Remote Sensing-Based Assessment of Vegetation and Land Surface Temperature Dynamics in Omo Forest Reserve and Obafemi-Owode Free Conservation Area

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ABSTRACT

This study analyzed vegetation variation and land surface temperature (LST) in Omo Forest Reserve and Owode Free Conservation Area over 24 years using GIS and Remote Sensing. Satellite images from 2000 and 2024 were processed using NDVI for vegetation assessment and the split-window algorithm for LST.

Results identified four land classes: Barren Land, Built-up Areas, Waterbody, Sparse Vegetation, and Dense Vegetation. In Omo, built-up areas, sparse vegetation, and shrubs/grasslands increased, while dense vegetation and waterbodies declined. In Owode, built-up areas and shrubs/grasslands expanded, whereas dense and sparse vegetation reduced significantly. LST in Omo ranged from 15.6°C–25.5°C (2000) to 16.1°C–28.5°C (2024). In Owode, it rose from 17.9°C–33.2°C (2000) to 18.8°C–35.3°C (2024). Temperature differences over 24 years were 0.9°C (minimum) and 2.9°C (maximum), with Owode experiencing a more pronounced rise. An inverse relationship was observed between vegetation and temperature, highlighting the role of vegetation in regulating LST. The study recommends afforestation in Owode to increase vegetation cover and mitigate temperature rise.

(Keywords: vegetative cover, land surface temperature, LST, vegetation assessment, remote sensing, satellite imaging)

INTRODUCTION

Forests in developing countries are under greater risk as the per capita land is limited (Himayah, *et al.*, 2019). Agricultural expansion in the forest land and illegal harvesting from the natural forest area are the major drivers of deforestation. Forest degradation in an alarming rate is a global issue now. Changes in vegetation can trigger weather variation (Adhyani, *et al.*, 2017) and its severity is dependent not only on the duration, intensity and spatial extent, but also on the demands made by human activities. Human activities are more impactful on the vegetation cover of terrestrial ecosystems thereby leading to environmental changes at local, regional and global levels (Kikon, *et al.*, 2016).

These environmental changes also include an increase in the surface temperature due to the transformation of vegetation covers to other land use forms such as bare surfaces, solid surfaces, and agricultural lands (Sahana, *et al.*, 2016). It has been predicted that the land surface temperature of most parts of the world, especially developing countries will increase geometrically due to the impacts of pollution and urbanization in the year 2050 (Hua and Ping, 2018).

Land surface temperature (LST) is a reflection of the energy flow in the interactions between the land surface and atmosphere as well as land surface and biosphere. The change in LST is an intuitive regional climate response to global climate change and has important research significance in agriculture, hydrology, ecology, environment, climate, and biogeochemistry (Zhao, *et al.*, 2016). Thermal infrared remote sensing provides a unique method for obtaining LST information at the regional and global scales since most of the energy detected by the sensor in this spectral region is directly emitted by the land surface (Jimenez-Munoz and Sobrino, 2008).

Remote sensing is an important tool to analyze the spatial and temporal changes of land coverage (Petropoulos, *et al.*, 2015). This is a potential technology for inventory and monitoring of world's natural resources (Goetz and Dubayah, 2011). Forest is an important natural component. It maintains the environmental and ecological balance (Liu, *et al.*, 2004) by preventing unwanted climate change and keeping ecosystems balance between human beings, plants, animals, and other abiotic components. Thus, forest cover changes and damages are eventually assessed by applying remote sensing technology (Zeng, *et al.*, 2016).

Remote sensing technology also obtains data that offers accurate geo-referencing information for harvest and analysis with comparatively low-cost but faster precise results (Lein, 2011). The land surface temperature represents the temperature of the earth's surface and is estimated from radiance measurements (Sekertekin and Bonafoni, 2020). Remotely sensed thermal infrared data analyze the large-scale temporal and spatial land surface temperature (LST) from local as well as global levels.

MATERIALS AND METHODS

Study Areas

The first study area is Omo Forest Reserve in Ogun State, Nigeria. Omo forest reserve is located between 6°35' to 7°05'N and 4°19' to 4°40'E in the South-West of Nigeria, about 135 km North-East of Lagos and 80 km East of Ijebu-Ode. It covers an area of about 130,500 hectares. The reserve was named after Omo Tree (*Cordia millenii*) which is an indigenous tree species in the area. It lies within the tropical lowland rainforest and houses about 8,000 species of plants.

