Mapping Spatiotemporal Variations of Land Surface Temperature in South East Nigeria with Landsat

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Keywords: LST, Landsat, Geothermal energy, Southeast Nigeria

SUMMARY

Despite the importance of Land Surface Temperature (LST) in climate, hydrology, ecological, biogeochemical and agricultural studies, no attempt has been made at comprehensively estimating and studying any spatial variation in LST in the south east region of Nigeria. Land surface temperature has been found to be an important factor in combination with NDVI in monitoring drought, estimation of radiation budgets and soil moisture, analysis of heat islands, and in detecting thermal anomalies such as underground fires and geothermal sources. The relevance of this study cannot be overstated as the south east region has the potential of being a geothermal energy source due to the huge deposits of coal in the region. In this paper, a long term monitoring of temporal and spatial variations of the LST in the region is presented. This is expected to serve, among other things, as a comprehensive inventory of LST for future research and predictions. Remote sensing was adopted as the most suitable and cost effective method for this study as against traditional methods, due to the fact that traditional methods rely on ground observations of temperature and meteorological data from irregularly and sparsely distributed field stations that require complex interpolations of data for a continuous coverage of a large expanse of land. Imagery from Landsat TM and ETM+ spanning the period between 1984 and 2013 (inclusive) were used to estimate long term land surface temperature in the region. Supervised classification and NDVI were also carried out based on satellite data obtained in 1987, 2003, and 2013, to identify any variation in land use within the study period. Some areas in the northern section of Enugu State were detected as having anomalously high LST, which indicate possible high subsurface heat generation (potential geothermal energy sources). Research is ongoing to analyse specific cause of the high LSTs with night time MODIS data.

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1. INTRODUCTION

Land surface temperature (LST) is an important variable in environmental and climate studies. It represents the temperature recorded at the interface between the earth surface and the immediate atmosphere (Valiente *et al*., 2010), and is thus a measure of how hot the land surface at a particular location feels to touch (NASA, 2000). Land surface temperature is the result of the combination of solar radiation and subsurface heat transferred from the earth's core through conduction and convention to the surface. It is thus controlled by the surface energy balance, atmospheric state, thermal properties of the surface, and subsurface mediums (Becker and Li, 1990).

Environmental researchers have recently focused attention on regional and global temperature variations, as heat emissions from the earth into the atmosphere are key contributors to global warming (Serban and Maftei, 2011). The LST is important in climatology as it has a direct impact on air temperature and it is also one of the main parameters in the underlying physics of land surface processes (Serban and Maftei, 2011; Dousset and Gourmelon 2003; Weng *et al*., 2004). It is also required in scientific studies, such as hydrology, ecology and bio-geology. For example, LSTs can be used in the large scale modelling of hydrological system, the greenhouse effect analysis, ecosystems vegetation, drought monitoring, evaluating water requirements for crops, or computing water deficit index and urban heat islands analysis. (Serban and Maftei, 2011; Mallick *et al*., 2008). LST is a good indicator of the energy balance at the earth's surface as it combines the results of surface-atmosphere interactions and energy flux between the atmosphere and the ground (Mannstein, 1987; Sellers *et al*., 1988 cited in Wan, 1999). Detailed and comprehensive information on LST in the south east of Nigeria are lacking. Land surface temperature is traditionally measured in the field at sparsely located field observation stations yielding discrete LST measurements. This approach has long been adopted in the south east of Nigeria. Discreet measurements of LST are usually not a good representative of the LST of an area, as gaps between the locations where LST were measured are usually filled with interpolated data. As LST tend to vary from one location to the other, the ability to measure the LST at every point over an area becomes highly desirable. Due to the fact there is a dearth of available information on LST in the south east of Nigeria as it is with the rest of the country, the use of an alternative means for deriving this important variable, become highly desirable. Satellite technology provides a suitable alternative for the comprehensive measurement of LST across an area or region, as satellite data provides spatially continuous coverage of a given area. Furthermore, the repetitive nature of satellite observations also makes it possible for the investigation of changes in the environment over a given period. Thermal infrared remote sensing (TIR) have been used as a viable means of estimating land surface temperature due to the sensitivity of the thermal infrared bands of environmental satellites such as Advanced Very High Resolution Radiometer (AVHRR), Moderate Resolution Imaging Spectroradiometer (MODIS), Landsat and Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) to heat from the earth surface. It has proved its cost effectiveness for the accurate determination of LST at every point over a wide area of study. Satellite derived LST is increasing being used in the detection of geothermal anomalies resulting from underground heat sources such coal fires and geothermal energy sources (Cracknell and Mansor, 1992; Coolbaugh *et al*., 2007; Qin *et al*., 2011), in addition to its commonly known applications in climatology, hydrology and bio-geology studies. Due to the huge deposit of coal in most parts of the South East and especially in Enugu State and presence of hot and warm springs at Oghe-Amansiodo and Umumba in Enugu State, there is a high potential for geothermal activities in the region.

The research is primarily aimed at providing a long term inventory of land surface temperature in the region from available satellite image, which could serve as a primary resource for further environmental and climatology studies, detection and mapping of spatiotemporal variations in the land use as a result of climate change, as well as detection of LST anomaly that could indicate potential geothermal resources areas in the region. This is important due to the increasing interest in the exploration of alternative and cleaner energy resources.

