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Research Article

Trends in Mean Annual Minimum and Maximum Near Surface Temperature in Nairobi City, Kenya

George Lukoye Makokha and Chris A. Shisanya

Geography Department, Kenyatta University, P.O. Box 43844, 00100 Nairobi, Kenya

Correspondence should be addressed to Chris A. Shisanya, shisanya@yahoo.com

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This paper examines the long-term urban modification of mean annual conditions of near surface temperature in Nairobi City. Data from four weather stations situated in Nairobi were collected from the Kenya Meteorological Department for the period from 1966 to 1999 inclusive. The data included mean annual maximum and minimum temperatures, and was first subjected to homogeneity test before analysis. Both linear regression and Mann-Kendall rank test were used to discern the mean annual trends. Results show that the change of temperature over the thirty-four years study period is higher for minimum temperature than maximum temperature. The warming trends began earlier and are more significant at the urban stations than is the case at the sub-urban stations, an indication of the spread of urbanisation from the built-up Central Business District (CBD) to the suburbs. The established significant warming trends in minimum temperature, which are likely to reach higher proportions in future, pose serious challenges on climate and urban planning of the city. In particular the effect of increased minimum temperature on human physiological comfort, building and urban design, wind circulation and air pollution needs to be incorporated in future urban planning programmes of the city.

1. Introduction

The concentration of socioeconomic activities in urban areas can be attributed to rapid expansion of industrialisation and urbanisation. In developing countries, unplanned and fast urbanisation in cities has caused environmental problems including increase in energy consumption, alteration of the local climate, and higher amounts of air pollution [1]. One of the consequences of these problems is a consistent rise in surface temperature within the urban environment [2–4]. Such noticeable surface temperature rise in urban environment is known as the "urban heat island". The heat island effect is the basic climatic response to urbanisation, and it begins being noticed in small to medium size cities with a population of less than 100,000 inhabitants [5–7]. Nairobi's population has increased from 120,000 when the first census was conducted in 1948 to 2, 137,570 in the 1999 population census [8]. The city's growth rate of about seven percent per annum is one of the fastest city growth in Africa and is projected to grow faster in future [9].

The factors causing the increase in urban temperatures are outlined by Todhunter [10] and Oke [11]. The largest increase in temperatures occurs during calm and cloudless nights [12]. During windy periods, the urban-rural temperature difference may be insignificant while during daytime the difference is usually smaller than at night. Sometimes the temperatures in the urban area during the daytime may be lower than the surrounding countryside, creating a "cool island" [13–15].

Unger [16] and Akbari and Rose [17] have shown that the actual magnitude of the "heat island" phenomenon depends on the size, population and industrial development of the city, topography and material of the surface, general climate of the region, and the antecedent meteorological conditions. The modification of temperature due to urbanisation therefore varies from city to city. The objective of this study was to examine the long-term changes in mean annual surface temperature in Nairobi City, with a view to discerning the urban modification of these changes.

2. Study Area

Nairobi, the capital city of Kenya, is located 140 kilometres south of the Equator and 480 kilometres from the Indian

