OSUN GEOGRAPHICAL REVIEW

Journal of the Department of Geography,
Osun State University, State of Osun, Nigeria

Volume 5, 2022

ISSN: 2695 - 1959

Published by the
Department of Geography, Osun State University,
State of Osun, Nigeria

CONTENTS

OSUN GEOGRAPHICAL REVIEW
Published by the Department of Geography, Osun State University, State of Osun, Nigeria
ISSN: 2695 - 1959 Volume 5, 2022; 63 - 74

URBAN DENSIFICATION AND LAND SURFACE TEMPERATURE IN KANO METROPOLIS, NIGERIA

[1]H. A. Idris and [2]A. I. Tanko
[1]Department of Environmental Management, Bayero University Kano, Nigeria
[2]Department of Geography, Bayero University Kano, Nigeria
Corresponding author: haidris.geo@buk.edu.ng

Abstract
Urban climates are known to differ from sub-urban or rural climates worldwide, often associated with altering the environment's natural state. The increases and concentration of populations in the cities of developing countries have increased the densities of built-up spaces, causing a warming up of the urban areas. This transformation of natural environments will continue to make cities prone to marked increases in temperature. Likewise, the rapid urban population growth rate in Kano Metropolis will likely increase this transformation of its natural environment. Therefore, this study investigated the spatial variation in building density around Kano Metropolis and its effect on land surface temperature distribution. The GIS and remote sensing techniques were employed for this study. Data were sourced from Landsat images of 1998, 2002, 2013 and 2018; these were used to derive the Built-up Index (BUI) and Land Surface Temperature (LST) for the study area; a correlation coefficient analysis was then carried out. The result shows a strong positive correlation between the built-up area and land surface temperature, meaning that building density influences temperature distribution in Urban Kano, where increasing building density tends to increase the temperature of a particular location. The study recommends a well-informed and extensive review of the Kano Master Plan to guide appropriate and systematic expansions in developing the urban environment and increasing green infrastructure in the Metropolis.

Keywords: Urban population, Urban densification, Built-up Index, Urban climate, Land Surface Temperature.

Introduction

Increasing global urban populations and transforming natural environments for human settlements have played a significant role in temperature distribution across cities worldwide, where cities are faced with unending changes in land use land cover (Deilami et al., 2018; Kim et al., 2019). This has made surface temperature one of the critical parameters of urban climate (Voogt & Oke, 2003). The increasing level of built-up spaces has caused a warming up of metropolitan areas across the world. With the increase and concentration of populations in cities of developing countries, natural environments will be transformed into built-up (Li et al., 2011); this is likely to cause marked increases in urban temperatures. Urban climates differ from sub-urban or rural climates worldwide due to alterations in the environment's natural state. Cities tend to have a more impervious surface, which increases the run-off that drains very quickly, leaving very little moisture available for evapotranspiration; thereby affecting urban surface energy balance (Gunawardena et al., 2017; Oke et al., 2017; Masson et al., 2020). Higher urban temperatures indicate the modifications that have occurred in urban areas' climates, making monitoring, analysing and evaluating the urban heat island effect significant for urban climate and environment studies (Macarof & Statescu, 2017). Many global cities in temperate and tropical regions are experiencing heat island effects due to high building densities (Wong et al., 2010; Amorim and Dubreuil, 2017; Marcotullio et al., 2021). Land Surface Temperature (LST) has been used at global, regional and local scales to determine temperature distribution. It is calculated from remote sensing data (Meng et al., 2019; Kaiser, 2022) and has been used in various scientific studies like agriculture, climate change, urban planning, forestry, hydrology and more. It has been used in different analyses of problems associated with the environment (Grimmond et al., 2010, Li et al., 2019; Ennouri et al., 2021).

Literature Review

The built-up surfaces are known to store enormous amounts of heat, so also do transport, cooling systems, and industrial activities produce heat, causing cities to have temperatures that are several degrees higher than the surrounding suburban and rural areas (American Meteorological Society, 2000; Elsayed, 2012; Lee et al. 2020). These higher temperatures that occur in urban areas tend to increase the severity of heat-stress situations in cities and can affect the health of the urban population, cause the formation of smog in cities and degrade available green spaces (Satterthwaite, 2008; Luo, 2018; Jiang et al., 2019). Thus, urbanisation alters local environments via a series of physical phenomena that can result in local environmental stresses. These stresses include urban heat islands (higher temperatures, particularly at night, in comparison to outlying rural locations), with trends in surface air temperature around urban centres found to be associated with the intensity of urbanisation (Revi et al., 2014).

Urban areas are characterised by a very high degree of soil sealing and continuous built-up areas, which causes a substantial spatial variation in surface temperature. Increased air temperatures can be expected to be particularly problematic in urban areas, where temperatures tend to be higher than in the surrounding countryside, modifying the urban microclimate and contributing to the urban heat island effect (Oke, 1987; Morabito et al., 2017). The rapid and unplanned urban growth results in a continuous increase in the permanent covering of soil by complete or partly impermeable artificial materials (Prokop, Jobstmann & Schönbauer, 2011; Artmann, 2014). The consequence of the Urban Heat Island (UHI) effect is that it represents one of the most significant human-induced changes to the Earth's surface climate (Zhao, Lee, Smith & Oleson, 2014). This modification in urban climate has caused an increase in the temperatures of urban areas (Oke, 1973; Nichol, 2005; Idris, 2005; Rosenzweig et al., 2011), making temperature an essential parameter for characterising the urban environment (Nichol & Wong, 2005; 2007; Ekanade, Ayanlade & Orimoogunje, 2008; Li et al., 2013; Yang et al., 2017; Assaye et al., 2017).

The rapid rate of urban population growth in Kano Metropolis has made it difficult to properly plan and control the sprawling development of houses and the provision of facilities in the city. The pre-colonial patterns of land use which are still in use can no longer meet up with the new demands of social changes, just as the various challenges such as lack of implementation guidelines, the entrenchment of the Land Use Act in the Constitution and clarity regarding rights and purposes, weak policies and institutions associated with the democratic process have hindered adequate growth and development in the urban centre. These are seen as institutional weaknesses causing an astronomical rise in land value and increased land speculation (Babalola and Hull, 2019; Otty et al., 2021). There also are increases in rates of rural-urban migration, illegal and unplanned settlements, built-up areas, decrease in vegetation, and disappearing open spaces in low and high-density areas of the city (Bichi, 2000; Maiwada, 2000; Barau, 2007; Dankani, 2013; Isah, 2015; Idris, 2022). For these reasons, this study investigated the spatial variation in building density around Kano Metropolis and its effect on land surface temperature distribution.

