Is It the Result of Global Warming or Urbanization? The Rise in Air Temperature in Two Cities in Ghana

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Key words: Urbanization, Global warming, Temperature; Diurnal temperature range; Anthropogenic heat; Population

SUMMARY

Increased population growth and human activities that result in the generation of anthropogenic heat have led to the development of urban heat in cities. This study was carried out to investigate the impact of urbanization on the long-term temperature rise in Accra and Kumasi, Ghana. Long-term climatic data showed increasing warming trends in both cities between 1971 and 2000. Maximum temperatures were almost identical in magnitudes and temporal variation and they increased at similar yearly rates in the two cities. Minimum temperatures were consistently higher in Accra than in Kumasi but the temporal trends were almost identical in both cities. There were no significant variations in DTR with time in both cities because the minimum and maximum temperatures increased at the same rates. Increased population growth accounted for increased urban warming in Accra and Kumasi. The effect of urbanization was more pronounced in Accra and this was strongly expressed in the night time temperatures. Higher numbers of sunshine hours in Accra also explain the higher degree of nighttime warming in this city compared to Kumasi. While the sun hour phenomenon cannot be controlled, legislature should be enacted by policy makers and city planners to control the generation of anthropogenic heat. These could include; (1) minimization of use of building materials with high heat absorption capacity, (2) development of infrastructure (road network, industries) that make efficient use of fossil fuel, (3) encourage of tree planting along streets and in residential areas, and (4) development of programs to educate the general public on the effects of urban heat islands

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1. INTRODUCTION

The growing incidence of global environmental degradation, especially the depletion of protective atmospheric ozone layer, rising levels of global temperatures, and loss of biodiversity, have attracted the attention of decision makers worldwide for quite sometime. A series of global environmental conferences in the 1970s, 1980s, and through to the 1990s which culminated in the United Nations Framework of the Convention on Climate Change (UNFCCC) in 1992 and Kyoto Protocol in 1997, sparked frenzy discussions about global environmental integrity.

While human impact on the environment has intensified, considerable attention has been directed towards the search for a means to reduce emissions caused by greenhouse gases like carbon dioxide (CO_2). In the process, the question of climate change and global warming continues to draw substantial interests from researchers. It is evident from recent studies that most cities around the globe have witnessed an increase in urban temperatures. As Landsberg (1970) stated in *Science* 32 years ago ". . . by far the most pronounced and locally far-reaching effects of man's activities on microclimate have been in cities. . . ". The results of urban expansion are increases in number of buildings, extensive road networks, and other paved surfaces. Urban areas generally have higher solar radiation absorption, greater thermal capacity and heat is stored during the day and realeased by night (Weng, 2001). Built up urban areas tend to have relatively higher temperatures compared to those of by non-urban areas. This thermal difference, combined with heat generated through urban houses, burning of fossil fuel in automobiles, and industry contribute to the development of urban "heat islands" (UHI). The difference in urban and rural areas according to Mather (1986) is generally less than 1^oC but it could be higher depending on other topographical and meteorological conditions. Several studies have demonstrated the potential for human activities to strongly influence urban atmosphere through the establishment of UHI (Oke, 1997; Magee et. al., 1999).

Several researchers have presented evidence to demonstrate that increase in temperatures have resulted from the daily minimum temperature increasing at a faster rate or decreasing at a slower rate than the daily maximum which results in a decrease in the duirnal temperature range (DTR) (Easterling et al. 1997). In the United States large-area trends showed that maximum temperatures have increased slightly but the minimum temperatures increased at a faster rate (Karl et al. 1990). A study carried out on climatic data in Kuwait showed that urban warming appeared to be both a daytime and night-time phenomenon. In another study in Turkey, Türkes et al. (2002) concluded that significant night-time warming trends could be likely related to urbanization. The mean maximum and minimum temperatures showed a considerable increase over a period of three decades (Al-fayed et al., 1997). Similar studies in other regions showed seasonal variations in long-term maximum and minimum temperatures (Philandras et al. 1999; Chung et al. 2004). In study on four large cities of Turkey by Tayanc and Toros (1997), seasonal analysis of individual 21.00 hr temperature series suggested that the regional warming is strongest in spring and weakest in autumn and winter. Urban warming was also detected to be more or less equally distributed over the year with a slight increase in the autumn months.