2. METHODOLOGY

2.1. Data

Landsat Thematic Mapper (TM4 and TM5), and Enhanced Thematic Mapper plus (ETM+) imagery acquired from 1984 to 2013 were the primary data used in this study. The Landsat data were obtained from the Global Visualization Viewer (USGS, 2012). Due to the high level of cloud cover in the region during the wet season, cloud-free images were only available during the months of December and January, corresponding to the dry season with harmattan conditions. The images were obtained between 9:03am to 9:47am, which is advantageous to the study as the intensity of solar radiation is still low, thus minimising the effects of the irradiation from the sun on the estimated LST values. Five Landsat scenes were used to obtain a complete coverage of the study area, which spans across the five south eastern states of Nigeria namely, Imo, Anambra, Abia, Enugu and Ebonyi States. Due to limited availability of cloud-free data, six epochs (1984, 1987, 2000, 2003, 2005 and 2013) were chosen for the estimation of the land surface temperature. Satellite scenes with closely matching acquisition dates were used in each epoch. On few occasions where there were no cloud-free closely acquired images within a particular epoch, images within a two month interval were used. However, most of the data used in each epoch were within a one month interval of each other and quite many were acquired on the same day. This was done to minimise any variation due to differences in acquisition dates that may have affected the results, as the data were acquired within the same climatic conditions. A total of thirty five Landsat scenes were processed for this research. The data used are listed in Table 1 below.

The images from 2005 to 2013 were slightly affected by the scan line correction (SLC) error, which resulted in some empty slices across the images. The 1987 image of Scene 4 has a 30% cloud cover; however the area affected by the cloud were outside the study area.

Table 1. List of Landsat images used in the study with supplementary information

				Epochs								
Scene	**Path/Row**	**Time**	**Cloud Cover**	**1984**	**1986**	**1987**	**2000**	**2003**	**2005**	**2007**	**2013**	**Sensor**
1	188/55	09:14:28	0%	13/12/1984								TM 5
	188/55	09:03:18	10%		19/12/1986							TM 5
	188/55	09:03:47	0%			04/01/1987						TM 5
	188/55	09:37:00	0%				04/03/2000					ETM+
	188/55	09:32:42	0%					08/01/2003				ETM+
	188/55	09:33:47	0%						13/01/2005			ETM+
	188/55	09:34:37	0%							19/01/2007		ETM+
	188/55	09:40:43	0%								03/01/2013	ETM+
2	188/56	09:14:52	0%	13/12/1984								TM 5
	188/56	09:03:42	0%		19/12/1986							TM 5
	188/56	09:05:50	0%			21/02/1987						TM 5
	188/56	09:35:12	0%				17/12/2000					ETM+
	188/56	09:33:06	0%					08/01/2003				ETM+
	188/56	09:34:11	0%						13/01/2005			ETM+
	188/56	09:35:01	0%							19/01/2007		ETM+
	188/56	09:41:00	0%								04/02/2013	ETM+
3	188/57	09:15:16	0%	13/12/1984								TM 5
	188/57	09:04:06	0%		19/12/1986	19/12/1986						TM 5
	188/57	09:35:36	0%				17/12/2000					ETM+
	188/57	09:33:30	0%					08/01/2003				ETM+
	188/57	09:34:35	0%						13/01/2005			ETM+
	188/57	09:35:25	0%							19/01/2007		ETM+
	188/57	09:41:21	0%								03/01/2013	ETM+
4	189/56	09:11:01	30%	xxxxxxxxx	xxxxxxxxx	27/01/1987						TM 4
	189/56	09:41:26	0%				09/01/2001					ETM+
	189/56	09:39:19	0%					30/12/2002				ETM+
	189/56	09:40:06	5%						03/12/2004			ETM+
	189/56	09:41:19	5%							28/12/2007		ETM+
	189/56	09:47:07	0%								10/01/2013	ETM+
5	189/56	09:10:10	0%	xxxxxxxxx	xxxxxxxxx	11/01/1987						TM 5
	189/56	09:41:02	0%				09/01/2001					ETM+
	189/56	09:38:55	0%					30/12/2002				ETM+
	189/56	10:09:42	0%						03/12/2004			ETM+
	189/56	09:40:46	12%							25/12/2006		ETM+
	189/56	09:46:43	0%								10/01/2013	ETM+

2.2 Methods

2.2.1 Estimation of Land Surface Temperature

To estimate the LST from the pre-processed Landsat images, the temperature data stored as DN values in the thermal band 6_1 (low gain band) for ETM+ and band 6 for TM were initially converted to spectral radiance values using the following standard LMin and LMax spectral radiance scaling factors equation (NASA, 2011):

$$\text{Radiance} = \frac{\text{LMax}_\lambda - \text{LMin}_\lambda}{\text{QCALMax} - \text{QCALMin}} * \text{QCal} - \text{QCalMin} + \text{LMin}_\lambda \ldots\ldots\ldots\ldots\ldots\ldots .(1)$$

Where:

QCAL = digital number
LMINλ = spectral radiance scales to QCALMIN
LMAXλ = spectral radiance scales to QCALMAX
QCALMIN = minimum quantized calibrated pixel value (usually = 1)
QCALMAX = maximum quantized calibrated pixel value (usually = 255)

The scene calibration data are usually available on the metadata file of each Landsat scene. Having computed the spectral radiance values for each of the Landsat scenes, they were subsequently converted to temperature values (Kelvin) using the inverse of the Planck function shown below:

$$T = \frac{K_2}{\ln\left[\frac{K_1 * \varepsilon}{Radiance} + 1\right]} \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where:

T = Effective at-satellite temperature in Kelvin
K2= Calibration constant 2 (see Table 2)
K1= Calibration constant 1 (see Table 2)
ε = Emissivity (typically 0.95)
Radiance = Spectral radiance

Table 2. ETM+ and TM Thermal Band Calibration Constants

Satellite	K1	K2
Landsat 7	666.09	1282.71
Landsat 5	607.76	1260.56

The LST datasets were classified into 5 temperature ranges (<=300K, 300K – 305K, 305K – 310K, 310K – 315K, >=315K), to obtain a more meaningful spatial distribution of the land surface temperatures.