Study Area

Kano Metropolis is located between latitudes $11^{o}\ 50^{1}$ and $12^{o}\ 07^{1}$ N and longitudes $8^{o}\ 22^{1}$ and $8^{o}\ 47^{1}$E. It is bounded by Madobi and Tofa Local Government Areas (LGAs) to the South West, Gezawa LGA to the East, Dawakin Kudu LGA to the South East, and Minjibir LGA to the North East (Figure 1). It is the capital of Kano state in North Western part of Nigeria and is known as the commercial centre of Northern Nigeria. Kano Metropolis covers about 499 square kilometres, with the urban area covering 251 square kilometres. It comprises eight local government areas Kano Municipal, Fagge, Dala, Gwale, Tarauni, Nassarawa, Ungogo and Kumbotso; with most parts of Urban Kano spanning over all the LGAs except for Ungogo and Kumbotso, where it occupies parts of them (Figure 1). The climate of the study area is the tropical wet and dry type- AW based on Koppen's climate classification. The temperature ranges from 19^{0} C in the coldest to 42^{0} C in the hottest months. The population is projected to be 4,331,790 (2018) at an Intercensal Growth Rate (ICGR) of 3.4% from 2,826,307 based on the 2006 Census.

The settlements are spread across different residential densities, the High-Density Residential Areas (HDRA) in districts of Bachirawa and Rijiyar Lemu in Ungogo and Gwammaja in Dala; Medium Density Residential Areas (MDRA) in sections of Gandun Albasa in Kano Municipal and Rijiyar Zaki in Ungogo; Low-Density Residential Areas (LDRA) in districts of Dan Agundi in Kano Municipal and Giginyu in Nassarawa and the Government Reserve Areas (GRA) of Nassarawa in Nassarawa and Hotoro in Tarauni (Figure 1 and 2).

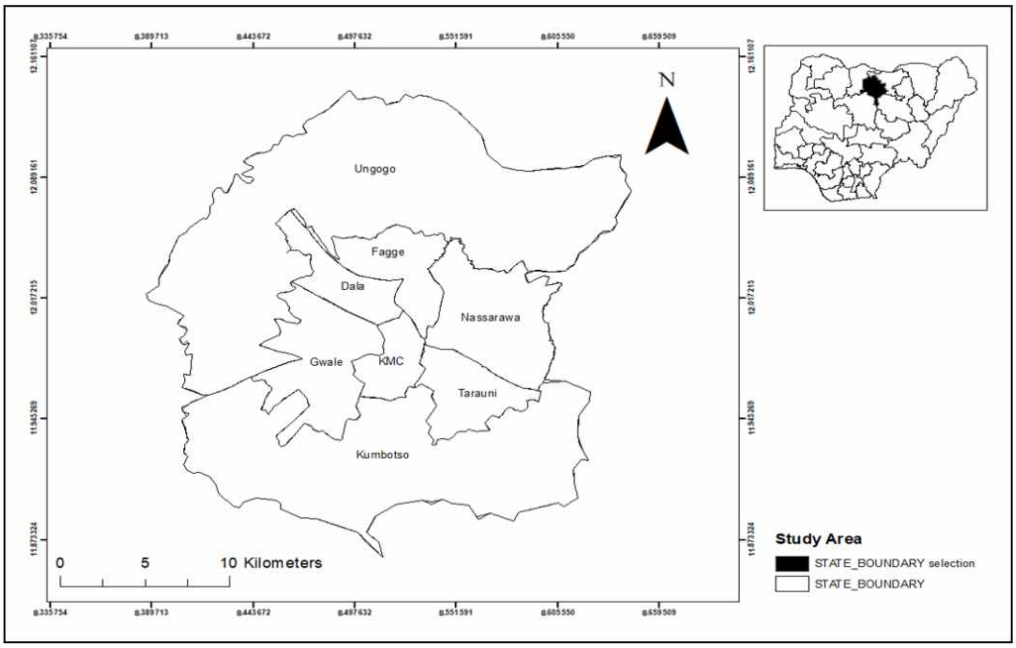


Figure 1: Study Area
Source: Department of Geography, BUK, 2022

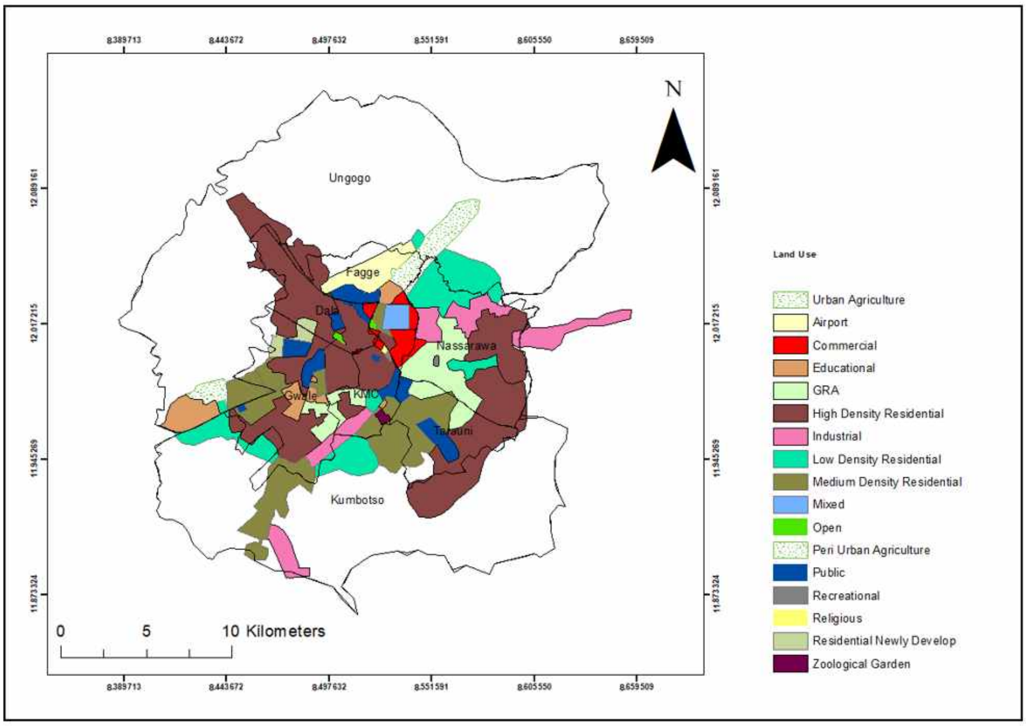


Figure 2: Land Use Pattern in Kano Metropolis
Source: Department of Geography, BUK, 2022

Material and Methods

For this study, the tools employed include the Global Positioning System (GPS), ENVI Software and ArcGIS software. The temporal monitoring of environmental changes was done using remote sensing techniques and the GIS tool because of their objective nature, repeatability and cost-effectiveness, especially over large areas of study and long periods (Amiri & Tayebeh, 2009; Sharma, Chakraborty & Joshi, 2015; Sharma & Joshi, 2016). The data sources for this research include Landsat images of 30m resolution for the years 1998, 2002, 2013 and 2018 (Table 1) downloaded from the Global Land Cover Facility (GLCF), Land Use Map of the study area, reference data collected from ground-truthing, high-resolution images from Quick Bird for the years 2012 and 2017 and Google Earth Map of the study area.