Ghanaian cities, like most cities around the globe, are experiencing increased urbanization. Since 1960, migration from rural areas to urban centers has increased twofold. Urban population in the country was 23% of the total population of 5.2 million people in 1960 compared to 47% in 2000 when the population reached 18.5 million (Ghana Statistical Service, 1970, 1984, 2000). In urban cities in Ghana, principally Accra and Kumasi, urbanization principally finds expression in outward expansion of built-up areas and conversion of prime agricultural lands into residential and industrial uses. The climatic implications could be expressed through temperature increase and environmantal degradation. Accepting the backdrop of global warming trends, the purpose of this paper is to investigate the relationship between rate, extent, and indicators of urbanization and long-term temperature rise in Accra and Kumasi. In pursuit of this inquiry, several relevant research questions will be posed. These questions will include the following: (1) What is the extent of urban expansion in these two cities? (2) Has there been long-term changes in air temperatures? (3) What forces are responsible for these changes? (4) What is the impact, if any, of these temperature changes?

2. MATERIALS AND METHODS

2.1 Study Areas

This paper focuses on the two largest cities in Ghana. Accra, the capital of Ghana is situated along the Atlantic Ocean. The geographical coordinates are latitude $5^0 33^{'}$N, longitude $0^0 13^{'}$W (Figure 1). Like any other colonial city in the sub-Saharan Africa, Accra is the center of most economic activities, and it is the seat of government. Since 1970, the population of Accra has been increasing rapidly at an annual rate of 3.0%. Accra is located in the dry equatorial climatic region. This region is the driest in Ghana. It has two rainfall maxima with a prolonged dry season. The mean annual rainfall is between 740 and 890 mm (Dickson and Benneh, 2004). Monthly humidity is higher in this region during the rainy season than the rest of the year.

Kumasi is the second largest city of Ghana. Its geographical coordinates are $6^0 41^{'}$N, longitude $1^0 37^{'}$W (Figure 1). In recent years, Kumasi has been experiencing urban growth. For example population increased from 346,000 in 1970 to 1.2 million in 2000 representing an annual increase of 4.14 percent. The overall rate of increase for Kumasi, between 1980-1984 was 41% and 135% between the 1984-2000 intercensal periods (Ghana Statistical Service, 1984, 2000). Unlike Accra, Kumasi is located in the wet semi-equatorial region. This region receives two rainfall seasons with mean rainfall between 125 and 200 centimeters (Dickson and Benneh, 2004).

Demographic data were obtained from the Ghana Statistical Service. Regional climatic data including daily minimum and maximum temperatures, rainfall, relative humidity at 6:00 a.m. and 3:00 p.m. and number of sunshine hours were acquired