It has a land area of 1,305.5km2 and is divided into Areas J1-J4 (519.3km2), Area J5 (565.8 km2), Area J6 (220.4 km2), and enclaves (65 km2) (Ola-Adams, 1999). Due to selective logging in the past, the forest is largely a secondary re-growth with pockets of primary forest in areas with restricted access, or where logging is difficult and along river courses (Bolaji, 2014).

The second study area is Obafemi-Owode Free Conservation Area is situated in Obafemi-Owode local government area (LGA). The LGA is situated within Ogun State, Nigeria, and had an estimated population of 334,349 as of 2017. It occupies an area of 104,787 hectares (1,410 square kilometres). Obafemi-Owode is located in the tropical forest zone and has two distinct climatic seasons: wet and dry.

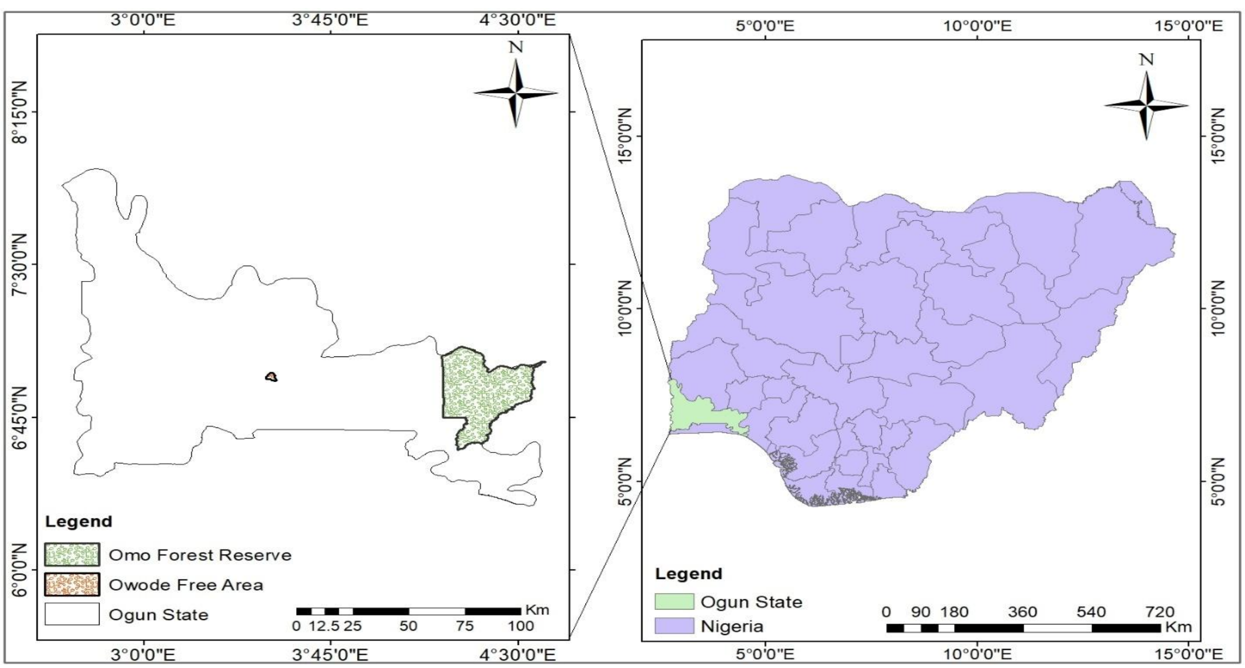

Figure 1: Map of the Study Areas.

METHOD OF DATA COLLECTION

A total of 4 Landsat images of the study area were downloaded from the earth explorer website (www.earthexplorer.usgs.gov) for the year 2000 and 2024. Two images for each study area and two different temporal periods. Each image was processed and the study areas were extracted from the images downloaded after which appropriate analysis was conducted on each of them.

