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Full Length Research Paper

Assessment of urban heat island and possible adaptations in Enugu urban using landsat-ETM

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Urban heat Island (UHI) is the name given to the characteristic warmth of both the atmosphere and the lithosphere in cities (urban) compared to their rural (non-urbanized) surroundings. This study investigates the application of Landsat-ETM in the study of UHI. The study employed the normalized difference method to estimate Land Surface temperature (LST). The research assessed the level of UHI in Enugu urban as well as the application of Land sat-ETM in the study of UHI compared to the traditional rural-urban method. Results demonstrate that LST positively correlate with concentration of urban structures, population density and human activities. Temperature gradients are formed at the Central Business District (CBD) in the downtown areas and progressively lowered to the suburbs. The study suggested the use of high density green cover, reflective roofing materials, building massing (arcades) and lightening of pavements as adaptive/mitigation measures against UHI in Enugu urban.

Key words: Urban heat Island, Land SAT/ETM, temperature, reflective, mitigation, adaptive.

INTRODUCTION

Urban heat Island (UHI) is the name given to the characteristic warmth of both the atmosphere and the lithosphere in cities (urban areas) compared to their rural (non-urbanized) surroundings (Voogt, 2004). UHI may be up to 10 - 15°C under optimum conditions (Oke, 1982).

For almost 200 years, climatic differences between urban and rural environments have been recognized (Taha, 1997), of which temperature is the most obvious (Unger et al., 2001).

This phenomenon has been well documented and found to be universally typical by many researchers (Shashua-Bar and Hoffman, 2000). UHIs develop when a large fraction of the natural land-cover in an area are replaced by built surfaces that trap incoming solar radiation during the day and then re-radiate it at night (Oke, 1982; Quattrochi et al., 2000).

The microclimate caused by urban heat Island (UHI) has the effect of increasing the demand for cooling energy in commercial and residential buildings. Increased demand for energy can cost consumers and cities thousands of additional naira in air conditioning bills in order to maintain comfort levels. In addition, increased electricity generation by power plants leads to higher emissions of sulfur dioxide, carbon monoxide, nitrous oxide and suspended particulates, as well as carbondioxide, a green house gas (GHG) known to contribute to global warming and climate change.

In particular, the energy implications of the climatic changes induced by UHI have received very little attention in urban design and planning. This is especially the case in Enugu, where urbanization is at its peak. Enugu is a city with an area of about hundred square kilometers. Here, the traditional ground observation method of UHI may not be able to reflect in details the urban heat Island distribution characteristics which satellite remote sensing technique can offer, and that is the reason for the choice of this technique to study UHI in Enugu Urban,

Landsat is a passive imaging instrument able to collect reflected and emitted electromagnetic radiation in seven (7) different spectral regions, spanning from the visible to the thermal infrared. Landsat-ETM data of October, 2007 was used in this study.

The goal of this paper, therefore, is to determine the sptial extent and behaviour of urban heat Island in Enugu Urban.