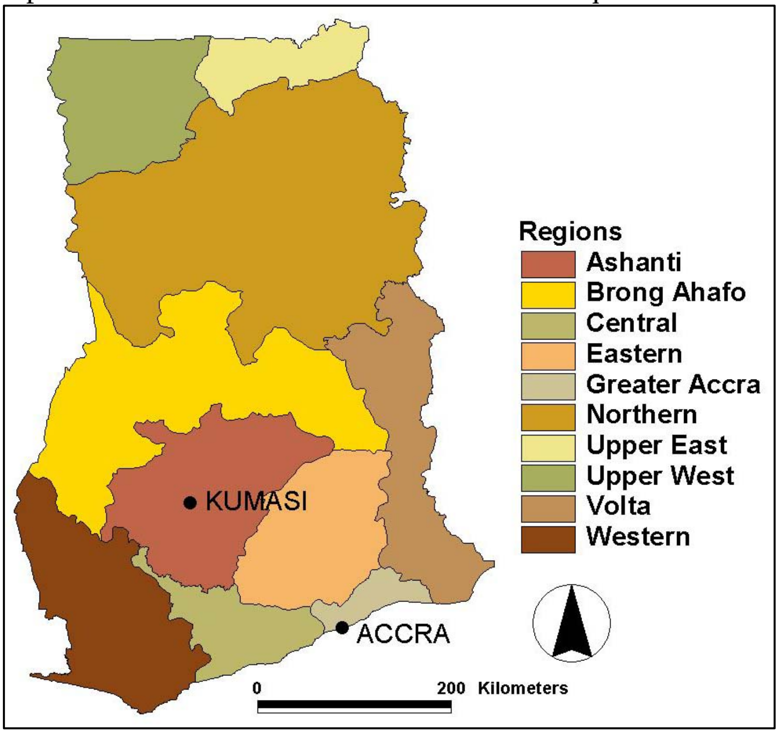

Figure 1: Map of Ghana showing study sites of Accra and Kumasi

from the Ghana Meteorological Agency. This data covered the three decades from 1971 to 2000. Mean monthly and annual maximum and minimum temperatures were derived from daily maximum and minimum temperatures. The annual mean temperatures were calculated by averaging the monthly mean maximum and temperatures over the year. The diurnal temperature range (DTR) is defined as the difference between the mean monthly maximum and minimum temperatures.

3. RESULTS

3.1 Temperature Patterns and Trends

The annual mean maximum temperature series for both Accra and Kumasi were characterized by significant increased warming trends during the study period (Figure 2). The test of significance was obtained from linear regression equations which best fit the characteristics of the time series. The rate of change of temperatures is defined by the slope of the linear regression curve. The average daytime temperatures rose by 0.03^{o}C (significant at the $p < 0.001$ level) and 0.04°C (significant at the $p < 0.001$ level) per year in Accra and Kumasi, respectively (Table 1) . Day time temperatures rose by 0.9°C in Accra and by 1.2°C in Kumasi for the three decades between 1971 and 2000. Maximum day time temperatures were similar in magnitude and showed almost identical time series for the two cities for the most part of the study period except between 1989 and 1995 when Kumasi experienced higher temperatures. There were significant increasing trends in minimum temperatures for both cities.

Minimum temperatures showed significant warming trends in both cities. Nighttime temperatures rose by 0.03°C (significant at the $p < 0.001$ level) per year in Accra and 0.04°C (significant at the $p < 0.001$) level per year in Kumasi but the temporal trends were similar for both cities (Figure 3.). While the difference in the average maximum temperatures for Accra and Kumasi was not significant, the average minimum temperature in Accra was 2°C higher than in Kumasi (Figure 3; Table 1). This finding is contrary to expectation because being at the coast, land and sea breezes are expected to play a significant role in moderating the temperatures in Accra compared to Kumasi especially during the night. There could, therefore, be other factors that would influence the daily temperature fluctuations in both cities.

Table 1: Range of minimum and maximum temperatures, their annual rate of change, and average minimum and maximum temperatures for Accra and Kumasi.

City	Range		Rate of change °C per year		Average temperature over study period	
	Minimum Temperatures	Maximum Temperatures	Min	Max	Minimum	Maximum
Accra	22.7- 24.7	30.2 – 31.9	0.03	0.02	23.7	30.9
Kumasi	21.1-22.8	30.0 – 31.8	0.03	0.04	21.8	31.0