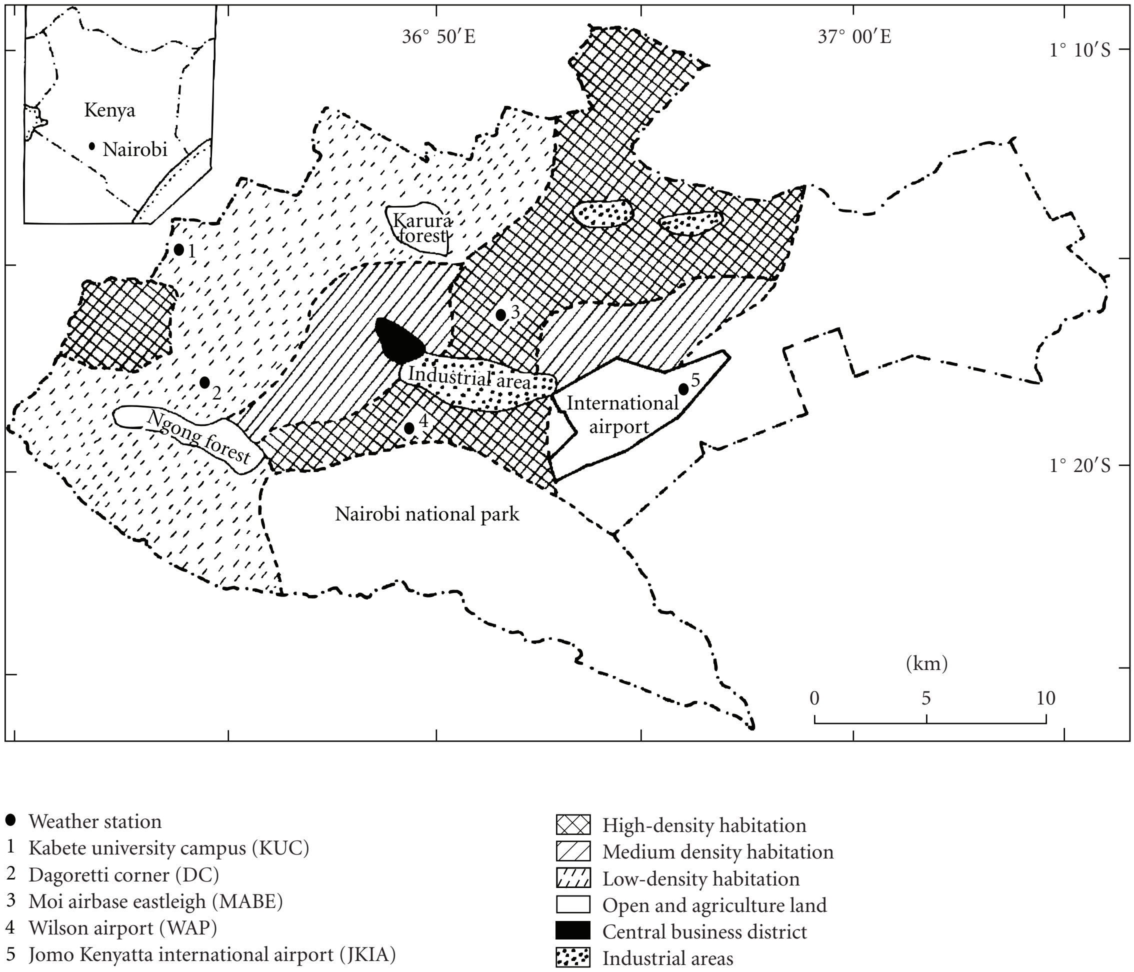

Figure 1: Land use and location of permanent weather stations in Nairobi.

Ocean, at around latitude 1°17′S and longitude 36°48′E. It covers an area of approximately 690 square kilometres and has a diverse physical environment. The altitude of Nairobi ranges from an average of 1500 metres in the East to approximately 1900 metres in the West (Figure 1).

The tropical character of Nairobi climate is exhibited as modified equatorial climate of the highlands, with temperatures and rainfall being influenced by the altitude. The mean annual temperature value is 19°C while the annual rainfall varies from 800 mm in the East to over 1000 mm in the West [18]. Relative humidity is higher in the morning (over 80%) and lower in the afternoon (below 40%), while sunshine duration varies from 4 to 9 hours per day [19].