Enugu urban is located on the eastern fringe of Udi

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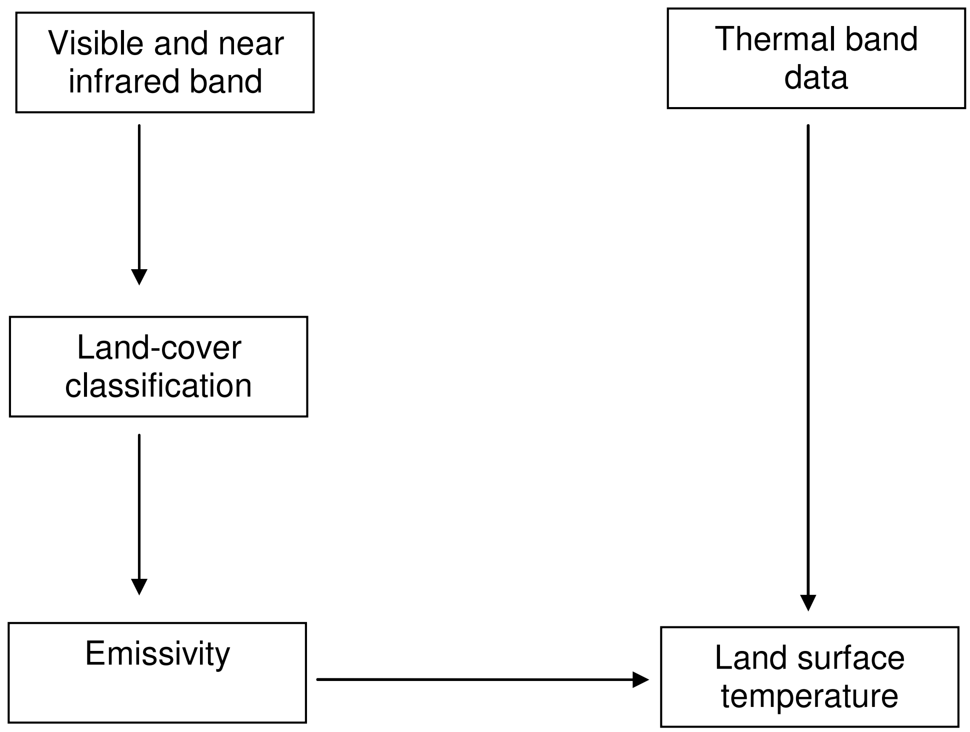

Figure 1. Data processing flow.

escarpment at an attitude of about 223 m and lies between latitude 6°20' and 6°30'N and longitude 7°25' and 7°30'E (Government of Anambra State, 1978). Its origin dates back to 1909 when Mr. Kitson, a British Minning Engineer together with British Geological Exploration Team discovered coal at the foot of Udi escarpment (Nnamani, 2002).

Coal mining activities and extension of railway line from Port Harcourt to enable the coal to be transported to the coast for export; attracted waves of migrants from the surrounding villages to the extent that in 1917, it attained a township status under Lord Lugard's Ordinance. The growth of the city is evident from the various population census figures from 1952 to 2006. It recorded a population of 62,764 in 1952; the 1991 census puts the population figure of Enugu to be 464, 514, accommodated in 28 residential Layouts. The 2006 census records the population of Enugu to be 722, 664 (NPC, 2006).

Enugu, since 1929 has remained an administrative headquarters. It served as the capital of southern provinces (1929 - 1938), capital of eastern provinces (1939 - 1950), capital of eastern region (1951 - 1955), capital of defunct republic of Biafra (1956 - 1969), capital of east central States (1970 - 1975), capital of old Anambra state (1976 - 1990) and capital of Enugu state from 1991 - till data.

Location of Enugu puts it firmly within the tropics; as such solar radiation is high all year round. Rainfall over Enugu is associated with the presence of moist tropical maritime (mT) and the location of intertropical discontinuity (ITD). Rainfall in Enugu is of two major types, conventional and rainfall associated with disturbances. The mean annual rainfall is heavy, varying from 1500 to 1750 mm. The study area lies within the rainforest – savanna Ecotone(Anyadike, 2002).

METHODOLOGY

The present study explores the conceptual and methodological issues of normalized surface temperature as shown in Figure 1.

Figure 1 shows the date processing flow in the study. The first step in the analysis was to make the landcover classification using the Erdas Imagine (8.7). In the study, supervised classification was employed to categorize the imagery into built-up 1, built-up 2, forest 1, forest 2 and farmlands.

The classification result was used to provide the emissivity of the land–cover categories. Emissivity was then used to estimate the land surface temperature from brightness temperature value in the thermal band image using the following steps:

Step 1. Conversion of Digital number (DN) to spectral radiance (L_x)

$L_X = (L_{max} - L_{min}) / (Q_{calmax} - Q_{calmin}) * (Q_{cal} - Q_{calmin}) + L_{min}$. ………… (4.2)

Where $Q_{calmin} = 1$, $Q_{calmax} = 235$, $Q_{cal} =$ DN (built-up 1 = 81, built-up 2 = 89, forest 1 = 58, forest 2 = 54, farmLand = 69). L_{mins} and L_{min} are the spectral radiance for band 6 at DN 1 and 255 respectively.

Step 2. Conversion of the spectral radiance to temperature using the following formula.

