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Regional Mapping of Land Surface Temperature (LST), Land Surface Emissivity (LSE) and Normalized Difference Vegetation Index (NDVI) of South-South Coastal Settlements of Rivers State in Nigeria

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ABSTRACT

This study is the regional mapping of Land Surface temperature (LST), Land Surface Emissivity (LSE) and Normalized Difference Vegetation Index (NDVI) of south-south coastal settlements of Rivers State in Nigeria. The Google Earth Engine (GEE) of satellite remote sensing origin was used in the study. It was observed that land surface area of the south-south coastal settlements of the region hosting a total population of 3,344,706 persons had undergone severe modification and alteration of vegetal cover by increased human activities especially in the central area. Emissivity in the region increased from the center to the rural settlements with values ranging 0.98 to 0.99 and difference of 0.01 indicating that there was increased modification of the regional land surface. Land surface temperature decreased from the regional center to the rural settlements ranging between 22.12 ºC to 35.99 ºC with a difference of 13.87 ºC. However, LST was scattered in different settlement spots especially in the northern region such as Aleto, Finema (south); Rumuolu, Odogwa, Abara, Umuechem, Rumuola, Ambroda (north) among others. The normalized vegetation index showed -0.54358 to 0.409327 having the difference of 0.952907 indicating greater variation in vegetal cover across the region. Thus, NDVI in the region increased from the regional center to the outskirts of the area. Urbanization in the south-south region of Rivers State had extended severely to the rural settlements. Therefore, it is recommended that policy makers and regional planners should protect the area from adverse vegetal lost and heat effects by implementing regional greening practices.

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***Keywords*:** Regional, land surface temperature, land surface emissivity, normalized difference vegetation index, population, urbanization

1. INTRODUCTION

In every region of the world, increased population has resulted to critical urbanization challenges. Thus, urbanization introduces rapid modification of the biophysical features of the earth surface. When the biophysical components of the earth surface are modified, it will result to alteration of the natural interaction of vegetation and climatic parameters of the surface area such as the Land Surface Emissivity (LSE), Land Surface Temperature (LST) and Normalized Difference Vegetation Index (NDVI) which are dependent on the sustained anthropogenic activities of the region [1] [2]. The energy budget of a region can be influenced by the thermal retention and release of heat from the various surface features of the area. Stable emissivity, temperature and vegetal interactions of a region would make occupants of that area comfortable to inhabit without heat effects. When a region is stressed beyond its natural limit with urbanization challenges, it will result to increased energy consumption, high emissions of air pollutants, heat stress, poor water quality and death of humans [3] [4].

Land surface emissivity is the average radiation of any component of the earth surface calculated from measured radiance and land surface temperature of the satellite remote sensing. It is the thermal efficiency which earth surface materials emit their stored heat as Thermal Infrared (TIR) radiation. LST is important as it is used to establish the composition of the radiating surface necessary to control atmospheric and energy balance of a region as it goes with the brightness temperature the area surface. LSE performance of a region accelerates the latent heat of evapotranspiration from water bodies and vegetation which is commonly noticeable at the rural fringes of an area due to high vegetal cover [4].

Land Surface Temperature (LST) is known to be the radiative skin temperature of the land surface from the satellite remote sensor. The LST is the estimation from Top-of-Atmosphere brightness temperatures of the infrared spectral channels of the satellite origin which is dependent on the material albedo vegetation, water bodies, soil moisture and other pavement materials. A mixture of vegetation and bare soil temperatures constitute the LST of a region because of their varied responses to changes in incoming solar radiation due to cloud cover and aerosol load of the atmosphere. The LST can influence energy variation between the ground, vegetation and the surface air temperature of a region [3].

Normalized Difference Vegetation Index (NDVI) is a satellite remote sensing procedure that quantifies vegetation of an area by measuring the difference between near-infrared (which vegetation strongly reflects) and red light (which vegetation absorbs). NDVI takes the ranges between -1 to +1. When NDVI has negative values it likely means that it is water; if close to +1 it is likely dense green leaves but when the value is close to zero it is very likely to be an urbanized area. Therefore this study mapped land surface temperature, land surface emissivity and normalized difference vegetation index of south-south coastal settlements of Rivers State Nigeria using satellite remote sensing in order to protect the area from life-threatening devastation of natural vegetation, water bodies and other natural features resulting to thermal discomfort of the settlements as the region is hosting accelerated multinational companies oil and gas activities [2].

