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

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

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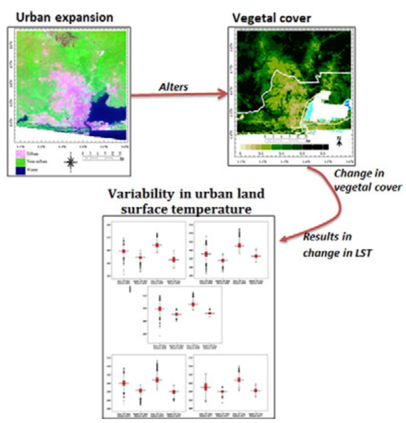
HIGHLIGHTS

- 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



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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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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 spatiotemporal 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

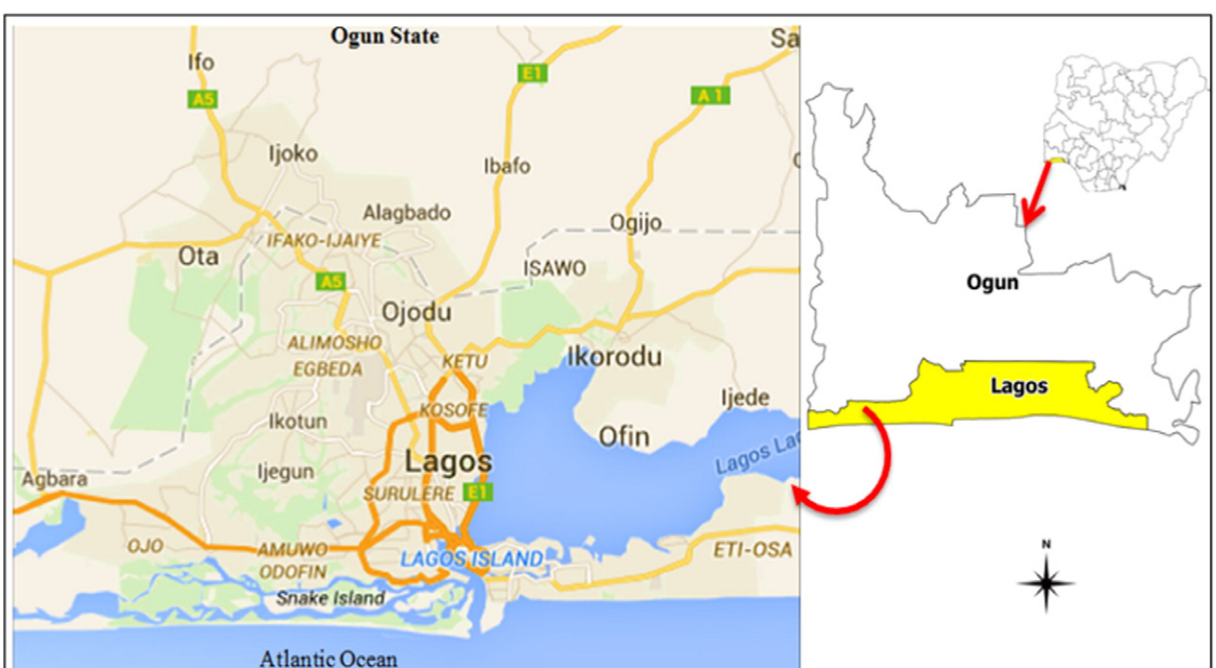

Fig. 1. Map of the study area (modified from Google Earth). The yellow shaded area indicates the location of Lagos state in relation to the neighboring state.

area as Nigeria (923,768 km^2) would be covered by a network of more than five hundred weather observing stations for better climate forecast. Even in some cities, there is no single working weather station which makes it difficult to evaluate the UHI in such a city. Irrespective of the mesh of the observing network of weather stations, the problem often arises as to what weather values to assign to some identified location, where there is no weather station, between the established meteorological stations. This makes it very challenging to have accurate and reliable UHI analysis using data from meteorological stations. Recent publications have shown that application of thermal remote sensing for UHI studies has been slowly progressed not only in Nigeria but also in other part of West Africa. Ayanlade and Jegede (2015) examined intensity of UHI only during the day time, using Landsat data, but, what is obvious is that the intensity of UHI varies between day and night times, and from one season to others. Therefore, the present study aims at using MODIS satellites data to assess seasonal variability in the intensity of UHI, using Lagos metropolitan city as a case study. The study applies remote sensing because it offers an efficient and speedy approach for monitoring spatiotemporal variation in UHI over a long period of time (Clinton and Gong, 2013).

2. Materials and methods

2.1. Data acquisition and study area

This study uses the Moderate Resolution Imaging Spectroradiometer (MODIS) data. An archive of 65 MODIS both Terra (from June 2002) and Aqua (from July 2002) for daytime and night-time images covering the entire Lagos metropolis were acquired (from http://lpdaac.usgs.gov), covering the period between 2002 and 2013. The USGS LandDAAC MODIS at 1 km spatial resolution, 8 day version-005 Terra and Aqua for both day and night images were used. Details information about this data has been detailed in Huete et al. (2002) and Vancutsem et al. (2010). Two sets of MODIS data were used: Aqua 8-day Land Surface Temperature/Emissivity (MYD11A2) and Terra Land Surface Temperature/Emissivity (MOD11A2). These dataset were used in this study because it comprised of daytime and nighttime LSTs and Temperature/Emissivity estimated in Bands 31 and 32 from land cover types. Besides, MODIS data was used because it provides better temporal resolution of twice-a-day capturing of image of a location, unlike Landsat that has 16-days temporal resolution. MODIS is a relatively cheap means of assessing landuse change impacts on LST in a location with frequent cloud cover and it also offers the possibility of monitoring spatiotemporal seasonality of LST for both day and night. Therefore, two thermal infrared bands 31 (10.78–11.28 μm) and 32 (11.77–12.27 μm) of MODIS data were used to derive LST. The study applied the split-window algorithm and techniques that correct for atmospheric effects and surface emissivity (Wan et al., 2002).