$T = K_2 / \ln (K_1 / L_X + 1)$ ………………………. (4.3)

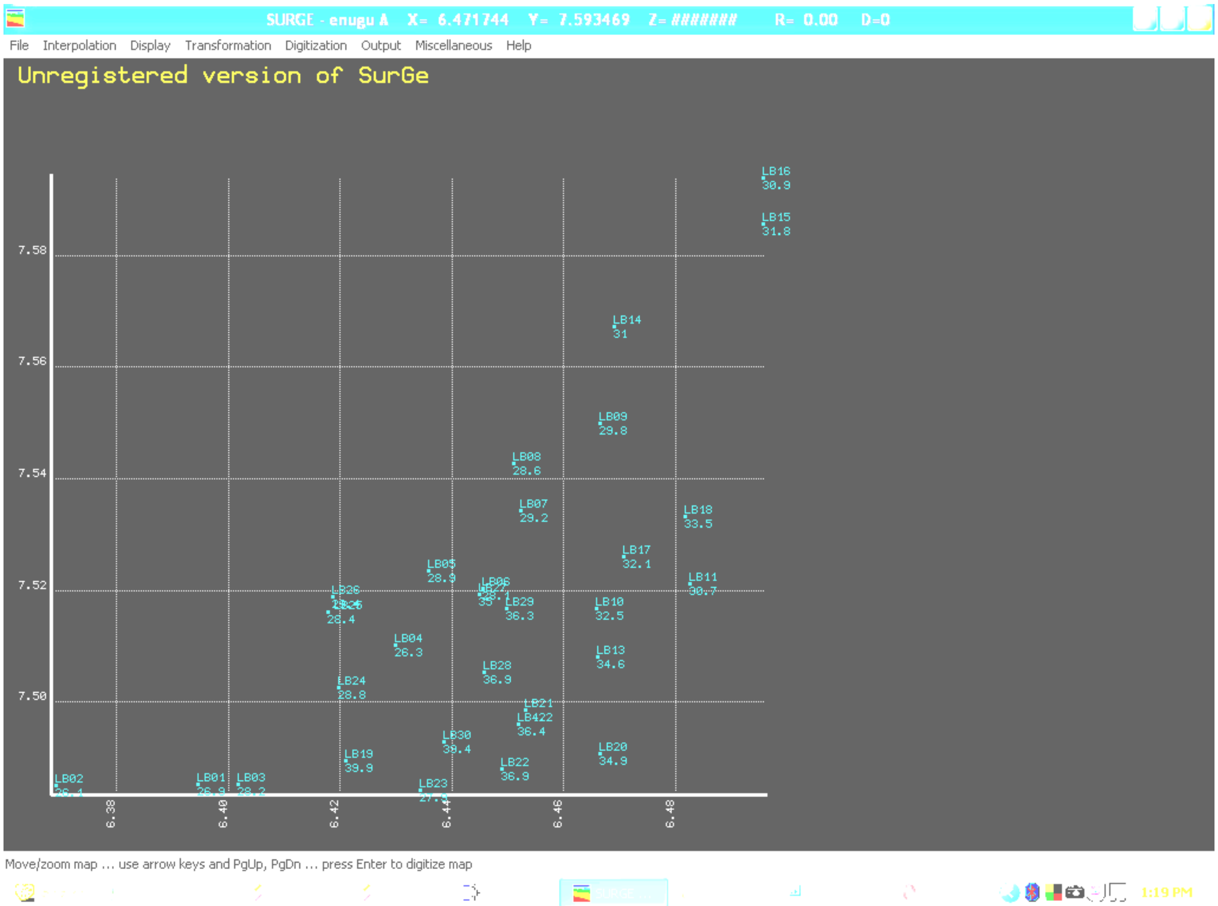

Figure 2. Transect points.

Where T = Effective as satellite temperature in Kelvin, K_1 = calibration constant + 1 in Watts (666.09), K_2 = calibration constant + 2 in K (1283.7), L_X = spectral radiance in Watts.

Step 3. Computation of the emissivity corrected surface temperature using the formular.