2. MATERIALS AND METHODS

2. 1. Description of Study Location

South-South coastal settlements of Port Harcourt in Nigeria (Figure 1) cut across the local Government Areas (LGAs) of Obio/Akpor, Port Harcourt City LGAs, Eleme, Degema, Oyibo, Emohua, Etche, Okirika, IkwereL, Ogubolo and Asari-Toru LGAs respectively (Figure 2). These eleven LGAs form the region in which Port Harcourt and Obio Akpo LGAs are the center of urban growth. The settlements in the region have total population of 3,344,706 persons (Figure 3) in the south-south coastal area of Rivers State of Nigeria. The topography of the region is plain and divided by rivers, lakes, creeks, lagoons and swamps of different categories making it very prone to seasonal flooding which empties into the Atlantic Ocean. The study region maintains equatorial rainfall of 4700 mm and decrease 4,700 mm to 1,700 mm from the coast to the northern areas [5] [6]. The mean peak temperature is 32 °C which lowers to 26 °C from January to March as it is influenced by equatorial monsoon climate [7]. Natural vegetal and ecological appearance of the region is devastated by oil and gas exploitation and exploration resulting to excessive rainfall and flooding [8].

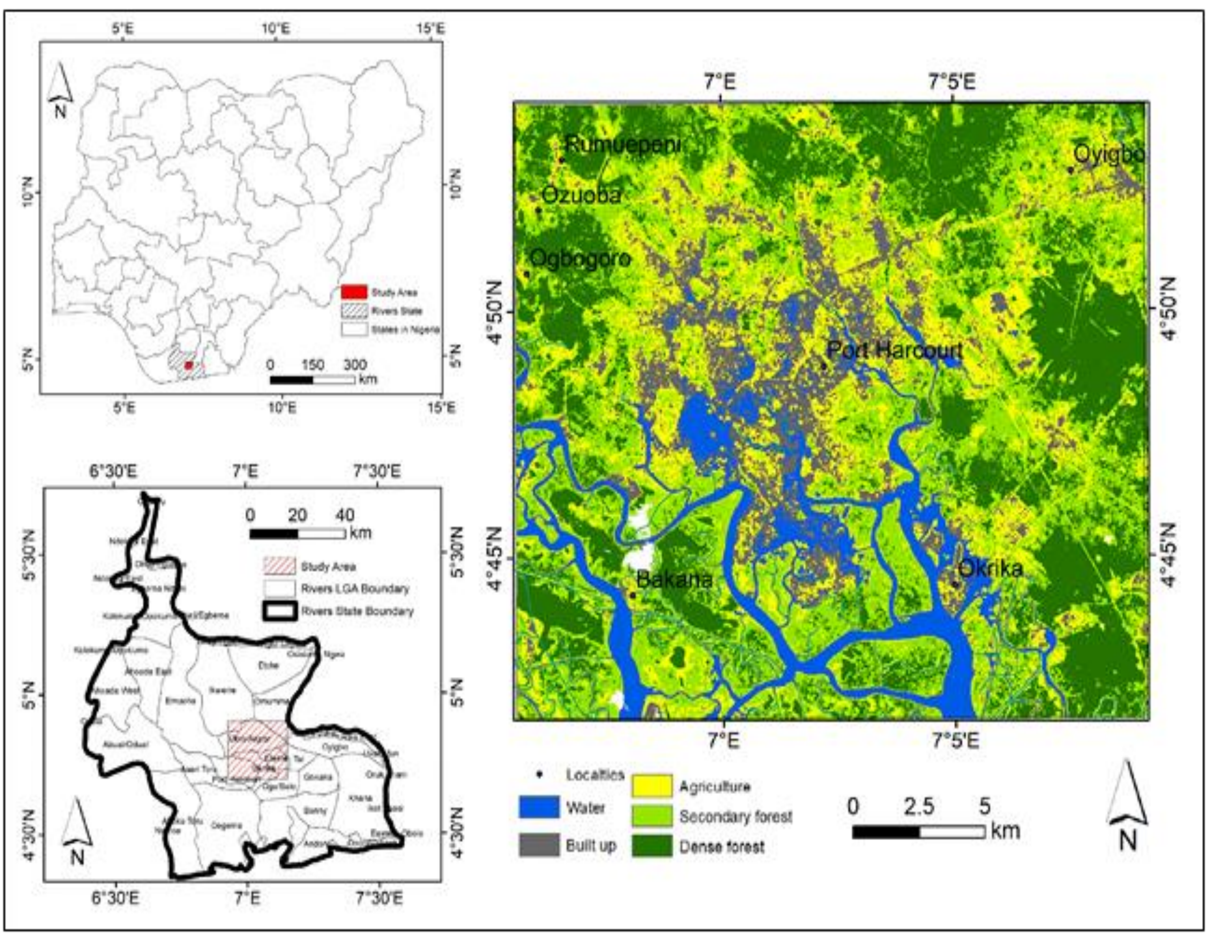

Figure 1. Settlements Study Area Coverage

Figure 2. Study Area LGAs of Rivers State in Nigeria

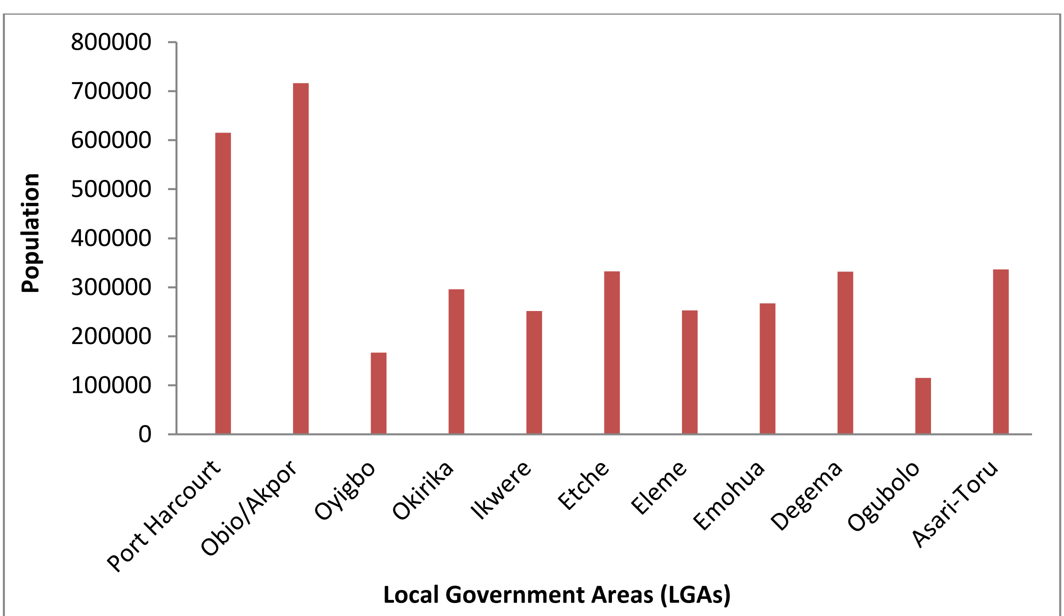

Figure 3. Study Population of LGAs in Rivers State of Nigeria

2. 2. Methods of Data Collection

The method of this study was adapted from [1]. Satellite data were retrieved by employing the algorithm for extracting LST from Landsat 5, 7 and 8 thermal infrared sensors of Google Earth Engine (GEE) and emissivity sources used for the estimation of LSE, LST and NDVI. GEE offers easy and instant access to satellite data, easy to compute and process directly on the platform without need for download. The Landsat 5, 7 and 8 satellites carry thermal infrared radiometers which allow data suitable for LST, LSE and NDVI estimation. The date of retrieval, satellite sensor and pathway are as in Table 1.

