Investigating the Effect of Land Use/Land Cover on Urban Surface Temperature in Makurdi, Nigeria

Dr. B.T.Tyubee

Bernard T. Tyubee[1], **Raymond N. C. Anyadike**[2]
1 *Benue State University, Makurdi, Nigeria,* bentyubee@yahoo.com
2 *University of Nigeria, Nsukka, Nigeria,* rncanyadike@yahoo.com
Dated: 10 June 2015

Abstract

The study utilizes remote sensing, in conjunction with geographic information system (GIS), to explore the effect of LULC change on land surface temperature (ST) over 15-year period in Makurdi, North central Nigeria. A total of twelve (12) Landsat TM/ETM+ images are acquired for April, June and January of 1991, 1996, 2001 and 2006 for the study. The Landsat TM/ETM+ images are analyzed using Integrated Land and Water Information System (ILWIS) 3.3, ERDAS Imagine 8.6 and ArcGIS 9.3 software. The Normalized Difference Vegetation Index (NDVI), Normalized Difference Wetness Index (NDWI) and Normalized Difference Built-up Index (NDBI) are used to represent the dominant land use/land cover (LULC) types in the study area. The effect of NDVI, NDWI and NDBI on ST is investigated using pixel-by-pixel correlation analysis. The results show that areas of water, forest, undergrowth/wetland and cultivated land have decreased by 4km^2, 37km^2, 119km^2 and 19km^2 from 1991-2006. The ST is negatively correlated with NDVI and NDWI but positively correlated with NDBI for all the months/seasons and years. The results suggest that change in land use/land cover, driven by urbanization, is the primary driver of surface and atmospheric temperatures in Makurdi.

Keywords: urbanization, land use/land cover, surface temperature, remote sensing, geographic information system.

1. INTRODUCTION

Land use/land cover (LULC) plays significant role in urban heat island (UHI) phenomenon. The role of LULC in UHI is related to changes in surface energy budget due to the replacement of permeable and evaporating surfaces with impermeable ones (Oke, 1987; Weng, 2001; Mills, 2004; Wong and Yu, 2005; Grimmond, 2007).

Due to the decrease in vegetation cover and increase in concretized surfaces in most cities, more incoming radiation is converted into sensible heat flux (Q_H) rather than latent heat flux (Q_E) (i.e. higher Bowen ration) resulting to higher surface and air temperature in cities relative non-urbanized areas (Wong and Yu, 2005). For instance, it has been reported that in rural areas in Christchurch, New Zealand, 40% of the net radiation is used in evaporation (Q_E), 26% goes into sensible heat (Q_H) and 33% into storage (Q_G). By contrast, in the industrial/commercial area, no energy is used for evaporation (Q_E), 64% is converted to sensible heat (Q_H), and 36% goes into storage (ΔQ_S) (Tapper et. al., 1981).

The major objectives of the study are: (1) to estimate the density (-1 to +1) of three LULC types namely vegetation cover, moisture and human structures; (2) to estimate surface temperature (ST) (°C); (3) to establish the relationship between ST and LULC types; and (4) to establish the relationship between ST and air (atmospheric) temperature (AT). Understanding the nexus between ST, LULC and AT is fundamental in urban heat island mitigation and urban planning.

2. APPLICATION OF REMOTE SENSING AND GEOGRAPHIC INFORMATION SYSTEM (GIS) IN LULC AND THERMAL STUDIES

Remote sensing is a global application methodology for assessing UHI effect of cities even in regions where pairs of urban and rural temperature records are not available (Gallo et al., 1993). Remote sensing, in conjunction with geographic information system (GIS), has been widely applied in detecting land use/land cover change, the basis for the inadvertent climatic modification of cities (Weng, 2001), assessing the distribution characteristics of surface temperature and surface urban heat island (SUHI) (Weng, 2001; Weng et al., 2006) and investigating the relationship between surface temperature and land use/land cover (Chen et al., 2006; Yuan and Bauer, 2007; Zhang et al., 2007).

3. MATERIALS AND METHODS

3.1 Study area

Makurdi is the administrative capital and economic center of Benue State, north central Nigeria. Makurdi is located between latitudes 7° 357 – ^{lo} 53 ^{l}N and longitudes 8° 24 8 - ^{lo} 42 ^{l}E and covers a land area of 800km^2 (Figure 1). The city lies entirely in the River Benue flood plains with fragile ecosystem comprising forest, alluvial soil and wetlands. The river Benue bisects the city into northern and southern parts.