2.2.2 Supervised Classification

To understand variations in Landuse distribution of the region within the study period, supervised classification was carried out on 15 Landsat images covering the 1987, 2003 and 2013 periods. These data taken from three different time periods were expected to be representative of Landuse distributions in the region during the period of study. The maximum likelihood classifier based on all the Landsat bands in conjunction with high resolution imageries available on Google Earth were used to map eight major land cover classes (thick vegetation, light forest, sparse trees, water, sands (in rivers), agriculture, bare land and built environment). Mangrove forests and sea water identified in the mosaiced dataset (from the five scenes), were outside the study area and were excluded after the results have been clipped to match the study area.

2.2.3 NDVI

To corroborate the results obtained from the image classification, Normalised Difference Vegetation Index (NDVI) was computed for the three selected years. NDVI are not only useful for vegetation studies, but also could be used to identify other land features such built environments water bodies and bare lands which are usually dis-highlighted (low values) by NDVI. The values of the NDVIs at locations identified with anomalous land surface temperature were used in a regression analysis carried to explore any underlying correlation.

2.2.4 Delineation of Geothermal Anomalous Areas

The LST datasets obtained were bimodally reclassified to isolate areas with anomalous LST values. As the average maximum land surface temperature in the region are expected to be about 305K, areas with values equal to or greater than 310K were reclassified as LST anomalous areas and given a value of 1 while the remaining areas were given a value of zero. Subsequently, the results obtained were overlaid with each other to isolate areas that were consistently identified as anomalously high LST areas. This was done to exclude areas that may have been erroneously identified with high LST due to scene conditions at the time of acquisition (satellite overpass). The areas identified as geothermal anomalous areas were subsequently converted to polygons, and noted as potential geothermal resource areas. These polygons were used as zonal areas to extract statistically values from the NDVIs for the regression analysis carried out.

3. RESULT AND DISCUSSION

The results of the image classifications carried out are shown in Figure 1. The results showed the region to be mainly agrarian as it was predominated by agricultural and light forest areas, especially in the southern belt of the region. The northern belt of the region was mainly identified as sparse trees, bare lands and light forests. Sparse trees classification group represents bare land areas sparingly mixed with trees.

The results also revealed interesting observation in the rate of urban growth in the region. The trend in urban growth was observed from the different classified images. A very interesting example was what appeared to be the stagnation of urban growth in Aba (Abia State) from 2003 to 2013, which contradicted its previous expansion from 1987 to 2003. Based on the area classified as built environment in the three images, Owerri on the other hand continuously grew from 1987 to 2013. The stagnation of Aba was assumed to be as a result of insecurity situations in the city, which may have forced people to relocate to neighbouring cities such as Owerri and Umuahia (which was also observed to have grown in the 2013 classification). The three classified images did not show significant change in the land cover, except in the 2013 image along the north eastern belt of the region, where the agricultural areas have been turned into bare lands. This may have been due to excessive dryness or as most of the images used for this year were acquired in January (after the harvest periods); the farms may have been cleared for the next planting season.