Table 1. Details of Landsat Data Retrieved

Dates of Retrieval	Satellite/Sensor	Reference System/Path/Row
01/01/16 - 30/01/16	GEE/Landsat 5/7/8	AoI
01/01/02 – 30/01/02	GEE/Landsat 5/7/8	AoI
01/01/86 – 30/01/86	GEE/Landsat 5/7/8	AoI

A Single Channel (SC) algorithm was used for consistency among the estimated LST, LSE and NDVI products and option of using emissivity from different points allows flexibility for the algorithm's performance. Among the three Landsat of 5, 7 and 8, it is only Landsat 8 that carries two thermal bands therefore the SC approach was used for consistency [9].

Using a SC approach, the LST (T_S) can be calculated from the radiance-at-the-sensor in a single band using the radiative transfer equation as follows:

$$B(LST) = Lsen - Lup - \tau \cdot (1 - \varepsilon) \cdot Ldown\pi\ \tau \cdot \varepsilon \quad \ldots\ldots (1)$$

where B is the Planck function, L_{sen} is the radiance-at-the-sensor, L_{up} is the thermal path radiance, L_{down} is the downwelling irradiance, ε is the surface emissivity and τ is the atmospheric transmissivity. In Equation (1) the L_{up}, L_{down} and τ were established to calculate the LST. They were also heavily dependent on the total water vapour in an atmospheric column (Precipitable Water (PW), which was easier to determine with the use of satellite data and LST estimation.

$$LST = Y \left[{}^{1}/_{\epsilon} . (\psi_1 . L_{sen} + \psi_2 + \psi_3) \right] + \dot{o} \ldots\ldots \quad (2)$$

where:

$$Y = \left[\frac{C_2 . L_{sen}}{T_b^2} \; . \; \left[(\lambda^4 . L_{sen})/C_1 + {}^1/_\lambda\right]\right] - 1 \quad \text{.......................(3)}$$

$$\dot{o} = -y . L_{sen} + Tb \text{........................ (4)}$$

$$\psi = C . \begin{Bmatrix} PW^2 \\ PW \\ 1 \end{Bmatrix} \rightarrow \begin{Bmatrix} \psi_1 \\ \psi_2 \\ \psi_3 \end{Bmatrix} \begin{Bmatrix} C_{11} & C_{12} & C_{13} \\ C_{12} & C_{22} & C_{23} \\ C_{31} & C_{32} & C_{33} \end{Bmatrix} . \begin{Bmatrix} PW_2 \\ PW \\ 1 \end{Bmatrix} \text{........................ (5)}$$

where: Planck's constant valuec1 is 1.19104 × 108 W μm^4 m^{-2} sr^{-1} and C2 is 14,387.7 µm K; λ is the central wavelength of the thermal band of the Landsat sensor in question; Lsen in W sr^{-1} m^{-2} μm^{-1}; Tb is the brightness temperature in Kelvin; C is the coefficients table, with cij derived by simulations using different atmospheric profiles and ψx is the coefficients weighted with PW.

In order to achieve the product of the Landsat Thermal Radiance-at-Sensor, the level 1T (precision Ortho-corrected) products for each Landsat stage provided by the USGS were orthorectified images of the thermal infrared radiance-at-the-sensor. These satellite products were available in the like of an image collection for each Landsat in the GEE catalogue. The images at different collection points possess digital number values, which were converted to radiance-at-sensor through GEE function using the scaling factors. Notably, the Landsat thermal bands were of varied spatial resolutions which have high reliability among different Landsat sensors as all derived products were resampled by the USGS up to 30 m × 30 m by applying a cubic convolution resampling method [10]. The Fmask is a good method for spotting clouds, cloud shadows, water surfaces and others in Landsat imagery. The red and near-infrared bands were used for the calculation of the NDVI, which was needed in order to estimate the NDVI-based emissivity and LST [10]. Three different sources of emissivity of ASTER and MODIS in GEE and NDVI-based emissivity estimated from Landsat red and near-infrared data were used. Fraction of vegetation cover (FVC) was estimated using Equation (6), by assuming the NDVI threshold for non-vegetated ($NDVI_{nonveg}$) and vegetated ($NDVI_{veg}$) surfaces to be 0.18 and 0.85, respectively. Emissivity was estimated using Equation (7), assuming a reference emissivity for non-vegetated (ε_{nonveg}) and vegetated surfaces (ε_{veg}) to be 0.97 and 0.99, respectively. The NDVI-based emissivity product was of 30m × 30m spatial resolution, matching exactly the Landsat thermal data [11]. The following formulas were applied:

$$FVC = \left[\frac{NDVI - NDVI_{nonveg}}{NDVI_{veg} - NDVI_{nonveg}}\right] 2 \quad \text{........................ (6)}$$

$$\epsilon = \epsilon_{nonveg} . \; (1 - FVC) + \epsilon_{veg} . FVC \quad \text{........................ (7)}$$

