Science of the Total Environment 557–558 (2016) 415–424

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Seasonality in the daytime and night-time intensity of land surface temperature in a tropical city area

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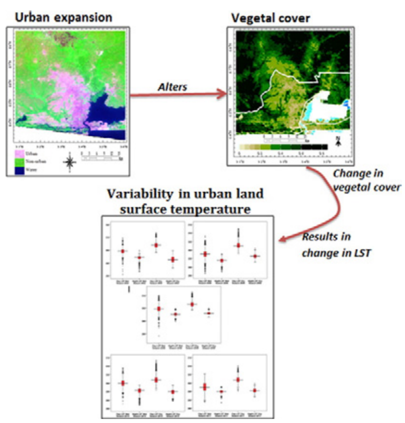
HIGHLIGHTS

- MODIS was used to assess seasonal variations in LST
- The LST increases during the daytime in areas with very low vegetal cover
- A negative correlation relationship between NDVI and the LST
- Reduction in vegetal cover altered the terrestrial thermal/aerodynamic processes
- Expansion in an urban area are responsible for intensive UHI

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 9 February 2016
Received in revised form 3 March 2016
Accepted 5 March 2016
Available online 24 March 2016

Editor: D. Barcelo

Keywords:
Urban heat island
Seasonality
MODIS
Nigeria

ABSTRACT

Variations in urban land surface temperature (LST) links to the surrounding rural areas result to urban heat island (UHI), which is a global problem challenging both cities in develop and developing countries. Satellite data from the Moderate Resolution Imaging Spectroradiometer (MODIS), covering the period between 2002 and 2013 were analysed to examine seasonal variability in the daytime and night-time intensity of urban heat island (UHI), using Lagos metropolitan city of Nigeria as a case study. Contribution index (CI) and landscape index (LI) were used to estimate the LST contributions from non-urban and urban areas to UHI and assess the relationship between the Normalized Difference Vegetation Index (NDVI) and LST. The LI showed that both non-urban and urban areas contribute greatly to strengthen the intensity of LST during the daytime (with $LI < 1.0$) and much more during the daytime in the dry seasons ($LI = 0.13$ in the year 2013). The correlation analysis showed seasonal variation in the relationship (R^2) between NDVI and the LST for both day and night times. The highest R^2 values were recorded for daytime, especially during the wet season ($R^2 > 0.90$), while R^2 were very low in the night-time especially during dry season. The study indicates that reduction in vegetal cover in Lagos urban areas altered the terrestrial thermal and aerodynamic processes hence resulted in an intensification of UHI in the metropolitan city.

1. Introduction

One of the major environmental challenges on city dwellers is urban heat island (UHI), despite the fact that about 54% of the total global

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http://dx.doi.org/10.1016/j.scitotenv.2016.03.027

population lives in urban areas in 2014, with a high possibility that this percentage will increase and a majority of people will be living in urban area even in less developed country, according to the report of WHO (2014) and World Urbanization Prospectus (2014). Several studies have revealed that increased in intensity and extents of UHI are the results of human activities such as urbanization and industrialization (Oke, 1982; Voogt and Oke, 2003; Wang et al., 2007; Hamdi and Schayes, 2008; Zhang et al., 2010). Majority of these studies have shown that the sources and the drivers of UHI in developed countries are mainly from the huge amount of heat generated from industrial activities and other anthropogenic heat sources which increase the thermal land surface temperature (LST) of an urban area as compared to its surroundings rural areas. Voogt and Oke (2003) defined UHI as a phenomenon where LSTs are modified due to urbanization and other anthropogenic processes, which lead to modification of urban thermal condition that is warmer than its surrounding rural areas. The fact remains the same that UHI resulting from urbanization is a global problem with emergent impacts which are not limited to cities in developed countries but affecting also cities in less developed country in the tropics (Clinton and Gong, 2013). Increase in the intensity of UHI has several implications not only for inhabitants in large cities but also in small cities (Wong and Yu, 2005; Radhi et al., 2013). Such impacts include change in urban microclimate, thermal comfort and urban environmental living conditions (Yang et al., 2011; Zhang et al., 2013a, 2013b); societal energy consumption (Konopacki and Akbari, 2002; Akbari and Konopacki, 2005; Zhang et al., 2010); human health are indirectly affected, thus increase mortality rates (Patz et al., 2005); and elevation in ground-level ozone (Strømann-Andersen and Sattrup, 2011). The adverse effects of UHI are even worse in some cities in tropical countries, especially where there is ever increasing population, in addition to extensive anthropogenic activities. Therefore, scientists have become highly interested in studying UHI because of its adverse environmental and societal impacts on urban areas (Oke et al., 1991; Zhang et al., 2010). It is obvious therefore that understanding of the increase in the intensity of UHI, its temporal and spatial variations in cities is important to the study of human–environmental relation (Weng et al., 2008). To achieve this level of understanding, several dataset and methods have been used in literature to assess urban climate and variation in LST distribution in cities.

What is obvious, from literature, is that the widely used approaches for measuring urban climate and variations in LST can be grouped into two major categories: conventional ground dataset and application of remote sensing data. The conventional ground method involves comparing of data from urban and rural weather stations (Rao, 1972; Hamdi and Schayes, 2008; Eludoyin et al., 2013). In this method, variations in air temperature from weather stations between urban and rural areas are classified as UHI. The majority of these studies observed the changes in urban air temperature and their results show that urban areas are warmer than rural. The traditional method is only effective where there is enough number of weather stations within reasonable distances over urban and rural areas (Rao, 1972; Stewart and Oke, 2006). In recent years, several studies have applied remote sensing data, which involves measurements of the LST obtained from satellites. Although the temporal resolution of most polar-orbited satellite-borne or airborne sensors is not very high compared to the ground observations, but studies have shown that using satellite data, LST is far easier to obtain and the data is of spatial and temporal resolution, effective for long-time spatial variation studies of UHI (Weng, 2009; Vancutsem et al., 2010; Qiao et al., 2013).

Despite several awareness and researches on the consequences of UHI in other part of the world, surprisingly little studies have been carried out in Nigeria using satellite or airborne sensors to monitor spatio-temporal variation in the intensity of UHI in urban areas in the country. The most prominent studies are the studies by Balogun et al. (2010), Ifeanyi et al. (2012) and Eludoyin et al. (2013) that used meteorological data to assess temperature variability in some cities in the country. But, it is practically difficult to monitor spatiotemporal UHI with conventional ground methods from weather stations. This is because application of conventional ground methods cannot provide adequate data per time with low spatial resolution and it is not cost effective (Zhang et al., 2010). What is obvious in Nigeria is that there are <60 standard and functioning meteorological stations. Any country with a similar land

Fig. 1. Map of the study area (modified from Google Earth). The yellow shaded area indicates the location of Lagos state in relation to the neighboring state.