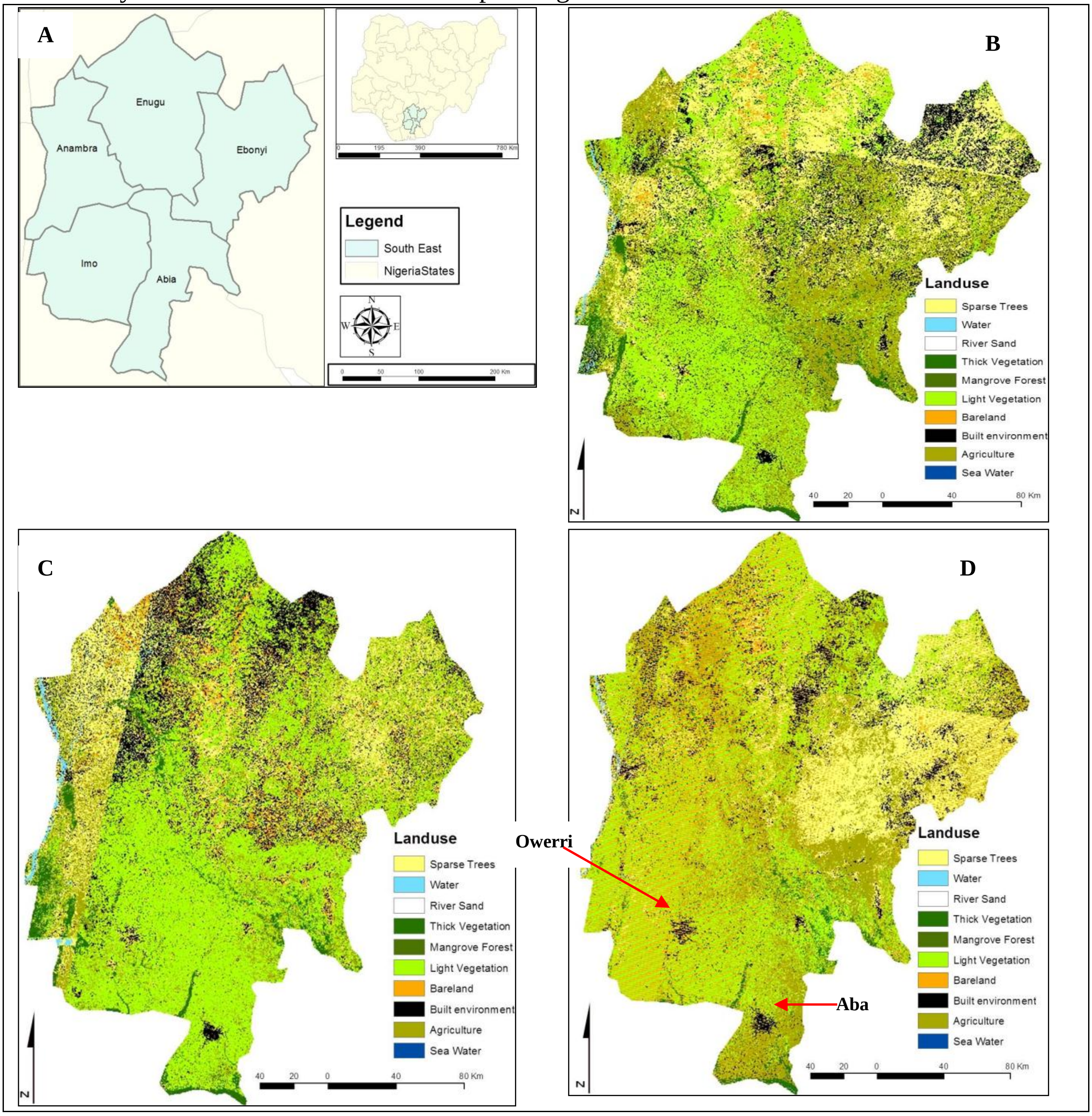
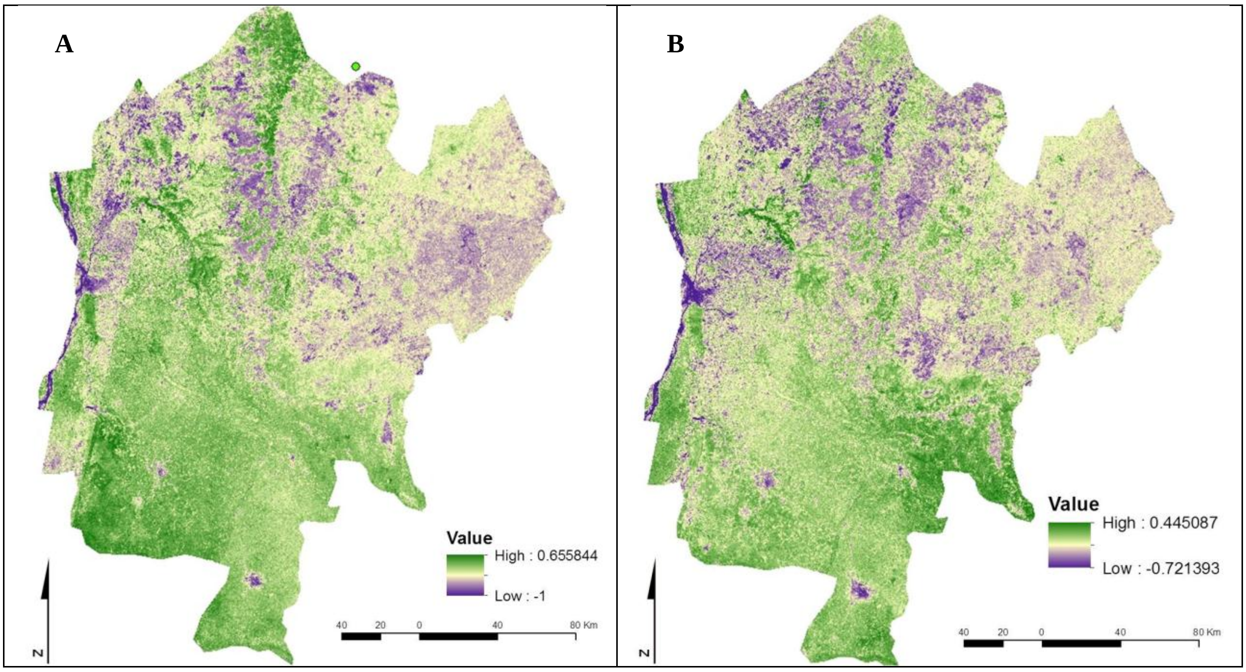


Figure 1. Maps showing results of the supervised classification carried with data from three separate years to

identify the key landcover classes in the south east region of Nigeria. A: Map showing the five component states of the region. B: Showing result from the classification of the 1987 image. C: Result of the classification of the 2003 image and D: Image classification result based on the 2013 image.