3. RESULTS AND DISCUSSION

Land surface emissivity increases from the center of the region to the outer areas (Figure 4). Emissivity was highest in the north-west and north eastern settlements but low in the southern region. Emissivity ranges from 0.98 to 0.99 with a difference of 0.01. The center of the region which is Port Harcourt and its close settlements had accelerated urbanization with high level urban pavement materials resulting to low emissivity. The settlements include Elekahia, Elelenwo, Mgbuoba, Diobu, Finema, Akpajo, Oyigbo among others. The settlements with moderate emissivity were Ebubu, Ekerenkoko (south); Okolama, Umuaka, Umuchoko (east); Igwuruta, Rumuoda, Umuechem (north-west). The settlements with high emissivity were Odogwa, Adanta, Alibroda, Rumuechem, Rumuohia (north); Umuekono, Chokota, Umuaka, Umuaturu (north-east) among others. The southern region is dominantly occupied by water bodies which empty in the Atlantic Ocean.

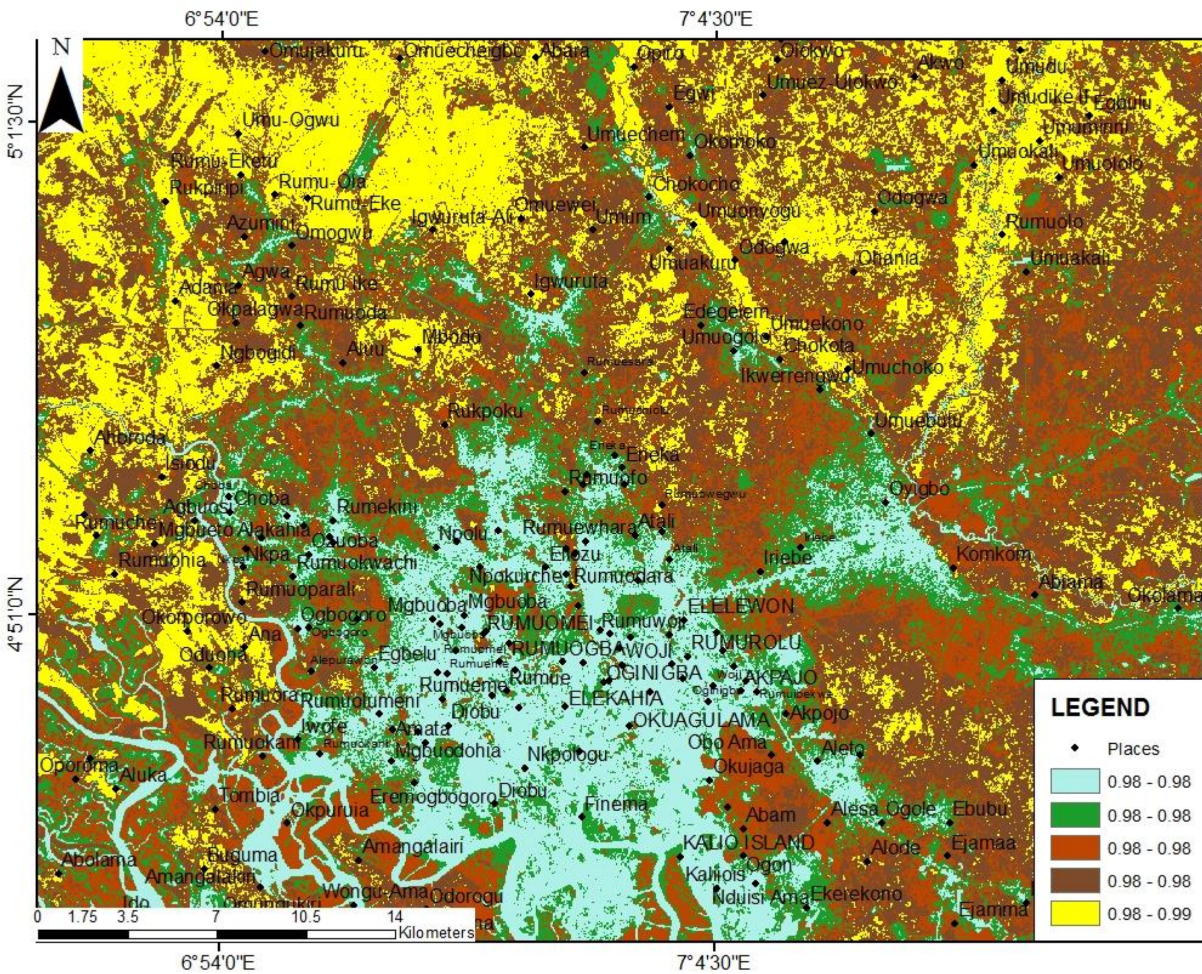

Figure 4. Land Surface Emissivity of the Region

The settlements with high emissivity were indication that they were surrounded by thick vegetation and were rural. These communities were likely to experience ambient surrounding with favorable thermal air and comfort. On the other hand, the settlements with low emissivity had the tendency to generate accelerated urban heat and discomfort due to increased removal of vegetal cover as absorber of solar radiation and latent heat phenomenon.

Land surface temperature decreases from center of the region to the outermost fringes (Figure 5). Land surface temperature ranged between 22.12 ºC to 35.99 ºC with a difference of 13.87 ºC across the region. The center of the region in Port Harcourt and other settlements such as Oginigba, Mgbuoba had land surface temperature varying between 29.19 ºC and 35.99 ºC.

Communities such as Oduohu, Mkpa, Rumuoparali (west), Rumuodo, Igkwerengwo (north) had land surface temperature ranging from 27.69 ºC to 29.16 ºC. Other settlements with land surface temperature ranged between 27.69 ºC and 24.96 ºC and were Ebubu, Nduisi (south); Ohanma, Umuololo, Akwo, Umudu (north-east); Umuogwu, Umuochigbe, Opiro, Umuakuru (north), Isiodu, Ambroda, Rumuahia (north-west) among others.