$T_S = T / [1+(\lambda T/ \propto) \ln \varepsilon]$ …………… (4.4)

Where λ = Wavelength of emitted radiance, ∝ = hc/K (1.438 x 10^{-2} mk), h = Planck's constant (6.26 x 10^{-34} J/s), c = Velocity of light (2.998 x 10^{8} m/s), k = Stefan Bolzmann's constant (1.38 x 10^{-23} J/K). Note that: (1) Thermal infrared band of LandSat ETM is (10.44 – 12.42 Nm) = 11.43.

RESULTS AND DISCUSSION

Landsat-ETM of October, 2007 was used for this research. The data acquisition date has a highly clear atmospheric condition, and the image was acquired from the Earth Resource Observation systems Data Center, which has corrected the radiometric and geometrical distortions of the images to a quality level before delivery. The Landsat image was further rectified to a common Universal Transverse Mercator coordinate system based on 1:24,000 scale topographic maps and was reassembled using the nearest neighbor algorithm with a pixel size of 30 by 30 m for all bands.

To examine the spatial patterns of temperature within Enugu urban, 30 transects (profile) were drawn across the center of the city as shown in Figure 2.

Since these transects pass over various landscapes with different environmental settings, an inquiry into the UHI characteristics of the profile will help to understand the factors shaping the city's thermal landscape. These factors include the spatial pattern of different land–cover classes, the occurrence of water bodies, parks, buildings and population densities and the division of the city's functional districts, among others (Weng, 2003).

Figure 3 shows the distribution of surface temperature values. The radiant temperature ranged from 26 – 39°C. An isotherm map (Figure 4) and a choropleth map (Figure 5) were produced based on the classification scheme of standard deviation, in which class 1 data values are less than one standard deviation below the mean, class 2 values fall between the mean, and so on (Smith, 1986).

Also, a Digital Elevation model (DEM) was constructed to further buttress the behaviour of temperature in Enugu urban (Figure 6).

Figure 3. Surface temperature values.

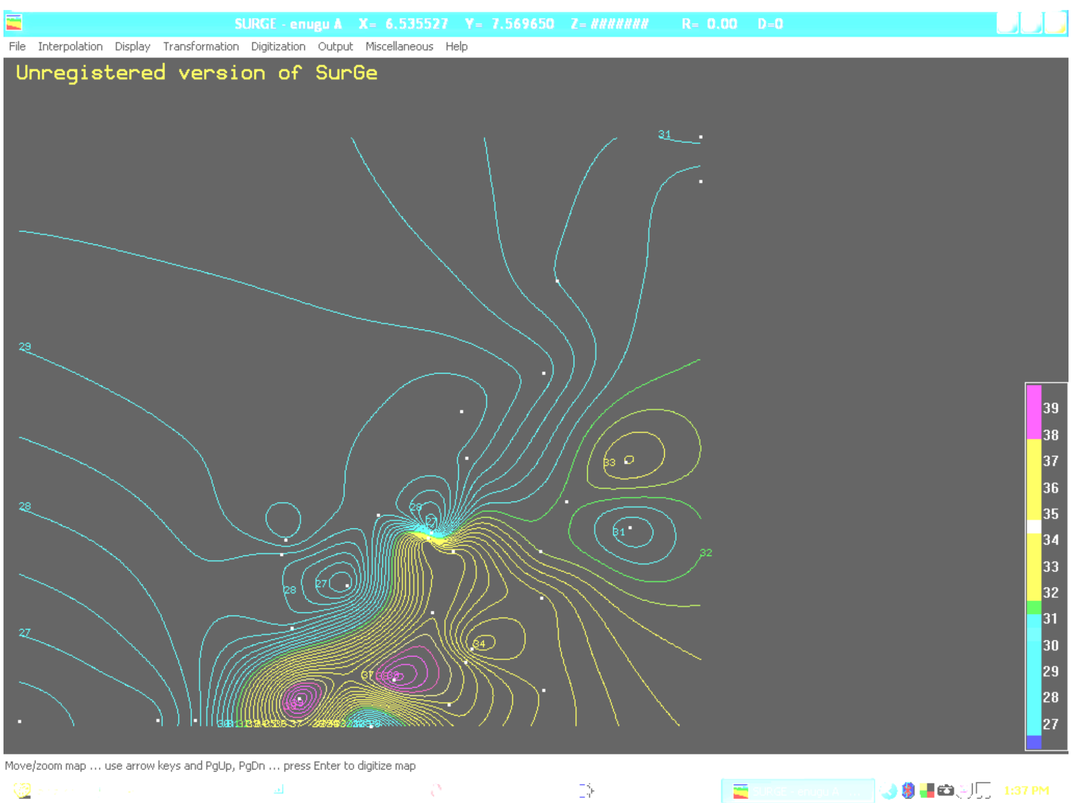

Figure 4. Isotherm map.