Lagos metropolis is located alongside the Atlantic coast of Nigeria (Fig. 1), within latitudes 6°23′ N and 6°41′ N and longitudes 2°42′ E and 3°42′ E, bounded by Benin to the West, Ogun State to the north and east, and the Atlantic Ocean to the south. Lagos is the most populous metropolitan city in Nigeria, the second fastest-growing city in Africa (after Bamako, Mali) with a population of 305,000 in 1950 to 5.3 million in 1991 and 9.1 million people in 2006 (Adelekan, 2010). The rainy season has two peaks; during May to July and September to October.

Table 1
Proportion of the areas selected for urban and non-urban LST assessment.

Year	Landscape	S (%)
	Urban	55
2002	Non-urban	45
	Urban	58
2005	Non-urban	42
	Urban	61
2008	Non-urban	39
	Urban	64
2011	Non-urban	36
	Urban	65
2013	Non-urban	35

S = the proportion of the selected sampled areas.

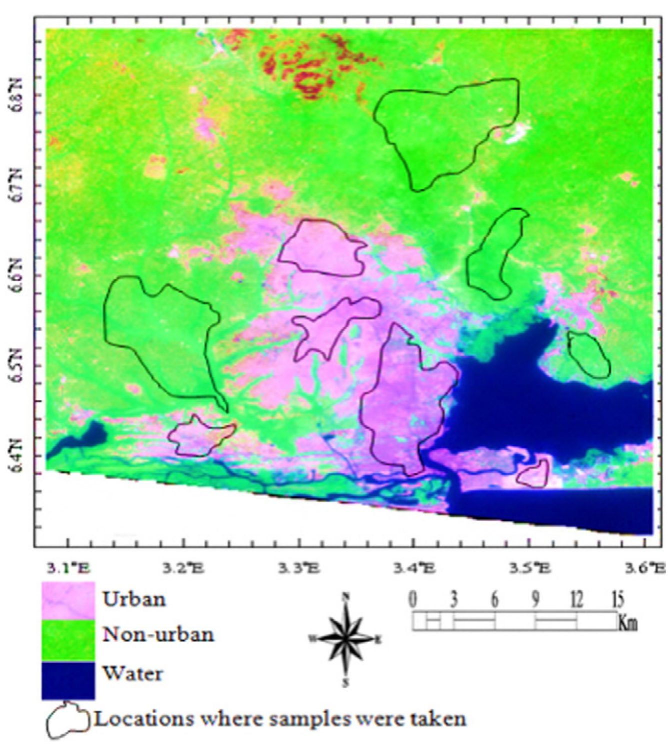

Fig. 2. Map of the study area, showing locations where samples were taken. The based map is a classification map developed for this study.

Table 2
Minimum (Min), maximum (Max), mean, standard deviation (SD), and number of samples (N) of seasonal land surface temperature (SLST) differentials by day and night. Units are °K.

		Wet season (°K)		Dry season (°K)	
		Day	Night	Day	Night
2002	Min	295	296	298	296
	Max	306	299	311	300
	Mean	300.94	298.96	304.12	299.79
	SD	2.68	1.98	2.57	2.52
	N	8720	8720	8720	8720
2005	Min	298	297	299	298
	Max	304	298	309	301
	Mean	300.59	297.7	302.95	299.39
	SD	2.67	1.42	2.04	1.21
	N	8720	8720	8720	8720
2008	Min	298	297	299	298
	Max	307	299	308	300
	Mean	300.43	298.26	303.31	299.12
	SD	2.81	1.32	2.50	1.04
	N	8720	8720	8720	8720
2011	Min	297	295	298	297
	Max	305	298	310	300
	Mean	300.68	298.86	301.96	298.5
	SD	3.16	1.07	1.88	1.21
	N	8720	8720	8720	8720
2013	Min	298	297	299	298
	Max	305	299	309	300
	Mean	299.95	298.36	302.26	294.7
	SD	2.35	1.86	2.61	1.67
	N	8720	8720	8720	8720

But, the city receives relatively high temperature with the mean monthly maximum temperature of about 30 °C (Iwugo et al., 2003). The highest temperature usually records in the months of November to March of each year while the lowest values occur at the peak of the raining season (BNRCC, 2012). In general, the climate of Lagos is type influenced by its closeness to the equator and the Gulf of Guinea and it is affected by atmospheric interactions of Intertropical Convergence Zone (ITCZ) associated with the coming onshore of a warm, humid maritime tropical air mass and hot and dry continental air mass.