The industrial area of Nairobi has expanded and new industrial zones have come up in hitherto green and open areas, leading to increased air pollution within the urban environment. Related to pollution is the ever-increasing number of motor vehicles. The proportion of the Kenyan vehicles registered in Nairobi is high and has increased from 55.5% in 1990 to 80.0% in 1999 [20]. This has implications on air pollution especially during peak traffic hours. There has also been an increase in built-up area over the last two decades. The city centre in particular has witnessed a tremendous increase in the construction of high rise commercial buildings leading to a complex urban geometry and high building density. In the eastern, north-eastern and south-eastern parts of the city centre, new residential estates have been and continue to be constructed. More open and green spaces have diminished leading to increase in the concrete jungle within the city environment. Further, immigration into the city for employment opportunities has led to growth of spontaneous squatter settlements in many places within the city. These settlements have a high concentration of built environment that is likely to affect the microclimate of the city. Again a large amount of energy in industrial and domestic uses is consumed, constituting a significant component of urban anthropogenic heat release.

The physical and socioeconomic changes occurring within the urban environment could lead to the long-term modification of the temperature conditions. We have analysed the nature of this modification in Nairobi City.

3. Data

The data used for this study were obtained from the Kenya Meteorological Department (KMD) for four weather stations situated in Nairobi area (Figure 1). Two of the stations were considered urban and the other two suburban.

The mean annual maximum and minimum temperatures for the period from 1966 to 1999 were considered useful in revealing the nature of urban modification.

The stations used included Moi Airbase Eastleigh no. 9136087 at an altitude of 1637 metres and Wilson Airport no. 9136130 at an altitude of 1683 metres. These stations are situated about 4 kilometres to the east and south of the CBD, respectively, and represent temperature conditions for an urban setting. The suburban stations were Dagoretti Corner no. 9136164 at an altitude of 1795 metres and about 8 kilometres west of the city centre and Jomo Kenyatta International Airport no. 9136168 at an altitude of 1624 metres and about 13 kilometres east of the CBD.

3.1. Data Analysis. For long-term climate trend analysis, data must be homogenous [21, 22]. A homogenous climate time series has variations caused only by variations in weather and climate [23]. Inhomogeneity in a time series can lead to misinterpretations of the studied climate parameters of a given climate [24–27]. The homogeneity test applied in this study was the Short-cut Barlet test [28]. The test established that the data for all the four stations were homogenous.

3.2. Regression Analysis. A simple linear regression model was applied to show the long-term annual and seasonal trends in temperature for the period from 1966 to 1999. Change in temperature over the study period and the coefficient of determination (r^2) were computed from the regression model [29].

3.3. Mann-Kendall Rank Statistic. To identify any abrupt change in the climatic trends, use was made of the sequential version of the Mann-Kendall rank statistics [22, 28, 30, 31]. The rank test is the most appropriate method for analysing climatic changes in climatological time series [32]. It is given by the following equation:

$$U(t_i) = \frac{[t_i - E(t_i)]}{\sqrt{\mathrm{Var}\cdot(t_i)}}, \tag{1}$$

where $U(t_i)$ is the trend value of t_i, t_i is the statistical test given by the expression $\sum_i n_i$, $E(t_i)$ is the mean of t_i given by the expression $i(i-1)/4$, $\mathrm{Var}\cdot(t_i)$ is the variance of t_i given by the expression $i(i-1)(2i+5)/72$, and i is the order of the year in the time series, for example, 1 for 1966, 2 for 1967, and so on.

When the values of $U(t_i)$ are significant, an increasing or decreasing trend can be observed depending on whether $U(t_i)$ is increasing or decreasing. However, when a series shows a significant trend, we can locate the start of the phenomenon by means of a sequential analysis. In this case, it can be usefully extended to the reversed series. In the reversed series, $U'(t_i)$ is calculated backward from the end of the time series, while $U(t_i)$ is computed forward. In the absence of any trend in the series, the graphical representation of $U(t_i)$ and $U'(t_i)$ gives curves which overlap several times. However, in the case of a significant trend, the intersection of these curves enables the start of the phenomenon to be approximately located.

Table 1: Mean annual rates of temperature change (°C/34 years) and coefficient of determination (r^2) for urban and suburban stations in Nairobi.

