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# Evaluation of Effects of Limestone Mining on Land Covers in Okpella, Nigeria

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***Abstract***

Sustainable development is one that meets the needs of the current generation without compromising the ability of future generations to meet their own needs. The geospatial approach was used to evaluate the degree of sustainability of the mining operations in Okpella, Nigeria. 2011, 2016, and 2021. Normalized Difference Vegetation Index (NDVI) revealed mean values of 0.36557, 0.32961, and 0.41674, respectively. This vegetation cover of shrubs, grassland, and relatively healthy vegetation remained after the mining activities in the research area. The surface water in the area is under stress due to the anthropogenic activities like mining, which is known to demand large amounts of water for mineral recovery and processing. Additionally, the Normalized Difference Moisture Index (NDMI) revealed that the mean values for the years 2011, 2016, and 2021 were, respectively, 0.01415, -0.32949, and -0.15331. The research area's NDMI showed little water stress. The Soil Moisture Index (SMI) for 2011, 2016, and 2021 indicated a moderate moisture content in the soil (0.73682, 0.58690, and 0.58897, respectively). The Land Surface Temperature (LST) data revealed that the LST levels (from 28.623 oC to 32.525 oC) had been rising. During the three years under study, aquatic bodies had the lowest LST values, whereas bare land and populated regions had the greatest LST values. According to the results of the NDVI, NDMI, and MNDWI investigations, this increase was caused by the intermediate vegetation levels and extremely low surface water. It is necessary to develop an environmental policy to mitigate the negative consequences of mining on land covers.

## 1. Introduction

The structure and function of ecosystems within the earth system are greatly impacted by the changes caused by humans to the terrestrial surface of the planet, and these effects have far-reaching implications for the human welfare [1]. Every terrain's pattern of land use reflects of the many physical processes affecting the Earth's surface [2]. There is a direct correlation between changes in the landscape and changes in the land use, as well as the human activity [3]. The mining sector is made up of a diverse spectrum of businesses, from low-tech, artisanal activities to major, global corporations that extract, and process minerals using the cutting-edge technologies [4]. Unquestionably, the mining process has increased the wealth and job opportunities in the mining communities, but it has also significantly degraded the environment, and undermined the traditional social norms [5]. The use of heavy equipment in modern mining processes can result in significant changes to the land cover in terms of both the ecology and hydrology [6]. Open-pit areas are not only affected vegetation, soil, and terrain, but has created big pits, transit sites, solid waste, and changed in Land Use /Land Cover (LULC) [7]. The direct negative effects of the mining activities can be an unsightly landscape, loss of cultivated land, loss of forest and pasture land, and the overall loss of production [8]. Large-scale disruptions brought about by mining have a detrimental effect on the

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soil, plants, and animals. It can also lead to habitat loss [9]. Mining, particularly continuous surface mining, has a major impact on the landscape both during and after the active mineral extraction [10]. Remote sensing data and aerial pictures are utilized to record continuous alterations in the structure of the terrain [11]. The environmentalists and managers of natural resources can now obtain a multi-temporal data, and identify periodic changes by the combining Remote Sensing (RS) and Geographic Information System (GIS) technologies [12]. The use of remote sensing for environmental monitoring is becoming more and more significant in the study of different ecosystem characteristics at the local, regional, and global levels [13]. In order to assess the effects of mining on the Okpella's natural land covers for environmental sustainability; the research work uses geospatial tools. Using land cover indices, it measures the effects of mining operations on the study area's plant, water, and soil dynamics.

### 1.1. Limestone mining in Okpella

Limestone is a carbonate sedimentary rock that mostly consists of calcium carbonate with magnesium carbonate, as a minor component in certain circumstances [14]. One of the most valuable industrial rock raw materials is limestone. It is a raw element that changes the direction of manufacturing in numerous sectors. Because it is used to make cement, limestone is one of the most important minerals collected from Nigeria. The open-pit method of mining, which is notorious with widespread negative impact on the adjoining environments, is adopted for mining limestone in the studied area. Crop productivity in Okpella has been negatively impacted by environmental degradation brought on by limestone excavation, as this has sealed off plant leaves, and decreased the rate of photosynthesis [15; 16].