2.2. Contributions of different landscapes to SUHI

The LST contributions from sink (non-urban areas) and source (urban areas) landscapes to SUHI were calculated using contribution index as proposed by Xu (2009). In this study, sink areas are those that absorbed the released heat from the sources. This was calculated using as follows:

$$CI = D_t \times S \tag{1}$$

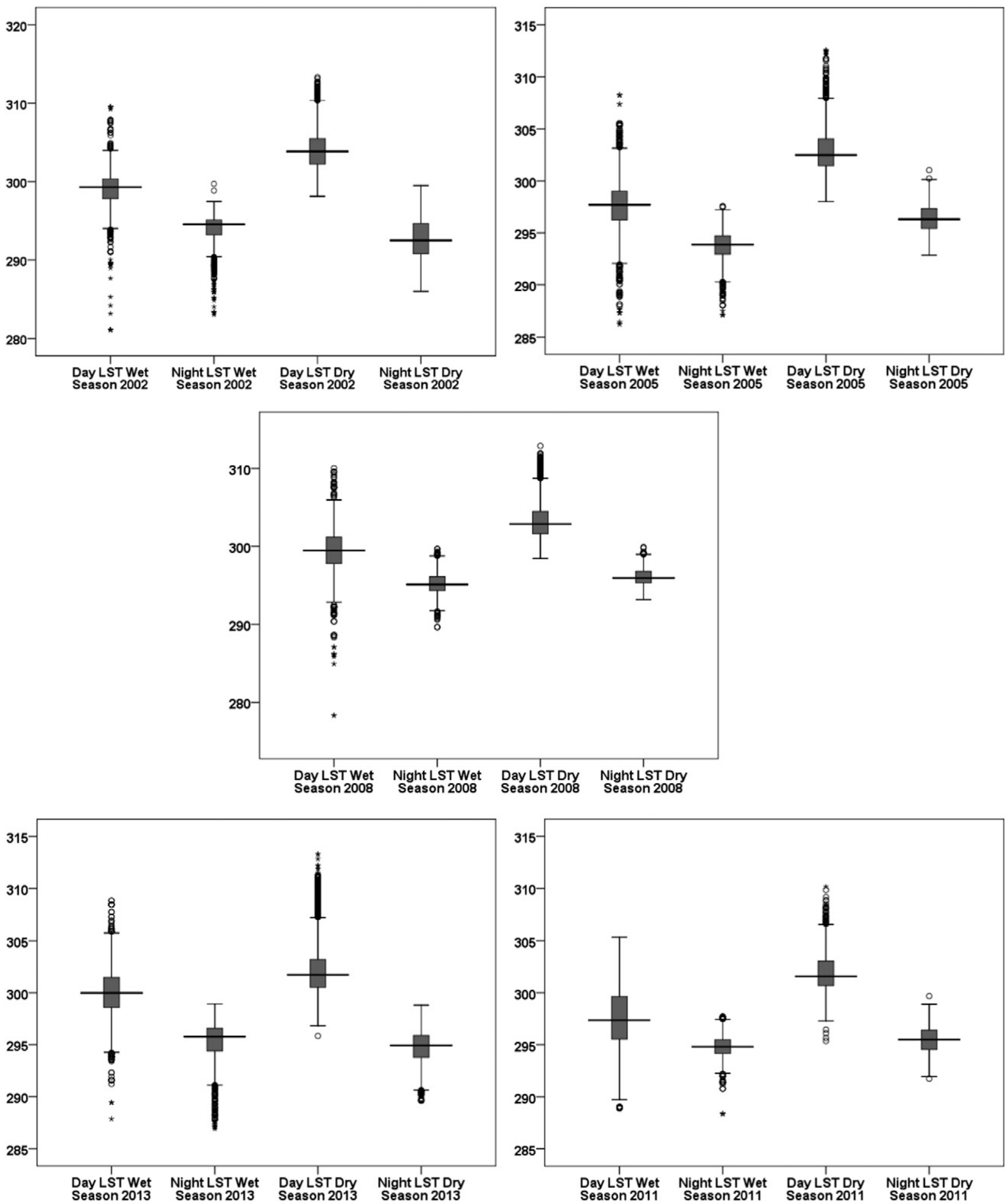

Fig. 3. Seasonal land surface temperature (SLST) differentials by day and night.

where *CI* is the contribution index; D_t is the difference in the temperature between the sink or source landscape and the entire region; *S* represents the proportion of the areas that were source landscape or sink landscape in the entire area (Fig. 2). In this present study, urban areas were defined as source landscape. Specific landscapes in this category include residential areas, industrial and commercial areas, airports and road networks. The sink landscapes are mainly vegetation and other greenery, because of their negative effects on SUHI (Chen et al., 2006). Different samples from urban areas and non-urban areas, regions cover by vegetation (Fig. 2), were identified on the MODIS and were selected in order to calculate the UHI Intensity. At least nine samples were taken in each location where samples were taken (Fig. 2). The proportion of the areas selected for urban and non-urban varies spatially and inter-annularly as summarized in Table 1. The variation was due to spatial and temporal changes in the landscape over the periods of study. Average day and night times, and seasonality in LST of urban were calculated for each of the sample locations. Seasonal and inter-annual variation in the Min, Max, Mean and SD of LST was calculated for wet and dry seasons. In this study, the wet season covers the periods of months from May to July and September to October while the dry seasons are the months from November to March. Daytime was considered to be from 6 am to 7 pm while night time was from 7.30 pm to 5.30 am of every month. Selection of these months was based on the climatic characteristics of the study area as discussed in the section above. For 5 years used in this study, Min, Max, and Mean LSTs were calculated for all available MODIS data for the months during the dry and wet seasons of each year. This was used to demonstrate and map the LST spatial and temporal pattern and the overall pattern of UHI in the study area.

