ANALYSIS OF TEMPORAL AND SPATIAL CHARACTERISTICS OF ENUGU URBAN HEAT ISLAND USING MULTIPLE TECHNIQUES

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Abstract: The temporal and spatial microclimate variations at several sites in Enugu urban were evaluated using paired measurement programme (PMP) and landsat/ETM satellite imagery. The aim was to determine the spatial extent of urban heat island (UHI) in the city. Temperature correlated to land-use and land-cover within the city. The results indicate that urban climate modifications at day and night were very different. A downtown centered heat island was observed at night in both dry and rainy seasons, while there was a mix of cool and heat islands by day especially during rainy seasons. The daytime variations were strongly correlated to the amount of tree shading. During the night, city climate was highly correlated to sky-view factors and thermal properties in the city. Based on these findings, the study proposed some new design strategies for the downtown core of Enugu and its periphery. They aim at maximizing shading on streets during the day while maintaining a large sky view to facilitate night cooling.

Keywords: Micro climate, urban heat island, temporal and spatial, land use.

INTRODUCTION

One of the fundamental attributes that set a city apart from its rural surroundings is the weather condition that prevails over it. Characteristically, the weather condition in the city exhibits thermal conditions different from that of its rural counterpart resulting to a phenomenon usually referred to as heat island. This is not surprising because in the city buildings and paved surfaces which have replaced vegetative and wet soils impede free flow of air and prevent the utilization of available net radiation for evaporation. Moreover, many activities of man including factories, vehicles and domestic cooking release hot air in the city, much of which are absorbed the construction material which vary greatly in terms of shapes, colours and aspects. In their study, Taha, Akvari and Sailor (1992) for example showed that radiant energy is absorbed into roads, and rooftops, raising the surface temperature of urban structures to 3.5^0c higher than the ambient air temperatures. This phenomenon has been well documented and found to be universally typical of cities by many researchers see (Shashua-Bar and Hoffinan, 2000). However, researchers are faced with the dilemma of separating the relative contributions each of the many factors make in 'urban heat island' (UHI).Even at that, Unger et al (2001) have observed that changes in surface characteristics (including geometry, thermal conductivity and wind speed) and concentrated release of anthropogenic heat are more significant than the influence of artificial (urban) factors and natural topographic conditions.

The microclimate caused by the 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 carbon dioxide, a green house gas known to contribute to global warming and climate change. These call for the need to generate data on spatial variations of temperature in the city necessary for the measures that could be taken to moderate or check the increase in intensity of UHI in cities in general and Enugu urban in particular.

The present study addresses the surface temperature estimation using Land Sat/ETM over Enugu urban and its environs to analyze heat island formations. Also temperatures were measured over the city using a paired measurement programme (PMP) suggested by Myrup, Micginn and Flocchini (1993). The aim is to identify the effect of land-use patterns and land-cover types on intra-urban air temperature differences under different vegetation shade types. Recognizing that intra-urban micro-climate variations are also influenced by macro scale weather patterns, the study explores the influence of land-use, land-cover under three atmospheric stability types: stable, neutral and unstable. The two methods (satellite analysis and paired measurement programme) enable a detailed data to be generated because where one may fails another complements.

The urban fabric of Enugu is very complex and composed of very different layouts. Each layout is characterized by the morphology of the settlement and by the land coverage. These structures have different influences on the energy balance (Arnfield and Grimmond, 1998). This is why we are attempting to analyze the temperatures spatial variability on Enugu according to weather classes and urban layouts characteristics.

AIM AND OBJECTIVES

The aim of this study is to explain spatial differences in the temperature of Enugu urban space through the determination of the temporal and spatial extent and characteristics of UHI, with a view to proffering means of reducing UHI and their effects in Enugu urban.

RESEARCH HYPOTHESIS

Ho: There is no significant relationship between land-use and temperature in the generation of UHI.
Ho: The use of landsat imagery and paired measurement programme in the determination of UHI does not yield the same result, i.e. they are not homogeneous.

METHODOLOGY

Site Selection.