### 1.2. Land covers in mining terrain

The term "land cover" describes the surface cover of the earth including any bare soil, water, urban infrastructure, and vegetation. These are the innate or fundamental components of the environment that connect and influence various local, regional, and global environmental levels.

The term "land covers" refers to the wide variety of surfaces and vegetation that can be found in areas where the mining operations take place. Because of the mining of materials like granite and limestone, these places undergo substantial changes. Changes in the land cover brought about by mining may have an impact on the local community, ecosystems, and environment.

Land cover transition in mining areas is a significant environmental issue that calls for thorough planning, ethical mining methods, and reclamation efforts when mining is completed. It is crucial to strike a balance between the financial benefits of mining and the protection of ecosystems, biodiversity, and community well-being in order to guarantee sustainable land use in the areas affected by mining [17].

### 1.3. Mining and sustainable development goals

Nigeria is among the 193 UN members that are signatories to the 17 Sustainable Development Goals (SDGs). These UNs SDGs include a broad range of global targets intended to address various social, economic, and environmental issues. The extraction of minerals from the earth presents opportunities, challenges, and risks to sustainable development [18]. The mining industry inserts itself in this context by its global presence and frequent location within ecologically sensitive and less developed areas [19]. There is congruency between the mining activity and the SDGs [20; 21]. The industrial mining projects can play an important role in global sustainable development if associated health risks are minimized and opportunities maximized [22]. The mining activities can also contribute to sustainable development, particularly to its economic dimension [18].

The SDGs, especially SDG 6 (clean water and sanitation), 7 (affordable and clean energy), 11 (sustainable cities and communities), 12 (responsible consumption and production), 13 (climate action), 14 (life below water), 15 (life on land), and 17 (partnerships for the goals) are highly imperative and relevant in the mining industry. It has been established that mining has direct connections to many of the 17 SDGs in the context of the current global development agenda [23]. Similarly, many of SDGs are directly linked to the environment, with the overarching aim of engendering environmental sustainability and tackling immediate and imminent environmental issues. They relate to and are imperative for fostering sustainable, and responsible for the development of the mining sector. Given its importance to the economies of many developing countries, and the direct proximity of many of its activities to people and natural environments, the mining industry has a major role to play in contributing to the realisation of the SDGs [24].

## 2. Materials and Methods

This section outlines the approach used to assess the impact of limestone mining on land cover in Okpella, Nigeria. Remote sensing techniques were applied to analyse the vegetation, water, soil moisture, and surface temperature changes using indices such as NDVI, MNDWI, NDMI, LST, and SMI.

### 2.1. Geology and description of studied area

The studied area is located on the BUA limestone mining facility in Okpella, Edo State Nigeria. The mining operations began in the studied area in 2014. It is generally called the BUA Cement OBU Plant. Okpella is located in the South Western Nigeria's basement complex and cretaceous to recent material. In the northeastern region of Edo State, Nigeria, Okpella is situated between latitudes N07$^0$ 16' and N07$^0$ 22' and longitudes E06$^0$ 18' and E06$^0$ 23' (Figure 1). It is within the eastern part of Igarra schist belt, which is part of the Precambrian basement complex of southwestern Nigeria (Figure 2). The region is part of the Anambra and Afikpo basins, which together created the sedimentary cycle [16]. The region represents the southwestern Nigerian Basement Complex's eastern extension of the Upper Proterozoic Igarra Schist Belt. The area comprises a variety of low to medium-grade metasedimentary rocks underlain by granitic gneiss, both of which were intruded by charnockites, granites, pegmatites, dolerite dykes, and quartz veins [16, 17]. The Paleoproterozoic granitic gneiss outcrops in the northeastern part of the Okpella, it is light grey, medium- to coarse-grained, granoblastic to weakly foliated with moderately thick mineralogical bands of light and dark-coloured minerals. The light bands are composed of felsic minerals such as quartz, potassic, and plagioclase feldspars, while the dark bands are dominated by biotite, hornblende, and other opaque minerals. The metasedimentary rocks of Neoproterozoic age in the area include garnet-biotite schist, calc-silicate gneiss and marble, quartzite and banded iron formation.

