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Evidence of Climate Change: Understanding the Land Surface Temperature of Akwa Ibom State

by

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Abstract

The quagmire of climate change is a global issue especially with rapid urban growth and development experienced in major cities over the past decades. This study was necessary to prove the evidence of the existence of climate change in the state within the last three decades, through understanding the land surface temperature of Akwa Ibom State. This study investigated Land Surface Temperature (LST) changes in Akwa Ibom State as an evidence of justifying climate change pandemic in the state. Landsat multispectral imageries covering the study area were acquired for three periods 1993-2003, 2003-2013 and 2013-2023. LST was derived using a single channel algorithm applied on the imagery thermal bands. Change statistics were computed to evaluate the transition dynamics of LST across the three decades under consideration. Result indicated that as of 1993, the surface temperature increased by between 1993-2003. Increase in surface temperature was also observed within the study area in 2013 compared to 2003. In 2023, the surface temperature keeps increasing above 40^{0}C with its minimum composition of 12.04^{0}C. This shows a steady increase in the land surface temperature of the area over decades. This increasing temperature status can be attributed to the reduction in vegetation in the progressive years due to high level of unguided anthropogenic activities and urbanization. This justifies the existence of climate change in Akwa Ibom State within the last three decades. It was thus recommended that government, NGOs and private individual should intensify efforts by taking deliberate measures like creating climate change awareness and policies on mitigation aimed at moderating urban growth while ensuring the conservation of urban greens spaces in the state and adaptation strategies in coping with the already changing climate.

1. Introduction

Evidence shows that climate change has increasingly become a global concern. Anthropogenic activities such as an upsurge of fossil fuel burning and inappropriate land use continue to emit greenhouse gases into the atmosphere. Urban sprawl which has to do with lop-sided and unplanned urban expanis characterized by low-density, transport-driven development, spreading out over large swathes of land towards the fringes of established urban centers. These unguided human activities have serious implications for the environmental sustainability, human wellbeing contributes generously to Changes in Climate. To substantiate the existence of climate change in Akwa Ibom, understanding the Land Surface Temperature is crucial. Geospatial techniques are among the most comprehensive and efficient approaches for developing land surface temperature variability maps. However, a combination of remote sensing data and field survey in a Geographic Information System (GIS) environment is necessary in assessing the dynamism in land surface temperature for decades. An understanding of this would aid in justifying the existence of climate change in Akwa Ibom State and help in developing policies that would ensure sustainable use of the environment.

Land Surface Temperature (LST) refers to the temperature of the Earth's surface as measured by remote sensing technologies, particularly satellites. This data is instrumental in understanding the changing climate dynamics and has become an essential tool for researchers and policymakers worldwide. One of the primary ways LST contributes to climate change justification is by revealing long-term temperature trends. Satellite-derived LST data allows scientists to observe and analyze temperature variations over extended periods. When aggregated, this information provides a comprehensive picture of how surface temperatures are evolving globally. Land Surface Temperature (LST) assesses the surface temperature at the canopy level for vegetation, at the soil surface for barren land, and at the surface layers for urban land cover types. Naturally, surface temperatures are expected to be higher in urban areas due to their physical properties than in vegetated and hydrated areas (Obiefuna *et al* 2018). In the application of GIS and remote sensing technology, thermal remote sensing collects data in the infra-red region of the Electromagnetic spectrum and is used to estimate surface temperature (Sekertekin and Bonafoni, 2020).

Land Surface Temperature (LST) analysis plays a crucial role in substantiating the reality of climate change, offering concrete evidence of global warming trends. The Intergovernmental Panel on Climate Change (IPCC, 2014) report, highlights the significance of LST as a key indicator for assessing climate change impacts and emphasize LST trends as compelling evidence, aiding in the comprehensive understanding and validation of climate change concerns. The IPCC report emphasizes that rising LST is consistent with broader climate change patterns. The documented increase in global average temperatures aligns with the predictions made by climate models, underscoring the reliability of LST data as a climate change indicator. The correlation between rising LST and other climate variables, such as sea level rise and changes in precipitation patterns, further strengthens the case for climate change impacts.

The analysis of LST is essential in justifying climate change, offering concrete evidence of temperature shifts. By examining satellite-derived LST data, researchers can discern warming patterns, urban heat island effects, and ecosystem impacts. This comprehensive approach enhances the credibility of climate change assessments, reinforcing the urgency for mitigation and adaptation strategies. The integration of LST data, as emphasized by IPCC findings, strengthens the scientific foundation for understanding and addressing the complex challenges posed by climate change.