Table 1: Details of Satellite Images

Landsat Image	Sensor ID	Date	Month	Year
Landsat 5	TM	18	November	1998
Landsat 7	ETM+	20	October	2002
Landsat 8	OLI/TIRS	26	October	2013
Landsat 8	OLI/TIRS	24	October	2018

Image Pre-processing

The Landsat images used were pre-processed to correct radiometric, atmospheric and geometrical distortions of the images. The Universal Transverse Mercator (UTM) coordinate system was used to rectify all the images; the pre-processing of the satellite images was done before image clipping was performed using the spatial analyst tool on all the images to extract the sub-scene from the full image. This extract covers the Metropolitan extent of Kano, the study site, and was done on the ENVI Software platform. This was then exported to the ArcGIS Software platform for further analysis.

Derivation of Built-Up Index (BUI)

The Built-up Index is the index for analysing urban patterns using NDBI and NDVI. A higher value indicates the densely built-up areas for the BUI, while lower values indicate the barren or non-built-up and low-density areas. Building density was then derived by subtracting the Normalized Difference Vegetation Index (NDVI) from the Normalized Difference Built-up Index (NDBI) using the Landsat images. NDBI was derived using the following equation:

$$NDBI = \frac{SWIR - NIR}{SWIR + NIR} \quad \text{....... Equation (1)}$$

Where:

SWIR = *DN values from the Short-Wave Infrared band*

NIR= *DN values from the Near-Infrared band*

BUI was then derived using the following:

BUI = NDBI – NDVI ....Equation (2)

Table 2: Built-Up Index

Category	Class Index
Very Low Density	-1.212 – -0.355
Low Density	-0.356 – -0.235
Moderate Density	-0.236 – -0.095
Moderately High Density	-0.096 – 0.180
High Density	0.181 – 0.890

Derivation of Normalized Differential Vegetation Index (NDVI)

NDVI is a linear combination between the near-infrared band and red band, which is regarded as the basic index for measuring the 'greeness' of the earth's surface. This was determined from the LANDSAT images using the following equation:

$$NDVI = \frac{NIR-R}{NIR+R} \quad \text{......Equation (3)}$$

Where:

R = DN values from the RED band

NIR= DN values from Near-Infrared band

Estimation of Land Surface Temperature (LST)

Thermal Infrared (TIR) data retrieve LST by measuring Top of Atmosphere (TOA) radiances. The Land Surface Temperature was estimated using the ArcGIS platform's Landsat Thematic Mapper (TM)/Enhanced Thematic Mapper Plus (ETM+) imagery. The United States Geological Survey (USGS) Landsat 8 data handbook (2016), with a description of a step-by-step process of deriving LST, was used.

Conversion to Top of Atmosphere (TOA) Brightness Temperature

Thermal band data can be converted from spectral radiance to top-of-atmosphere brightness temperature using the thermal constants in the MTL file:

$$T = \frac{K_2}{\ln\left[\frac{K_1}{L\lambda} + 1\right]} - 272.15 \quad \text{……..……Equation (4)}$$

Where:

T = *Top of atmosphere brightness temperature (^{0}C)*
L_λ = *TOA spectral radiance (Watts/(m2 * srad * µm))*
K_1 = *K1 Constant Band (No.)*

K_2 = *K2 Constant Band (No.)*

272.15 is the constant for conversion from Kelvin to Celsius

Land Surface Emissivity (LSE)

Land surface emissivity (LSE) is the average emissivity of an element on the surface of the Earth calculated from NDVI values.

PV = [(NDVI – NDVI min) / (NDVI max + NDVI min)]^2…………..Equation (4)

Where:

PV = Proportion of Vegetation

NDVI = DN values from NDVI Image

NDVI min = Minimum DN values from NDVI Image

NDVI max = Maximum DN values from NDVI Image

E = 0.004 * PV + 0.986 ……....Equation (5)

Where:

E = Land Surface Emissivity

PV = Proportion of Vegetation

Land Surface Temperature (LST)

The Land Surface Temperature (LST) is the radiative temperature calculated using the Top of atmosphere brightness temperature, Wavelength of emitted radiance, and Land Surface Emissivity.

LST = (BT / 1) + W * (BT / 14380) * ln (E)…...........Equation (6)

Where:

BT = Top of atmosphere brightness temperature (°C)

W = Wavelength of emitted radiance (11.5µm)

E = Land Surface Emissivity

Results and discussion

The Built-Up Index (BUI) and the Land Surface Temperature (LST) were computed, showing the trend in the variations in building density and distribution of land surface temperature across the Metropolis. Selected BUI values were correlated with LST values to compute regression equations to understand the relationship between building density variation and surface temperature distribution.

Built-Up Index (BUI)

The Built-Up Index for the study periods was calculated from the Landsat images of 1998, 2002, 2013 and 2018 (Figures 3, 4, 5 and 6). From the maps, the pixel values of building density for 1998 were between -1.212 to 0.889; for 2002, they were between -0.905 and 0.442; for 2013, the range was between -1.033 to 0.225 while for 2018, the values were -0.903 to 0.221. This shows that building density continued to increase over study in the Metropolis, especially in areas such as the MDRA, HDRA, Recreational, Industrial and Commercial Land Use. This has been a result of the continuous expansion of the Metropolis through infrastructure development by way of building structures (homes, schools, markets, malls etc.), roads, and more. This signifies increases in building density, with 1998 having the least building density and 2018 having the most.

Notably, areas with lower building density as of 1998 have had increases in building density; these are the Recreational and Public places, Newly Developed areas, MDRA, LDRA, Industrial areas and the GRA. Table 4 presents minimum values depicting sparsely built-up areas and maximum values depicting densely built-up areas, with the trend showing increasing building density over the years of study.