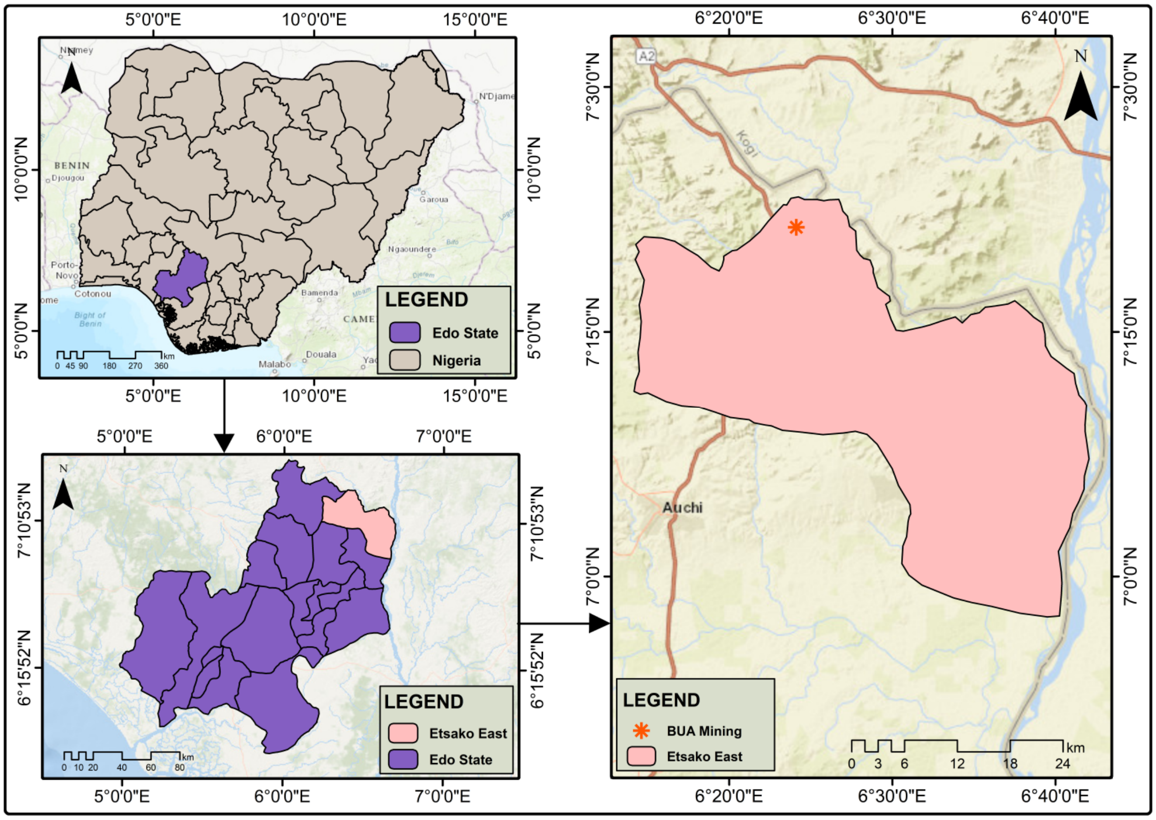

**Figure 1. Map of the studied area.**

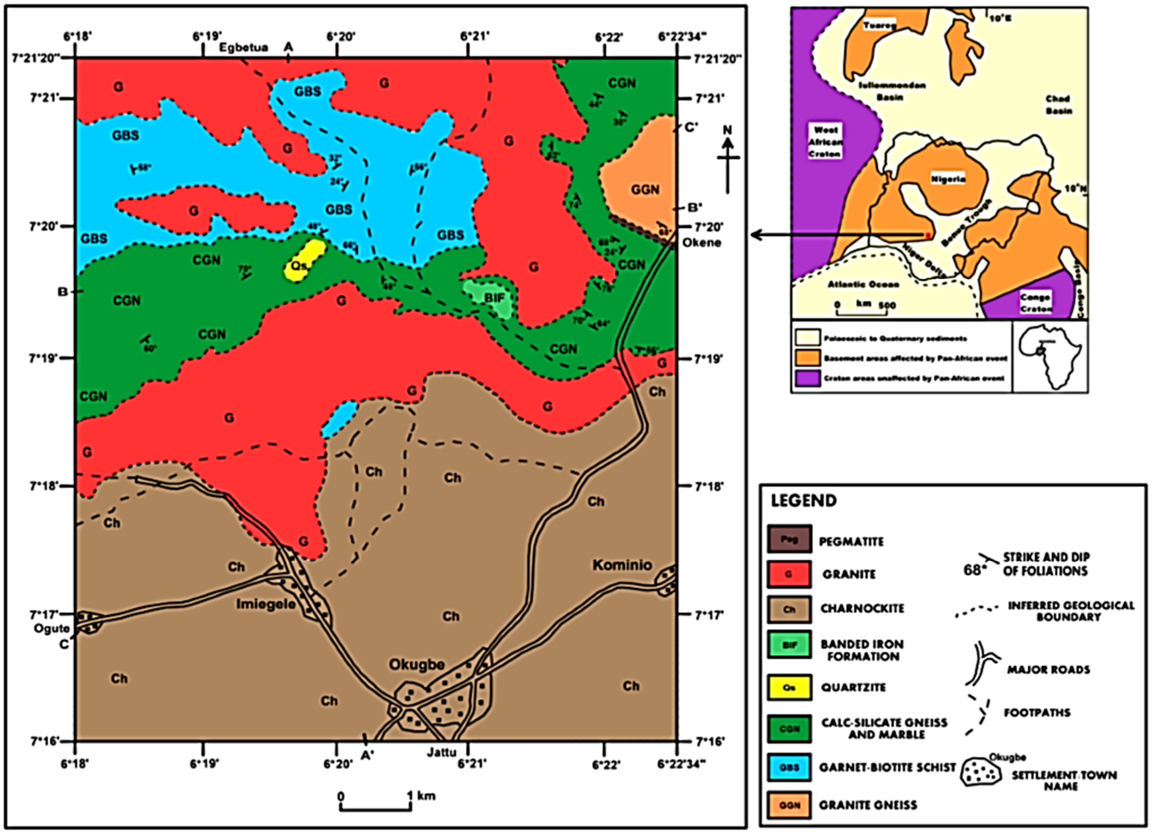

Figure 2. Geological map of Okpella area [16].

### 2.2. Landsat imagery processing and analysis

The land cover of the studied region was estimated by combining spectral bands from multi-spectral satellite imagery. Geospatial or spectral indices are empirical indicators that are created by integrating two or more spectral bands of multi-spectral satellite pictures for the purpose of assessing land cover [17]. These geospatial indices also known as the land use/land cover (LULC) indices are used to evaluate the presence or absence of different types of land cover. Using these indices improves discrimination and classification of various land cover types since they serve as LULC indicators [17].

### 2.2.1. Normalized difference vegetation index estimation (NDVI)

NDVI is a numerical indicator that is used to analyze the remote sensing data, and determine whether or not the target being examined has live, green vegetation. It does this by using the visible and near-infrared bands of the electromagnetic spectrum [25]. Equation 1 was used to determine the NDVI [25].

$$\mathrm{NDVI} = \frac{\rho\mathrm{NIR} - \rho\mathrm{RED}}{\rho\mathrm{NIR} + \rho\mathrm{RED}} \tag{1}$$

where ρNIR is the surface reflectance of band 4, and ρRED is the surface reflectance of band 3 in Landsat 7 ETM+. In Landsat 8 OLI, ρNIR is the surface reflectance of band 5, while ρRED is the surface reflectance of band 4.