Makurdi grew from a small river port in the 1920s, with few thousand people, to a population of 238 000 and 300 000 people in 1991 and 2006 (census data). The city is subdivided into eleven administrative divisions known as “Council Wards”.

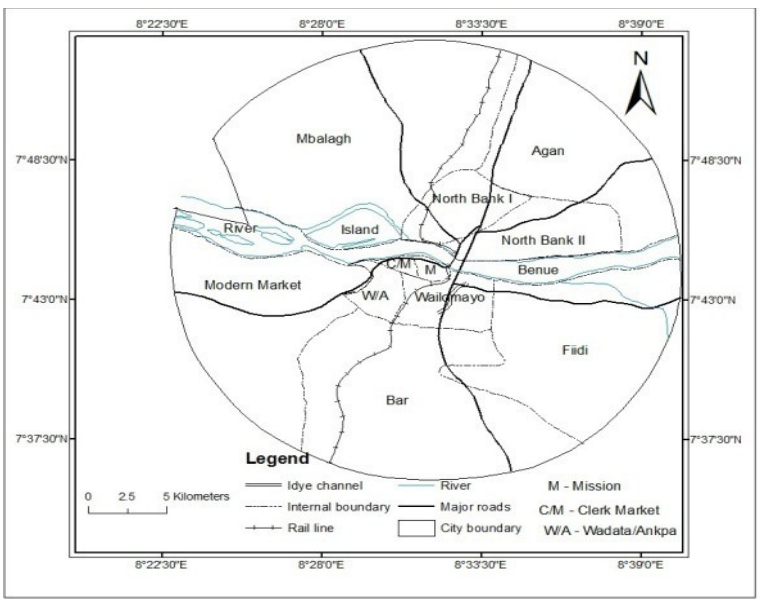

Figure 1: Location and political divisions of Makurdi

3.2 Data

A total of twelve (12) Landsat TM/ETM+ images are acquired for a 15-year period (1991 – 2006). These comprised Landsat 5 TM images (April 11, 1991; June 16, 1991; January 17, 1991; April 25, 1996; June 11, 1996; January 14, 1996) and Landsat 7 ETM+ images (April 13, 2001; June 21, 2001; January 26, 2001; April 12, 2006; June 30, 2006; January 26, 2006) respectively. All the raw images are geo-referenced to a common Universal Transverse Mercator (UTM) co-ordinate system using a 1:50 000-scaled topographical map of the study area and re-sampled to pixel size of 30m x 30m for all bands including thermal infrared (TIR) band (band 6). The Landsat TM/ETM+ images of the study area are retrieved from scenes of paths 187-188 and rows 054-055. In situ data are collected at two weather stations on the 12 dates namely Makurdi Airport (7° 41' N; 8° 37' E) and Lower Benue River Basin Development Authority (LBRBDA) headquarters (7° 38' N; 8° 32' E).

3.3 Classification of LULC, derivation of LULC indices and retrieval of ST

Five land use/land cover (LULC) types namely water, forest, undergrowth/wetland, cultivated land and built-up land are categorized in the study area using the supervised classification method.

Three LULC indices are used to represent the nature and density of LULC 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 NDVI, NDWI and NDBI measure the densities of vegetation cover, water content within vegetation and human structures respectively. The values of the three LULC indices range from -1(least) to +1(highest) density. The NDWI is used as a substitute for the surface moisture. The procedure for estimating NDVI, NDWI and NDBI is adopted from Chen et al. (2006).

The method of retrieving ST from Landsat TM/ETM+ images is based on the method of Chen et al. (2006). The digital numbers (DNs) of TIR band (band 6) are first converted to radiance luminance which is converted to brightness temperature. Since the DNs are not first converted to black body temperature, correction for emissivity (ε) is not necessary.

Due to the number of pixels covering the study area, a 1 x 2 (minutes) grid cell, comprising 17 rows (latitude) x 14 columns (longitude) is produced and superimposed on the ST, NDVI, NDWI and NDBI maps and a total of 178 pixels are then randomly selected for correlation analysis (Figure 2).