Table 4: BUI Pixel Values (Min and Max) 1998 to 2018

Pixel Value	1998	2002	2013	2018
Min	-1.212	-0.905	1.033	0.903
Max	0.889	0.442	0.225	0.221

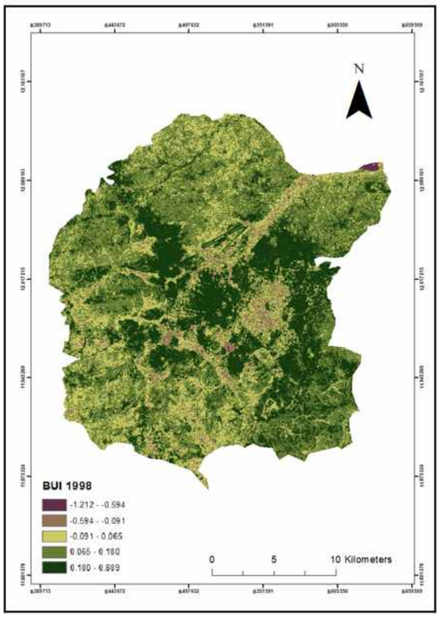
Land Surface Temperature (LST)

The Land Surface Temperatures (LST) for the study periods were calculated from Landsat images of 1998, 2002, 2013 and 2018 (Figures 7, 8, 9 and 10).

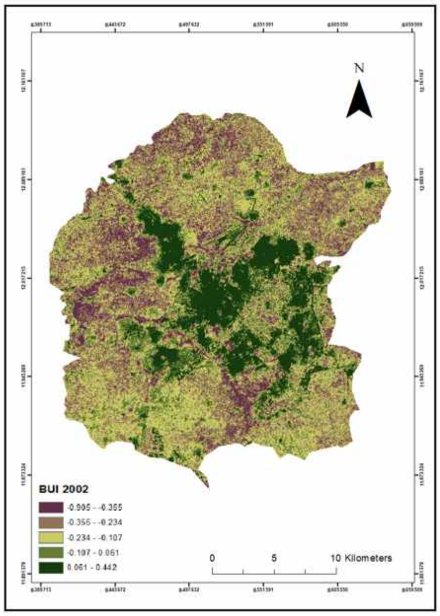
Table 3: Temperature Index for thermal comfort

Category	Temp. (^{0}C)	Impact on Physiology	Impact on Health
Neutral	21 – 25	Regulation by vascular change	Normal Health
Slightly warm	26 – 30	Normal Regulation by sweating and vascular change	Normal Health
Warm	31 – 34	Increasing stress caused by sweating and blood flow	Cardiovascular Embarrassment
Hot	35 – 39	Increasing stress caused by sweating and blood flow	The increasing danger of Heatstroke
Very hot	40 and above	Body heating and Failure of regulation	Circulatory collapse

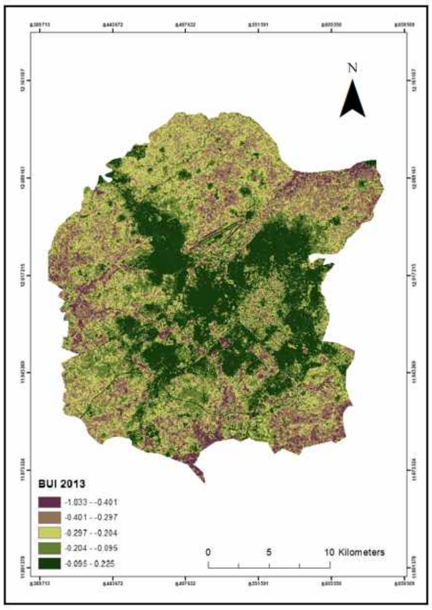
Source: Modified from Ghani et al., 2017