The NDVIs computed (Figure 2) closely matched the general distribution of land covers in the region as identified by the classification. Three main land covers notably identified were vegetated areas (predominantly in the southern belt), with the highest NDVI values; rivers, built environment and bare lands, with the lowest NDVI values; and light forest areas/agriculture. Low NDVI values obtained in the research were reflective of the fact that the data used were obtained during the peak of dry season and harmattan conditions in the region, characterised by dryness, low humidity and leaf fall from deciduous trees. Thus most of the vegetated covers have either dried up, or lost a great deal of their greenness.

Figure 3 illustrates the results obtained from the LST estimation of some the years used in the research. Only three Landsat scenes, which covered most of the region, were available for use for the LST estimation of 1984. The LSTs mainly ranged between 290K and 310K as clearly demonstrated by the histograms of the land surface temperatures (Figure 4). Agricultural and light vegetated areas were found to have temperatures between 300K to 305K, while barelands and built environments have land surface temperatures from 305 to 310K. Thick vegetation and water bodies expectedly have the lowest LST values (<300K) due to the cooling effects of vegetation and water. The region generally appeared warmer from the year 2000, with most parts of the region found with relatively higher land surface temperatures especially in the 305K – 310K range (Figure 3). LST class with range 300K – 305K were found to have the highest level of occurrence (Figure 4), corresponding with results from classifications and NDVIs, which showed that the region is highly vegetated.



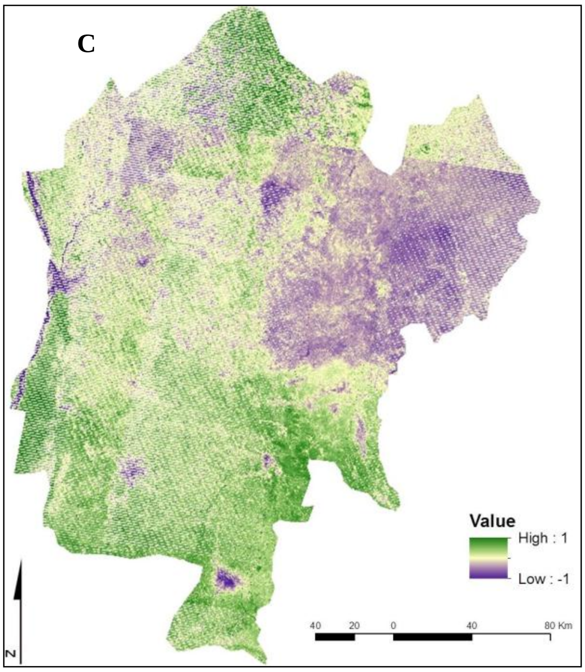
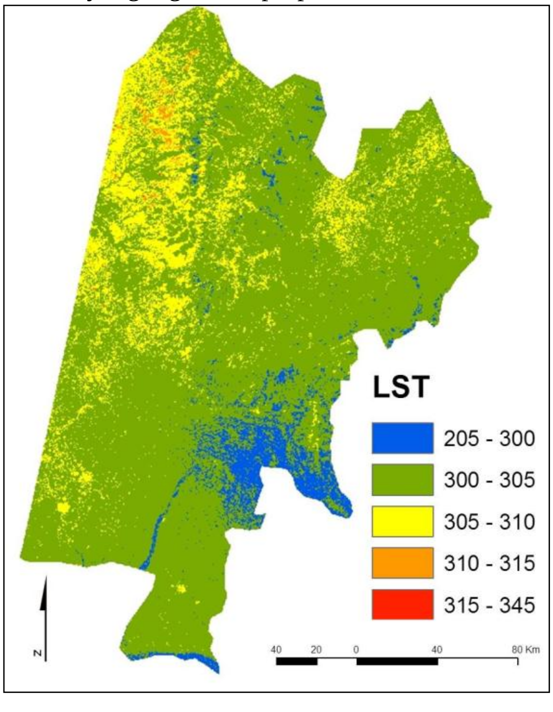
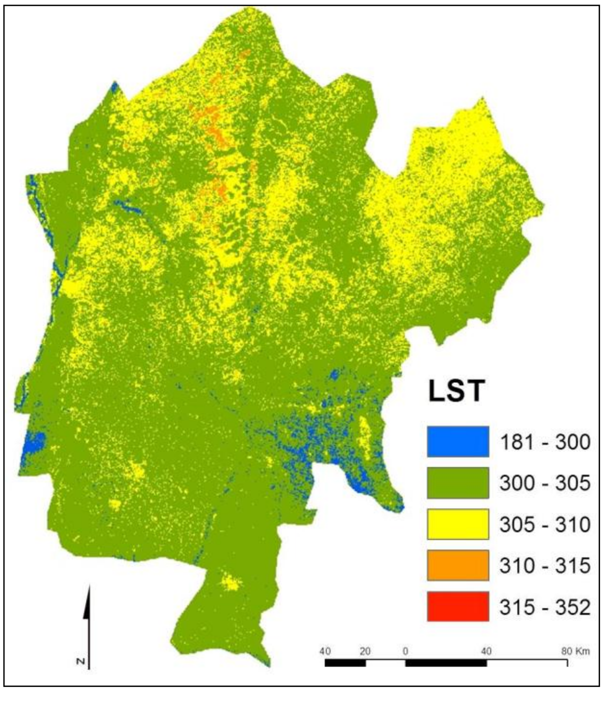


Figure 2. NDVI maps computed based on the 1987 (A), 2003 (B), and 2013 (C) Landsat images of the study area. The vegetated areas are clearly highlighted in green while the bare lands, rivers, and built environments are distinctly highlighted in purple.