Two land-use classes (residential and commercial) and two land-cover types (paved and green surfaces) were considered for this study. Purposive sampling was employed in the selection of the following sites. (a) High-density, high-rise, non-residential areas with no greenery (DTL). (b) High density, high-rise, residential areas with low greenery (HDR). (c) Medium density, mixed residential (some residential, some commercial/ institutional area with a greenery extent) between (a) and (b) above (NW_2). (d) Areas with similar land-use, building density and greenery, one having more fully developed vegetation canopy than the other (LVR and LOR). The following sites were then selected: (i) DTL = Downtown location = Ogui Road (ii) HDR = High-density Residential Site = Achara Layout (iii) NW_2 = Multi-family Residential Institutional = UNEC (iv) LVR = Low-density Vegetated Residential Neighbourhood = GRA (v) LOR = Low-density Open-canopy Residential Neighborhood = Independence Layout.

Land-cover Estimation

Streets and paved areas were estimated from digitized satellite imagery using computer aided design (CAD) software “Erdas Imagine”. Green area was assumed to be land not covered by residential, commercial/institutional or streets/paved land-uses.

METHODS OF DATA ANALYSIS

Atmospheric Stability Estimation

Since simultaneous measurement at all the sites were not made, it was necessary to classify the measurement period according to atmospheric conditions so that data from different sites could be compared. Although many methods of estimating atmospheric stability near the ground exist, the Pasquil-Turner Index modified by Karlson (Karlson, 1986) is the most relevant for the study since it utilized solar radiation and wind speed only.

$$MPT = Q^*/(U)^2 \qquad \text{…………} (1)$$

Where Q^* = Hourly average net radiation at 1.5m above ground (Wm^{-2})

U = Hourly average wind speed at 7.4m above ground (Ms^{-1}).

The following MPT values were selected as cut-off points for the three atmospheric stability conditions.

$MPT > 30$ Unstable
$-10 < MPT < 30$ Neutral/Near Neutral
$MPT < -10$ Stable

Temperature Measurement

For the paired measurement programme, transect and fixed point measurements were taken hourly and averaged over a month. All temperature differences were calculated as site temperature minus reference temperature. Thus, a negative (-) temperature difference indicates that the site was cooler than the reference station; and positive (+) indicates the site was warmer than the reference station. For the satellite imagery, figure 1 shows the data processing flow in the study. Detailed explanations of the two methods have been outlined elsewhere (Adina et al, 2009a, 2009b).

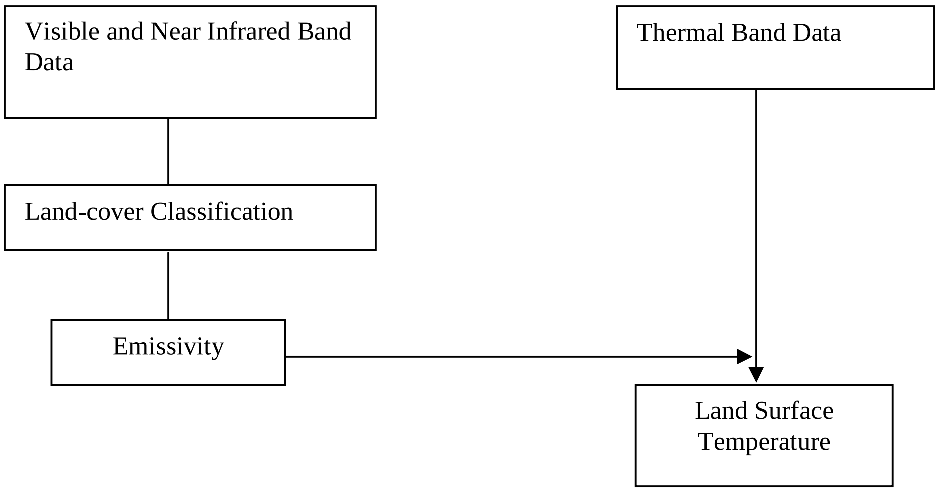

Fig. 1: Data Processing Flow
Source: Wend (2003)

Statistical Analysis

Spearman's Ranking Correlation technique, Student's't' test, as well as Chi-square test analysis was employed in this paper. Spearman's ranking correlation analysis used is of the form:

$$1 - \frac{6\sum d^2}{n(n^2 - 1)}$$

and applying students "t" test of the form:

$$t = \frac{r \text{ x } \sqrt{n-2}}{\sqrt{\ } - r^{2}}$$

RESULTS AND DISCUSSIONS

Rainy Season Day-Time

Table 1 shows temperature variation during stable atmospheric conditions during the day under stable conditions.