The relationship between Land Surface Temperature (LST) and climate change is multifaceted, with LST serving as a valuable indicator and contributing factor in the broader context of global climate shifts. LST is key in understanding and quantifying the Urban Heat Island Effect. As urban areas expand, impervious surfaces and human activities cause local temperature increases (Datta, Prasad, and Mandla, 2017) This microscale warming, observed through LST analysis, exemplifies the localized impact of human-induced changes on climate. UHIs contribute to and are influenced by broader climate change patterns (Mehmood and Butt, 2019). Climate change, reflected in rising LST, affects ecosystems globally. Changes in LST influence vegetation health, alter growing seasons, and impact wildlife habitats. Studies utilizing LST data, such as those examining vegetation indices, contribute to understanding ecosystem responses to climate change. LST analysis plays a crucial role in assessing the impact of climate change on water resources. Variations in LST are linked to changes in evapotranspiration, affecting water availability and hydrological cycles (Okey, 1984).

2. Study Area

Akwa Ibom State is one of the states on southern Nigeria, located between latitude 4°32'34.165"N to 5°31'55.115"N and longitude 7°27'53.429"E to 8°19'6.578"E. It has 31 local government areas with its capital in Uyo (Figure 1). Annually, rainfall is about 2509 mm, with only three months having considerably low rainfall, from December to February. The average annual temperature is 26.4 °C and the yearly temperature range is approximately between 22 °C and 35 °C. The climate is classified as rainforest monsoon on the Koppen-Geiger climate classification system. Generally, the lowest minimum and maximum temperatures occur during the months from June to September, which is the peak period of the rainy season. The highest temperatures are usually recorded in the months of November to March, February/March being the peak of the dry season.