The contributions of the sink and source landscapes were used to determine the intensity of the SUHI in the study area. The landscape index (LI) approach was used to examine the intensity of the SUHI in Lagos metropolis. This was also used to compare the intensity of the LST in different zones in Lagos metropolitan areas. Landscape index was calculated using Eq. (2) below.

$$\mathrm{LI} = \left| CI_{sink} / Ci_{source} \right| \tag{2}$$

where LI is landscape index; *CI* represents the contribution index of source and sink to SUHI.

2.3. The relationship between NDVI and LST

One of the objectives of this study is to explore the possibility of retrieving LST data from MODIS over a different periods of time and to assess the relationship between the Normalized Difference Vegetation Index (NDVI) and LST. The MODIS global vegetation indices products used in this study were analysed to derive the NDVI. The NDVI was derived from MODIS data in order to analyse the relationship between UHIs and urban surface characteristics such as vegetation cover. Vegetation indices, especially NDVI, are well established in the literature as being good quantitative remote sensing measurements to quantify vegetation biomass for each pixel in an image (Ouyang et al., 2010). This is because NDVI is directly related to the photosynthetic capacity and hence energy absorption of plant canopies (Matricardi et al., 2010). The NDVI was calculated from surface reflectance in the near-infrared and red portions of the electromagnetic spectrum. NDVI combines two channels (NIR and RED) in a ratio which makes it possible to differentiate vegetation cover signal from other objects signals. By design, the NDVI value varies between −1.0 and +1.0 for each pixel and this helps in identifying variation in the level of vegetation vigor (Ouyang et al., 2010). The NDVI model used to compute the vegetation indexes in this study was carried out in ENVI environment using Eq. (3)

$$NDVI = \frac{NIR - RED}{NIR + RED} \tag{3}$$

where RED and NIR are ray values of Red and Near-Infrared (NIR) bands respectively. The values of this index range from −1 to +1. It has been shown in the literature that −1 value is generally from ice or cloud on the image, zero values stand for areas with no vegetation and +1 values signify the maximum potential density and greenness of leaves. The common range for green vegetation is 0.2 to 0.8. The values for vegetated land are generally >0.2, with values exceeding 0.5 indicating dense vegetation.

NDVI image differencing was used as change detection method. Pairs of consecutive multi-date NDVI image were subtracted (2002–2005; 2005–2008; 2008–2011 and 2011–2013) to produce a map showing the change in vegetation over the period of time. Change images were created by subtracting image of the previous date (X_1) from later date (X_2), following Eq. (4):

$$DF = NDVI_{x_1} - NDVI_{x_2}. \tag{4}$$

Four images were generated and compared to examine changes in vegetation cover changes in the region. This was used to map the overall change in vegetal cover in the study area. Thus, the Pearson correlation coefficient (R^2) between the LST and NDVI were calculated, R^2 was used to represent the coefficient of determination in order to assess the relationship between urban vegetal cover and seasonality in UHI.

3. Results and discussions

3.1. Seasonal land surface temperature (SLST) differentials

To explore the seasonal variability in land surface temperature (LST) over the period of study, minimum (Min), maximum (Max), mean, and standard deviation (SD) were calculated for the entire study area, using 8720 (N) sample locations. Table 2 summarizes the seasonal land surface temperature (SLST) differentials by day and night. The result reveals two foremost patterns: (1) that there appears to be differentials by day and night in LST frequency in Lagos metropolis, (2) there appears to be seasonal and inter-annual variation in the Min, Max, Mean and SD of LST. In general, Min, Max, and Mean LST values during the daytime appear greater than night-time. In all years, what is obvious from Table 2 is that the mean LST during the daytime are not <300 °K, with the exception of 2013 (299.95 °K). Comparing this with the night-time LST, there appears to be a reduction in the LST during night time compared to that of daytime in all season. Also, the results show variability in the amount of LST by seasons. Through the study periods, the LST values during dry season appear greater than that of wet season (Fig. 3). Higher mean LST values were observed for daytime during dry season compared to that of other seasons and periods: 304.12 °K in 2002; 302.95 °K in 2005; 303.31 °K in 2008; 301.96 °K in 2011; and 302.26 °K in 2013 (Table 2).

Fig. 3 illustrates seasonal land surface temperature (SLST) differentials by day and night times over the study period. What is noticeable

Table 3
Seasonality and variation in LST between daytime and night-time.

		Wet season (°K)		Dry season (°K)	
		Day	Night	Day	Night
2002	Urban	301.32	300.98	302.57	301.59
	Non-urban	298.43	297.61	300.29	299.56
2005	Urban	301.86	300.49	303.25	302.58
	Non-urban	300.78	298.65	300.67	299.31
2008	Urban	302.56	300.49	304.27	303.29
	Non-urban	298.54	297.35	301.26	300.18
2011	Urban	304.42	300.41	305.48	301.37
	Non-urban	300.78	299.39	300.64	299.29
2013	Urban	304.36	302.34	305.67	303.46
	Non-urban	300.45	299.81	301.56	299.63

Table 4
Daytime spatiotemporal contributions of the different landscape to the intensity SUHI during the wet season.

Year	Landscape	Contribution index (CI)	Landscape index (LI)
2002	Urban	0.7315	0.203008
	Non-urban	−0.1485	
2005	Urban	0.8178	0.30301
	Non-urban	−0.2478	
2008	Urban	0.8113	0.32208
	Non-urban	−0.2613	
2011	Urban	0.6272	0.888889
	Non-urban	−0.7056	
2013	Urban	0.8515	0.127422
	Non-urban	−0.1085	

Table 6
Daytime spatiotemporal contributions of the different landscape to the intensity SUHI during the dry season.