Station name	Maximum temperature		Minimum temperature	
	°C/34 years	r^2	°C/34 years	r^2
MABE (Urban)	−0.3200	0.0529	1.1730	0.6053
WAP (Urban)	0.1768	0.0132	0.9486	0.2852
DC (Suburban)	0.5236	0.1108	1.5436	0.6281
JKIA (Suburban)	0.3060	0.0417	1.7850	0.6518

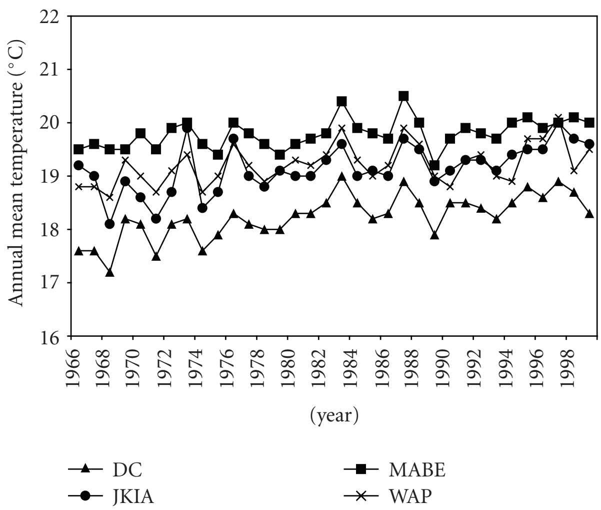

Figure 2: Annual mean time series of temperature at all four stations.

4. Results and Discussions

4.1. Trends for Linear Regression Model. The mean annual minimum temperature in Nairobi generally shows a higher increasing trend and higher coefficients of determination (r^2) than the mean annual maximum temperature for all the stations used in the study (Table 1). The reason for such a trend in minimum temperature compared to maximum temperature can be attributed to the effect of urban modification, which is well manifested in minimum temperature than maximum temperature [18, 33–37].

As shown from the table, both the rate of annual mean maximum temperature increase for every 34 years (°C/34 years) and r^2 are generally higher at the suburban DC and JKIA stations. The urban MABE station has a negative trend, while its counterpart at WAP has the lowest positive trend. The negative trend value of maximum temperature at the urban MABE station is an indication of the existence of episodes of urban cool-island, which is not the case for the suburban stations at DC and JKIA. The rate of temperature increase (°C/34 years) and r^2 for annual mean minimum temperature are higher at suburban stations than the urban stations. This can partly be explained in terms of the urban effect caused by the increasing urban sprawl toward the outskirts of the Central Business District (CBD), since current urban developments are relatively