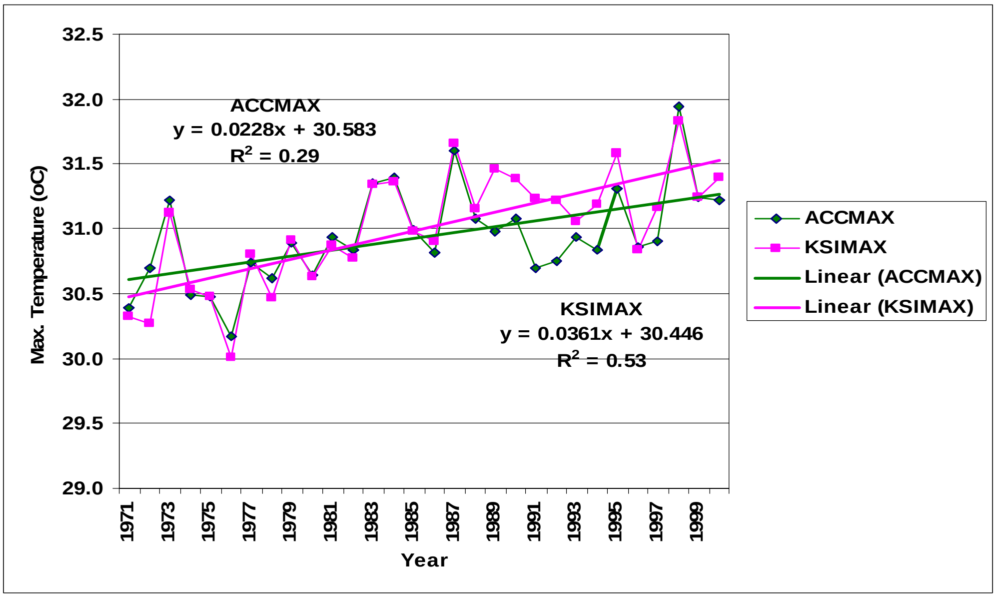

Figure 2: Average maximum temperatures for Accra (ACCMAX) and Kumasi (KSIMAX) from 1971 – 2000**.**

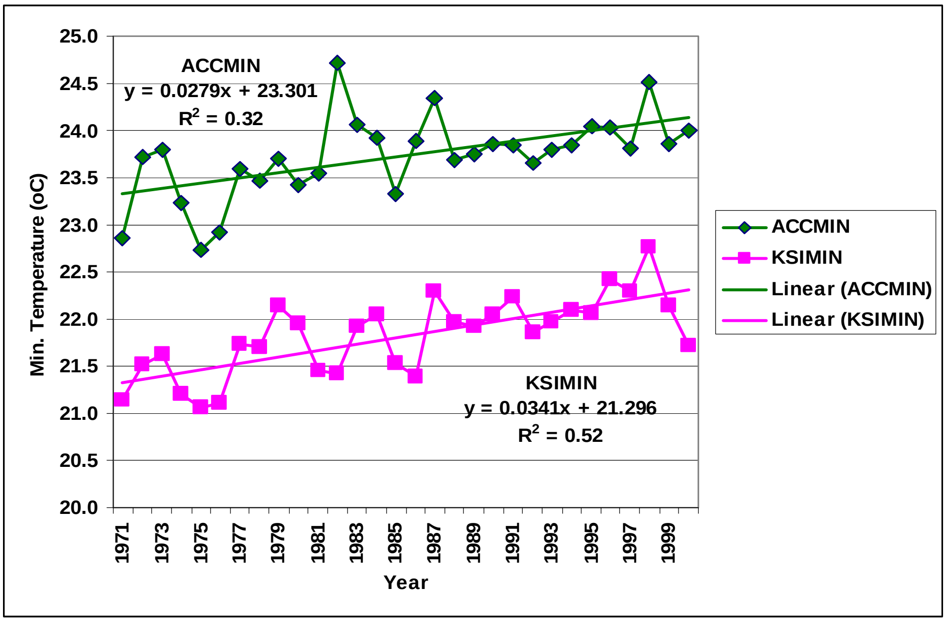

Figure 3: Average minimum temperatures for Accra (ACCMIN) and Kumasi (KSIMIN) from 1971 – 2000**.**