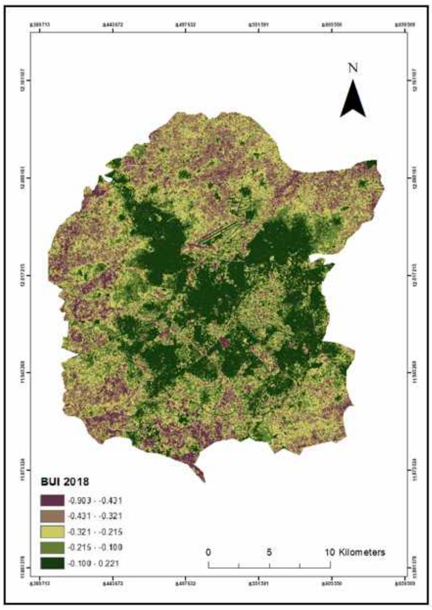
3



4

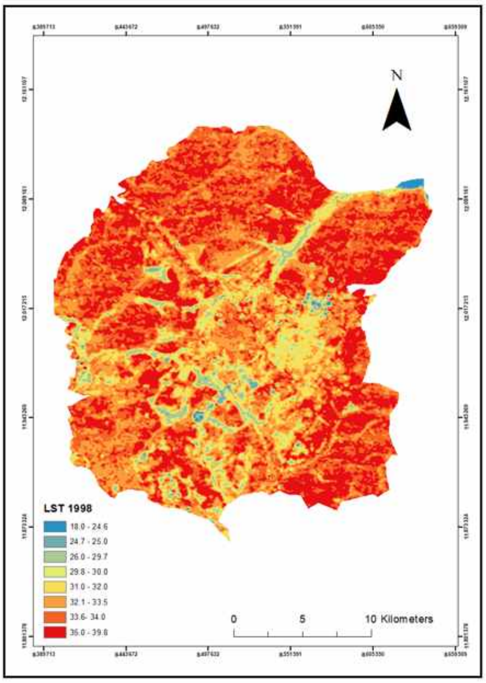


5

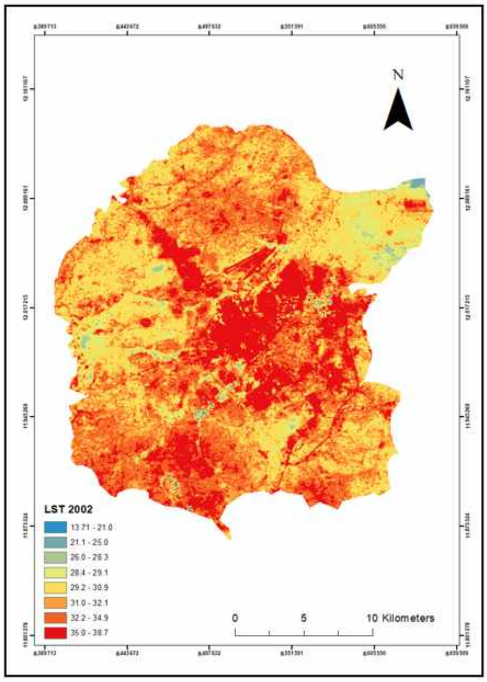


6

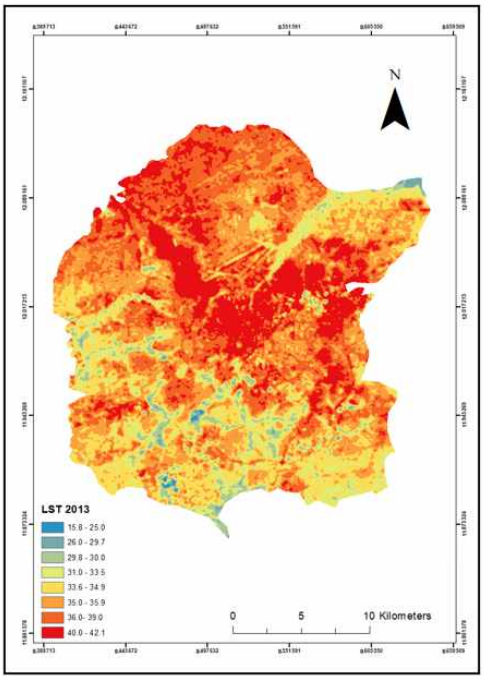
Figures 3 – 6. Built-up Index for 1998, 2002, 2013 and 2018, respectively



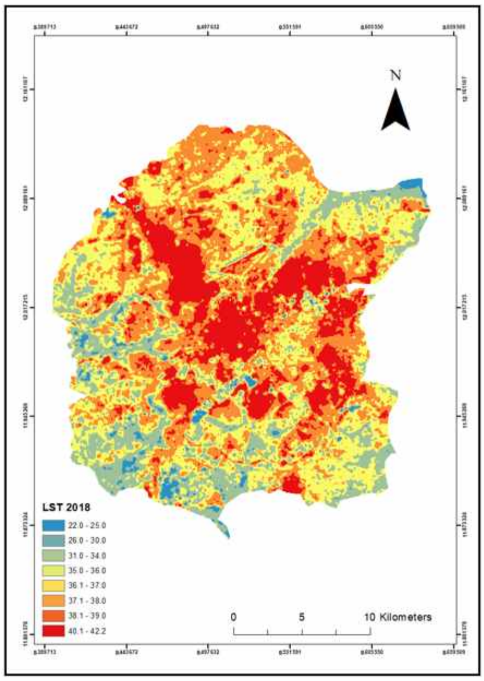
7



8



9



10

Figures 7 – 10: Land Surface Temperature for 1998, 2002, 2013 and 2018

From the LST maps, 1998 had pixel values of temperature ranging between 18.01°C to 39.76°C with the highest land surface temperatures found around the densely built-up areas and lowest temperatures around the most vegetated parts of the Metropolis. The year 2002 shows a land surface temperature between 13.71°C and 38.74°C; here, more areas of the Metropolis fall within the highest temperature range. For 2013, the highest temperature was 42.06°C while the lowest was 15.81°C, while for 2018, temperature ranges were between 22.09°C to 42.17°C. Across the years of study, it can be observed that increasing expansion in urban extent came increasing temperature levels. In contrast, lower temperatures were recorded for the more vegetated areas within and around the Metropolis.