DATA ANALYSIS

Vegetation Analysis

Analysis was conducted on the satellite images to see the spatial variation of the vegetation across the years in the study area using ARCGIS software. NDVI was computed for the period of the years studied which are 2000 and 2024 in order to see the variation of vegetation across those years. Vegetation maps were produced after the analysis. NDVI was computed for the study area using the formula

$$NDVI = (NIR-RED/NIR+RED) \qquad \textbf{(1)}$$

NDVI: Normalized Difference Vegetative Index

NIR: Near InfraRed (NIR)

RED: Red Band

Land Surface Temperature (LST)

The retrieval of LST followed the mono-window algorithm method for Landsat 7 images (Year 2000) and Split-window algorithm for Landsat 8 images for 2024 (Obiefuna, *et al.*, 2013). The key stages of the methodology are as follow:

Conversion of Digital Number (DN) to Spectral Radiance

The formula for converting DN in Landsat 7 to spectral radiance is given by Zareie et al. (2016):

$$L\lambda = ((Lmax-Lmin)/(QCalMax-QCalMin))\times(Qcal-Qcalmin)+Lmin \qquad \textbf{(2)}$$

where:
$L\lambda$ is spectral radiance at the sensor's aperture (W m−2 sr−1 μm−1),

Qcal is a quantized calibrated pixel value in DN,

Lmin is spectral radiance scaled to Qcalmin,

Lmax is spectral radiance scaled to Qcal¬max,

Qcalmin is the minimum quantized calibrated pixel value (corresponding to Lmin) in DN,

Qcalmax is the maximum quantized calibrated pixel value (corresponding to Lmax) in DN.

The formula to derive the spectral radiance for Landsat 8 is given by USGS (2015):

$$L\lambda = ML \times Qcal + AL \qquad \textbf{(3)}$$

where:
ML is Radiance multiplicative scaling factor for the band,

AL is Radiance additive scaling factor for the band.

The values for Lmin, Lmax, Qcalmin, Qcalmax, ML and AL were derived from the Landsat metadata file.

Conversion of Spectral Radiance to Top Of Atmosphere (TOA) Brightness Temperature

After calculating the spectral radiance ($L\lambda$), the TOA brightness temperature was calculated. The TOA approximation formula is given by Zareie. *et al*. (2016).

$$T = K2 / \log(1 + K1 / L\lambda) \qquad \textbf{(4)}$$

where:

T is TOA brightness temperature (K),

K1 (W cm−2 sr−1 μm−1) and K2 (K) are pre-launch calibration constants.

Conversion of Brightness Temperature to LST

The brightness temperature was subsequently converted to LST using the equation below (Hamoodi, *et al.* 2019):

$$S_T = T/(1+(\lambda \times T/(\rho) \log \varepsilon)) \qquad \textbf{(5)}$$

where:

S_T is LST (K)

λ is the Wavelength of emitted radiance (11.5 μm),

ε is Land surface emissivity (typically 0.95),

$\rho = h \times c / \sigma = 1.438 \times 10^{-2}$ m K

(σ = Boltz¬mann constant = 1.38×10^{-23} J K^{-1}, h = Planck's constant = 6.626×10^{-34} J s, c = velocity of light = 2.998 × 108 m s^{-1}).

Finally, the LST in Kelvin was converted to degree Celsius by subtracting from 273.15

RESULTS

Figure 2 showed the result of the state of vegetation in 2000 and 2024 of Omo Forest Reserve. It showed that in 2000, the study area was covered with vegetation and waterbody with little or no built-up areas and barren land in view. In 2024, however, the dense vegetations have reduced and more of sparse vegetation with more shrubs coupled with scattered traces of built-up areas were visible. Also, waterbody shrunk significantly in 2023 in the study area.

Figure 3 showed the vegetation map of Owode free conservation area in 2000 and 2024. The variation in vegetation is clearly observed on the map especially the built-up areas spreading across the area in 2024 while vegetation kept shrinking.