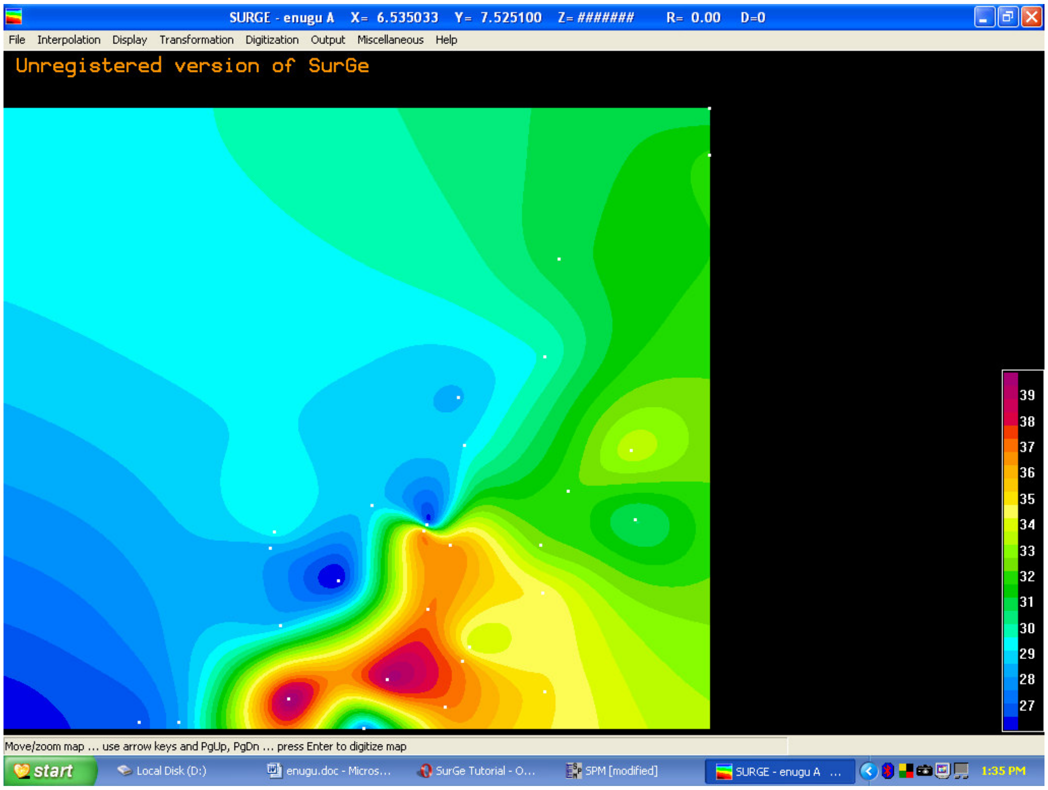

Figure 5. Choropleth map.