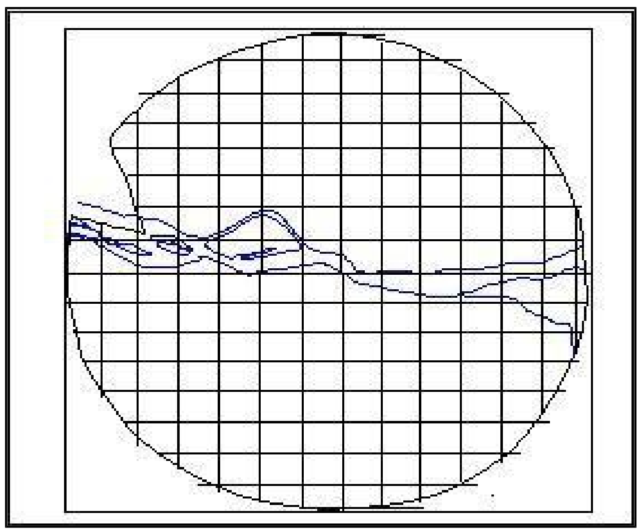

Figure 2: The 1 x 2 minutes grid cells used to sample pixels

3.4 Data analysis

Pixel-by-pixel correlation analysis is used to assess the relationship between ST and LULC using the 178 sampled pixels of ST, NDVI, NDWI and NDBI for all the 12 images. Correlation analysis is also used to establish the relationship between ST and AT from 1991 – 2006 in the study area. The significance of the relationships is tested using student's t-test at 95% confidence level.

The Landsat TM/ETM+ images are processed and analyzed using Integrated Land and Water Information System (ILWIS) 3.3, ERDAS Imagine 8.6 and ArcGIS 9.3 software.

4. RESULTS AND DISCUSSION

4.1 Changes in land use/land cover

The result of changes in land areas of the five LULC types shows 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 whereas the area of built-up land has increased by 179km^2 (130%) during the same period (Table 1). The temporal trend in urban LULC change in the study area between 1991 and 2006 is attributed to the increase in population and socio-economic activities which leads to increase in the need and demand for buildings and other infrastructure in the Makurdi region.

Table 1: Changes in land use/land cover in Makurdi, 1991 – 2006.

ULC types	1991		1996		2001		2006	
	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%
Water	21	3	147	18	21	3	17	2
Forest	133	17	116	14	102	13	96	12
Under-growth/ Wetland	370	46	268	34	253	31	251	31
Cultivated land	138	17	118	15	280	35	119	15
Built-up land	138	17	151	19	144	18	317	40

4.2 Relationship between ST and LULC

The ST, NDVI, NDWI and NDBI maps were superimposed on LULC maps. The result shows that minimum and maximum ST of 27.5ºC and 50.7ºC occur in River Benue and built-up area. The minimum and maximum NDVI values of -0.53 and 0.18 are observed in water and forest. For NDWI, the least and maximum values of -0.35 and 0.16 occur in built-up land and forest. Moreover, forest and built-up land exhibit the lowest and highest NDBI values of -0.01 and 0.57 respectively.

Surface temperature is negatively correlated with NDVI for all the twelve images. However, only the coefficients of April (1991) and June (1996 and 2001) are significant at 95% confidence level (table 2). Negative and significant correlation coefficients are observed between ST and NDWI for all the twelve images (table 3). In addition, ST is positively and significantly correlated with NDBI for all the twelve images (table 4).

The results of ST – LULC relationship, tables 2 – 4, indicate a direct relationship between ST and NDBI and inverse relationship between ST and NDVI and NDWI. The results suggest that both densities of vegetation cover and moisture diminish ST whereas the density of developed materials enhances ST. However, the significant linear relationship between ST and NDWI, compare to ST and NDVI, suggests that the cooling potential of moisture exceeds that of vegetation cover. The results confirm previous findings (Chen et al., 2006; Yuan and Bauer, 2007; Zhang et. al., 2007).

Table 2: Correlation coefficients of ST and NDVI

Year	Month/season		
	April	June	January
1991	-0.148*	-0.077	-0.114
1996	-0.098	-0.167*	-0.088
2001	-0.086	-0.125*	-0.057
2006	-0.056	-0.081	-0.061

*Significant at 95% confidence level.

Table 3: Correlation coefficients of ST and NDWI

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

*Significant at 95% confidence level.

Table 4: Correlation coefficients of ST and NDBI

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

*Significant at 95% confidence level.