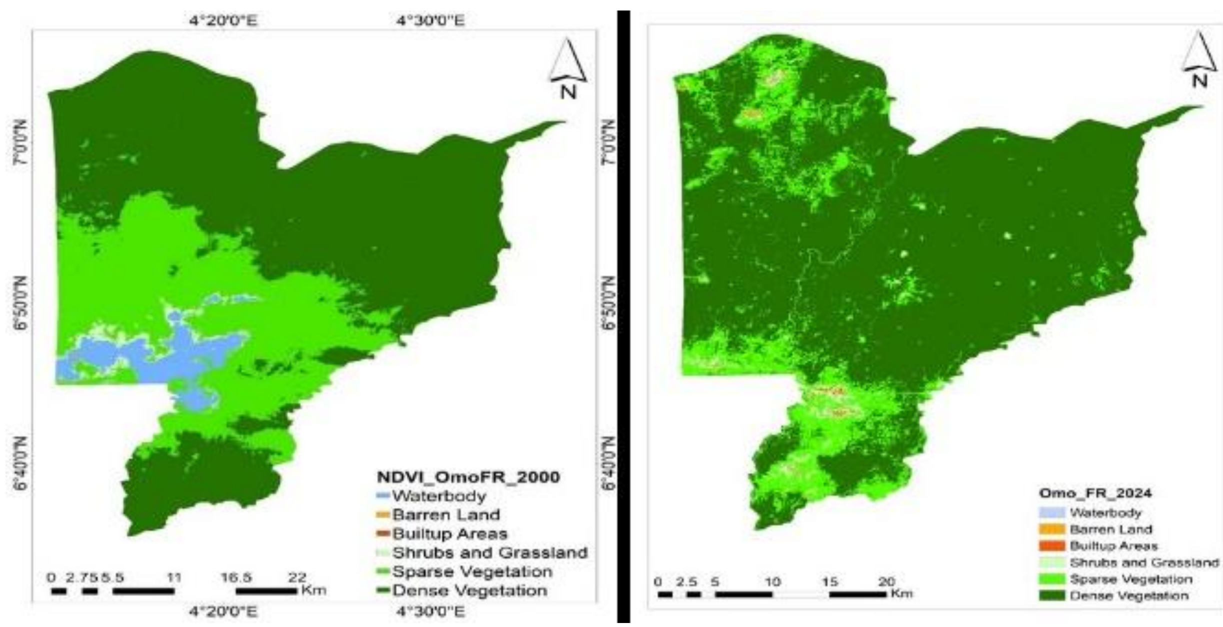

Figure 2: NDVI of Omo Forest Reserve in 2000 and 2024.