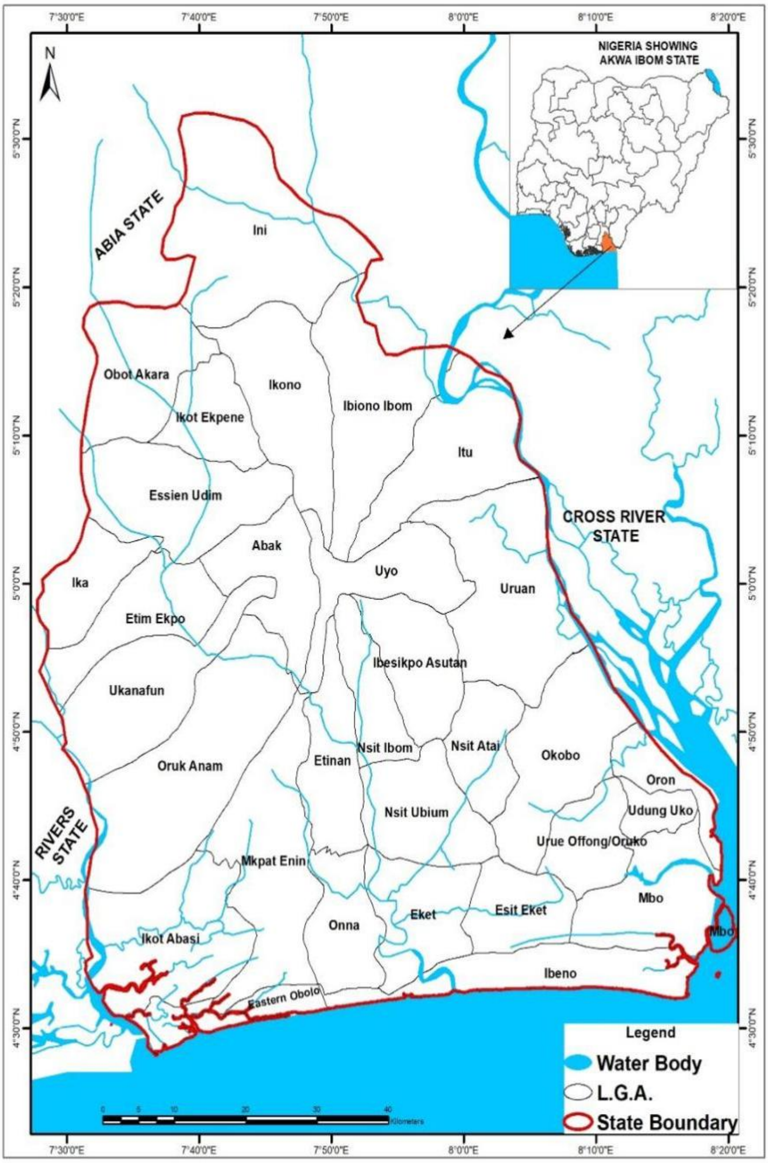

Figure 1: Location Map of Akwa Ibom State

3. Materials and Methods

To examine the evidence of climate change in Akwa Ibom State, a land surface temperature map of three decades (1993-2023) were taken into consideration to established if there is any significant changes/increase in the surface temperature as a major determinant of climate change. Decadal satellite imagery were acquire for 30years with 1993 as the baseline. This to covered the entire 31 local government areas of the state. The dataset for the analysis of land surface temperature is presented in Table 1.

Table 1: Dataset and Sources for the LST Mapping

S/N	Imagery	Sensor	Year	Spatial References
1	Landsat 5	Enhanced Thematic Mapper	1993	WGS84 UTM
2	Landsat 7	Enhanced Thematic Mapper Plus (ETM+)	2003	Zone
3	Landsat 7	Enhanced Thematic Mapper (ETM+)	2013	ZONE 32
4	Landsat 8	Landsat 8 OLI/TIRS (Operational Land Imager/ Thermal Infrared Sensor)	2023	

Analysis of Land Surface Temperature (LST) Changes in Akwa Ibom State

Studies in different parts of the world show a significant change in the surface temperature over time due to climate change. This study takes a look at 31 local government areas in Akwa Ibom State between 1993-2023 (30 years). The methodology in the analysis of LST follows the single-channel method (Oguz, 2013). The single-channel algorithm overcomes the drawback of having to obtain the near-surface air temperature needed for the effective mean atmospheric temperature computation in the MWA method. The LST was retrieved using the following expression applied to the thermal infrared region:

$$LST \circ C = \left(\frac{BT}{1+\left(W*\frac{BT}{p}\right)*In\,(e)}\right) - 273.15$$

Where:

BT - At-sensor brightness temperature

W - Wavelength of emitted radiance

ρ = h ∗ c/s (1.438 ×10 −2 m K) or 14,380

h - Planck's constant (6.626 ×10 −34 Js)

s - Boltzmann constant (1.38 ×10 −23 J/K)

c - Velocity of light (2.998 ×10 8 m/s)

e – Emissivity

To obtain the LST using the above equation, the effective at-satellite temperatures of the viewed Earth-atmosphere system is a physically useful variable. It can be obtained when the spectral radiance of the thermal bands TM and ETM + + under the assumption of unity emissivity are converted using the following expression:

$$BT = \frac{K2}{(\frac{K1}{L}\lambda+1)}$$

Where:

BT - Effective at-satellite temperature in Kelvin

$K1$ - Calibration constant 1 (w/(cm 2 ∗ sr ∗ μm))

$K2$ - Calibration constant 2 (K)

$L\,\lambda$ - Spectral radiance (watts/(m ² ∗ sr ∗ μm))

***Conversion of Digital Numbers to Top of Atmosphere Radian*ce**

The amount of solar radiation reflected by the Earth's surface and measured by the satellite sensors is modified by its interaction with the atmosphere. The raw digital numbers are not reflective of the true surface reflectance values. Therefore, atmospheric correction is required to bring the image to top of atmosphere (TOA) radiance, by removing atmospheric effects from satellite imageries. To obtain the effective at-sensor brightness temperature, radiometric corrections were carried out to obtain TOA radiances. First, the digital numbers were converted to spectral radiance using the following expression:

$$L\lambda = \left(\frac{LMAX\lambda - LMIN\lambda}{QCALMAX - QCALMIN}\right) * (QCAL - QCALMIN) + LMIN\lambda$$

Where:

$L\lambda$ - Spectral radiance at the sensor's aperture (Watts/ (m^2 * sr * μm))

QCAL - Quantized calibrated pixel value in DN

LMIN λ - Spectral radiance scaled to QCALMIN (Watts/ (m^2 * sr * μm))

LMAX λ - Spectral radiance scaled to QCALMAX (Watts/ (m^2 * sr * μm))

QCALMIN - Minimum quantized calibrated pixel value (corresponding to LMIN λ) in DN