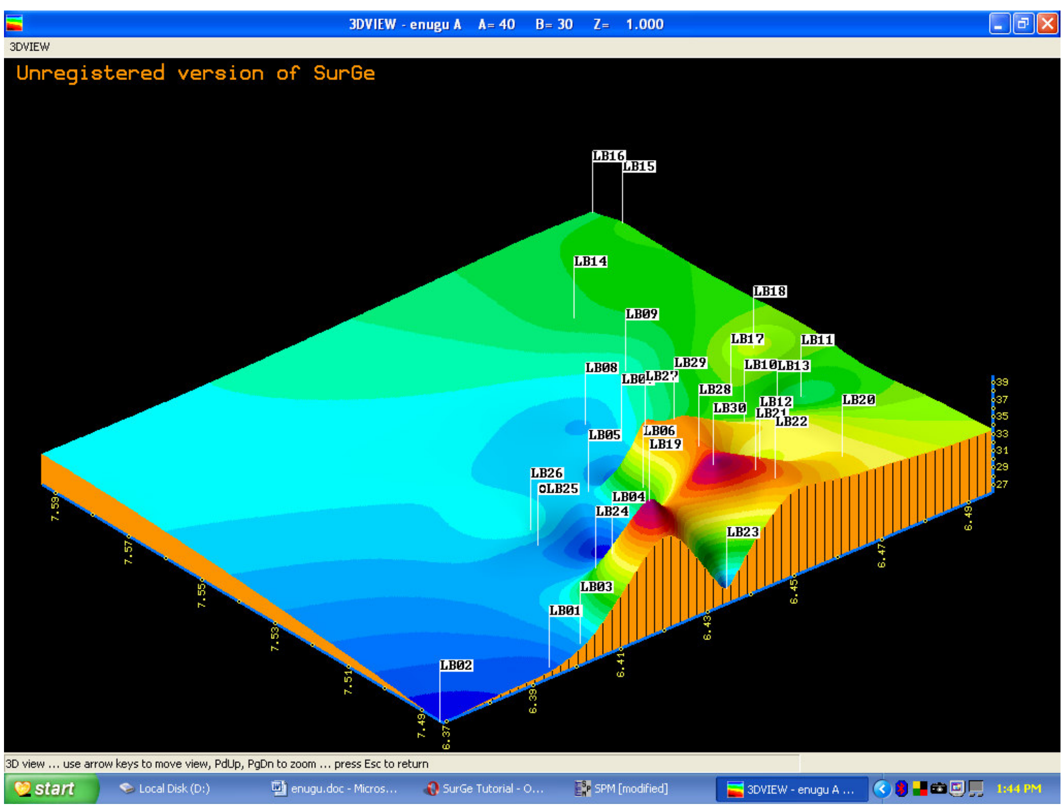

Figure 6. Digital elevation map.

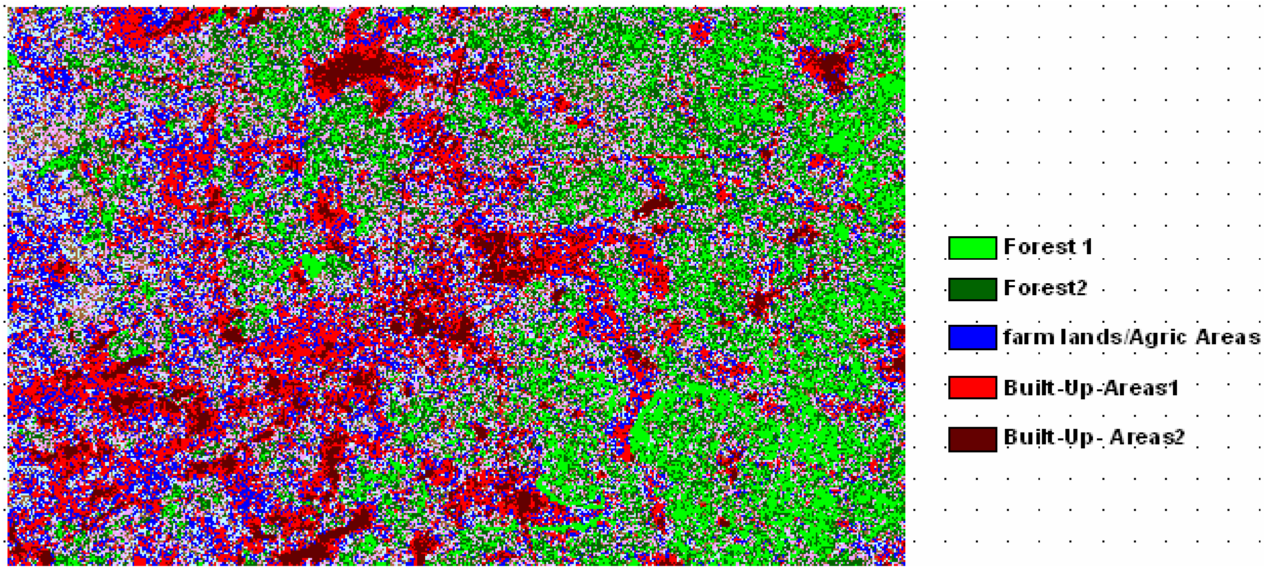

Figure 7. Classified map of Enugu.

