Investigating Urban Land Use/Land Cover-Surface Temperature-Air Temperature Nexus

Bernard T. Tyubee[1] and Raymond N. C. Anyadike[2]

[1]Department of Geography, Benue State University, Makurdi, Nigeria. [2]Department of Geography, University of Nigeria, Nsukka

Abstract

Land use/land cover (LULC)-surface temperature (ST)-atmospheric (air) temperature (AT) nexus is fundamental in understanding the dynamics of urban climate. Remote sensing, in conjunction with Geographic Information System (GIS), is used to investigate the relationships between LULC and ST, and ST and AT in Makurdi, North central Nigeria. A total of twelve (12) Landsat TM/ETM+ images are acquired for January, April and June of 1991, 1996, 2001 and 2006 for the study. Air temperature data are collected from two weather stations on dates of the twelve images. Three LULC indices namely the Normalized Difference Vegetation Index (NDVI), Normalized Difference Wetness Index (NDWI) and Normalized Difference Built-up Index (NDBI) are chosen to represent the densities of vegetation cover, moisture and built-up structures in the study area. The effects of NDVI, NDWI and NDBI on ST, and ST on AT are investigated using correlation analysis with test of significant relationships using students' t-test at 95% confidence level. The results show that areas of water, forest, undergrowth/wetland and cultivated land have decreased by 4km^2 (19%), 37km^2 (28%), 119km^2 (32%) and 19km^2 (14%) from 1991-2006. Conversely the area of built-up land has increased by 179km^2 (130%) during the same period. ST is negatively correlated with NDVI and NDWI but significant correlation occurs only between ST and NDWI for all the 12 images. There is a positive and significant correlation between ST and NDBI for all the 12 images. ST is significantly and positively correlated only with maximum and mean AT. The study concludes that both vegetation cover and moisture diminish ST but the cooling potential of the latter is higher than the former. Built-up structures enhance ST, which in turn enhances AT particularly during daytime.

1.0 Introduction

- The surface is the location of sources and sinks of heat, mass and momentum which controls the partitioning and conversion of these entities and also strongly conditions the behavior of the lowest layers of the atmosphere (Voogt and Oke, 1997).
- In cities, the conversion of natural surfaces to impervious ones due to urbanization affects the partitioning of radiation and anthropogenic sources of energy into sensible (Q_H), latent (Q_E) and stored (ΔQ_S) heat fluxes (Tapper et . al., 1981; McPherson, 1994).
- Remote sensing, in conjunction with Geographic Information System (GIS) has been successfully utilized in assessing LULC/ST and ST/AT relationships in cities (Weng, Lu and Schubring, 2004; Wilson and Lindsey, 2005; Chen et. al., 2006; Weng, et. al., 2006).
- The major objectives of the study are 1) to investigate LULC change and 2) to assess the relationships between LULC and ST and ST and AT from 1991 to 2006 in Makurdi, North central Nigeria.
- The study is fundamental in understanding the dynamics of surface and air urban heat islands, urban pollution, human comfort and urban planning.

2.0 Study Area

- Makurdi, administrative capital of Benue State, Nigeria is located between latitudes 7^o 35^l – 7^o 53^l N and longitudes 8^o 24^l - 8^o 42^l E in the North central geo-political region (Figure 1).
- The city covers a land area of 800km^2 and has a population of 300 000 people (2006 census data).
- The city lies entirely in the flood plains of Benue River which bisects the city into northern and southern parts.
- Makurdi is subdivided into eleven administrative divisions known as Council Wards. These are Agan, Bar, Clerk/Market, Fiidi, Mbalagh, Mission, Modern Market, North Bank 1, North Bank 2, Wadata/Ankpa and Wailomayo.