QCALMAX - Maximum quantized calibrated pixel value (corresponding to LMAX λ) in DN

For Landsat TIRS, the following expression was applied to bring the thermal band (Bands 10) to TOA radiance

$$L\lambda = M_L Q_{cal} + A_L$$

Where:

M L - Band-specific multiplicative rescaling factor

A L - Band-specific additive rescaling factor

Q Cal - Quantized and calibrated standard product pixel values (DN)

Retrieval of Surface Reflectance Values

As pointed out by Sobrino *et.al* (2004), accurate estimation of Land Surface Emissivity (LSE) is vital to the retrieval of LST using any retrieval algorithm. An easy approach involves the estimation of LSE from the NDVI. On the other hand, to have accurate NDVI, more representative of the natural surfaces, surface reflectance values corrected for solar irradiance, solar zenith and atmospheric effects must be used. For TM and ETM + imageries, the relationship between the TOA radiance values and surface reflectance is given by the following expression.

$$P\lambda = \frac{\pi * L\lambda * d2}{ESUN\lambda * \cos\theta s}$$

Where:

π - Mathematical constant approximately equal to 3.14159

d - Earth-Sun distance in Astronomical Units

$E\lambda$ - Exo-atmospheric solar irradiance in each spectral band in Watts/ (m^2 * μm)

θs - Solar zenith angle (degrees)

TOA reflectance with a correction for the sun angle of Landsat 8 OLI imageries was obtained using the following expression.

$$P\lambda = \frac{Mp\ Qcal + Ap}{\sin\theta SE}$$

Where:
$\rho\lambda$ - TOA planetary reflectance,
θSE - Local sun elevation angle.
$M\,\rho$ - Band-specific multiplicative rescaling factor from the metadata
$A\,\rho$ - Band-specific additive rescaling factor from the metadata, and
$Q\,cal$ - Quantized and calibrated standard product pixel values (DN)

Furthermore, NDVI was a prerequisite for the calculation of LSE. The NDVI model was used to calculate emissivity across the different Landsat datasets, to avoid uncertainty in variations in the LST. The NDVI calculation is a combined operation between the red spectral band (R) and near-Infrared spectral band (NIR) as follows:

$$NDVI = \frac{NIR-R}{NIR+R}$$

Bands 3 and 4, located in the red and near-infrared regions, respectively for TM and ETM + imageries; and bands 4 and 5 located in the red and near-infrared regions for OLI were utilised for NDVI calculation.

Land Surface Emissivity

The ability of the surface to transform heat energy into measurable radiant energy is the surface emissivity of a body. Retrieval of LST is hinged on the ability of the land surface to convert heat energy into radiant energy. The emissivity (ε) is calculated according to the following expression.

$$\varepsilon = 0.004\,PV + 0.986$$

Where:

Pv is the proportional vegetation given by $[\frac{NDVI-NDVI\,min}{NDVImax-NDVImin}]^2$

4. Results and Discussion

Land Surface Temperature (LST) Mapping

As depicted in Figure 1, the LST of Akwa Ibom State as at 1993 ranges from 0.00-20.57°C. The lowest temperature was recorded along those communities in the coastal areas and in the inland areas with dense vegetation, i.e. places like Ikot abasi, Eastern Obolo, Ibeno, Mbo, Uruan, Ini, Ika Etim Ekpo and Udung Uko, while northwards, the temperature increased especially in semi-urban areas (Eket, Uyo, Ikot Ekpene, and Obot Akara) to a maximum temperature of 20.57°C. Coastal regions benefit from the moderating influence of large water bodies, such as oceans. Water has a higher heat capacity than land, leading to more stable temperatures. This moderating effect results in generally cooler conditions in coastal areas compared to inland regions. Also, coastal regions often experience sea breezes, providing additional cooling during the day. Sea breezes bring cooler air from the water to the land, influencing LST and contributing to the overall climate dynamics in these areas (Nichol, Wong and Lee, 2009).

Between 1993-2003, the surface temperature increased by 9°C as shown in Figure 2. In 2003, the lowest temperature was 1.25°C captured towards the coastline where the temperature reached its peak along the urban cities of Uyo, Ikot Ekpene and Eket, with a maximum of 29.26°C. Urban centers exhibited higher LST compared to their surrounding rural areas due to the UHI effect. The prevalence of impervious surfaces, reduced vegetation, and anthropogenic heat emissions in urban environments leads to localized warming. Again, urban centers release significant anthropogenic heat from various sources, including buildings, vehicles, and industrial activities. This additional heat contributes to elevated LST in urban areas, intensifying the UHI effect (Oke, 1982).