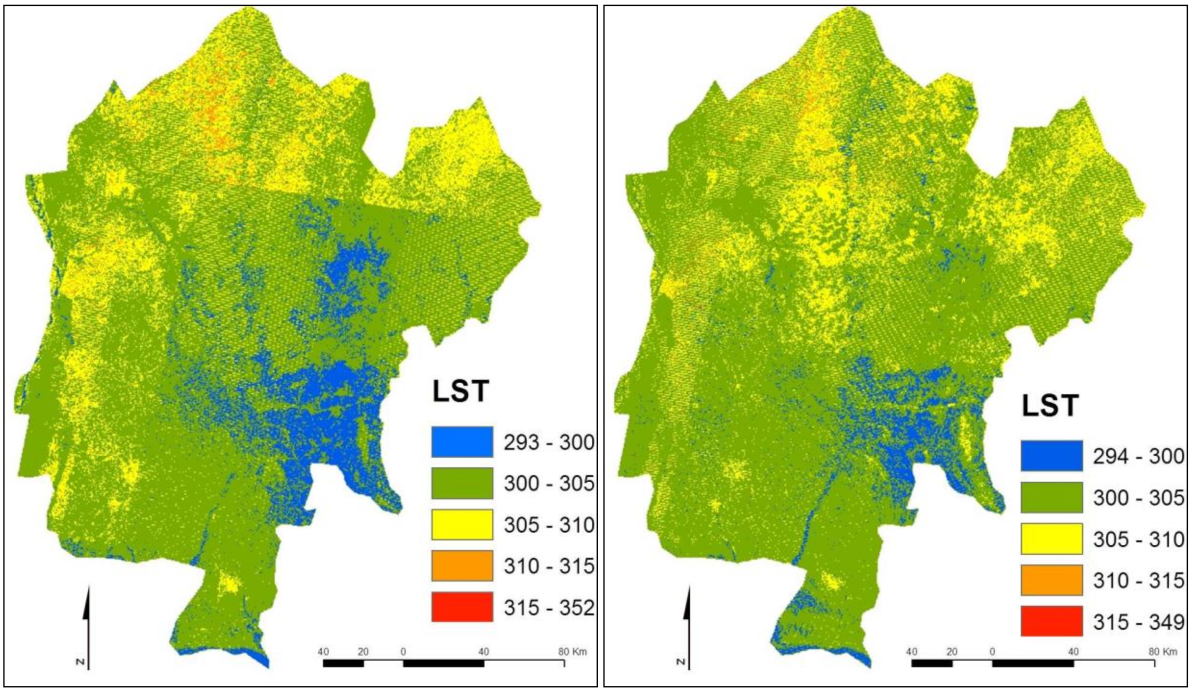


Figure 3. Maps showing some of the results of the land surface temperature of the south east of Nigeria. A: 1984 LST. B: 200 LST. C: 2005 LST. D: 2013 LST.