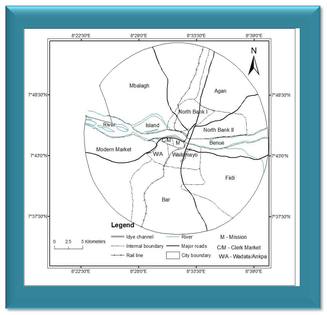

Figure 1:
Location and administrative divisions of Makurdi

3.0 Data

- A total of Twelve (12) Landsat TM/ETM+ images, covering the study area, were acquired for January, April and June of 1991, 1996, 2001 and 2006 from Landsat scenes of path 187/188 and row 054/055. These comprised Landsat 5 TM images (January 17, 1991; April 11, 1991; June 16, 1991; January 14, 1996; April 25, 1996; June 11, 1996) and Landsat 7 ETM+ images (January 26, 2001; April 13, 2001; June 21, 2001; January 14, 2006; April 12, 2006; June 30, 2006) respectively.
- All the raw images were geo-referenced to a common Universal Transverse Mercator (UTM) co-ordinate system using a 1:50 000-scaled topographical map of the study area.
- All the raw images, including thermal infrared band (TIR) (band 6), were also re-sampled to a pixel size of 30m.
- Air temperature (daily minimum, maximum and mean) data were acquired at Makurdi airport (7^o 41^l N; 8^o 37^l E) and Lower Benue River Basin Development Authority (LBRBDA) headquarters (7^o 38^l N; 8^o 32^l E) weather stations on the 12 dates of Landsat TM/ETM+ images.

3.1 LULC Types and LULC Indices

- Five LULC types were classified in the study area using supervised classification method.
- Three LULC indices were chosen to represent the different categories of LULC types in the study area.
- These are the Normalized Difference Vegetation Index (NDVI), the Normalized Difference Water Index (NDWI) and the Normalized Difference Built-up Index (NDBI).
- The three indices measured the densities of vegetation cover (NDVI), water content within vegetation and water state of vegetation (NDWI) and impervious materials (NDBI). The NDWI is used as substitute for surface moisture (Chen, et. al., 2006).
- The indices were computed from bands 3 and 4 (NDVI) and 4 and 5 (NDWI and NDBI) of Landsat TM/ETM+ respectively.
- The values of the LULC indices ranged from -1 (least) to +1 highest.

3.2 Retrieval of ST from Landsat TM/ETM+ Images

- The land surface temperature (ST) was retrieved from both Landsat TM and Landsat ETM+ images using the method of Chen, Zhao, Li and Yin (2006).
- The method simulates ST by converting digital numbers (DNs) of band 6 to radiation luminance (R_{TM6}).
- Correction for emissivity (ε) is not necessary in this method because the DNs are converted directly to radiation luminance and not to black body temperature.
- Landsat TM/ETM+ images were analyzed using Integrated Land and Water Information System (ILWIS) 3.3, ERDAS Imagine 8.6 and ArcGIS 9.3 software.

3.3 Sampling of ST and LULC Indices' Pixels/Data Analysis

- Due to the enormity of pixels covering the study area, some manageable pixels were systematically sampled from ST, NDVI, NDWI and NDBI maps.
- To randomly and systematically sample the pixels, a 1 x 2 minutes grid cell, comprising 17 rows (latitude) x 14 columns (longitude) (Figure 2) was produced and superimposed on all the ST, NDVI, NDWI and NDBI maps.
- As the result, a sample of 178 pixels was then selected at the grid nodes.
- The sampled 178 pixels or observation units were chosen to represent ST and LULC conditions in study area.
- The values of the 178 pixels for ST, NDVI, NDWI and NDBI were then extracted from each of the 12 Landsat TM/ETM+ images.
- The location coordinates were used to extract ST at the airport and LBRBDA weather stations. Mean ST was also computed for each of the 12 Landsat TM/ETM+ images.
- Pixel-by-pixel correlation analysis was used to assess the relationship between LULC and ST, and ST and AT, with test of significant relationship at 90% confidence level using Students' t-test.

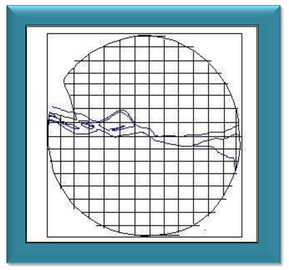

Figure 2:
The 1 x 2 grid cells used in sampling the 178 pixels or observation units.