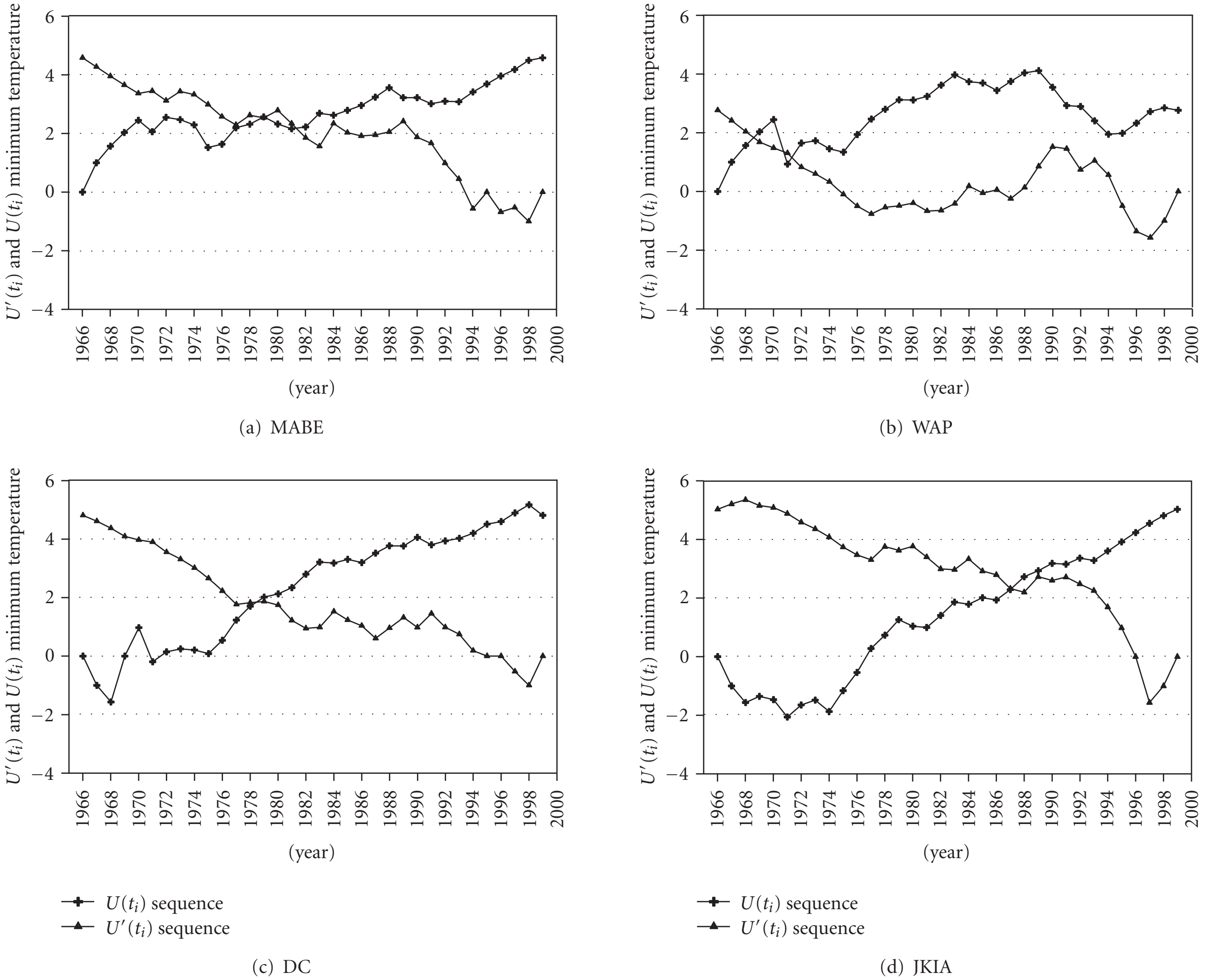

FIGURE 3: Annual trends of minimum temperature (1966–1999) at four weather stations in Nairobi.

concentrated toward the suburbs as compared to the CBD. At suburban station of DC, other than the effect of the highly populated nearby estates, the persistent easterly winds reach the station at slowed speeds due to surface friction as they flow westward. According to Todhunter [10] and Oke [11], reduced wind speed caused by the aerodynamically rough urban fabric leads to increased minimum temperature during the night. At JKIA suburban, the urban effect caused by the recently developed estates that began in the early 1980 s and the nearby industries along Mombasa road may be contributing to the observed increasing trends.

The annual-mean time series of temperature at all the four stations (Figure 2) shows that the urban station at MABE has the highest mean annual temperatures while the suburban station at DC has the lowest. This can be attributed to the high minimum temperatures at MABE compared to the other three stations.

4.2. Trends for Mann-Kendall Test

4.2.1. Maximum Temperature. Generally climatic series of mean annual maximum air temperature at the four weather stations in Nairobi show lack of trends in their climatic series. At the MABE urban station, a negative trend in maximum temperature indicates occurrence of daytime urban cooling, a situation contributed by higher heat absorption and the effect of shadows caused by the reduced sky view factor in the built environment. The suburban weather stations, which have more vegetation than built environment, lose terrestrial radiation much faster leading to warming of the lower atmosphere [19, 38].