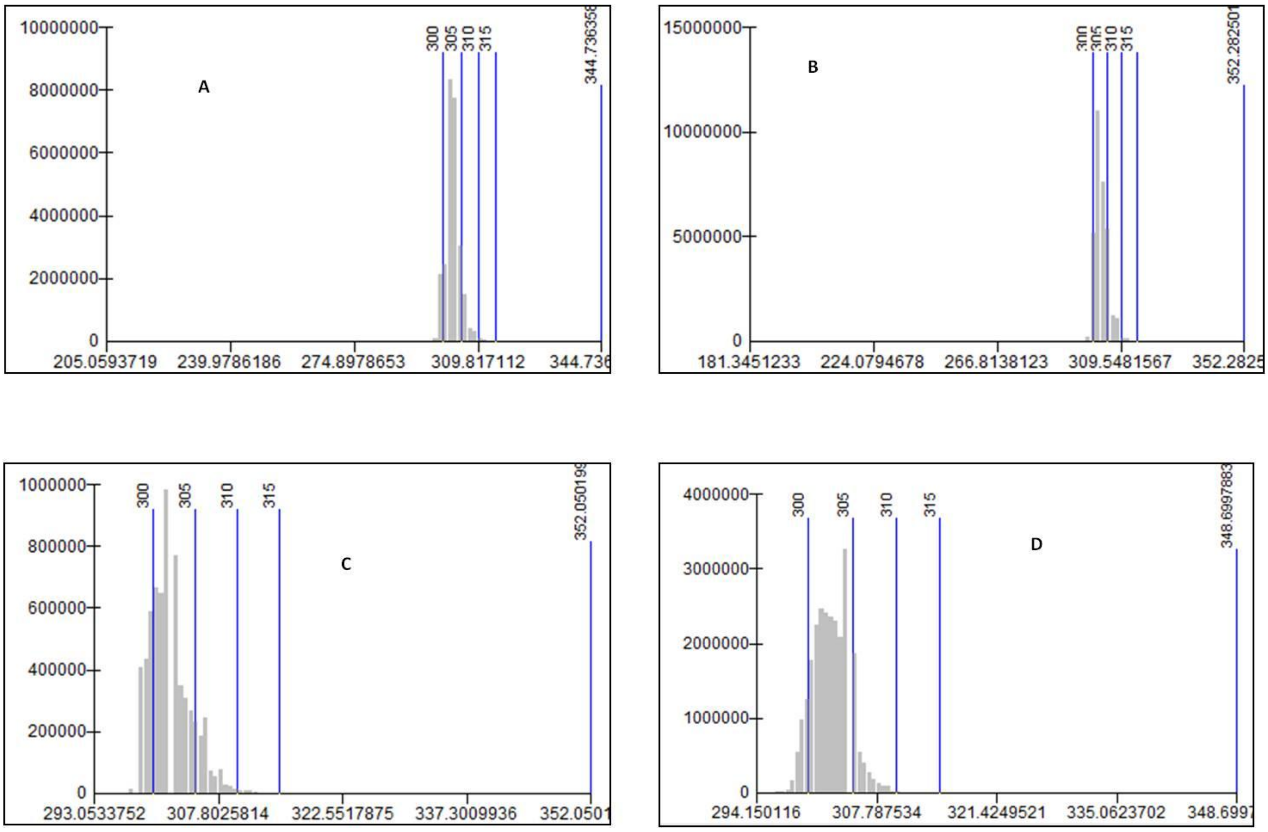


Figure 4: Histogram of the estimated LSTs of based on Landsat images of south east Nigeria. A: Result from

1984. B: Result from 2000. C: Result from 2005. D: Result from 2013.

Analysis of the various LSTs to detect geothermal anomalous areas identified some areas in the north central part of the region, having LST values greater than or equal to 310K as potential geothermal anomalous areas (Figure 5). These geothermal areas fall within the Enugu State, with huge resources of coal (thus potential for underground coal fire) as well as hot springs. However, further investigations is being carried out with night time MODIS data, which has a higher temporal resolution than Landsat, in conjunction with topographic information (DEM), to ascertain the veracity of this finding. Exploration of underlying relationship between the NDVI and the geothermal anomalous areas did not yield any definitive result. Some of the areas identified were examined with high resolution imagery available on Google Earth, and it was found that the geothermal areas identified falls within bare lands and sparsely vegetated areas (Figure 6). This sparse vegetation was interpreted as a result of the excessive heat around the area, which may not sustain the growth of trees. This interpretation was based on the fact that most of the bare lands and sparsely vegetated areas were not identified as LST anomalous areas.