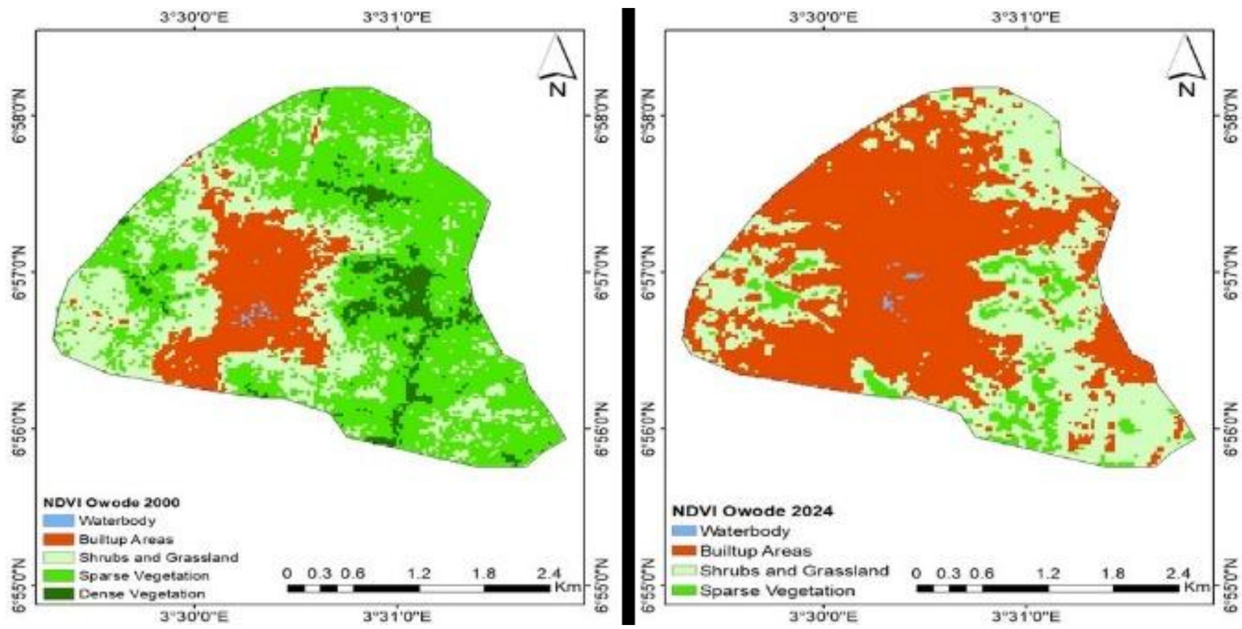

Figure 3: NDVI of Owode Free Conservation Area in 2000 and 2024.

Table 1: Table of NDVI Class of Omo Forest Reserve in 2000 and 2024.

NDVI Class	2000		2024	
	Area	Percentage	Area	Percentage
Builtup Areas	0.239607	0.02%	3.023189	0.225%
Dense Vegetation	826.2594	61.46%	261.0177	19.417%
Shrubs and Grassland	23.15508	1.72%	50.97649	3.792%
Sparse Vegetation	429.6194	31.96%	1029.226	76.565%
Waterbody	65.06652	4.84%	0.0099	0.001%
Grand Total	1344.34	100.00%	1344.253	100.000%

The result showed from Table 1 above revealed that built-up areas, sparse vegetation as well shrubs and grassland increased by 0.2%, 2.07% and 44.61% respectively while dense vegetation and waterbody reduced significantly by 42.05% and 4.84%, respectively, from 2000 to 2024.

This showed that the areas with dense vegetation were the major focus of deforestation in the study area while leaving other areas. In addition to this, the emergence of built-up areas also reflected which contributed the expansion of shrubs and grasslands in Omo Forest Reserve.

This finding corroborated Oguntoyinbo, *et al.*, who confirmed that the size of farmlands (indicating the shrubs and grasslands) in a community is related to the number of houses (or built-up areas) and households in that community.

Table 2: Table of NDVI Class of Owode Free Conservation Area in 2000 and 2024.

NDVI Class	2000		2024	
	Area	Percentage	Area	Percentage
Builtup Areas	1.94	15.7%	7.21	58.3%
Dense Vegetation	0.73	5.95%	0.00	0.00%
Shrubs and Grassland	3.55	28.7	4.37	35.42%
Sparse Vegetation	6.10	49.39	0.75	6.09%
Waterbody	0.02	0.15	0.02	0.16%
Grand Total	12.3	100.0	12.3	100.00%

The result in Table 2 showed that built-up areas, waterbody and shrubs and grasslands increased by 42.59% and 6.66% respectively whereas dense vegetation and sparse vegetation dropped significantly by 5.95%, 0.01 and 43.3% respectively.

Warner, *et al.*, (2016) confirmed that NDVI method of assessing and quantifying vegetal cover gives a higher validation accuracy.

The result showed that bulk of the land was utilized for building which was what informed vegetation degradation in the study area. Trees were visibly cleared in Owode for building construction while little were left for shrubs and grassland which comprises of agricultural farmlands. This result agrees with Twumasi, *et al.*, 2021 who noted that urbanization impacts on vegetation.

Figure 4 showed the land surface temperature of Omo Forest Reserve in the year 2000 and 2024. In 2000, the value ranged from 15.3℃ to 26.5℃. The colors variation on the map showed the temperature variation across the study area. Areas with the lowest temperature were represented with blue color while areas with the highest temperature were depicted with brown color. In 2024, the value ranged from 16.1℃ to 28.5℃. The colors variation on the map showed the temperature variation across the study area. Areas with the lowest temperature were represented with blue color while areas with the highest temperature were depicted with brown color.