3.2 Diurnal Temperature Range

An expected impact on the surface temperature regime of the earth is the change in diurnal temperature range (DTR) which is the difference between the maximum and minimum temperatures. The time series of DTR for Accra and Kumasi during the study period is presented in Figure 4. There was no significant temporal variation in DTR for either city over the study period. Urban warming was both day time and night time phenomena; there were significant increases in both maximum and minimum temperatures in both cities during the study period but there was a parallel increase in both temperatures and they increased at almost identical rates during the three decades. This made their difference non significant over time. This is contrary to several observed trends in DTR in other parts of the world which is characterized by larger increases in the daily minimum temperatures but a significantly smaller increases in the maximum daily temperatures. This has resulted in a decreasing trend in DTR as observed by Karl et al. (1988) and Cohen and Stanhill (1996). This phenomenon has been attributed to increased cloud cover which tend to backscatter incoming radiation and diminish any daytime surface warming. In the night the clouds absorb the terrestrial infrared radiation emitted from the surface that enhances nighttime warming. (Dai et al., 1997; Hansen et al., 1995). Effects of cloud cover on daytime and nighttime temperatures could not be determined for the study area because no cloud cover data was available. On the other hand, it must be emphasized that much of the research on relationships between urbanization and temperature change is based on records from developed countries which are mostly in temperate climates. These regions are characterized by extreme seasonal and daily variations in temperature as opposed to the cities of interest in this study which does not show much of annual temperature variations.

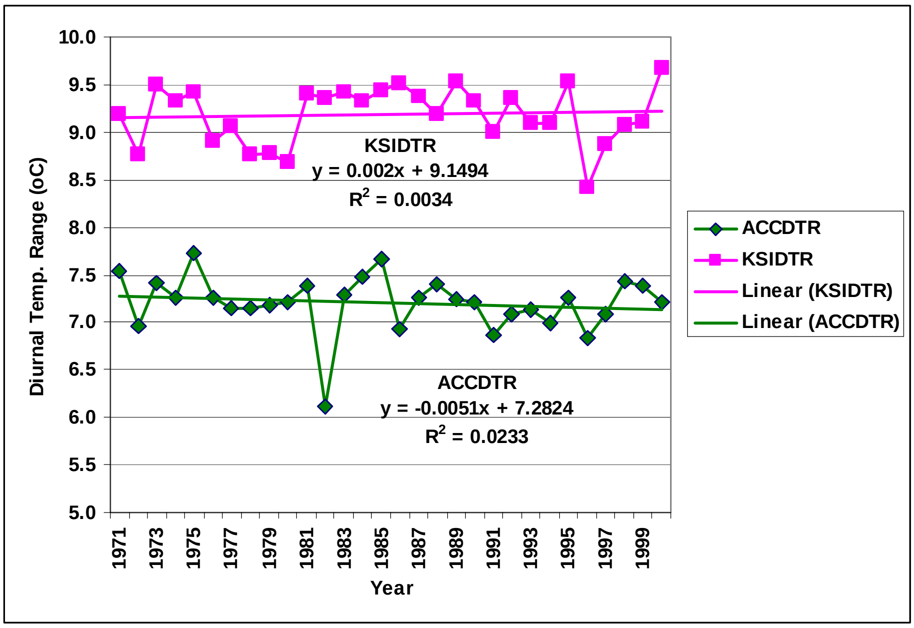

Figure 4: Time series of diurnal temperature range for Accra (ACCDTR) and Kumasi (KSIDTR) from 1971-2000.

3.3 Factors Influencing Temperature Rise

There are several possible causes for the increases in the average maximum and minimum temperatures in Accra and Kumasi during the three decades of this study but the major factors for urban warming in Accra and Kumasi could be both anthropogenic land-use modification and changes in climatic factors.

Like most cities in Africa, Accra and Kumasi are experiencing tremendous urban growth with associated increase in human population. In both cities, urbanized areas increased more than twenty fold between 1970 and 2000 and the population increased at the rates of 247% in Accra and 112% for Kumasi during the same time period (Table 2).

The population growth associated with the rapid urbanization could have contributed to the development of urban heat islands in these cities with simultaneous increase in both minimum and maximum temperatures at almost identical rates. Sources of anthropogenic heat include cars, homes and factories. Of significant importance is heat captured and radiated by impervious layers including concrete, black asphalt, bricks and stones. These have high capacity to absorb and store heat.

The effects of urbanization and urban heat intensities were expressed in nighttime temperatures. Differences in minimum temperatures in Accra and Kumasi could be directly linked to population. Population in Accra was double that of Kumasi in 1970 and more than three times in 2000.