### 2.2.2. Modified normalized difference water index estimation (MNDWI)

Because MNDWI has the advantage of lowering and even eliminating built-up land noise over NDWI, it is more appropriate for enhancing and extracting water information for a water region with a background dominated by built-up land areas [26]. The MNDWI has a value between -1 and +1. Short-Wave InfraRed (SWIR) band and the green band were used in the MNDWI [20]. Equation 2 was used to determine MNDWI.

$$\mathrm{MNDWI} = \frac{\rho\mathrm{GREEN} - \rho\mathrm{SWIR}}{\rho\mathrm{GREEN} + \rho\mathrm{SWIR}} \tag{2}$$

where ρ GREEN is the surface reflectance of band 2, and SWIR is the surface reflectance of band 5 in Landsat 7 ETM+. In Landsat 8 OLI, ρGREEN is the surface reflectance of band 3, while SWIR is the surface reflectance of band 6.

### 2.2.3. NDMI estimation

Crop water stress may be accurately predicted using the NDMI [27]. Vegetation water content is determined using NDMI [27]. The NDMI value range is -1-+1. SWIR and Near-InfraRed (NIR) reflectance are used to determine it [28]. Equation 3 can be used to compute the NDMI.

$$\text{NDMI}=\frac{\rho\text{NIR} - \rho\text{SWIR}}{\rho\text{NIR} + \rho\text{SWIR}} \tag{3}$$

where ρNIR is the surface reflectance of band 4 in Landsat 7 ETM+, and ρSWIR is the surface reflectance of band 5 in Landsat 7 ETM+. In Landsat 8 OLI, ρNIR is the surface reflectance of band 5, while ρSWIR is the surface reflectance of band 6.

### 2.2.4. LST retrieval

LST is a measurement of an object's temperature on the surface of the earth [29]. Together with the spectral bands for NDVI retrieval, emissivity-corrected LST was extracted from thermal band 6 of the Enhanced Thematic Mapper Plus (ETM+), and thermal band 10 of the TIRS using Equation 4 [30].

$$\mathrm{T_s} = \frac{\mathrm{BT}}{1 + \left(\lambda \times \frac{\mathrm{BT}}{\rho}\right) \times \mathrm{In}(\varepsilon)} \tag{4}$$

where, $\mathrm{T_s}$ is the LST in Celsius (°C), BT is At-Sensor Brightness Temperature (°C), λ is the emitted radiance wavelength (λ = 11.5 µm for Landsat 7 band 6 and 10.8 µm for Landsat 8 band 10. ε is the Land Surface Emissivity (LSE), while ρ is retrieved from Equation 5.

$$\rho = \frac{\mathrm{h} \times \mathrm{c}}{\sigma} = (14388\ \mu\mathrm{m\ K}) \tag{5}$$

where h is the Planck's constant ($6.626 \times 10^{-34}$ Js), c is the velocity of light ($2.998 \times 10^{8}$ m/s), and σ is the Stefans Boltzmann's constant ($1.38 \times 10^{-23}$ J/K).

### 2.2.5. SMI estimation

Soil moisture is the amount of water that is retained in the soil, and is influenced by various factors such as temperature, rainfall, and soil properties [31]. The NDVI and the LST are two factors that determine the SMI estimation. Equation 6 was used to determine the SMI [32].

$$\mathrm{SMI} = \frac{LST_{\mathrm{MAX}} - LST}{LST_{\mathrm{MAX}} - \mathrm{LST_{MIN}}} \tag{6}$$

where $LST_{MAX}$ and $LST_{MIN}$ are the maximum and minimum surface temperature in $^{0}$C for a given NDVI, while LST is land surface temperature, the surface temperature of a pixel for a given NDVI derived using the remotely sensed data [32].

## 3. Results and Discussions

This section presents the key findings of analysis generated, and highlights the patterns of the land cover change and their broader environmental implications.