Each component surface in urban landscapes exhibits a unique radiative, thermal moisture, and aerodynamic properties and relates to their surrounding site environment (Oke, 1982).

This result correlates very well with the result of processed imagery shown in Figures 7 and 8 respectively.

It is evident from our imagery (Figure 7 and 8) that there is a thermal gradient as progressed from the central Business District (CBD) out into the country side. Some hot spots or UHI can be easily identified. The most extensive UHI was distributed in the central part of the CBD, comprising Ogbette market, Okpara Avenue, Zik's Avenue, and presidential Road.

There were also many smaller UHIs along the highways that crossed the town as well as on the residential Layouts of New Layout, New Heaven, Abakpa, Emene, Garriki, Uwani and Achara Layouts. However, there did not exist an extensive UHI in the North–West and South–East, except for a few small ones. Apparently, forest and agricultural uses in these areas contain the development of UHI.

The result of the processed imagery shows clearly that commercial and industrial areas exhibited the highest temperature, followed by residential areas. The lowest temperature was observed in forest zones followed by farmlands. This implies that urban development raised the temperature by replacing natural environment (forest, water and pasture) with non – evaporating, non – transpiring surfaces.

Adaptation measures

The study, based on the findings, proposed some design strategies for the mitigation of Enugu urban heat Island. Most of these strategies are applicable to the downtown location. Employing these strategies will result in substantial green cover increase in the downtown locations while street level thermal comfort is enhanced by avoiding compact designs. The building design should be such that taller buildings are on the north–east side of city blocks while green areas are at center and to the north–side.

Two other design strategies aimed at enhancing the thermal properties of the high-density residential areas and multi–family residential neighborhoods includes: The design strategy for the former proposes a 50% increase in tree cover. Suggestions for the multi–family residential areas include a courtyard built-form with grass–covered inner lawns to allow for building shade.

Finally, using light-colored materials for roofing of downtown locations as well as improving the reflectivity of pavement within the urban centers will reduce UHI.

Conclusion

It was observed in this study that temperature and land-use information can be directly derived from remotely sensed data, which provides a powerful way to monitor urban environment and human activities. This can effecttively replace the traditional analogue system of urban studies particularly as the study relate to the physical aspects of the city environment namely geology, relief, drainage, vegetation and some cultural landscapes-urban agriculture, roads/streets and buildings. This information enhances our understanding of urban environment and can be further used to improve environmental quality.

The present study assessed the level of UHI as well as explored the applicability of Land sat-ETM in monitoring