Year	Landscape	Contribution index	Landscape index
2002	Urban	0.8525	0.21754
	Non-urban	−0.2025	
2005	Urban	0.9454	0.30863
	Non-urban	−0.5754	
2008	Urban	0.9577	0.17511
	Non-urban	−0.1677	
2011	Urban	0.8448	0.28977
	Non-urban	−0.2448	
2013	Urban	0.858	0.130536
	Non-urban	−0.112	

from Fig. 3 is that the SLST differentials by day and night for the entire Lagos metropolitan city reached maximum during daytime in dry seasons and minimum during night time in the wet season of the year. For example, the highest mean LST value was observed during daytime in 2002 (304.12 °K) dry season while the least mean LST value was during the night time in 2005 (297.70 °K) wet season as detailed in Table 2. In addition, there appears to be great inter-annual variability in the mean daytime LST while the mean LST appears relatively stable during the night time throughout the years (Table 2). The observed variability in LST might be due to the variation in the amount of solar radiation received during both seasons, which lead to differentials in the landscapes thermal inertias by day and night couple with the anthropogenic heat of the daytime. Perhaps the anthropogenic heat and landscape thermal inertias were relatively stable during the night time.

3.2. Variation in landscape thermal environment

To examine the variation in landscape thermal environment from the different landscape, seasonality and differences in the average LST between day time and night time were calculated (Table 4). Three distinct patterns could be observed from the results: (1) there appears to be variation in the average LST from the different landscape, the main source of LST is mainly from urban areas throughout the study periods (Fig. 4); (2) the average LST varies between the daytime and nighttime, mostly higher during the day (Figs. 4 and 5); and (3) there appeared to be seasonal deviation in the average LST for both day and night times with highest average LST observed during the dry seasons (Table 3). Generally, the average LSTs of the urban areas were significantly higher than those for the non-urban areas in the entire Lagos metropolitan province. Over the years, there appeared to be an increase in the average LST over the two landscapes. In 2002 for example, the average daytime LST, during the wet season, for urban areas was 301.32 °K but increases to 304.36 °K in the year 2013. The average day LST was 305.67 °K during the dry season in the year 2013, which represents the highest average LST in ten years (Table 3). Likewise, the average LST in the non-urban areas increased. These scenarios might be due to the expansion of urban areas leading to forest degradation around Lagos and this was discussed fully in the last section of this study.

Generally, the difference in LST was observed for both day and night time, and wet season and dry season. The average LST of the two periods were great in such that average LSTs of the night time were lower than the LST of the day time in the whole region. The decline in the night-time LST was particularly distinct during the wet season while higher LST was prominent during the day time of the dry season (Table 3). The results imply that the average LST was higher in urban areas than that of non-urban areas, but much more during the daytime in the dry season.

3.3. Contributions of the different landscapes to the SUHI intensity

To determine the contributions of the different landscapes to the intensity of surface urban heat island (SUHI), the CI and LI were calculated and their results were summarized in Tables 4, 5, 6, and 7. Largely, positive CI was obtained for urban areas but negative values for non-urban areas throughout the seasons. CI values show that urban areas have significant positive contributions to SUHI both day and night times. The highest CI was 0.9577 obtained for the urban area during the 2008 dry season day time (Table 4) while the least was 0.5632 obtained during the 2011 dry season night time (Table 6). This implies that urban areas are the main contributor to the intensity of SUHI in the study area and the values were high both in different seasons and time of the day. CI values for non-urban landscape appear negative throughout the season and time of the day. This actually implies that the contribution of non-urban to the intensity of the UHI is significantly lower than that of urban areas (Tables 4, 5, 6, and 7). What is clear from the results is that built-up areas are the main sources of UHI while non-urban is the major sink landscape in the metropolis (Figs. 4 and 5).

There appears to be variation in the seasonal contribution of both landscapes. CI values for the urban areas were higher during the day than night time, but much more during the day time in the dry season (Table 6). Likewise, CI values from non-urban landscape were higher during daytime in the dry season compared to other seasons of the

Table 5
Night time spatiotemporal contributions of the different landscape to the intensity SUHI during the wet season.

Year	Landscape	Contribution index	Landscape index
2002	Urban	0.6765	1.95238
	Non-urban	−0.3465	
2005	Urban	0.5916	1.43732
	Non-urban	−0.4116	
2008	Urban	0.7686	1.13263
	Non-urban	−0.6786	
2011	Urban	0.5632	1.39683
	Non-urban	−0.4032	
2013	Urban	0.793	1.27287
	Non-urban	−0.623	

Table 7
Night time spatiotemporal contributions of the different landscape to the intensity SUHI during the dry season.

Year	Landscape	Contribution index	Landscape index
2002	Urban	0.671	1.91168
	Non-urban	−0.351	
2005	Urban	0.6438	0.81104
	Non-urban	−0.7938	
2008	Urban	0.7564	1.10198
	Non-urban	−0.6864	
2011	Urban	0.6208	0.875353
	Non-urban	−0.7092	
2013	Urban	0.741	1.13825
	Non-urban	−0.651	