The downtown location site was the warmest (+0.64) warmer than the residential sites. The high density, urban residential sites (HDR) – Achara Layout, and heavily vegetated urban sites (LVR) – GRA, with fully developed vegetation canopy were the coolest (-2.31 and -3.3) respectively.
The number of sites that witnessed unstable conditions on multiple days were very few (DTL, LVR and NW_2), the patterns were very similar to those produced by stable conditions (see table 2)

Table 1: Temperature Variation under Stable Day-Time Conditions

Sites	Location Names	Temperature Difference
DTL	Ogui Rd	+0.64
LOR	Independence L/O	-0.22
LVR	GRA	-3.3
NW_2	UNEC	-2.0
HDR	Achara L/O	-2.31

Table 2: Temperature under Unstable Day-time Conditions

Sites	Location Names	Temperature Difference
DTL	Ogui Rd	+1.52
NW_2	UNEC	-3.0
LVR	GRA	-3.45

Table 3: Rainy Season Temperature Deviation during the Night

Sites	Location Names	DTN
DTL	Ogui Rd	+1.48
LOR	Independence L/O	-0.64
LVR	GRA	-0.34
NW_2	UNEC	-0.39
HDR	Achara L/O	-0.52

Under unstable conditions too, downtown location sites (DTL) were the warmest. Maximum day-time UHI was about 3.2^0C and hour-to-hour difference was about 3.5^0C. Unlike stable conditions, differences between LVR and NW2 under unstable conditions were 0.45^0C warmer than the reference site. Rainy season UHI at the city-wide scale correlated well with ground cover characteristics.

Rainy Season: Night-Time

Unlike the daytime (rainy season) temperature differences, night temperature variation (DTN) showed a clear downtown-centered heat Island (see table 3).

All residential sites were cooler than the reference site (from 0.34^0C to 0.64^0C cooler) while the downtown location was up to 1.48^0C warmer; cumulating in a maximum night-time air temperature of about 2.0^0C heat Island during the study period. The intra-urban differences among the other sites (LOR, LVR, NW2 and HDR) however, were very small. The highest night-time intra-urban air temperature difference was observed during early night period (1800hrs to 2300hrs).

Dry Season - Daytime

Data were also analysed for the months of dry season. Temperature variability was high especially between day and night (see table 4).

The downtown site was the warmest (2.0). The variability between day-time (dry season) and day-time (rainy season) temperature value was high. Also, the heavily vegetated urban residential sites (LVR) and suburban sites (LOR) with fully developed vegetation canopy were the coolest (-3.8 and -2.68) respectively. The hour-to-hour variation in air temperature during daytime was significant. During the day, some cool islands were observed along the vegetated areas of GRA (Bent Lane), and the urban plantation along WAEC road. The peak temperature value was recorded between 1300hrs and 1500hrs.

Table 4: Dry Season Day-time Deviation

Sites	Location Names	DTD
DTL	Ogui Rd	+2.0
LOR	Independence L/O	-2.35
LVR	GRA	-3.8
NW_2	UNEC	-2.2
HDR	Achara L/O	-0.45

Table 5: Night-time Temperature Deviation in Dry Season

Sites	Location Names	Temperature Variation
DTL	Ogui Rd	+2.3
LOR	Independence L/O	+0.4
LVR	GRA	+1.1
NW_2	UNEC	+0.8
HDR	Achara L/O	+2.1

Dry Season-Night-Time

Night-time temperature showed a clear downtown – centered heat island. Table 5 clearly depicts this variation.All residential sites were warmer than the reference site (0.4 to 2.1^{0}C) while the downtown location was up to 2.3^{0}C warmer. A maximum night-time air temperature heat Island of a bout 2.3^{0}C was observed during the study. The highest night-time intra-urban air temperature difference was observed during the early evening period (1500hrs to 2300hrs).

Satellite Imagery

Landsat/ Enhanced Thematic Mapper image dated 12/10/2007 was used in this research. Figure 2 shows the classified imaging of Enugu while figure 3 gives the range of temperature within Enugu urban as detected by the
Enhanced Thematic Mapper (ETM).