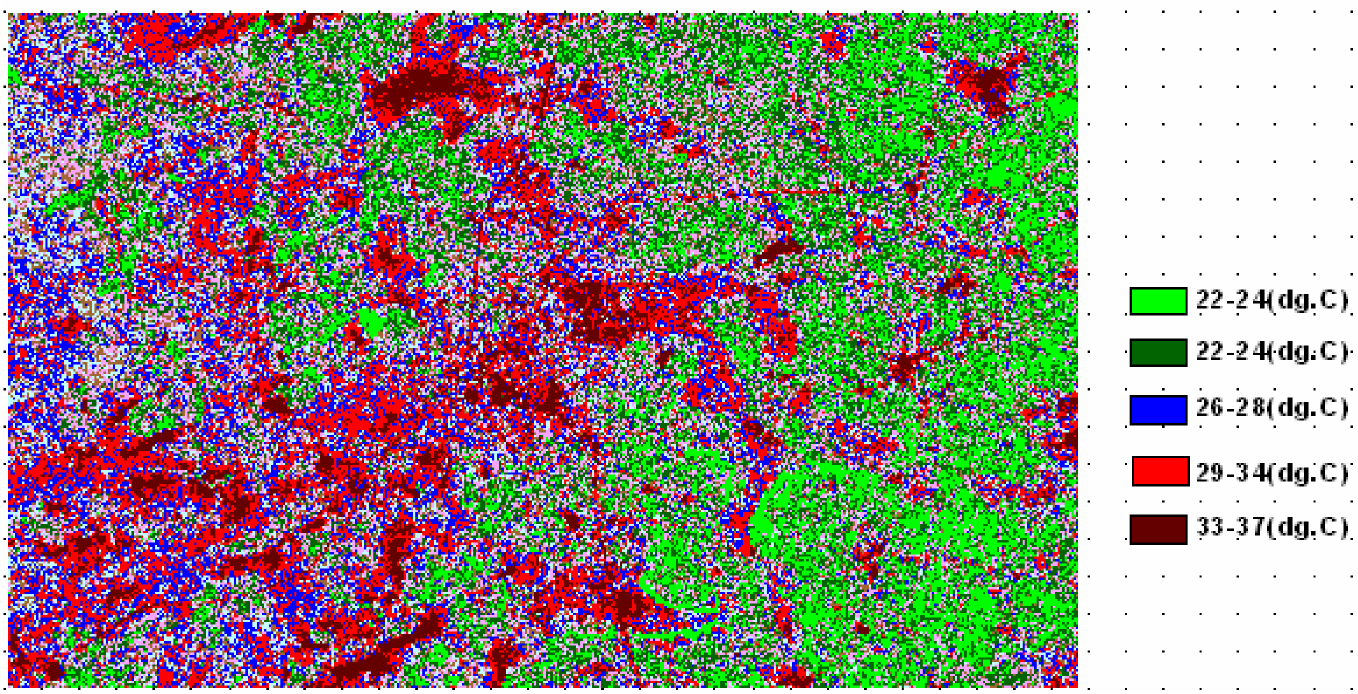

Figure 8. Classified temperature range of Enugu.

UHI in Enugu urban compared to the traditional urban-rural method. The Landsat-ETM imagery employed in this research was able to determine the spatial extent and behavioral patterns of UHI in Enugu urban center. UHI correlated positively with population density and concentration of human activities. The instrument was able to determine the temperature ranges of different land–use classes in Enugu urban.

REFERENCE

Anyadike RNC (2002). Climate and Vegetation. In a Survey of the Igbo Nation (ed) by G.E.K Ofomata. Africana First Publishers, Ibadan.

Government of Anambra State (1978). A comprehensive physical Development plan for Enugu, Government press Enugu.

N P C - National population commission (1991, 2006).

Nnamani C (2002). "By the Hills and Valleys of Udi and Nsukka". The People, their Heritage, their Future," Tell Magazine, No. 50, December 16. pp. 64 – 69.

Oke TR (1982). The Energetic Basis of Urban Heat Island. J.R. Meteorol. Soc. 108 (455): 1 – 24.

Quattrochi D, Rickman D, Estes M, Caymon C, Howell B, Luvall J (2000). A Decision Support information System for Urban Landscape Management Using Thermal Infrared data. PhotogrammetricEngineering and Remote sensing. 66(10): 1195 – 1207.

Shashua – Bar L , Hoffman ME (2002). Vegetation as a climatic Component in the Design of an Urban Street; An Empirical Model for predicting the Cool Effect of Urban Green Areas with Trees. Energy and Building 31 (3): 221 – 235.

Smith RM (1986). Comparing Traditional methods for Selecting Class Intervals on Choropleth maps. Professional Geographer, 38 (1): 62 – 67.

Taha H (1997). Urban Climates and Heat Islands:Albedo, Evapotranspiration, and Anthropogenic heat. Energy and Buildings. 25 (2): 99 – 103.

Unger J, Simeghy M , Zoboki J (2001).Temperature cross – section Features in an Urban Area. Atmospheric Research. 58 (2):117 – 127.

Voogt JA (2004). Urban Heat Islands: Hotter Cities. America Institute of Biological Sciences.

Weng O (2003). Fractal Analysis of Satellite – detected Urban heat Island effect. Photogrammetric Engineering and Remote Sensing, (69): 555 – 566.