4.3 Relationship between surface and air temperature

Surface temperature (ST) and daily mean surface temperature (ST_{DM}) are positively correlated with air temperature (AT), except for minimum air temperature at LBRBDA. In addition, all the correlation coefficients are significant except for minimum air temperature (table 5). The result suggests that surface temperature influences air temperature mostly during daytime whereas during nighttime, other factors may exert greater influence.

Table 5: Correlation coefficients of surface and air temperature (°C) for selected locations in Makurdi, 1991-2006

	Makurdi Air port			LBRBDA+		
	Min AT	Max AT	Mean AT	Min AT	Max AT	Mean AT
ST	0.64*	0.63*	0.73*	0.08	0.76*	0.57*
ST_{DM}	0.40	0.89*	0.67*	-0.08	0.78*	0.50*

+Only data from 1996 - 2006 are available.
*Significant correlation at 95% confidence level.

5. CONCLUSION

The results of the study suggest that there is a very strong relationship between ST and density of moisture compared to density of vegetation cover. There is also a very strong relationship between ST and density of human structure. There is also a very strong relationship between ST and mean and maximum AT compared to minimum AT.

The results have shown that the potential of moisture is higher than vegetation cover in diminishing ST. The influence of human structures in enhancing ST magnitude is higher during daytime in the study area.

6. ACKNOWLEDGMENTS

The study was partially funded by the African Climate Change Fellowship Program (ACCFP). The ACCFP was administered by Global System Analysis for Research and Training (START), Washington DC, USA; African Academy of Science (AAS), Nairobi, Kenya and Institute of Resource Assessment (IRA), University of Dar es Salaam, Tanzania.

The support of Dr. C. P. K. Basalirwa and Dr. J. G. M. Majaliwa, Makerere University, Kampala, Uganda; Prof. Timothy T. Gyuse, Benue State University, Makurdi, Nigeria, and Women Environmental Program (WEP), Abuja, Nigeria during the ACCFP Doctoral Fellowship Program is highly appreciated.

The paper is dedicated to the memory of Late Professor Raymond N. C. Anyadike.

7. REFERENCES

Chen, X. - L., Zhao, H. - M., Li, P. - X. and Z. - Y. Yin, 2006: Remote Sensing Image – based Analysis of the Relationship between Urban Heat Island and Land Use/Cover Changes. *Rem. Sen. Env.*, **104**, 133 – 146.

Gallo, K. P., McNab, A. L., Karl, T. R., Brown, J. F., Hood, J. J. and J. D. Tarpley, 1993: The Use of NOAA AVHRR Data for Assessment of the Urban Heat Island Effect. *J. Appl. Meteor.*, **32**, 899 – 908.

Grimmond, S., 2007: Urbanization and Global Environmental Change: Local Effects of Urban Warming. *Cities and Global Env. Change*, 83 – 88.

Mills, G., 2004: The Urban Canopy Heat Island. IAUC Teaching Resources. Accessed May 9, 2007 at www.urban-climate.org.

Oke, T. R., 1987: Boundary Layer Climates (2nd ed.). Methuen, New York, 435pp.

Tapper, N. J., Tyson, P. O., Owens, I. F. and W. J. Hastie, 1981: Modelling the Winter Urban Heat Island over Christchurch, New Zealand. J. *Appl. Meteor.*, **20**, 365 – 376.

Weng, Q., 2001: A Remote Sensing – GIS Evaluation of Urban Expansion and its Impact on Surface Temperature in the Zhujiang Delta, China. *Int. J. Rem. Sen.*, **22**, 1999 – 2014.

Weng, Q., Lu, D., and B. Liang, 2006: Urban Surface Biophysical Descriptors and Land Surface Temperature Variations. *Photogram. Eng. Rem. Sen.*, **72**, 1275 – 1286.

Wong, N. H. and C. Yu, 2005: Study of Green Areas and Urban Heat Island in a Tropical City. *Habit. Int.*, **9**(3), 547 – 558.

Yuan, F. and M. E. Bauer, 2007: Comparison of Impervious Surface Area and Normalized Difference Vegetation Index as Indicators of Surface Urban Heat Island Effects in Landsat Imagery. *Rem. Sen. Env.*, **106**, 375 – 386.

Zhang, J., Wang, Y. and Z. Wang, 2007: Change Analysis of Land Surface Temperature based on Robust Statistics in the Estuarine Area of Pearl River (China) from 1990 to 2000 by Landsat TM/ETM+ data. *Int. J. Rem. Sen.*, **28**, 2383 – 2390.