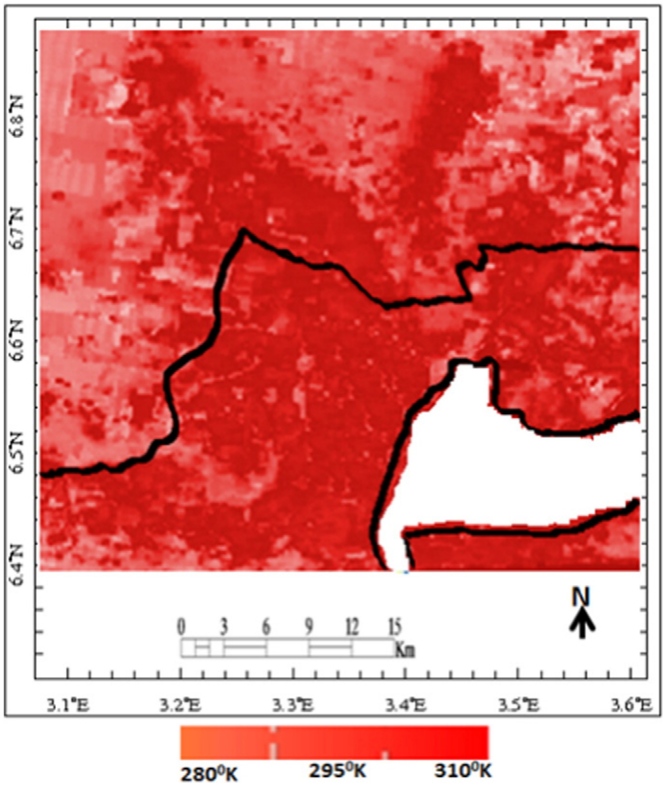

Fig. 4. Overall pattern of UHI between 2002 and 2013, during daytime.

year (Tables 4, 5, 6, and 7). Landscape index (LI) was used to assess the joint contribution of both landscapes to the intensity of SUHI. The interpretation of LI values is in such that when the value of LI is higher than 1, the contribution of the urban and forest areas weakens the intensity of the SUHI. Also, the value of LI is <1 which implies that the contributions of both landscapes stimulate the intensity of the SUHI. What is apparent from Tables 4, 5, 6 and 7 is that both have high contribution during the day time with LI values <1. The LI values were above 1 during the night time of both seasons. These values imply that both landscapes contribute greatly to strengthen the intensity of SUHI during the day time (with $LI < 1.0$) and much more during the day time in the dry seasons ($LI = 0.13$ in the year 2013). On the other hand, they both contribute to weakening the intensity of SUHI during the night time (with $LI > 1.0$) and this was much more during night time of the wet seasons with LIs of 1.9; 1.43; 1.13; 1.39; 1.27 during 2002; 2005; 2008; 2011 and 2013 respectively (Table 7).

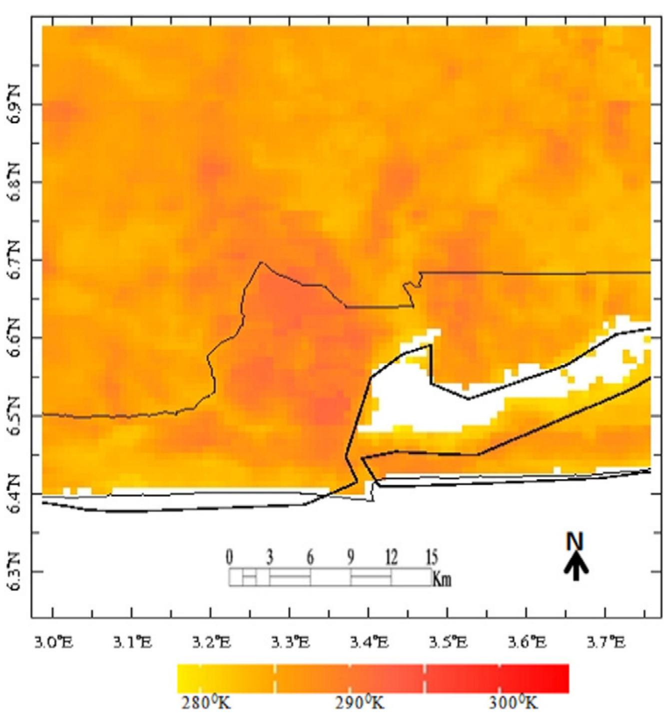

Fig. 5. Overall pattern of UHI between 2002 and 2013, during night time.

Table 8
The seasonal statistics of NDVI.

Time	Season	
	Wet season	Dry season
2002	0.69	0.54
2005	0.67	0.52
2008	0.68	0.53
2011	0.64	0.50
2013	0.62	0.49

3.4. Relationship between NDVI and SUHI

Table 8 presents the seasonal statistics of NDVI analysis for different image dates (2002, 2005, 2008, 2011 and 2013). The NDVI results show that vegetation around Lagos metropolis has been under pressure (Fig. 7) with gradual reduction of vegetation from the year 2002 through 2013 (Table 8). Correspondingly, Fig. 6 illustrates gradual reduction in the forested area around the city. Table 8 shows the extent of the dynamic and seasonal changes in vegetation cover within the period of 2002 and 2013. The NDVI result shows very low values during dry season compared with the wet season (Fig. 6). These values are not surprising since much green vegetal cover is expected during the wet season when the plant generally blossoms with fresh new leaves, but dry season is known for low leave due to very low rainfall and an increase in temperature. Also, gradual decrease in NDVI between 2002 (0.69 and 0.54 in wet and dry seasons respectively) and 2013 (0.62 and 0.49 in wet and dry seasons respectively) as in Table 8, might be the consequence of high rate of deforestation resulting from urbanization, commercial logging of forest around the city and firewood collection by local people (in rural areas city suburb) for domestic purposes.