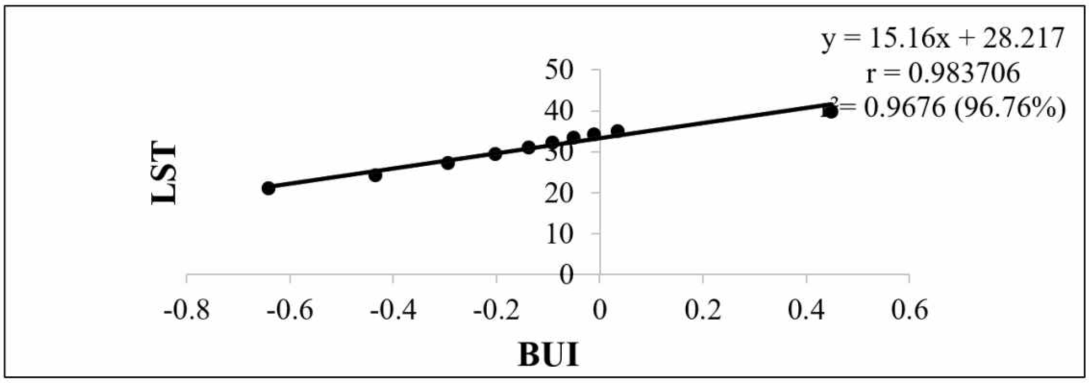


Figure 11: Relationship between LST and BUI for 1998

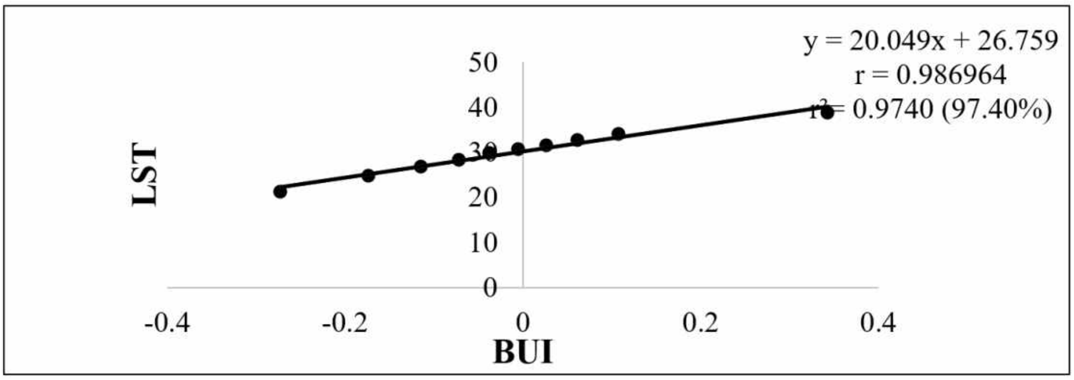


Figure 12: Relationship between LST and BUI for 2002

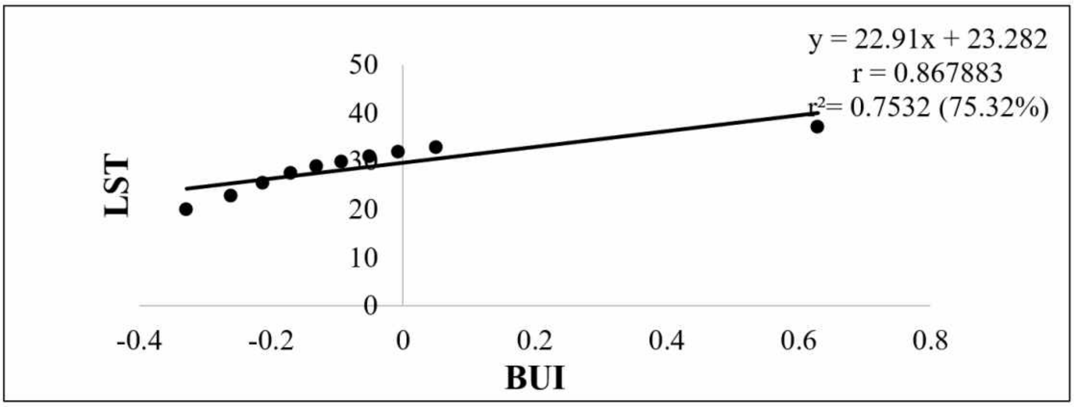


Figure 13: Relationship between LST and BUI for 2013

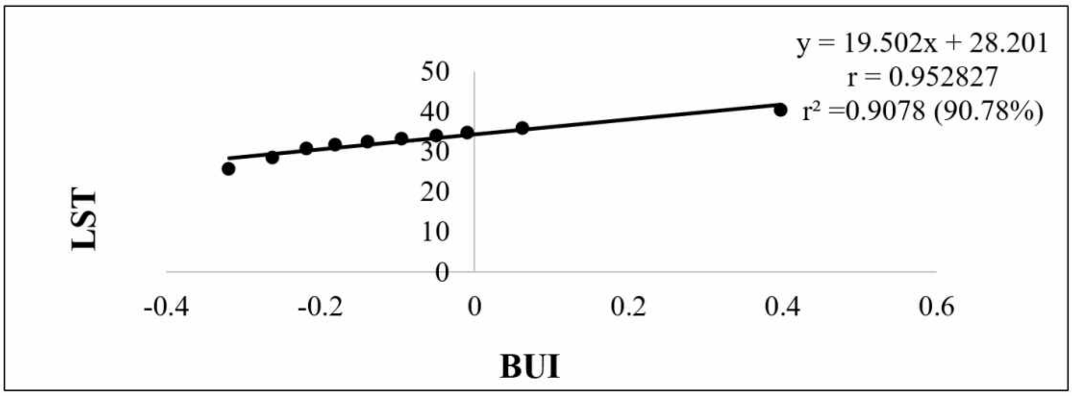


Figure 14: Relationship between LST and BUI for 2018

Land Surface Temperature (LST) and Built-Up Density (BUI)

This section covers the relationship between different land use/land cover types, particularly the built-up areas and the temperature distribution in Kano Metropolis, with Figures 11, 12, 13 and 14 showing the nature of the relationship. BUI and LST correlation for all the years of study show a strong positive linear relationship between land surface temperature and built-up density with r^2 values of 0.9676 for 1998, 0.9740 for 2002, 0.7532 for 2013 and 0.9078 for 2018, indicating that as at 1998, 96.76% of the increase in land surface temperature is as a result of the rise in the density of buildings within the study area; 97.40% for 2002; 75.32% for 2013 and 90.78% for 2018.

All these showed that as building density increased, the temperature increased within and around the Metropolis, depicting the hotspots as the innermost parts of the Metropolis, especially around the High. Medium Density Residential Areas and Recreational, Mixed and Commercial land use. At the same time, the Public Spaces, Educational Spaces, Parts of the GRA, Water bodies and Urban Agricultural Areas had lower temperatures. This result conforms to findings from the works of Thomas, Sherin, Ansar & Zachariah (2014); Alhawiti & Mitsova (2016); Macrof & Statescu (2017); Singh, Kikon & Verma (2017); Kaplan, Avdan & Avdan (2018); Jamei, Rajagopalan & Sun (2019); where strong linear relationships were established between temperature and building density suggesting that urban zone accounts for most of the variation in land surface temperature dynamics and that the built-up area does strengthen the effect of urban heat island that is usually experienced in higher temperatures. These were mainly noted in the high-density residential and commercial areas where surface temperatures are higher in contrast to vegetated areas and areas near water bodies that exhibit lower radiometric temperatures. At the same time, the surrounding areas that were further away from the densely built-up areas were found to have comparatively lower temperatures. These studies also agree that higher impervious surface density and the removal of urban vegetation cover were considered to produce higher urban temperatures. Therefore, the nature of the building density distribution plays a role in determining the temperature distribution. This also affects the quality of the environment and human comfort where high temperatures are associated with heat exhaustion and worsening chronic health conditions such as cardiovascular diseases, respiratory diseases, cerebrovascular disease and diabetes-related diseases (Sarofim et al., 2016; Heaviside, Macintrye & Vardoulakis, 2017).

Conclusion

The study shows that there is a strong positive correlation between the built-up area and Land Surface Temperature with r^2 value of 0.9676 for the year 1998, 0.9740 for 2002, 0.7532 for 2013 and 0.9078 for 2018, meaning that building density influences the temperature distribution of Urban Kano and this may contribute to aggravating specific health-related issues regarding the populace as well. The spatial distribution of the temperatures has increased from one period to another, where the lowest temperatures rose from 18.01°C in 1998 to 22.09°C in 2018, while the highest temperatures increased from 39.76°C to 42.17°C. The most elevated temperatures were concentrated in the densely built-up parts of the Metropolis, covering the MDRA, HDRA, Recreational, Mixed and Commercial areas. In contrast, the lowest temperatures were found around the water bodies; Urban Agricultural uses parts of GRA, Public and Educational land use. This result necessitates the need for urban greening that will have the potential cooling effect and, in the long and short term, help lower temperatures in the Metropolis. A well-informed and extensive review of the Kano Master Plan will also guide appropriate and systematic expansions in the development of the Urban Environment. The smart city initiatives must be incorporated into the plan as well.

Acknowledgement

I wish to acknowledge the Directorate of Research, Innovation and Partnership (DRIP) Bayero University Kano, Nigeria, for funding part of this research.