### 3.1. Spatial distribution of vegetation, water, soil, and vegetation moisture

The spatial distribution of vegetation, water, soil, and vegetation moisture is closely linked to the ecological health of landscapes affected by limestone mining. The mining activities often lead to the removal of vegetation and alterations in hydrology, impacting the soil properties and moisture levels. It is imperative to comprehend these spatial variations in order to evaluate the ecological repercussions of mining and to develop sustainable land management strategies for the rehabilitation of impacted communities.

### 3.1.1. NDVI

The NDVI acts as an indicator of vegetation health and density. The NDVI values for the years 2011, 2016, and 2021 in Okpella offer insights into the changes in the vegetation cover over the past decade. The NDVI values typically fall within the range of -1-1, where higher values indicate a healthier and denser vegetation. The negative values suggest areas with little to no vegetation or non-photosynthetic surfaces such as water bodies or bare ground. The positive values point to the areas with varying degrees of vegetation cover, with higher positive values indicating a healthier and denser vegetation.

Table 1 and Figure 2 give an explanatory visual representation of the spatial distribution of vegetation analysis using NDVI within Okpella. The NDVI values in Okpella -0.00008-0.59474 in 2011, from -0.71300 to 0.76728 in 2016, and from -0.66038 to 0.79108 in 2021. A significant change was evident across the studied area when the NDVI values from 2011, 2016, and 2021 are compared. The spatial pattern of the NDVI variation shows that the vegetated areas have values between 0.2

and 0.5, while the values between 0.1 and 0.2 represent bare soil, barren rocks, and built-up areas. Values for the water bodies are negative.

According to the mean NDVI values for 2011 (pre-mining), 2016, and 2021 (0.36557, 0.32961, and 0.41674), the Okpella limestone mining area's vegetation level decreased slightly after two 2 years of mining operations, which began in 2014. The vegetation declined by 2016 but reached its highest mean peak in 2021 over 10 years of investigation. The gradual increase in the vegetation over 10 years, as indicated by the NDVI values, may reflect effective natural vegetation regeneration or the limited spatial extent of limestone mining activities.

The findings reveal that the studied area, dominated by shrubs and grasslands had moderately healthy vegetation prior to the commencement of mining in 2014. Despite a slight decline in vegetation in the early years of mining, the NDVI values show a gradual recovery over the following five years, with greenery improving by 2021. This trend, where vegetation remains moderately healthy (NDVI values between 0.2 and 0.5), aligns with the findings of several studies [18]; indicating that mining operations have not significantly affected the vegetation in the area [33].

The resilience in vegetation health, despite the onset of mining, aligns with several studies [18]; suggesting the dominance of shrub and grassland in the mining area [33]. The findings from the NDVI analysis support the potential for achieving several SDGs, particularly those related to environmental sustainability and ecosystem management. Specifically, this aligns with SDG 13 (climate action), as the gradual recovery of vegetation despite active mining operations highlights the resilience of the ecosystem, and underscores the importance of maintaining green spaces. This resilience contributes to climate regulation and balance, with increased vegetation helping to mitigate carbon emissions by acting as carbon sinks. Additionally, the results align with SDG 15 (life on land), as improved vegetation cover and the moderate health of shrubs and grasslands reflect sustainable land management practices. With proper reforestation efforts and responsible mining, the area could continue to support biodiversity and protect ecosystems, ensuring that land degradation is minimized. Moreover, the findings relate to SDG 3 (good health and well-being) as increased vegetation contributes to a better air quality and reduced soil erosion, both of which are vital for public health. This aligns with several studies [34 - 36], which emphasized the environmental health benefits of increasing vegetation cover.

Overall, the relatively limited impact of mining on vegetation in the Okpella area suggests that, with a proper environmental management and restoration efforts such as reforestation, the area could continue to make progress toward these key SDGs, contributing to a sustainable development and an ecological balance.

It can be concluded that the mining operation is not causing unhealthy vegetation in the studied area. However, palpable and deliberate measures such as the reforestation of mined areas in the Okpella area must be taken to ensure environmental sustainability, and the availability of trees, which act as carbon sinks and promote carbon sequestration.