Table 9 presents the seasonal relationships between the mean NDVI for urban and non-urban areas around Lagos metropolis and their LST as derived from MODIS data. Fig. 8 shows spatial and temporal pattern of urban expansion while the trend of relationship between day and night times LST and NDVI for some selected areas is presented in Fig. 9 (for the wet season) and Fig. 10 (for dry season). The results show a negative correlation (R^2) and seasonal variation in the relationship between NDVI and the LST for both day and night times. From Figs. 9 and 10 what is obvious is that LST decreased with rising NDVI in both

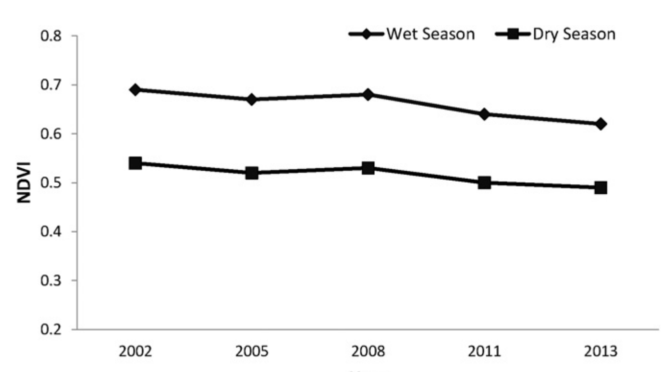

Fig. 6. The seasonal changes in vegetation cover within the periods of 2002 and 2013.

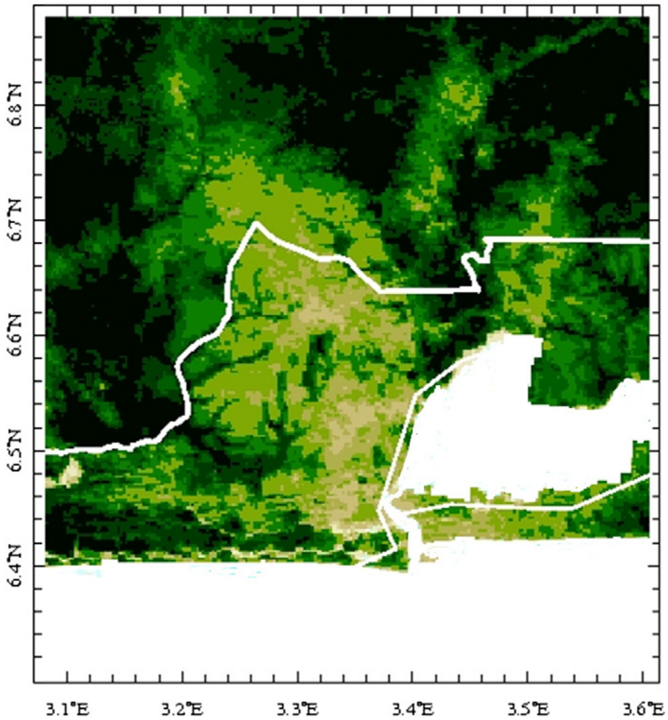

Fig. 7. NDVI image differencing between 2002 and 2013.

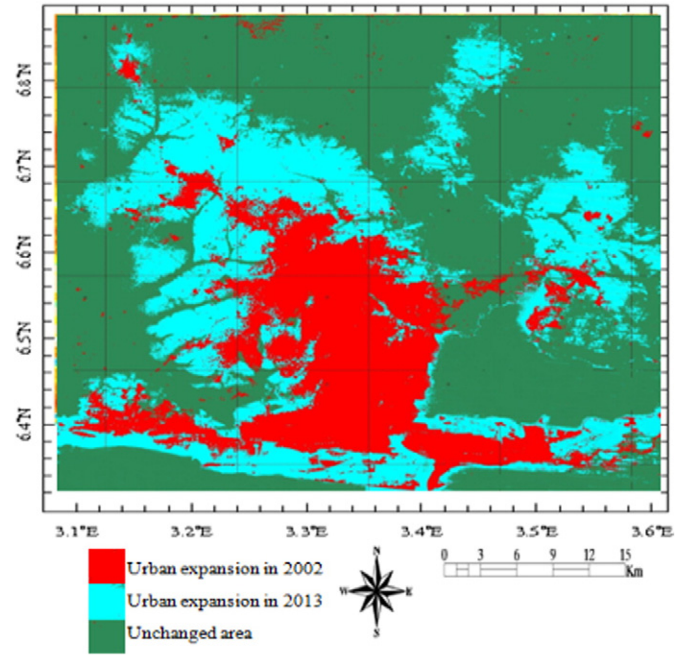

Fig. 8. Overall pattern of urban expansion between 2002 and 2013.

day and night times. Generally, 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 (Table 9). Significant correlations were notable between the LST and NDVI during the day time but much more during day time in the wet season. These values suggested a strong negative relationship between NDVI and LST. The LST increases during the daytime in areas with very low vegetal cover.