References

Alhawiti, R. H. and Mitsova, D. (2016) Using Landsat-8 Data to Explore the Correlation between Urban Heat Island and Urban Land Uses *IJRET: International Journal of Research in Engineering and Technology* Volume 5 Issue 3 Page 457 – 466.American Meteorological Society (AMS), "Glossary of Meteorology," 2000.

Amiri, F., and Tayebeh, T. (2009) Operational Monitoring of Vegetative Cover by Remote Sensing in Semi-arid Lands of Iran. *Advanced Technology for Cadastre and Land Management*, 7th FIG Regional Conference, 1 – 18.Amorim MCdCT, Dubreuil V. Intensity of Urban Heat Islands in Tropical and Temperate Climates. *Climate*. 2017; 5(4):91. https://doi.org/10.3390/cli5040091. Artmann, M., (2014) Assessment of Soil Sealing Management Responses, Strategies and Targets toward Ecologically Sustainable Urban Land Use Management. *Ambio* 43, 530 - 541.

Assaye, R., Suryabhagavan, K. V., Balakrishnan, M., Hameed, S. (2017) Geo-Spatial Approach for Urban Green Space and Environmental Quality Assessment: A Case Study in Addis Ababa City *Journal of Geographic Information System*, 2017, 9, 191 – 206.

Bichi, M. H. (2000) Surface Water Quality in Kano Industrial Environment in Issues in Land Administration and Development in Northern Nigeria, Falola, J.A; Ahmed, K; Liman, M.A; Maiwada, A. (Eds.) Department of Geography, Bayero University, Kano.

Babalola, K. H. and Hull, S. A. (2019) Examining the Land Use Act of 1978 and Its Effects on Tenure Security in Nigeria: A Case Study of Ekiti State, Nigeria *PER / PELJ 2019(22).*

Barau, A. S. (2007) The Great Attractions of Kano. Research and Documentation Directorate, Government House, Kano.

Dankani, I. M. (2013) Constraints to Sustainable Physical Planning in Metropolitan Kano, *International Journal of Management and Social Sciences Research,* 2(3), 34 - 42.

Deilami. K., Kamruzzaman, Md. and Liu, Y. (2018) Urban Heat Island Effect: A Systematic Review of Spatio-temporal Factors, Data, Methods and Mitigation Measures. *International Journal of Applied Earth Observations and Geoinformation* 67: 30 – 42.

Ekanade, O., Ayanlade, A. and Orimoogunje, I. O. O. (2008) Geospatial Analysis of Potential Impacts of Climate Change on Coastal Urban Settlements in Nigeria for the 21st Century, *Journal of Geography and Regional Planning* 1(3), 49 – 57.

Elsayed, I. S. M. (2012) Mitigation of the Urban Heat Island of the City of Kuala Lumpur, Malaysia *Middle-East Journal of Scientific Research* 11 (11): 1602-1613.

Ennouri. K., Smaoui, S. and Triki, M. A. (2021) Detection of Urban and Environmental Changes via Remote Sensing *Circular Economy and Sustainability* 1:1423–1437.

Ghani, S., Bialy, E., Bakochristou, F., Gamaledin, S. M. A., Rashwan, M. M. and Hughes, B. (2017) Thermal comfort investigation of an outdoor air-conditioned area in a hot and arid environment *Science and Technology for the Built Environment* 23, 1113–1131.

Grimmond, S., Blackett, M., Best, M. J.,...Zhang, N. (2010), The International Urban Energy Balance Models Comparison Project: First Results From Phase 1, *J. Appl. Meteorol. Climatol.* 49, 1268 – 1292.

Gunawardena, K. R., Wells, M. J. and Kershaw, T. (2017) Utilising green and bluespace to mitigate urban heat island intensity Science of The Total Environment Vol. 584-585, Pp1040-1055.

Heaviside, C., Macintyre, H. and Vardoulakis, S. (2017) The Urban Heat Island: Implications for Health in a Changing Environment *Curr Environ Health* 4 (3): 296-305.

Idris, H. A. (2005) A Geographical Study of the Urban Heat Island Phenomenon in Kano Metropolis. Unpublished Undergraduate Thesis, Bayero University Kano, Nigeria.

Idris, H. A. (2022) Declining Urban Greenery in Kano Metropolis, Nigeria *AFRIGIST Journal of Land Administration and Environmental Management*, 2 (1): 1-13.

Isah, T. (2015) Remote Sensing Studies on Urban Change Detections. *International Journal of Computer Science and Information Technology Research*, 3(3), 62 - 71.

Jamei, Y., Rajagopalan, P. and Sun, Q. C. (2019) Time-Series Dataset on Land Surface Temperature, Vegetation, Built-Up Areas and Other Climatic Factors in Top 20 Global Cities (2000-2018) *Data in Brief* 23 (2019) 103803.

Jiang, S., Lee, X., Wang, J., and Wang, K. (2019) Amplified urban heat islands during heat wave periods. *Journal of Geophysical Research: Atmospheres*, 124, 7797–7812.

Kaiser, E. A.; Rolim, S. B. A.; Grondona, A. E. B.; Hackmann, C. L.; de Marsillac Linn, R.; Käfer, P. S.; da Rocha, N. S. and Diaz, L. R. (2022) Spatiotemporal Influences of LULC Changes on Land Surface Temperature in Rapid Urbanization Area through Landsat-TM and TIRS Images. *Atmosphere*, 13, 460.

Kaplan, G., Avdan, U. and Avdan, Z. Y. (2018) Urban Heat Island Analysis Using the Landsat 8 Satellite Data: A Case Study in Skopje, Macedonia

Conference Proceedings Paper, The 2nd International Electronic Conference on Remote Sensing (ECRS 2018), 22 March–5 April 2018; Sciforum Electronic Conference Series, Vol. 2, 2018.

Kim, J., Jun, M., Yeo, C., Kwon, K. and Hyun, J. Y. (2019) The Effects of Land Use Zoning and Densification on Changes in Land Surface Temperature in Seoul *Sustainability*, 11, 7056.

Landsat 8 (L8) Data Users Handbook (2016) Department of the Interior U. S. Geological Survey.

Lee, K., Kim, Y., Sung, H. C., Ryu, J. and Jeon, S. W. (2020) Trend Analysis of Urban Heat Island Intensity According to Urban Area Change in Asian Mega Cities *Sustainability* 12, 112.

Li, J., Song, C., Cao, L., Zhu, F., Meng, X. and Wu, J. (2011) Impacts of Landscape Structure on Surface Urban Heat Islands: A Case Study of Shanghai, China. *Remote Sens Environ* 115, 3249 – 3263.