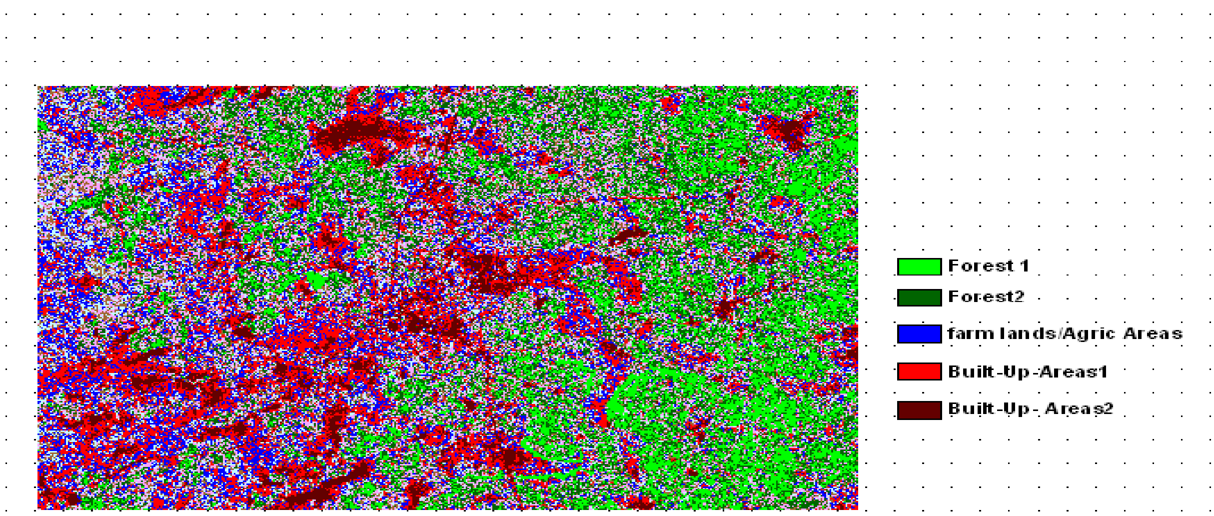

Fig.2: Classified imagery of Enugu.
Source: Landsat/ETM of 12/10/07

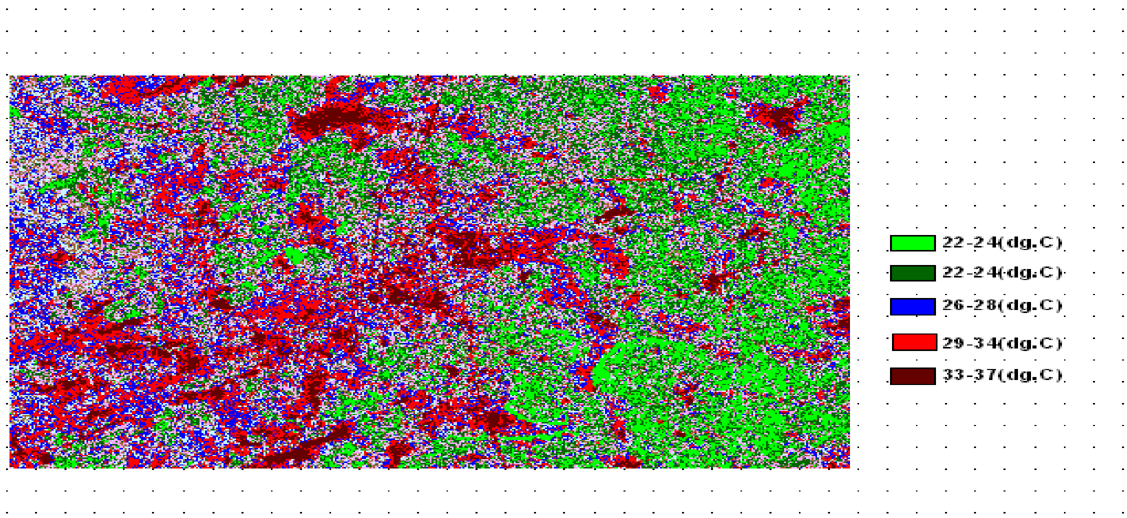

Fig.3: Temperature Range for Enugu.
Source: Landsat/ETM of 12/10/07

It is evident from the imageries that a thermal gradient progressed from the Central Business District (CBD) out into the country side. Some hot spots, or UHI, can easily be identified. For example, the most extensive UHI occurred in the Central part of the CBD, comprising Ogbete market, Ogui road, Ziks Avenue, Okpara Avenue and Presidential road. There were also many other smaller UHIs along the major highways (Enugu-Onitsha expressway, Enugu-Port Harcourt express way) as well as on the residential layouts of new layout, New Heaven, Abakpa, Emene, Uwani and Achara Layouts.