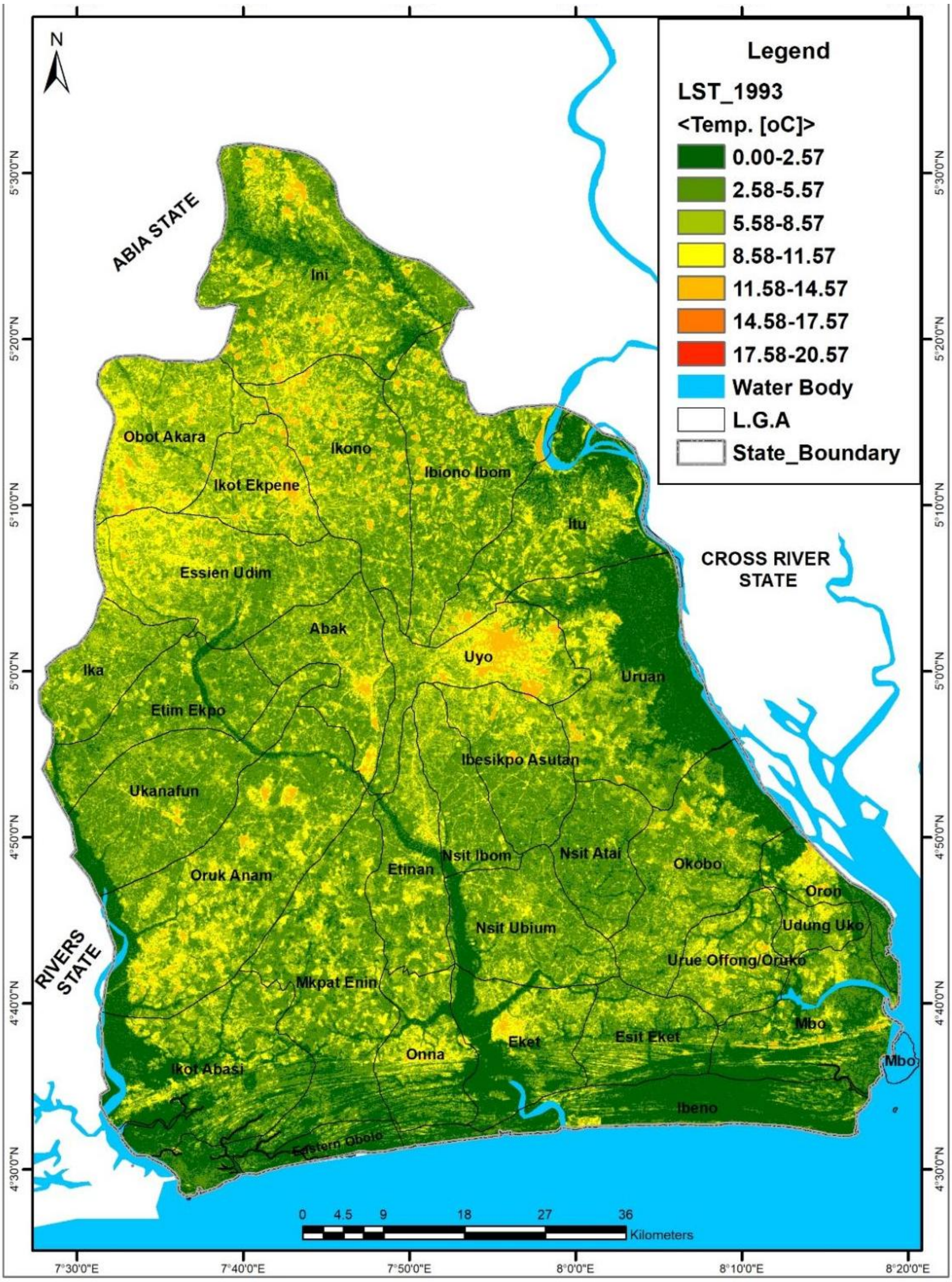

Figure 1: 1993 Land Surface Temperature Map of the Study Area

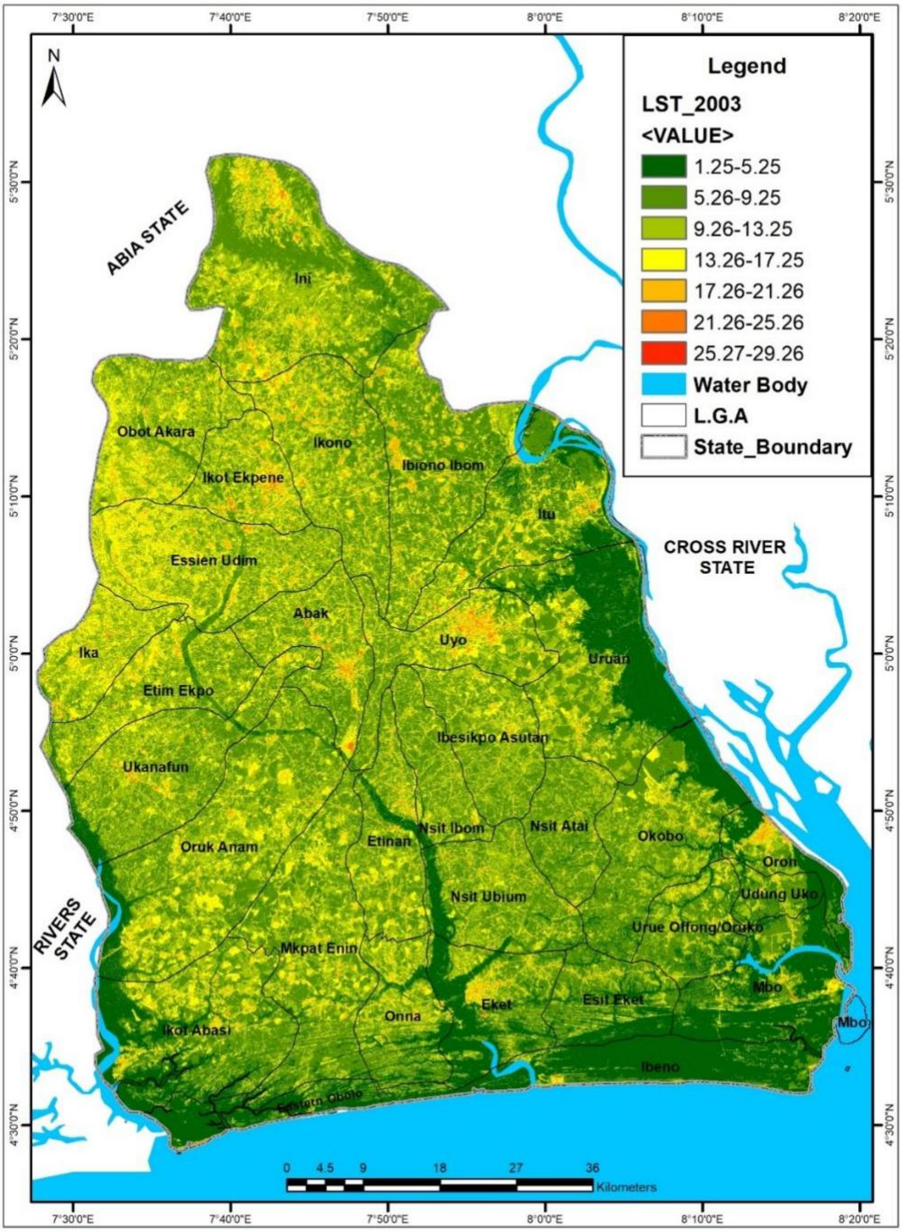

Figure 2: 2003 Land Surface Temperature Map of Akwa Ibom State

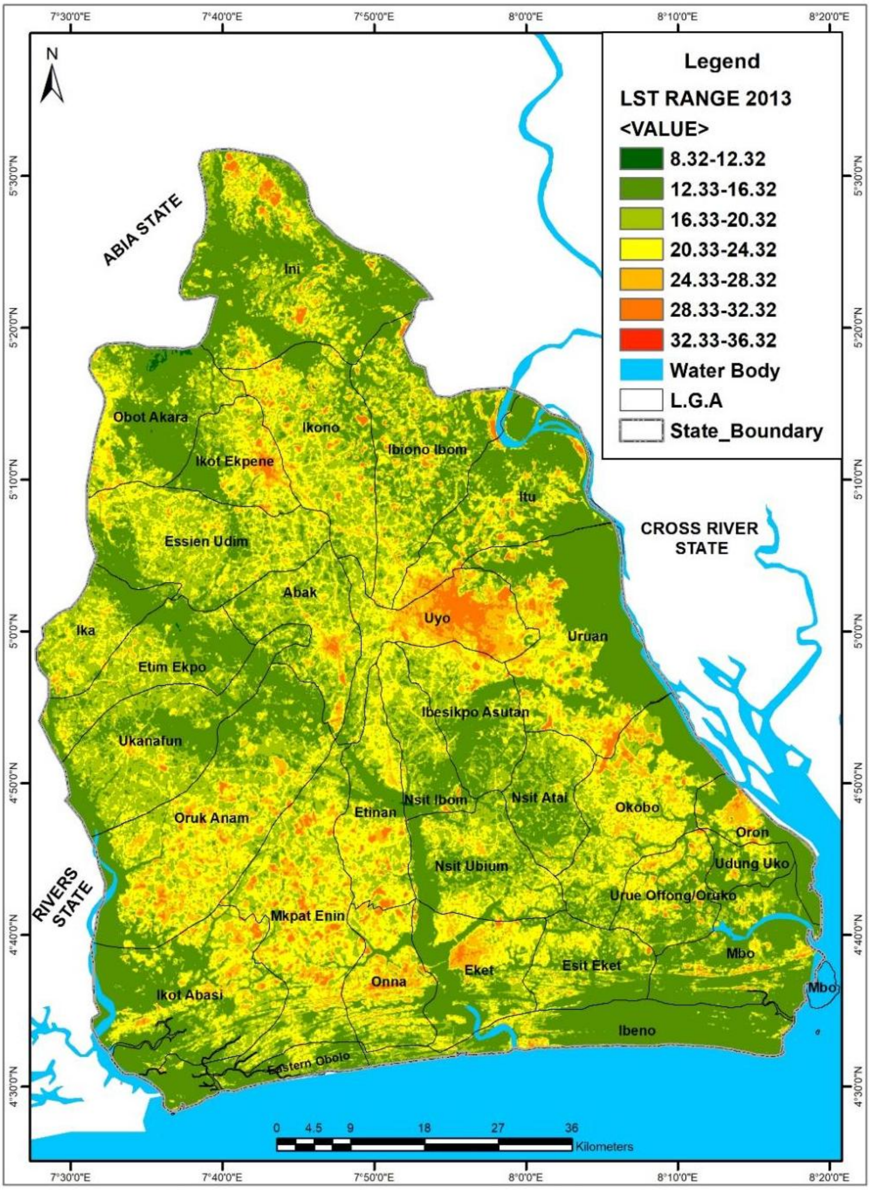

Figure 3: 2013 Land Surface Temperature Map of the Study Area

Figure 3 shows a continuous increase in surface temperature within the study area in 2003- 2013 compared to 1993 - 2003. The minimum temperature was 8.32^{o}C and a maximum of 36.32^{o}C. The temperature was high in urban centres, like Uyo, Ikot Ekpene and Mpat Enin while Eastern Obolo, Ibeno and Mbo located on the coastal experience a little increase in surface temperature, compared to the last decades.