Table 2: Population dynamics for Accra and Kumasi between 1971-2000

City	1970	1984	2000	Rate of Change (%)		
				1970-1984	1984-200	1970 - 2000
Accra	734,896	1,203,292	2,548,975	55	71	247
Kumasi	354,117	489,586	730,376	42	49	112

Source: 2000 Population and Housing Census, Special Report on Urban Localities

The anthropogenic heat generated in Accra was subsequently higher due to this population than that in Kumasi over the study period resulting in an average minimum temperature difference of 2^{o}C over three decades.

Figure 5 shows the time series of sunshine hours for Accra and Kumasi. There was a nonsignificant decrease in sunshine hours in both cities over time; however, sunshine hours were consistently longer in Accra than in Kumasi. This could significantly contribute to the higher minimum temperatures experienced in Accra compared to Kumasi. With longer sunshine hours in Accra, more solar radiation is absorbed and radiated and this could relatively increase the night temperatures compared to Kumasi.

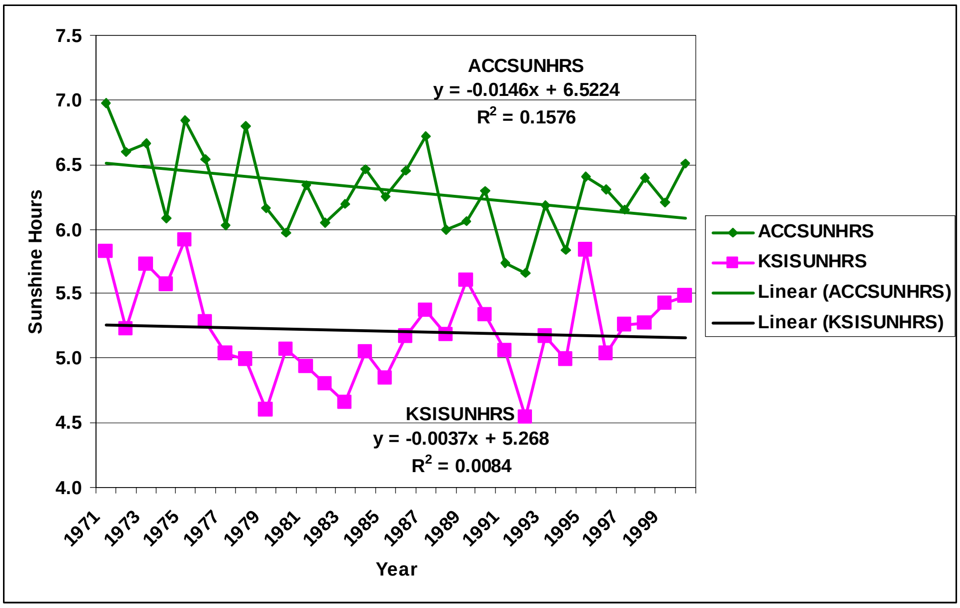

Figure 5: Time series of average sunshine hours for Accra (ACCSUNHRS) and Kumasi (KSISUNHRS) between 1971 -2000

3.4 Implications of Study

This study shows a gradual but significant increase in air temperatures in both Accra and Kumasi over the three decades between 1971 and 2000. There is a direct link between population growth and urban warming. It must be emphasized that this trend will continue because it is estimated by the World Bank (1977) that with the annual growth rate of 4.87%, Africa will become the most urbanized continent in 2030. This increased urbanization will have a significant impact in these cities where human activities have the greatest impact on the climate and the urban ecosystem. It is being suggested based on the results of this study that policy makers and city planners enact policies that mitigate further urban warming. This would include (1) appropriate zoning policies; (2) use of building materials and paving surfaces that minimize absorption of heat. This could be the use of light-colored building and roofing materials on commercial and residential property and discourage use of reflective glass on private and commercial properties; (3) encouragement of tree planting in residences and along streets to provide shade and promote evapotranspiration processes in plants to help cool the cities; and (4) develop effective programs to educate the general public regarding the effect of urban heat islands.