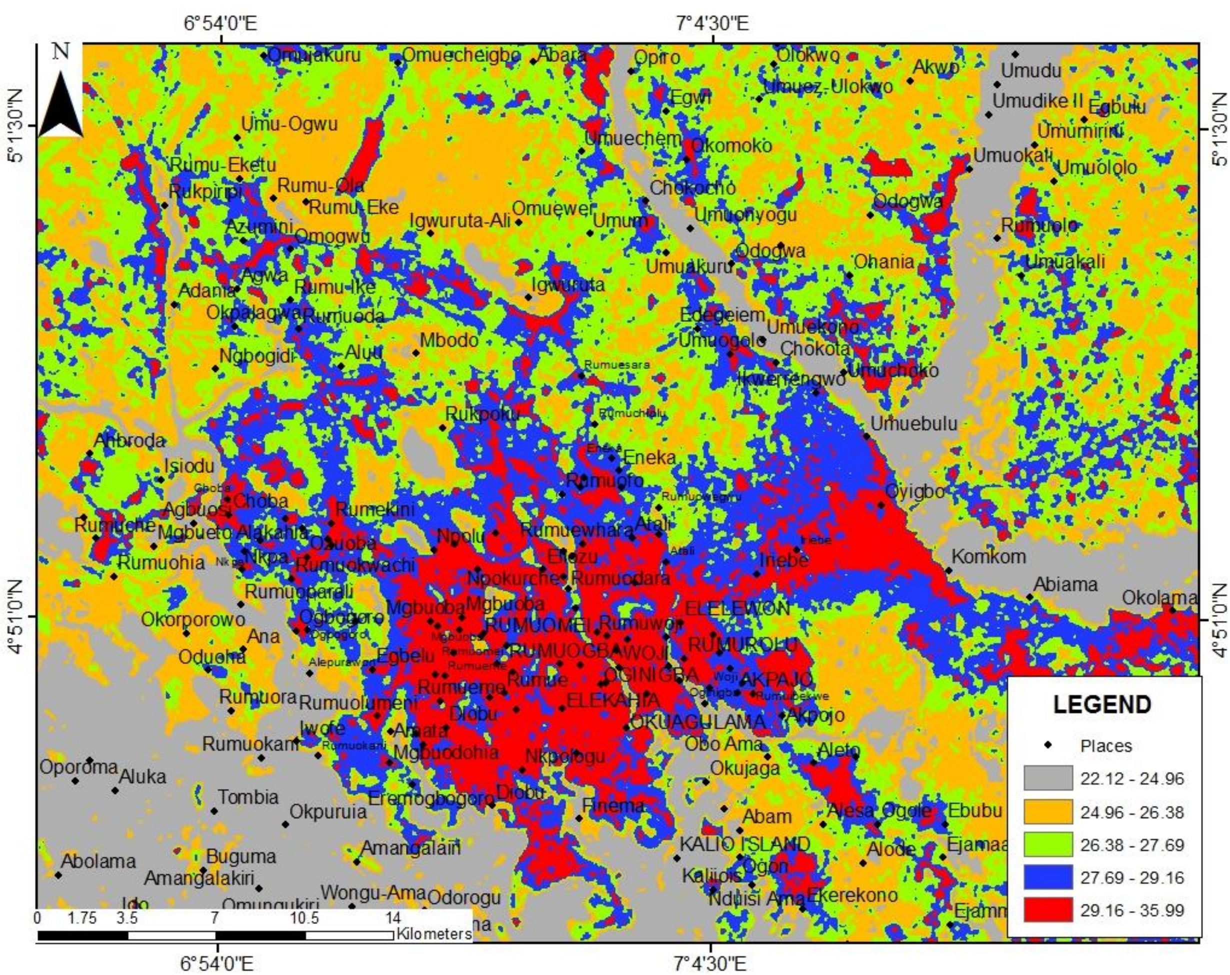

Figure 5. Land Surface Temperature of the Region

The southern part of the region had very low land surface temperature due to dominant water bodies and difficult terrain inhibiting urbanization and its urban pavement materials which were critical factors contributing to accelerated land surface temperature. In the region, high land surface temperatures were scattered across settlements of Aleto, Finema (south); Rumuolu, Odogwa, Abara, Umuechem, Rumuola, Ambroda (north) among others.

Land surface temperature was dominant at the center, eastern, western and northern settlements of the region. Areas with land surface temperature of 22.12 ºC to 24.96 were likely water bodies occupying in the south-west and north eastern segments of the region.

Normalized Difference Vegetation Index was low at the center (Figure 6). Normalized difference vegetation Index ranged between -0.54358 to 0.409327 and having the difference of 0.952907. Settlements with thick vegetal cover were located in the northern region such as Abara, Umujakwu, Egbulu among others. The southern part of the region had low normalized vegetation index such as Nduisiama, Amangalari, Aboloma etc.

However, low NDVI in the southern part of the region was contributed by water bodies occupying the area. Central settlements such as Rumuogba, Elekahia, Elelenwo among others had very weak NDVI due to urbanization and rapid population modifying the land surface area by replacing vegetal land cover with urban fabrics. The normalized difference vegetation index is one critical phenomenon that influences the thermal conductivity and performance of settlements land surfaces.

