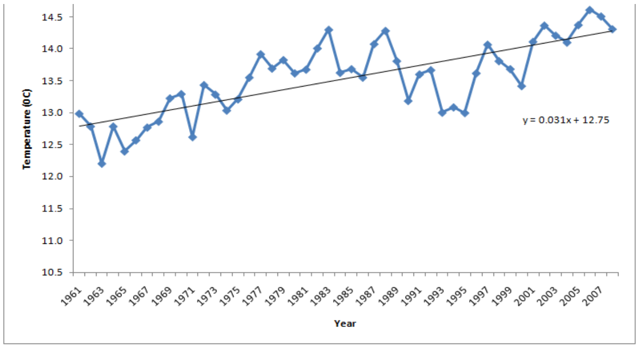

Figure 8: *Variation and trend of mean annual minimum temperatures for Wilson*

The minimum temperature over WA station shows year to year variability (Figure 8). There is also evidence of steeper increase of minimum temperature than the corresponding maximum temperature.

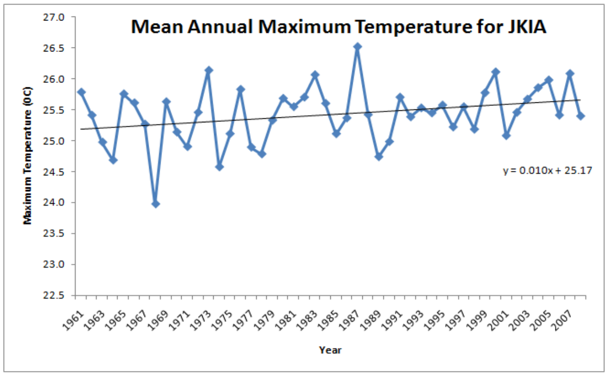

Figure 9: *Variation and trend of mean annual maximum temperatures for JKIA*

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 9).

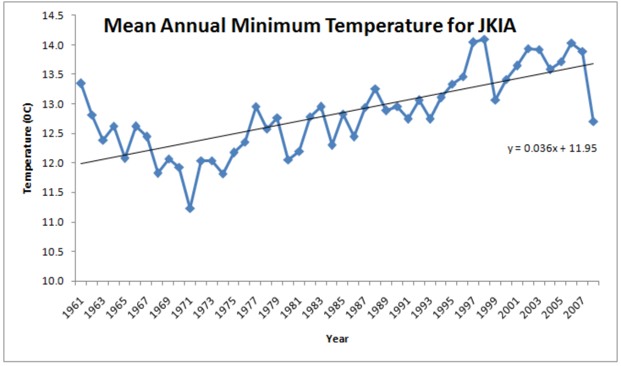

Figure 10: *Variation and trend of mean annual minimum temperatures for JKIA*

Inter-annual minimum temperature over JKIA shows low variability (Figure 10). However, the period 1961 to 1971 portrays a curios pattern of general decrease in temperature. This pattern is unique compared to the other three stations. This may be attributed to some microclimatic influence over the area. Further investigation of the data collection and handing during those years at JKIA can also reveal what was happening and might shed more light to this result.

Table 1: *Significance of trends and average temperature changes in various areas of Nairobi from 1961 to 2007*

Station	**Climate Parameter**	**Regression equation**	**Significance of Trend**	**Average Decadal Change of Temperature**
DC	Maximum Temperature	Y= 23.3+0.02X	Significant	0.11^{0} C
	Minimum Temperature	Y= 11.8+0.04X	Significant	0.43^{0} C
WA	Maximum Temperature	Y= 24.6+0.01X	Not Significant	0.10^{0} C
	Minimum Temperature	Y=12.8+0.03X	Significant	0.30^{0} C
JKIA	Maximum Temperature	Y=25.2+0.01X	Not Significant	0.11^{0} C
	Minimum Temperature	Y=12+0.04X	Significant	0.38^{0} C
MAB	Maximum Temperature	No sufficient Data	N/A	N/A
	Minimum Temperature	No sufficient Data	N/A	N/A

Minimum temperature across the city of Nairobi shows a significant increase (Table 1). All the stations depict this pattern. The slope terms of all the stations are comparable. This may suggest an enhanced Urban Heat Island effect (Ongoma, *et al*., 2013). However, there is a significant increase in maximum temperature over DC station alone. This is a further evidence of the existence of a unique microclimate over DC station as compared to the other stations.

The influence of urbanization on minimum temperature in all stations is significant and positive. The results of correlation analysis for minimum temperature (Tables 2a) show that minimum temperature in all the stations is significantly and positively correlated with population. This is true for not only the annual mean temperature but also temperature during each of 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 provide further information on the urbanization impact on Nairobi's minimum temperature. Comparison of the city's minimum temperature with the adjacent rural areas will shed more light on the impact of urbanization on minimum temperature

Table 2a: Correlation of Population with Minimum Temperature NB: *Bold correlations are significant*

DAG					WILSON					JKIA				
0.60	**0.70**	**0.63**	**0.80**	**0.83**	**0.55**	**0.47**	**0.51**	**0.49**	**0.63**	**0.67**	**0.66**	**0.55**	**0.82**	**0.83**

Table 2b: Correlation of Population with Maximum Temperature NB: *Bold correlations are significant*

DAG					WILSON					JKIA				
JF	MAM	JJA	SOND	ANN	JF	MAM	JJA	SOND	ANN	JF	MAM	JJA	SOND	ANN
0.10	0.11	**0.42**	0.13	**0.31**	0.10	0.21	**0.44**	0.10	**0.36**	0.10	0.18	**0.39**	0.10	**0.31**

For maximum temperature, correlations were found to be significant during June, July, August season. This is the season when Nairobi experiences the lowest temperatures and therefore use of anthropogenic heat is enhanced. Correlations of population with mean annual maximum were positive and significant as shown in Table 2b.

Conclusions

There is an increasing trend in minimum temperature across all the four stations in the city of Nairobi, attributable to urbanization effect. Increasing minimum temperature patterns in the city are not uniform due to the different rates of local urbanization and population dynamics. However, there is significant positive trend in maximum temperature over DC station as compared to the other 3 stations. This could be attributed to the fact that this meteorological station is located downwind of Nairobi's CBD. The spatial differences in minimum and maximum temperatures could be due to warming effect of urban land use characteristics in Nairobi. These results have revealed that decadal minimum temperatures in Nairobi have been increasing by 0.43^0C and maximum temperatures by 0.11^0C during the 47 year period (1961 to 2007). This is a strong evidence of climate change warming at local scale. These results of increasing temperatures demand serious considerations in planning of climate sensitive urban services for a rapidly expanding city of Nairobi. Increasing temperatures may not necessarily be due global scale climate warming, but could be manifestation of the local scale signal of micro-climate warming due to rapid urbanization and the accompanying increase in energy consumption, changes in land use and land cover mainly associated with removal of vegetation. The main purpose of vegetation removal is to create space for construction of commercial, public utility institutions like schools, colleges and residential dwellings. There is a need to establish more weather observation stations in Nairobi and its adjacent rural areas for a comprehensive investigation of urban heat island effect on temperatures.

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