4. CONCLUSION

Increased urbanization and human activities in cities such as burning of fossil fuel in automobiles and in industries, creation of impervious layers and destruction of vegetative cover have led to the development of urban heat islands. There has therefore been increased long-term warming in cities. This is especially important in African cities which are undergoing tremendous expansion. The purpose of this study is to investigate the impact of urbanization on the long-term temperature rise in Accra and Kumasi, Ghana.

Analysis of long-term climatic data showed increasing warming trends in both cities between 1971 and 2000. Maximum temperatures rose at annual rates of 0.03°C and 0.04°C in Accra and Kumasi, respectively. Trends in maximum temperatures were almost identical for both cities. While the average minimum temperature in Accra was 2°C higher in Accra than in Kumasi, the temporal trends were similar in both cities.

There was no significant temporal variation in DTR, an indicator of global warming, during the study period in both cities. The reason is that the minimum and maximum temperatures increased at almost identical rates during the study period. This is contrary to results from several studies carried out in the northern hemisphere. In these studies DTR decreased with time because minimum temperatures increased at higher rates compared to maximum temperatures.

Two possible causes were identified for the creation of heat islands in the two cities. Urbanized areas in Accra and Kumasi increased more than twenty fold and the population also increased at rates of 247% in Accra and 112% in Kumasi. Activities of urban dwellers could, therefore, have generated significant anthropogenic heat resulting the urban warming. The effect of urbanization on air temperature rise was more pronounced in Accra more than in Kumasi and this was mostly expressed in the nighttime temperatures. Another factor causing the higher urban warming in Accra is the number of sunshine hours. Although all cities showed a non-significant decrease in the number of sunshine hours, Accra consistently had a higher number of sunshine hours than Kumasi.

To mitigate further urban warming, it is suggested that legislature be enacted by policy makers and city planners to: (1) encourage use of building materials that will minimize absorption of heat; (2) promote increased tree planting; (3) develop road networks and industries that will promote efficient burning of fossil fuel; and (4) develop programs to educate the general public on the effects of urban heat islands.

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BIOGRAPHICAL NOTES

Dr. **Andrew Manu** is an Associate Professor in Soil Science, Remote Sensing and Environmental Pedology at Iowa State University. Dr. Manu received a BS. degree in Soil Science from the University of Ghana. He received his MS. And PhD degrees from Iowa State University. Seven years after graduating from Iowa State University, Dr. Manu served as Research Director on a regional project in West Africa through Texas A&M University and the United States Agency for International Development. His activities included soil resource inventory using remote sensing technologies and the restitution of degraded tropical lands. He joined Alabama A&M University in Huntsville, where he taught courses in soil science and carried out research in the use of passive microwave remote sensing to detect surface soil moisture. Dr. Manu has been with Iowa State University for the past four years where he teaches the applications of digital soil information in agronomy, landscape architecture and horticulture. He has adapted an innovative multimedia technology as a system of instruction and has received several teaching awards and recognition. His research activities include: (1) Use of Digital Elevation Models in Landscape Modeling; (2) Use of statistical models as well as neural networks to model and predict the growth of cities; (3) Impact of urbanization of urban soil quality; and (4) Remote sensing of earth processes. Dr Manu has published over 30 refereed articles in reputable journals and served as Associate Editor for the Journal of Natural Resources and Life Sciences Education from 2002 – 2004. He is a member of the following Associations and Organizations: Gamma Sigma Delta, Phi Beta Delta, Sigma Xi, American Society of Agronomy, Soil Science Society of America, International Society of Soil Science, The Institute of Electrical and Electronics Engineers, Association for International Agriculture and Rural Development; Soil and Water Conservation Society and African Association of Remote Sensing and the Environment. Dr. Manu currently serves as Chair of the International Agriculture Division of the American Society of Agronomy.