4.0 LULC in Makurdi, 1991-2006

- A total of five (5) LULC types were classified in the study area namely water, forest, undergrowth/wetland, cultivated land and built-up land (Figures 3 and 4).
- Water has lost total area of 4km^2, representing 19%, from 21km^2 in 1991 to 17km^2 in 2006. The area of forest has also decreased by 37km^2 (28%) from 133 km^2 in 1991 to 96km^2 in 2006.
- The areas of undergrowth/wetland and cultivated have declined by 119km^2 (32%) and 19km^2 (14%) from 370km^2 and 138km^2 in 1991 to 251km^2 and 119km^2 in 2006 respectively.
- Conversely, the area of built-up land has increased by 179km^2 (130%) from 138km^2 in 1991 to 317km^2 in 2006.
- The result suggests that urbanization has decreased natural land materials and simultaneously increased developed surface materials that are associated with urban growth and development from 1991 – 2006 in the study area.

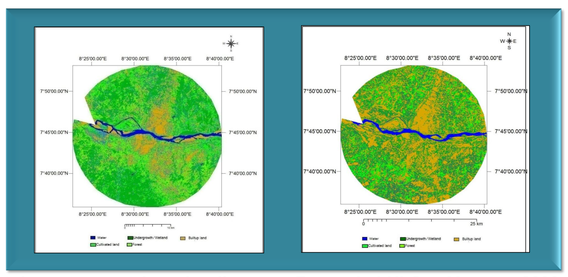

Figure 3: LULC in Makurdi, 1991 **Figure 4: LULC in Makurdi, 2006**

4.1 LULC-ST Relationship

- The relationships between ST and NDVI, NDWI and NDBI are presented in tables 1 – 3.
- NDVI is negatively correlated with ST. However, only the coefficients of -0.148 (April, 1991), -0. 167 (June, 1996) and -0. 125 (June, 2001) are significant (Table 1).
- NDWI is negatively and significantly correlated with ST in all the three seasons (Table 2).
- NDBI is positively and significantly correlated with ST in all the three seasons (Table 3).
- The results (tables 1-3) suggest that NDVI and NDWI diminish ST magnitude whereas NDBI increases ST magnitude in the study area.
- In addition, the cooling potential of moisture (NDWI) exceeds that of vegetation cover (NDVI) in all the three thermal seasons.

Year	Month/season		
	January	April	June
1991	-0.114	-0.148*	-0.77
1996	-0.088	-0.098	-0.167*
2001	-0.057	-0.086	-0.125*
2006	-0.061	-0.056	-0.081

* Significant correlation at 95% confidence level

Table 1: Correlation coefficients of ST and NDVI

Year	Month/season		
	January	April	June
1991	-0.226*	-0.221*	-0.218*
1996	-0.225*	-0.197*	-0.150*
2001	-0.229*	-0.192*	-0.209*
2006	-0.222*	-0.203*	-0.217*

* Significant correlation at 95% confidence level

Table 2: Correlation coefficients of ST and NDWI

Year	Month/season		
	January	April	June
1991	0.229*	0.220*	0.235*
1996	0.222*	0.194*	0.159*
2001	0.233*	0.197*	0.201*
2006	0.230*	0.203*	0.222*

* Significant correlation at 95% confidence level

Table 3: Correlation coefficients of ST and NDBI

4.2 ST-AT Relationship

- The relationship between ST and AT is presented in Table 4.
- ST is positively and significantly correlated with AT at both stations except for minimum temperature at LBRBDA.
- Mean ST is positively correlated with ST except for minimum temperature at LBRBDA.
- The result in table 4 suggests that ST influences daytime temperature (maximum AT) compared to nighttime temperature (minimum AT).

ST	Makurdi Airport			LBRBDA		
	Min. AT	Max. AT	Mean AT	Min. AT*	Max. AT*	Mean AT*
ST	0.639**	0.625**	0.733**	0.076	0.761**	0.574**
Mean ST	0.397	0.891**	0.670**	-0.075	0.775**	0.501**

* Only data from 1996 – 2006 were available

** Significant correlation at 95% confidence level

Table 4: Correlation coefficients of ST and AT

5.0 Conclusion

- There is a general decline in natural surfaces and increase in developed surfaces from 1991 – 2006.
- NDVI and NDWI diminish ST magnitude in all seasons.
- However the cooling potential of moisture (NDWI) exceeds that of vegetation cover (NDVI).
- NDBI increases ST magnitude in all seasons.
- ST influences AT mostly during daytime than nighttime.
- LULC influences AT through changes in ST.

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