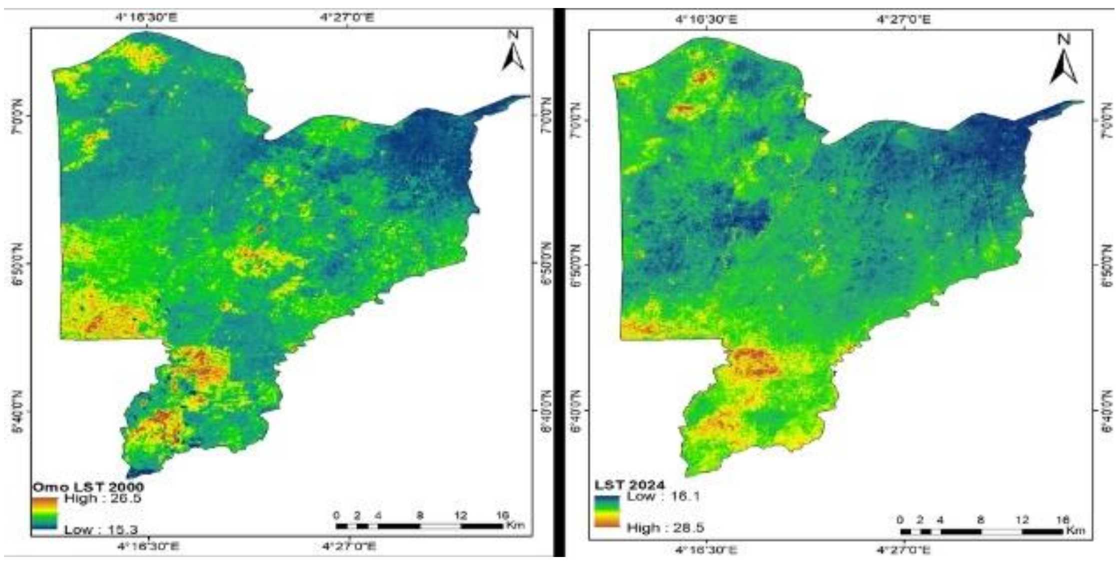

Figure 4: Land Surface Temperature of Omo Forest Reserve in 2000 and 2024.

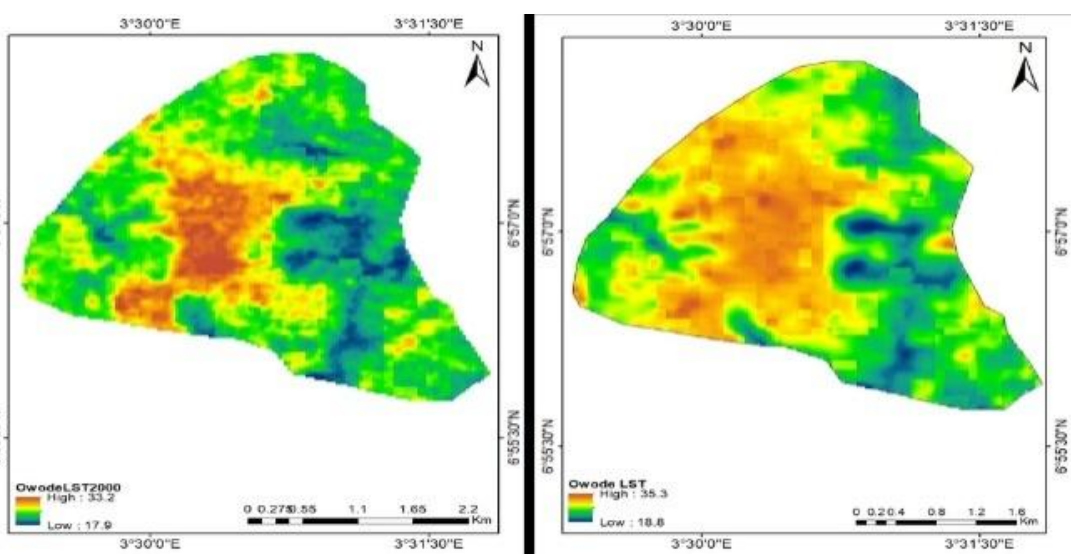

Figure 5: Land Surface Temperature of Owode Free Conservation Area in 2000.

Figure 5 above showed the map of Owode free conservation area represented with different colors on the map each representing variations in temperature. Blue and brown colored areas are locations with the lowest and highest temperature respectively while the green and yellow-colored areas are locations with mid-temperature areas. The land surface temperature showed that the temperature range was between 18.8℃ and 35.3℃.

Table 3: Correlation Table for NDVI and Land Surface Temperature.