The most influential factors controlling UHI are the distribution of surface cover characteristics, and urban morphology such as building materials, geometry and density (Oke, 1982). Each component surface in urban landscapes exhibits unique radiative thermal, moisture, and aerodynamic properties.

The result shows clearly that commercial and industrial land exhibited the highest temperature, followed by residential land. The lowest temperature was observed in forest areas, followed by agricultural lands and pasture. This implies that urban development brought up the temperature by replacing natural environment (forest, water and pasture) with non-evaporating, non-transpirating surfaces such as stone, metal and concrete surfaces.

Hypothesis 1

Ho: There is no significant relationship between land use and temperature variation in the generation of UHIR =0.69

Calculated value = 3.75 and Table value = 1.86. Since Calculated value 3.75 is greater than the table value 1.86. Ho is rejected and H_1 is accepted. H_1 states that there is a significant relationship between land-use/land-cover and temperature. The degree of explanation offered by R_0 is then $r^2 = (0.69^2) \times 100 = 47.6\%$. Although 47.6% is not a smashingly pass mark, we accept the validity of the result in view of the fewness of the variable items (N = 10) that generally give themselves up to weak correlation.

Table 6: Rank-Order Correlation of Land-use and Temperature for some Sites (X)

Land-use	Ogbete	Ziks Ave.	Ogui	Coal Camp	Asata	Ebonyi Rd	Mary Land	Gariki	Cattle Mkt	Okpara Sq
Ranking	9	7	8	10	6	3	4	2	1	5

Temperature Values (Y)

Temp	39.4	39.9	36.3	35.2	36.9	26.9	28.4	26.1	28.6	28.1
Rank	9	10	7	6	8	2	4	1	5	3

Table 7: Temperature reading for PMP and Satellite imagery.

Land-use	PMP ("E")	Satellite ("0")
Forest 1	27	24
Forest 2	27	24
Agric	26	28
Built 1	28.8	34
Built 2	39.9	37

$$X^2 = \sum \frac{(0 - E)^2}{E}$$

Hypothesis 2

H_0: The use of satellite imagery and paired measurement programme (PMP) in the determination of UHI do not yield the same results, that is, are not homogeneous. A chi-test of homogeneity was used.

Calculated value 1.97 and Table value 0.711. Calculated value 1.97 is greater than the table value 0.711. H_0 is rejected and H_1 is accepted. H_1 states there are some agreement in the use of either paired measurement programme and satellite imagery in the study of UHI. Therefore, satellite imagery and PMP are complementary and one may be used to verify the other.

Conclusions and Recommendation

The present study explored the effects of land-use/land-cover types on urban air temperature variations under different atmospheric stability conditions, using paired measurement programme and satellite based imagery. Unstable day-time shows the maximum heat island effect. Vegetation shade showed little impact on the intra-urban variations in downtown locations. However, shaded sites heated up much more slowly than open ones and this leads to cooler day-time temperatures in LVR areas like GRA. The UHI situation in Enugu can be remedied through the application of the following recommendations which include but not limited to design strategies. To mitigate Enugu UHI there should be substantial green cover increase in the downtown locations while street level thermal comfort is enhanced by arcades and suitable building massing (compact designs).

Planting street trees has greater cooling potential than planting open-surface trees; and the cooling effects of open-space trees tend to be localized. Mitigation strategies should be chosen to reflect neighborhood conditions. For example, in Achara Layout, Abakpa and New Heaven, with the greatest available rooftop space, living roofs and green roofing could have a greater impact. Again, developing a heat watch warning system as part of the strategy to lessen the negative health impacts of heat will help (Kalkstein and Greene, 1997).Finally, operational urban mass transit programme for transportation, open green spaces, alternative source of energy in place of generators are recommended

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