4.2.2. Minimum Temperature. Figures 3(a) to 3(d) show the result of the climatic series for the annual minimum temperature at the four stations in Nairobi. At each of the four stations, a significant abrupt climatic change indicating a warming trend took place. The warming trend is first noticed at the urban WAP station in 1971, and the trend is significant with $U(t_i)$ values ≥ 2 between 1976 and 1999 (Figure 3(b)). At the suburban DC station, a significant warming trend with $U(t_i)$ greater than 2 began from 1979 to 1999 (Figure 3(c)), while at the urban MABE station, a significant warming trend with $U(t_i) \geq 2$ began from 1981 to

1999 (Figure 3(a)). Figure 3(d) shows that at suburban JKIA station, a significant climatic trend toward warming began from 1987 to 1999, having $U(t_i)$ values greater than 2.

From the above results, it can be seen that the urban modification of near surface annual minimum air temperature in Nairobi started much earlier at the urban WAP station than the other stations. Two reasons can explain this behaviour of temperature at the said station. First is the closeness of the station to the industrial area and the development of earlier residential estates close to it. Second, the said developments obstruct the upwind flow making it reach the station at a reduced speed. Since the "heat island", which is a night time phenomenon, is most sensitive to wind speed, due to the mixing effect brought about by turbulent and advective activity, low wind speeds enhance the development of urban heat island [10, 11]. At the urban MABE station, there were no early developments toward the upwind direction of the station until mid 1970 s. Most of the early residential developments took place toward the north west, west, and south west in the downwind direction of the station. Since most of the land in the upwind direction was open land, and the station is nearer to the upwind eastern direction than the one at WAP, high wind speeds are experienced at the urban MABE station than the urban WAP station. The increased wind speeds decrease the effects of the "heat island".

As shown in Figures 3(a) to 3(d), minimum air temperature trends have significant $U(t_i)$ values from the late 1970 s and 1980 s for all the four stations in Nairobi. This can be attributed to the rapid expansion of residential estates during this period. Due to this expansion, the urban modification of air temperature began to be noticed in areas toward the suburbs of the CBD such as JKIA (Figure 3(d)). At the suburban DC station, the urban modification of mean annual minimum surface temperature began as early as 1979 and has shown a progressive increase to 1999 (Figure 3(c)). The location of the station to the downwind in the western direction, which is affected by low easterly wind speed accompanied by the development of residential estates around the station could explain this significant warming trend.

5. Conclusion

By using the linear regression model, it has been shown that mean annual trends in near surface air temperature exist at all stations in Nairobi City. The rate of change of surface temperature over a period of 34 years and the coefficient of determination (r^2) indicate this. The annual minimum air temperature is shown to have higher rates of change and also higher r^2 compared to the annual maximum air temperature. The rates of change of temperature and r^2 are higher for suburban stations compared to urban stations, an indication of increasing urban sprawl.

These results are in agreement with the studies from other tropical and sub-tropical cities by Jauregui et al. [39], Adebayo [34], and Robaa [38], which established consistent development of urban heat island by minimum temperature than maximum temperature. The results of Mann-Kendall test have established that in all the four stations in Nairobi City significant warming trends in mean annual minimum temperature took place. This warming began earlier at the urban WAP station and later at the suburban JKIA station, an indication of the spread of urbanisation from the CBD outward.

Finally, the findings of this study have established that the urban modification of minimum temperature in terms of a warming trend is on the rise in Nairobi City and is likely to reach higher proportions given the current level of urban population growth estimated at seven percent per annum. The environmental implications of such urban temperature modification on human comfort, building design and orientation, wind circulation and air pollution dispersion must begin to be incorporated in the current urban planning programs of the city.