The results show that the higher the vegetal cover the lower the level of LST. The results imply that areas with low vegetal cover are prone to high LST, especially during the daytime in both seasons (Table 9, Figs. 9 and 10). From Fig. 8, it is evident that the Lagos metropolis has undergone dramatic urban expansion over the period of study, with an increase in built-up areas and a large amount of natural green land have been converted to various developed urban development. The major reason for expansion is because of rapid population growth and migration has taken Lagos at an unprecedented rate. These results indicate that expansion in an urban area (Fig. 8) is responsible for intensive UHI while non-urban area and other vegetal cover had a prominent cooling effect in the day time both during the wet and dry season. Thus, the findings of this study are useful to determine the relationship between UHI and land cover change in tropical cities. These results imply that the major factor driving UHI in the study area appears to be land use change resulting from the expansion of urban areas (Fig. 8). Also, the results imply that the contributions of forested area to LST are very little and varied seasonally between day and night times. Previous studies have shown that the roles of landscapes in LST process varied diurnally and seasonally (Shashua-Bar and Hoffman, 2000; Voogt and Oke, 2003; Qiao et al., 2013). The reason for this variation, according to Kondoh and Nishiyama (2000) and Liu et al. (2005), might be due to the fact that declines of the vegetation index and their thermal inertia usually limit evaporation processes, thus decrease the loss of heat by latent heat flux. Urban expansion (Fig. 10) and reduction in vegetal cover around urban areas altered the thermal and aerodynamic processes around urban environment resulting in an increase in UHI (Oke et al., 1991; Atkinson, 2003; Stewart and Oke, 2006). Stewart and Oke (2006) further noted a major environmental impacts of urban expansion to be modified of urban land surface temperature and atmospheric temperature. Such changes in urban land surface temperature usually influence urban internal microclimatology and surface energy change, which might result from anthropogenic heat discharge. The implications of this study for urban planning and policy in tropical countries are obvious, as an urban population continues to growth in upcoming several decades, there is a need for proper urban planning policy to combat the subsequent effects of conversion results in the alteration of physical properties of the urban land surface.

Table 9
The coefficient of determination between the mean NDVI and seasonal LST for urban and non-urban areas.

Time	Wet season		Dry season	
	Daytime (R^2)	Night-time (R^2)	Daytime (R^2)	Night-time (R^2)
2002	0.94	0.73	0.91	0.64
2005	0.91	0.68	0.87	0.65
2008	0.92	0.71	0.82	0.61
2011	0.90	0.63	0.79	0.59
2013	0.93	0.69	0.90	0.62

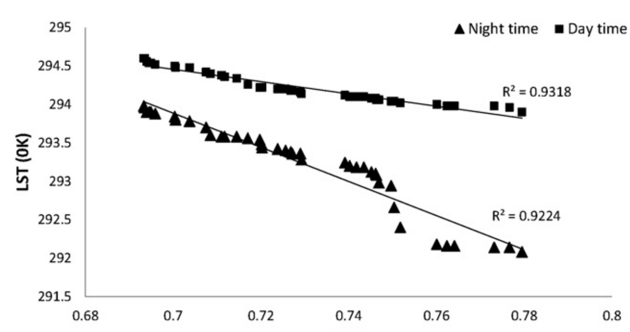

Fig. 9. The trend of relationship between day/night times LST and NDVI, wet season.

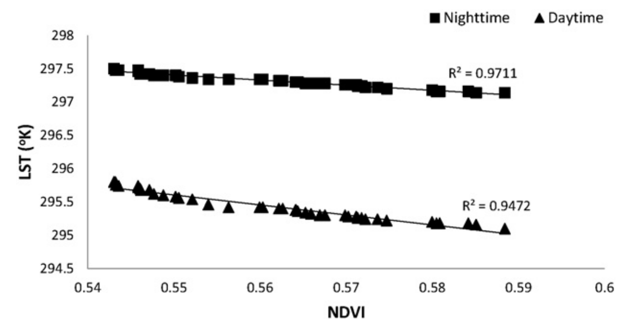

Fig. 10. The trend of relationship between day/night times LST and NDVI, dry season.

4. Conclusions

In this study, the seasonality of urban heat island in a tropical city area was examined. Using MODIS data, an assessment of seasonal variability between day and night-time LST and the intensity of UHI in Lagos metropolitan city were presented as a case study. Though, the majority of the previous studies of UHI in the tropical countries used ground-based data from the weather station, some of which are not accurate for detail assessment of LST in cities. Besides, it is practically difficult to monitor spatial and temporal variation in UHI with conventional ground methods from weather stations. Remote sensing data was used in this study because it offers an efficient and speedy approach for monitoring spatiotemporal variation in UHI over a long period time. What is evident from the results of the present study is that the Lagos metropolis has undergone dramatic changes in land cover over the period of study, with an increase in built-up areas and reduction in vegetation around the city. The results from this study show that forested areas may be considered as sink landscapes because of its contribution in weakening the intensity of UHI. On the other hand increase in the urban areas is source landscapes because of their positive contributions to the intensity of UHI. Chen et al. (2006) have earlier noted that the nature of city landscapes is the major drivers of UHI. The main difference between the present study and that of Chen et al., is that the present study examined the seasonal and diurnal variations in LST between different landscapes. The results show that reduction in vegetal cover around Lagos areas altered the thermal and aerodynamic processes, resulting in an increase in UHI. The implications of this study to Lagos metropolis are obvious. As Lagos urban area is expanding, there are possibilities that the urban microclimate, thermal comfort and urban environmental living conditions will change. This is because of increasing concentration of human activities in the urban area leading to artificial changes in the landuse/landcover (Zhang et al., 2011). Changes in land surface due to urban construction materials, have very high heat conductivities to amplify the urban land surface and atmospheric temperature. This study agrees with the previous studies that extremely large negative storage heat fluxes occurred in urban areas, both daytime and nighttime due to several anthropogenic activities in the urban areas (Zhang et al., 2010; Radhi et al., 2013; Zhang et al., 2013a, 2013b). Thus, the differences in the LST patterns between the urban areas and its surrounding rural areas might be due to urban expansion resulting in removal of vegetation and high heat capacity of construction materials in the central of urban area.

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