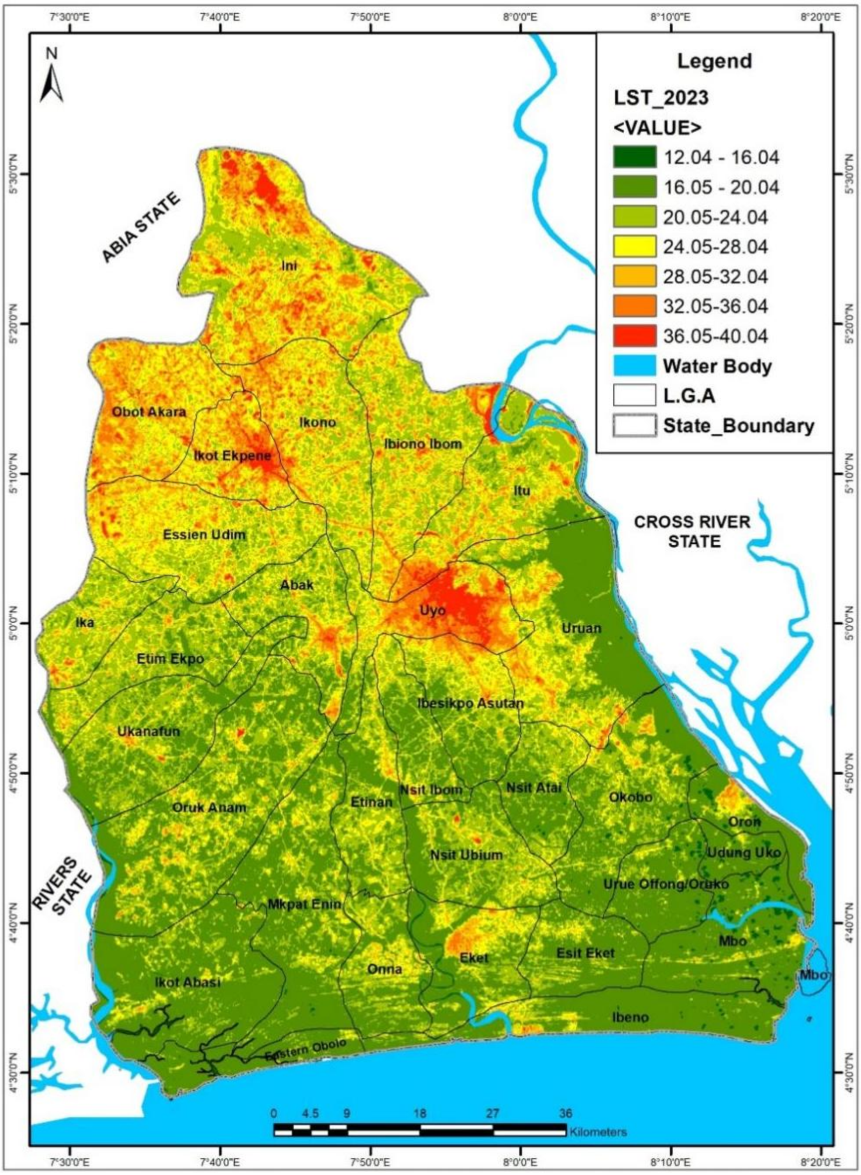

Figure 4: 2023 Land Surface Temperature Map of the Study Area

In Figure 4, the surface temperature increases above 40 °C with its minimum composition of 12.04°C between 2013 - 2023. This shows a steady increase in the land surface temperature of the area over the decades.

The analysis shows a summary of land surface temperature (LST) in Akwa Ibom State. As of 1993, the surface temperature ranged from 0.00-20.57°C. Between 1993-2003, the surface temperature increased by 9°C with a maximum of 29.26°C. Continuous increase in surface temperature was observed within the study area between 2003-2013 compared to 1993-2003 ranging between 8.32°C to 36.32°C. Between 2013-2023, the surface temperature keeps increasing above 40°C with its minimum composition of

12.04°C. This shows a steady increase in the land surface temperature of the area over decades with an average increase of 9.8°C.

In a nutshell, the land surface temperature of the study area has increased from 20.57°C to 29.26°C between 1993-2003, the trend increases from 29.26°C to 36.32°C between 2003-2013. Between 2013-2023, the temperature increased from 36.32°C to 40.04°C. This shows a cumulative increase in land surface temperature from 20.57°C to 40.04°C between 1993 and 2023. Thus, the temperature was observed to be very high in urban centres while the coastal area experience a little increase in its surface temperature, compared to the last decades. However, this increase may be attributed to the reduction in vegetations in progressive years due to high level of unguided anthropogenic activities and urbanization. This justifies the existence of climate change in Akwa Ibom State within the last three decades. Moreover, LST data aided in assessing the impact of climate change on ecosystems. Temperature changes influence vegetation growth, water availability, and the distribution of species. By monitoring LST, scientists can track shifts in ecosystems and identify areas vulnerable to climate-induced changes. This information is crucial for developing strategies to protect biodiversity and support ecosystem resilience in the face of ongoing climate challenges.

5. Conclusion and Recommendation

In conclusion, the integration of LST data into climate change assessments significantly enhances the scientific understanding of global warming. The IPCC's recognition of LST as a valuable tool underscores its importance in justifying climate change concerns. By providing a tangible and measurable indicator of temperature shifts, LST data reinforces the urgency for global efforts to mitigate climate change and adapt to its inevitable impacts. As technology continues to advance, LST analysis will remain a cornerstone in climate science, contributing to informed decision-making and effective climate policies.

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