Data	2000		2024	
Layer	NDVI	LST	NDVI	LST
NDVI	1.00	-0.672	1.00	-0.931
LST	-0.672	1.00	-0.931	1.00

The correlation table showed the relationship between vegetation and land surface temperature. It showed that in the year 2000, the relationship between NDVI and LST was 67.2% while in 2024, it had risen drastically to 93.1%. This implied that vegetation contributed about 67.2% to the land surface temperature in 2000 while in 2024, it increased significantly by 25.9%. This implied that vegetation changes contributed more to change in land surface temperature in 2024.

DISCUSSION

In Omo forest reserve, the rise in dense vegetation is indicative of effective conservation and reforestation initiatives, which has translated into enhanced biodiversity and higher carbon sequestration. The reforestation exercise was confirmed by the staffs of the forest reserve orally.

In Owode Free conservation area, natural vegetation is being replaced by urbanization, which is growing quickly. Deforestation was clearly visible, as dense vegetation disappeared. Halidu, *et al.*, (2020) noted in his findings that one of the major drivers of deforestation is building and construction of house alongside urbanization.

In Omo Forest Reserve, land surface temperature ranged from 15.6°C to 25.5°C and 16.1°C to 28.5°C in 2000 and 2024, respectively. This revealed that there was an increase of 0.5°C in the minimum temperature range, while in the maximum temperature range, there was a 3°C increase within 24 years.

In Owode Free Conservation Area, temperature ranged from 17.9°C to 33.2°C in 2000 while in 2024, it varied from 18.8°C to 35.3°C. The minimum temperature range difference within 24 years was 0.9°C while the maximum temperature range value was 2.9°C.

This result showed that some areas in Omo forest reserve and Owode free conservation area experienced higher temperature and as a result became warmer than it was 24yrs ago. The portion of land that experienced higher land surface temperature were areas with bare land and built-up areas.

However, Omo had much vegetation and the locations with high temperature were scanty on the LST map while in Owode, locations with high temperature covered a sizeable portion of the map. Fashae, *et al.*, (2020) deduced that decrease in vegetation over an area will inadvertently lead to temperature increase, which is also evident from the result obtained in this study. This also confirmed what Yue et al., (2024) documented in his findings when he noted that land surface temperature is closely related to land surface characteristics.

Abubakar, *et al.*, (2021), who assessed the land use and land cover change, also noted that the increase in human activities brought marked reduction in vegetation, which has been replaced with other land use features like barren land and built-up areas. Falloon, *et al.,* (2012) confirmed that global warming increase is associated with vegetation reduction.

The combined result of the vegetation and the land surface temperature in the study area revealed that the variation in vegetation had an inverse or negative impact on the land surface temperature. This implied that the more the vegetation in an area, the lower the temperature becomes, while the lesser the vegetation becomes, the higher the temperature, which thus showed that an inverse relationship exists between vegetation and temperature (Yue, *et al.*, 2024). The results showed that there was a general increase in the temperature of Omo Forest Reserve and Owode Free Conservation

Area, confirming the impact of climate change as well as land use impact.

CONCLUSION

The research was carried out to know the state of Omo Forest Reserve and Owode Free Conservation Area from 2000 to 2024 using the Geographic Information System (GIS) and Remote Sensing approach through the analysis of satellite images. The study revealed that there were four land classes in the two study areas but with varying proportions which are barren land, built-up areas, waterbody, sparse and dense vegetation. It further revealed that Owode Free Conservation Area was heavily deforested while Omo Forest Reserve still maintained its vegetation status although relatively few changes were observed. Furthermore, Omo Forest Reserve is a secured area and by implication contributed to the vegetation state while on the other hand, Owode Free Conservation Area was obviously degraded due to the policy that governed it.

The Land Surface Temperature result showed that both areas had a significant increase in land surface temperature after 24 years. Also, Owode is getting hotter even as the temperature variation gets higher. There was also an observed relationship between temperature and vegetation. The higher the vegetation over an area, the lesser the temperature and vice versa.

RECOMMENDATION

The study recommends that

1. Stricter policy should be made to protect Owode Free Conservation Area
2. Afforestation projects should be introduced in Owode to increase vegetal cover over the forest
3. Land use should be regulated in Owode.

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