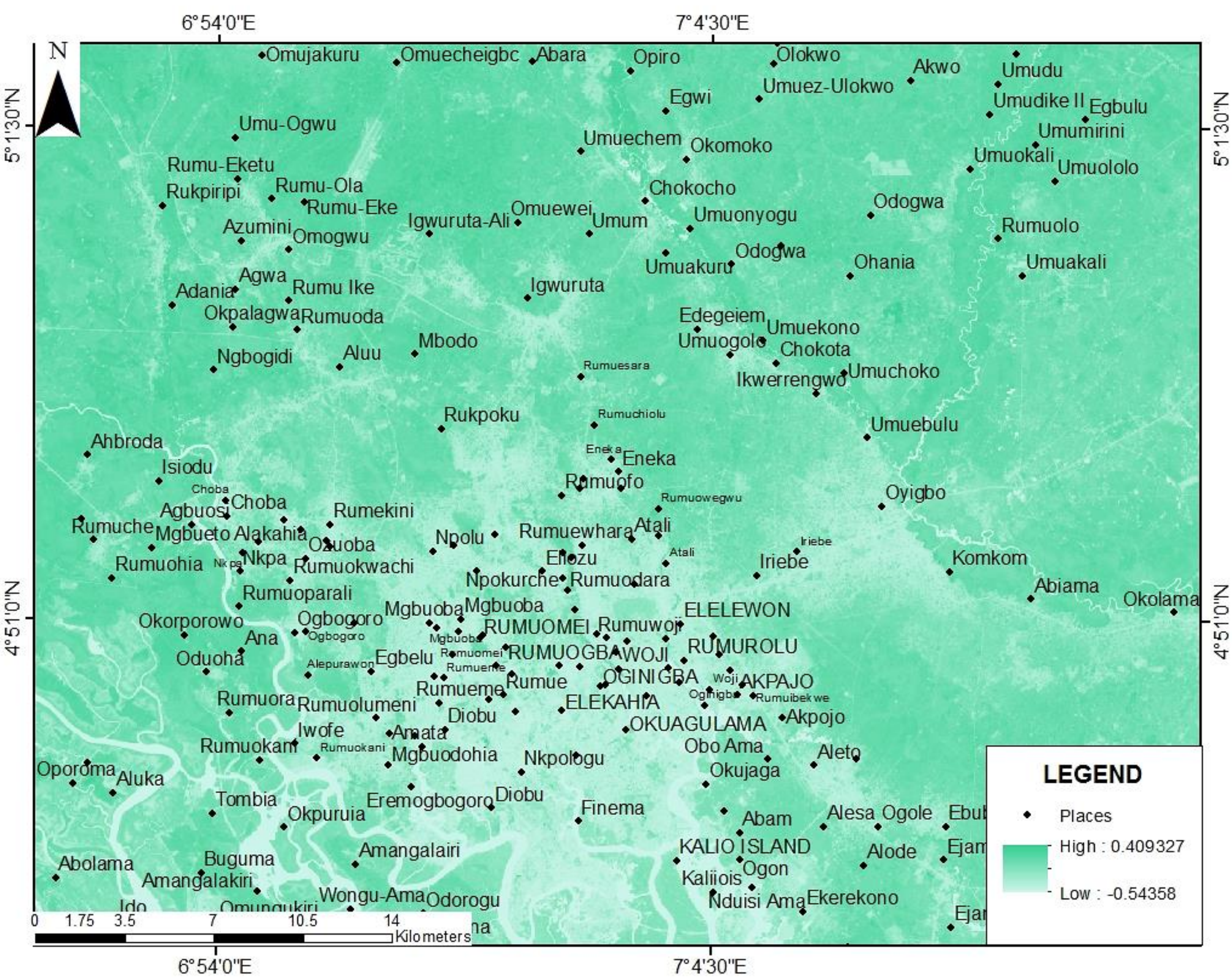

Figure 6. Land Surface Temperature of the Region

4. CONCLUSIONS

Land surface area of the south-south coastal settlements of Rivers State in Nigeria has undergone severe modification and alteration of vegetal cover by increased human activities especially in the central area. Emissivity in the region increased from the center to the rural settlements with values ranging 0.98 to 0.99 and difference of 0.01 indicating that there is increased modification of the regional land surface. In the region, land surface temperature decreased from the regional center to the rural settlements ranging between 22.12 ºC to 35.99 ºC with a difference of 13.87 ºC. However, LST was observed scattering in different settlement spots especially in the northern region showing that some settlements have started accelerating land surface modification activities. The normalized vegetation index showed -0.54358 to 0.409327 and having the difference of 0.952907 indicating poor regional greening. Thus, NDVI in the region increased from the regional center to the outskirts of the area. Urbanization in the settlements of the south-south region of Rivers State has extended severely to rural settlements. Therefore, regional planners should consider the extent of land modification of the area before approving further development activities and their location in order to protect the region from any thermal negative consequences.

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