Dr. **Yaw A. Twumasi** is currently a Reserach Assistant Professor of Remote Sensing and Geographic Information Systems (GIS) at Alabama A&M University. He received his Bachelor of Arts degree in Geography and Master of Environmental Studies with concentrations in Environmental Planning and GIS both from York University, Toronto, Canada. He also holds a Ph.D. degree from Alabama A&M University, U.S.A. Dr. Twumasi is an author, experienced researcher, scholar and analyst in a number of areas such as protected area planning, environmental management and the application of remote sensing and GIS technology in natural resources management. He has published and authored or co-authored several publications in a variety of refereed journals and international conferences and symposia proceedings addressing the use of remote sensing and GIS technology in assessing and managing Earth’s natural resources. His recent book on “Park Management in Ghana Using Geographic Information Systems (GIS) and Remote Sensing Technology” published by Edwin Mellen Press, New York, addresses the use of both technologies in managing Park resources in Ghana. Dr. Twumasi has also been inducted into this years' Marquis Who’s Who in America award for his outstanding publications. He is currently involved in the study of National Parks planning and management, environmental degradation, vegetation assessment and urban sprawl using satellite imagery and aerial photograph in Niger, Burkina Faso, Mali and Ghana. Dr. Twumasi is also involved in the use of remote sensing data to assess land use and land cover change study in other sub-Saharan African countries. He is also proficient in image processing, classification and analysis, GIS database construction as well as the development of policies using GIS and remote sensing techniques to guide natural resource managers. Dr. Twumasi is a member of the American Society for Photogrammetry and Remote Sensing (ASPRS), the Remote Sensing and Photogrammetry Society of Great Britain (RSPSoc), African Association of Remote Sensing and the Environment (AARSE), IEEE Geoscience and Remote Sensing Society (IGARSS) and the Alabama Academy of Science (AAS).

Dr. **Tommy L. Coleman** is the Director of the Center for Hydrology, Soil Climatology and Remote Sensing (HSCaRS) at Alabama Agricultural and Mechanical University, Normal, AL. He earned a Bachelor of Science Degree from Fort Valley State College in Agronomy in 1974; a Master of Science Degree from the University of Georgia in Soil Morphology and Classification in 1977; and a Doctor of Philosophy Degree from Iowa State University in Soil Morphology and Genesis in 1980. He acquired additional training in remote sensing and geographic information systems applications from the University of Southern Mississippi and The Ohio State University from 1985 through 1987.

Dr. Coleman has been employed at AAMU since 1981 and has earned the rank of Professor of Soil Science and Remote Sensing. He has received several honors for his contributions to the field of soil science and remote sensing and GIS. Some of the awards include the NAFEO Distinguished Leadership Research Achievement Award 1999; elected as a Soil Science Society of America Fellow 1998; elected as an American Society of Agronomy Fellow 1997; the Morrison-Evans Outstanding Researcher Award 1997 given by the 1890 Association of Research Directors, and a three-time recipient of the School of Agricultural and Environmental Sciences Outstanding Researcher Award, 1996, 1995 and 1992. His current duties are to serve as the primary University Administrator who is responsible for the financial management, staffing operations, and evaluation of the HSCaRS Center. His duties involve working closely with other University Administrators and units to achieve and/or develop a broad-based hydrology and remote sensing research capability at AAMU. The mission of HSCaRS is fourfold: (1) to develop a research program that will foster new science and technology concepts; (2) To expand the nation's base for hydrology and remote sensing research development; (3) To develop mechanisms for increased participation by faculty and students in mainstream research, and (4) to increase the production of under-represented minorities who are U.S. citizens with advance degrees in NASA-related scientific fields.

The Center's main research and technology topics are focused on the development of a multi-frequency approach for studying the Earth's terrestrial ecosystems using remote sensing technology and the applications of remote sensing and GIS technology in soil science and water resource management. Specifically, his work addresses investigations of hydrologic processes, with emphasis on remote sensing measurements and modeling of soil moisture; development of spectral signatures for assessing vegetation health; using GIS to understand spatial variability in the chemical and physical properties of soils; and the development of robust spectral algorithms for analyses of multispectral and hyperspectral data.

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