Li, Z. L., Tang, B. H., Wu, H., Ren, H., Yan, G., Wan, Z., Trigo, I. F. and Sobrino, J. A.(2013) Satellite-Derived Land Surface Temperature: Current Status and Perspectives. *Remote Sens. Environ.* 131, 14 - 37.

Li, X., Chen, W. Y., Sanesi, G. and Lafortezza, R. (2019) Remote Sensing in Urban Forestry: Recent Applications and Future Directions *Remote Sens.*, 11, 1144.

Luo, M., and Lau, N.-C. (2018) Increasing heat stress in urban areas of eastern China: Acceleration by urbanization. Geophysical Research Letters, 45, 13,060–13,069.

Macarof, P. and Statescu, F. (2017) Comparison of NDBI and NDVI as Indicators of Surface Urban Heat Island Effect in Landsat 8 Imagery: A Case Study of Iasi. *Pesd*, 11(2) 141- 150.

Marcotullio, P. J., Keßler, C., Quintero, Gonzalez R. and Schmeltz, M. (2021) Urban Growth and Heat in Tropical Climates. *Front. Ecol*. Evol. 9:616626.

Masson, V., Lemonsu, A., Hidalgo, J. and Voogt, J. (2020) *Annual Review of Environment and Resources: Urban Climates and Climate Change* Annual Review of Environmental Resource 2020. 45:411 - 44.

Meng X., Cheng, J., Zhao, S., Liu, S. and Yao, Y. (2019) Estimating Land Surface Temperature from Landsat-8 Data using the NOAA JPSS Enterprise Algorithm *Remote Sens.* 11, 155.

Morabito, M., Crisci, A., Messeri, A., Orlandini, S., Raschi, A., Maracchi, G. and Munafò, M. (2017) The Impact of Built-Up Surfaces on Land Surface Temperatures in Italian Urban Areas *Science of the Total Environment* 551 – 552, 317 – 326.

Nichol, J. and Wong, M. S., (2005) Modeling Urban Environmental Quality in a Tropical City. *Landscape and Urban Planning* 73, 49 - 58.

Nichol, J. E. and Wong, M. S. (2007) Assessing Urban Environmental Quality with Multiple Parameters in Urban Remote Sensing edited by Weng, Q. and Quattrochi, D. (eds) 2007. Boca Raton, London and New York, CRC Press, Taylor & Francis Group Pp. 253 -268 Weng, Q., Quattrochi, D.A., 2007. Urban Remote Sensing. CRC Press LLC.

Oke, T.R. (1973) City Size and the Urban Heat Island. Atmospheric Environment, 17, 769-779.

Oke, T.R. (1987) Boundary Layer Climates. 2nd Edition, Methuen Co., London, New York, 435.

Oke, T. R., Mills, G., Christen, A. and Voogt, J. A. (2017) *Urban Climates* (Cambridge Univ. Press, Cambridge, 2017).

Otty, E., Nwosu, C. C. and Alexander, N. U. (2021) Critique of Nigerian Land Use Act of 1978. *IJESC*, 11 (6) 28115 – 28120.

Prokop, G., Jobstmann, H. and Schönbauer, A. (2011) Report on best practices for limiting soil sealing and mitigating its effects. Study Contracted by the European Commission, DG Environment, Technical Report-2011-50, Brussels, Belgium pp 231.

Revi, A., Satterthwaite, D. E., Aragón-Durand, F., Corfee-Morlot, J., Kiunsi, R. B. R., Pelling, M., Roberts, D. C., and Solecki, W. (2014) Urban areas. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C.B., V.R. Barros, D. J. Dokken, K. J. Mach, M.D. Mastrandrea, T. E. Bilir, M. Chatterjee, K. L. Ebi, Y. O. Estrada, R. C. Genova, B. Girma, E.S. Kissel, A. N. Levy, S. MacCracken, P. R. Mastrandrea, and L. L.White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 535-612.

Rosenzweig, C., Solecki, W. D., Hammer, S. A. and Mehrotra, S. (2011): Urban Climate Change in Context. *Climate Change and Cities: First Assessment Report of the Urban Climate Change Research Network* , C. Rosenzweig, W. D. Solecki, S. A. Hammer, S. Mehrotra, Eds., Cambridge University Press, Cambridge, UK, 3 - 11.

Sarofim, M. C., Saha, S., Hawkins, M. D., Mills, D. M., Hess, J., Horton, R., Kinney, P., Schwartz, J and St. Juliana, A. (2016): Ch. 2: Temperature-Related Death and Illness. The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment. U.S. Global Change Research Program, Washington, DC, 43–68.

Satterthwaite, D. (2008) Climate Change and Urbanization: Effects and Implications for Urban Governance, United Nations Expert Group

Meeting on Population Distribution, Urbanization, Internal Migration and Development.

Sharma, R., Chakraborty, A. and Joshi, P. K. (2015) Geospatial Quantification and Analysis of Environmental Changes in Urbanizing City of Kolkata (India) *Environ Monit Assess* 187, 4206.

Sharma, R. and Joshi, P.K. (2016) Mapping Environmental Impacts of Rapid Urbanization in the National Capital Region of India using Remote Sensing Inputs *Urban Climate* 15, 70 -82.

Singh, P., Kikon, N. and Verma, P. (2017) Impact of Land Use Change and Urbanization on Urban Heat Island in Lucknow City, Central India. A Remote Sensing Based Estimate Sustainable Cities and Society 32, 100 - 114.

Thomas, G., Sherin, A. P., Ansar, S. and Zachariah, E. J. (2014) Analysis of Urban Heat Island in Kochi, India, Using a Modified Local Climate Zone Classification. P*rocedia Environmental Sciences,* 21, 3 - 13.

Voogt, J. A. and Oke, T. R., (2003) Thermal Remote Sensing of Urban Climates. *Remote Sens. Environ*. 86 (3), 370 - 384.

Wong, M. S., Nichol, J. E., To, P. H. and Wang, J. (2010) A Simple Method for Designation of Urban Ventilation Corridors and its Application to Urban Heat Island Analysis. *Building and Environment* 45, 1880 - 1889.

Yang, C., He, X., Wang, R., Yan, F., Yu, L., Bu, K., Yang, J., Chang, L., and Zhang, S. (2017) The Effect of Urban Green Spaces on the Urban Thermal Environment and Its Seasonal Variations *Forests* 8, 153.

Zhao, L., Lee, X., Smith, R. B. and Oleson, K. (2014) Strong Contributions of Local Background Climate to Urban Heat Islands. *Nature* 511, 216 - 219.