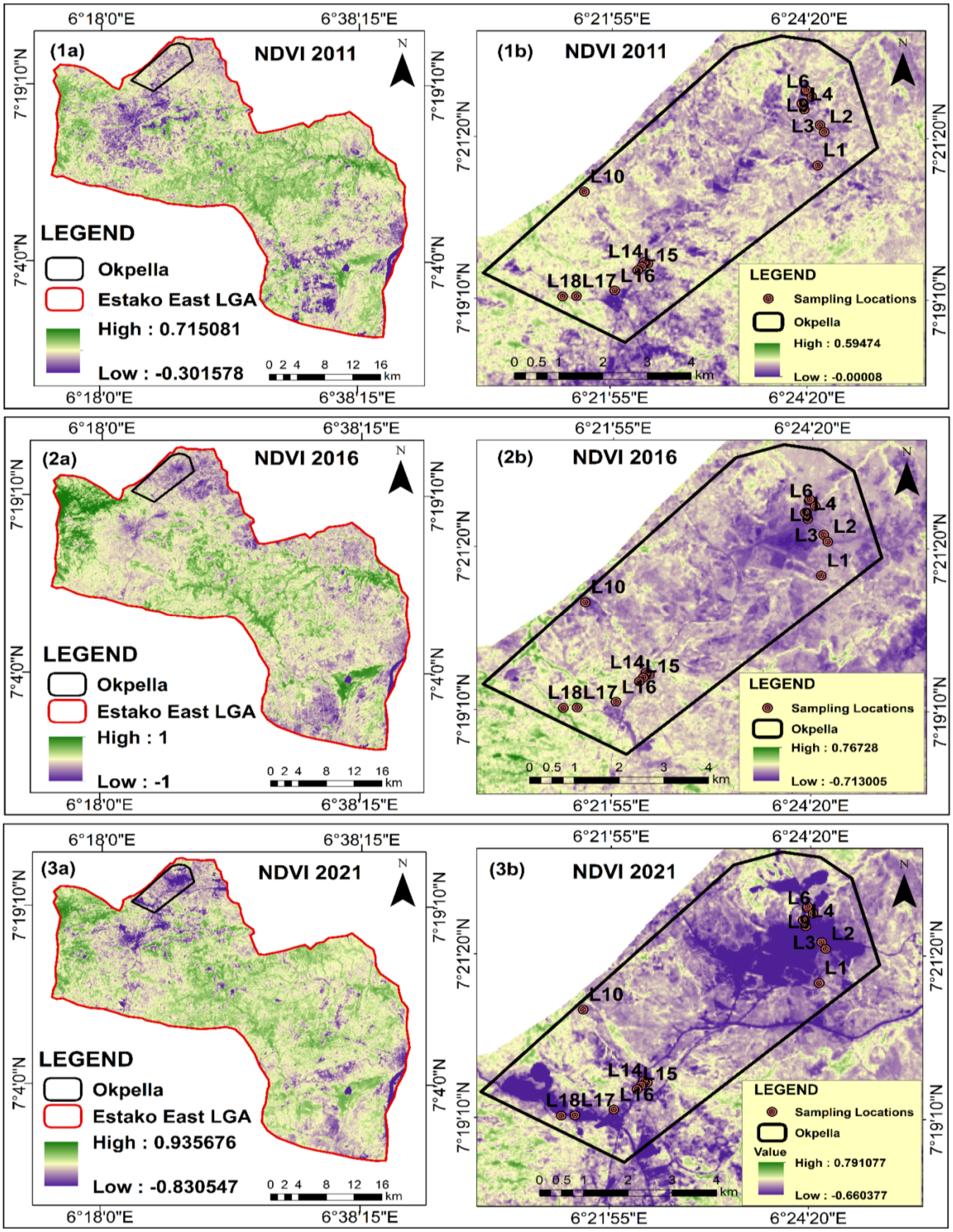

**Figure 2. Spatial distribution map of NDVI in 2011, 2016, and 2021.**

**Table 1. Descriptive statistics of NDVI**

| Year | Minimum | Maximum | Mean | Standard deviation |
|---|---|---|---|---|
| 2011 | -0.00008 | 0.59474 | **0.36557** | 0.06143 |
| 2016 | -0.71300 | 0.76728 | **0.32961** | 0.09221 |
| 2021 | -0.66038 | 0.79108 | **0.41674** | 0.14585 |