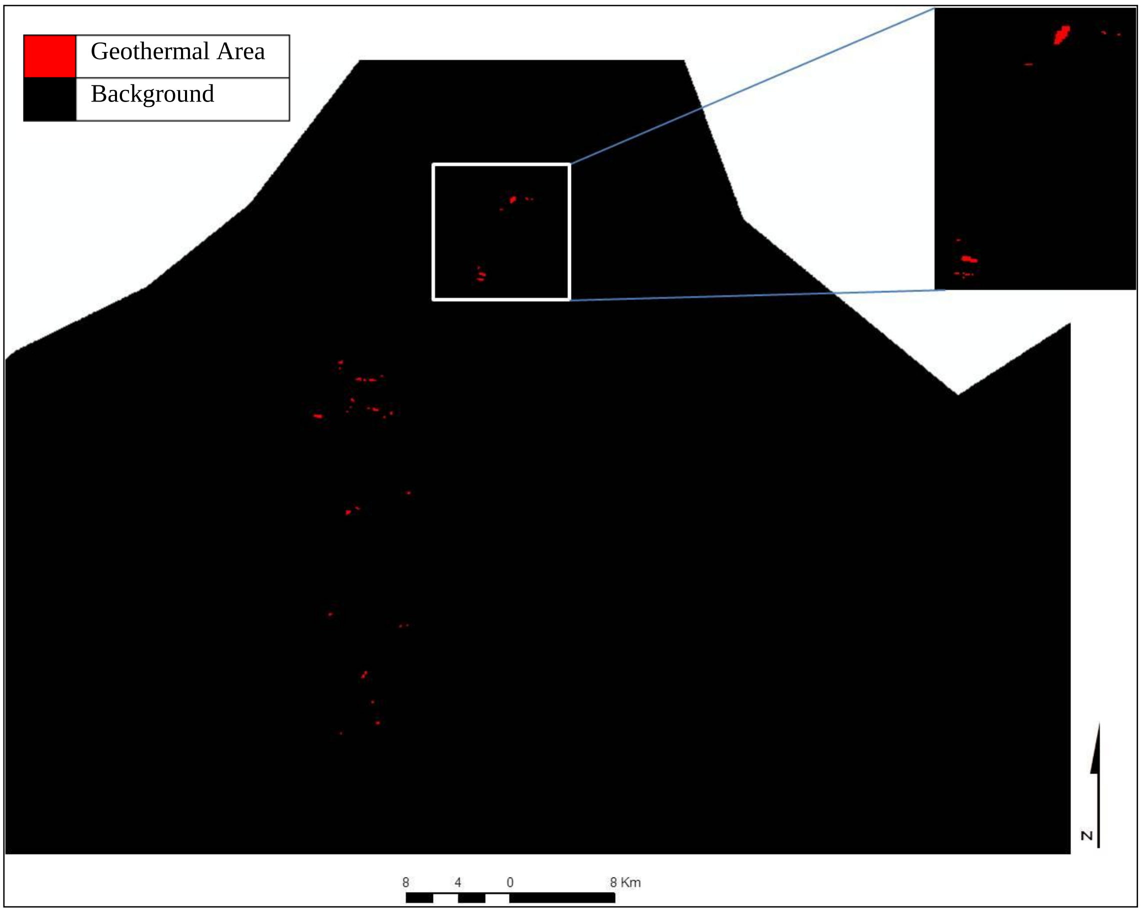


Figure 5: Potential geothermal resource areas in the south east of Nigeria

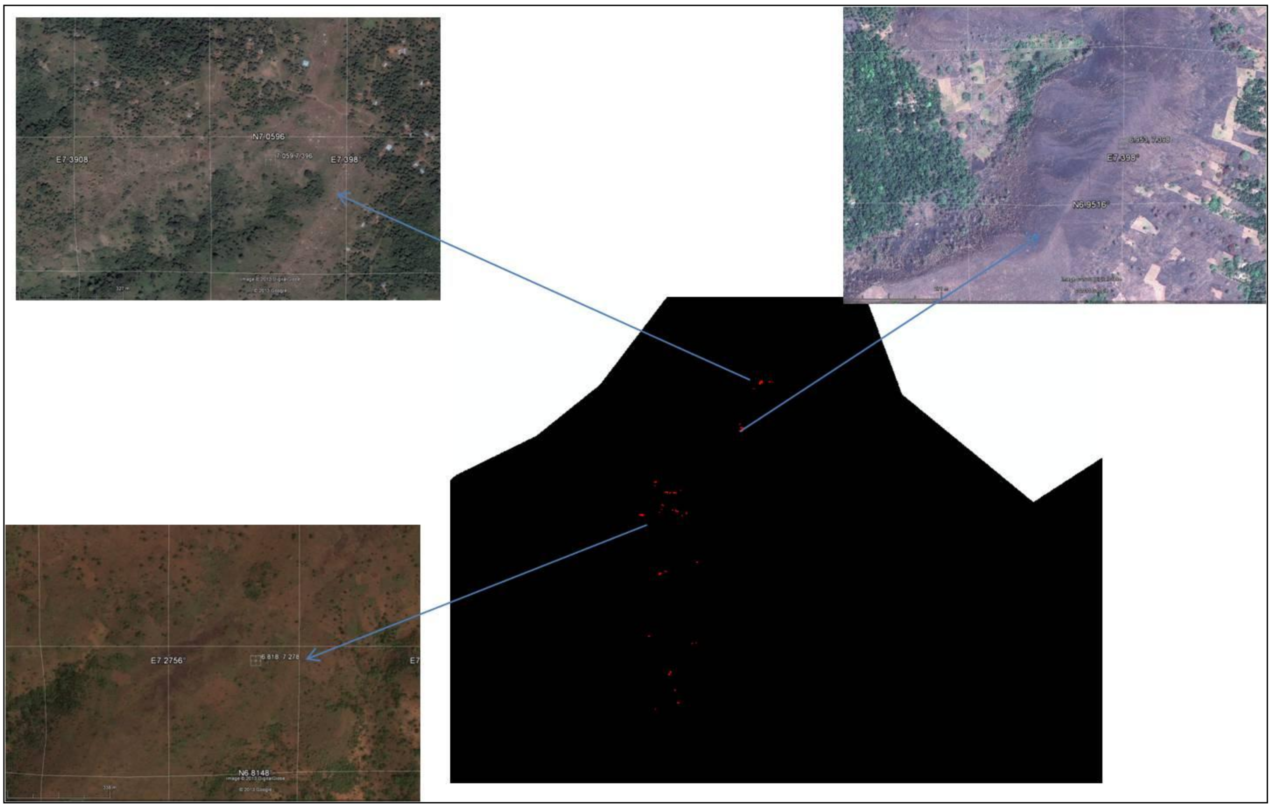


Figure 6. High resolution images (Google Earth) of some the areas detected with LST anomaly in the south east region of Nigeria.

4. CONCLUSION

Detailed information on land surface temperature in the south east of Nigeria are lacking. Environmental satellite data provides an efficient and cheap way of estimating land surface temperature of an area, as it provides spatially continuous data/measurement (coverage) of a particular region on a regular basis. In this research, long time land surface temperature of the south east region of Nigeria were computed using spectral information available on the thermal infrared band of Landsat images, for a period of study between 1984 and 2013 (inclusive). These were used to provide long time analysis of LST variation in the region in conjunction with land use changes. The region was found to be dominated by LST values between 300K and 305K. However, more areas were relatively found to have increasing warmer temperatures from 2000.

Potential geothermal resource areas were found in the North central part of the region (Enugu State), indicated by areas with consistently anomalous LST values greater than or equal to 310K across the study periods. Further investigations are ongoing to definitively confirm the validity of the results obtained and identify causative agents of the anomalous LST observations, through the integration of night time MODIS data. The night time data is expected to help in isolating areas potentially identified as geothermal areas that may have

been influenced by solar radiation (diurnal heating effects of the sun). The rationale being that only truly geothermal areas will retain an anomalous land surface temperature during the night.
This research has once again demonstrated the efficiency of satellite remote sensing in the analysis of environmental phenomena. Results from this research are expected to boost further interests on the application of environmental satellites in studying the Nigeria environment and natural resources. A role, which surveyors in the country stand a greater chance of effectively controlling. Detection of the potential geothermal energy resource areas in the region is expected to have greater impact in government circles due to the quest for increased energy and power output in the country, currently struggling at a maximum power output of less than 5000 megawatts, as well the increasing global interest on cleaner energy resources.

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