References

[1] P. I. Figuerola and A. N. Mazzeo, "Urban-rural temperature differences in Buenos Aires," *International Journal of Climatology*, vol. 18, no. 15, pp. 1709–1723, 1998.

[2] T. R. Oke, "Review of urban climatology 1973–76," Technical Note 134, World Meteorological Organization, Geneva, Switzerland, 1979.

[3] R. Bohn, "Urban bias in temperature time series—a case study for the city of Vienna, Austria," *Climatic Change*, vol. 38, no. 1, pp. 113–128, 1998.

[4] W. Eva, *The Heat Island Mitigation Strategies Guidebook*, US Environmental Protection Agency, Washington, DC, USA, 2007.

[5] A. F. M. Carlos, "Urban climate models: limitations and applications," in *Proceedings of the Technical Conference on Urban Climatology and Its Application with Special Regard to Tropical Areas*, WMO, no. 652, pp. 237–275, World Meteorological Organization, Geneva, Switzerland, 1986.

[6] R. S. Giridharan and L. S. S. Yao, "Daytime urban heat island effect in high-rise and high-density residential developments in Hong Kong," *Energy and Buildings*, vol. 36, no. 6, pp. 525–534, 2004.

[7] T. W. Hawkins, W. L. Stefanov, W. Bigler, and E. M. Saffell, "The role of rural variability in urban heat island determination for Phoenix, Arizona," *Journal of Applied Meteorology*, vol. 43, no. 3, pp. 476–486, 2004.

[8] Republic of Kenya, *Population and Housing Census 1999, Volume 1*, Central Bureau of Statistics (CBS), Ministry of Finance and Planning, Nairobi, Kenya, 2001.

[9] African Population and Health Research Centre (APHRC), "Popuation and Health Dynamics in Nairobi's Informal Settlement. Report of the Nairobi Cross-Sectional Slums Survey (NCSS) 2000," 2002.

[10] P. E. Todhunter, "Microclimatic variations attributable to urban-canyon asymmetry and orientation," *Physical Geography*, vol. 11, no. 2, pp. 131–141, 1990.

[11] T. R. Oke, "The energetic basis of the urban heat island," *Quarterly Journal of the Royal Meteorological Society*, vol. 108, no. 455, pp. 1–24, 1982.

[12] B. Givoni, "Urban design for hot dry regions," *African Urban Quarterly*, vol. 5, no. 1-2, pp. 118–123, 1990.

[13] P. Jonsson, "Vegetation as an urban climate control in the subtropical city of Gaborone, Botswana," *International Journal of Climatology*, vol. 24, no. 10, pp. 1307–1322, 2004.

[14] X. Picot, "Thermal comfort in urban spaces: impact of vegetation growth. Case study: piazza della scienza, Milan, Italy," *Energy and Buildings*, vol. 36, no. 4, pp. 329–334, 2004.
[15] T. R. Oke, *Boundary Layer Climates*, Routledge, London, UK, 2nd edition, 1987.
[16] J. Unger, "Heat island intensity with different meteorological conditions in a medium-sized town: Szeged, hungary," *Theoretical and Applied Climatology*, vol. 54, no. 3-4, pp. 147–151, 1996.
[17] H. Akbari and L. S. Rose, *Characterizing the Fabric of the Urban Environment: A Case of Salt Lake City, Utah*, Lawrence Berkeley National Laboratory, Berkeley, Calif, USA, 2001.
[18] K. Nakamura, "City temperature of Nairobi," *Japanese Progress in Climatology*, pp. 61–65, 1967.
[19] G. L. Makokha, *Controls of Climate in Nairobi City*, Seminar Paper, Geography Department, Kenyatta University, Nairobi, Kenya, 1997.
[20] Registrar of Motor Vehicles, *Registration of Motor Vehicle Files*, Nairobi, Kenya, 2000.
[21] M. Tayanç, H. N. Dalfes, M. Karaca, and O. Yenigün, "A comparative assessment of different methods for detecting inhomogeneities in turkish temperature data set," *International Journal of Climatology*, vol. 18, no. 5, pp. 561–578, 1998.
[22] M. Tayanc and H. Toros, "Urbanization effects on regional climate change in the case of four large cities of Turkey," *Climatic Change*, vol. 35, no. 4, pp. 501–524, 1997.
[23] T. C. Peterson, D. R. Easterling, T. R. Karl, et al., "Homogeneity adjustments of in situ atmospheric climate data: a review," *International Journal of Climatology*, vol. 18, no. 13, pp. 1493–1517, 1998.
[24] P. D. Jones, S. C. B. Raper, B. Santer, et al., "A grid point surface air temperature data set for the northern hemisphere," Tech. Rep. TRO22, Department of Energy, Washington, DC, USA, 1985.
[25] T. R. Karl and C. N. Williams Jr., "An approach to adjusting climatological time series for discontinuous inhomogeneities," *Journal of Climate & Applied Meteorology*, vol. 26, no. 12, pp. 1744–1763, 1987.
[26] D. W. Gullet, L. Vincent, and P. J. F. Sajecki, "Testing for homogeneity in temperature time series at Canadian climate stations," Tech. Rep., Canadian Climate Center, Ontario, Canada, 1990.
[27] R. Heino, *Climate in Finland during the Period of Meteorological Observations*, Contributions, no. 12, Finish Meteorological Institute, 1994.
[28] A. M. Aesawy and H. M. Hasanean, "Annual and seasonal climatic analysis of surface air temperature variations at six southern Mediterranean stations," *Theoretical and Applied Climatology*, vol. 61, pp. 55–68, 1998.
[29] H. L. Alder and E. B. Roessler, *Introduction to Probability and Statistics*, Freeman, San Francisco, Calif, USA, 1977.
[30] M. Kadioglu, "Trends in surface air temperature data over Turkey," *International Journal of Climatology*, vol. 17, no. 5, pp. 511–520, 1997.
[31] J. M. Mitchel Jr., B. Dzerdeevskii, H. Flahn, et al., "Climate change," Technical Note 79, World Meteorological Organization, Geneva, Switzerland, 1966.
[32] C. H. Goossens and A. Berger, "Annual and seasonal climatic variations over the northern hemisphere and Europe during the last century," *Annals of Geophysics*, vol. 4B, pp. 385–400, 1986.
[33] Y. R. Adebayo, "A note on the effect of urbanization on temperature in Ibadan," *Journal of Climatology*, vol. 7, no. 2, pp. 185–192, 1987.
[34] Y. R. Adebayo, "Heat island in a humid tropical city and its relationship with potential evaporation," *Theoretical and Applied Climatology*, vol. 43, no. 3, pp. 137–147, 1991.
[35] E. Jauregui, "Tropical urban climates: review and assessment," in *Proceedings of the Technical Conference on Urban Climatology and Its Applications with Special Regard to Tropical Areas*, WMO, no. 652, pp. 26–45, World Meteorological Organization, Geneva, Switzerland, 1986.
[36] B. Padmanabhamurty and H. D. Bahl, "Isothermal and isoyetal patterns of Delhi as a sequel of urbanization," *Mausam*, vol. 35, no. 4, 1984.
[37] R. E. Okoola, "The Nairobi heat-island," *Kenya Journal of Science and Technology, Series A*, vol. 1, pp. 53–61, 1980.
[38] S. M. Robaa, "Urban-suburban/rural differences over Greater Cairo, Egypt," *Atmosfera*, vol. 16, no. 3, pp. 157–171, 2003.
[39] E. Jauregui, L. Godinez, and F. Cruz, "Aspects of heat-island development in Guadalajara, Mexico," *Atmospheric Environment. Part B*, vol. 26, no. 3, pp. 391–396, 1992.