### 3.1.2. MNDWI

The Modified Normalized Difference Water Index (MNDWI) serves as an essential indicator of surface water availability and fluctuations in the studied area. Table 2 and Figure 3 provide a visual depiction of the temporal and spatial water fluctuations in Okpella over the years 2011, 2016, and 2021. The MNDWI values in Okpella vary from -0.85365 to 0.47893 in 2011, -0.52078 to -0.34460 in 2016, and -0.90350 to 0.52655 in 2021. Non-negative MNDWI values represent available surface water, while negative values indicate the presence of other land covers such as dry land or built-up areas.

The mean MNDWI values for the studied years are -0.32040 for 2011, -0.75125 for 2016, and -0.64796 for 2021. These values suggest a significant decline in the surface water levels from 2011 to 2016, with only a slight recovery noted by 2021. The consistently negative mean values observed over the years (2011 to 2021) suggest that Okpella could be one of the most water-stressed towns in the Etsako East Local Government Area of Edo State, Nigeria.

These findings highlight a concerning trend in water availability, which is critical for both the local ecosystem and the community well-being. Reduced surface water levels can have detrimental effects on biodiversity, agricultural productivity, and overall environmental health. The decline in water availability underscores the necessity for sustainable water management practices, aligning with SDG 6 (clean water and sanitation). Effective management strategies such as rainwater harvesting and the protection of existing water bodies can help mitigate water stress in the region [18].

Moreover, the findings relate to SDG 15 (life on land), as maintaining healthy aquatic ecosystems is essential for a biodiversity conservation. The increasing water stress in Okpella may lead to challenges in achieving these goals, particularly if the mining operations continue to impact water resources negatively. Therefore, proactive measures must be taken to ensure the sustainability of water resources in the area including regular monitoring and restoration of water bodies. This approach is critical for promoting the ecological balance and ensuring the availability of clean water for future generations.

In conclusion, the findings from the MNDWI analysis indicate a troubling trend in water availability in Okpella, emphasizing the need for immediate and effective water management strategies to address these challenges, and support sustainable development.

### 3.1.3. NDMI

The Normalized Difference Moisture Index (NDMI) acts as a reliable indicator of vegetation water stress. The NDMI values for the years 2011, 2016, and 2021 highlight these variations, with values ranging from -0.29619 to 0.41873 in 2011, from -0.82784 to 0.10741 in 2016, and from -0.65404 to 0.26319 in 2021. Visual representation of these moisture variations are provided in Table 3 and Figure 4.

The mean NDMI values for the respective years indicate a trend in moisture availability: 0.01415 in 2011 (pre-mining), -0.32949 in 2016, and -0.15331 in 2021. These mean values suggest a low to very low water stress state in the vegetation across the studied area, with the vegetation having a range from mid-low canopy cover to low canopy cover. The findings indicate that, although there was a decline in the NDMI values from 2011 to 2016, which corresponds with the early years of mining activities, the vegetation's moisture levels show a gradual, but insignificant recovery by 2021. Vegetation water stress has not attained to pre-mining times in the studied area.

Furthermore, the NDMI results underscore the importance of maintaining adequate moisture levels in supporting healthy vegetation, which plays a crucial role in the ecosystem services such as carbon sequestration and air quality improvement. The trends observed in NDMI may also suggest the potential for achieving SDGs related to environmental sustainability, particularly SDG 15 (life on land), as effective moisture management supports the resilience and health of ecosystems.

The NDMI analysis indicates that while the Okpella area has faced challenges related to water stress, the observed moisture could not attain to pre-mining times in the studied area, reflecting a possible impact of limestone mining in the area. Continued monitoring and better management practices are necessary to ensure that the moisture levels remain adequate to support sustainable vegetation health, contributing to ecological balance and resilience in the face of ongoing mining activities.

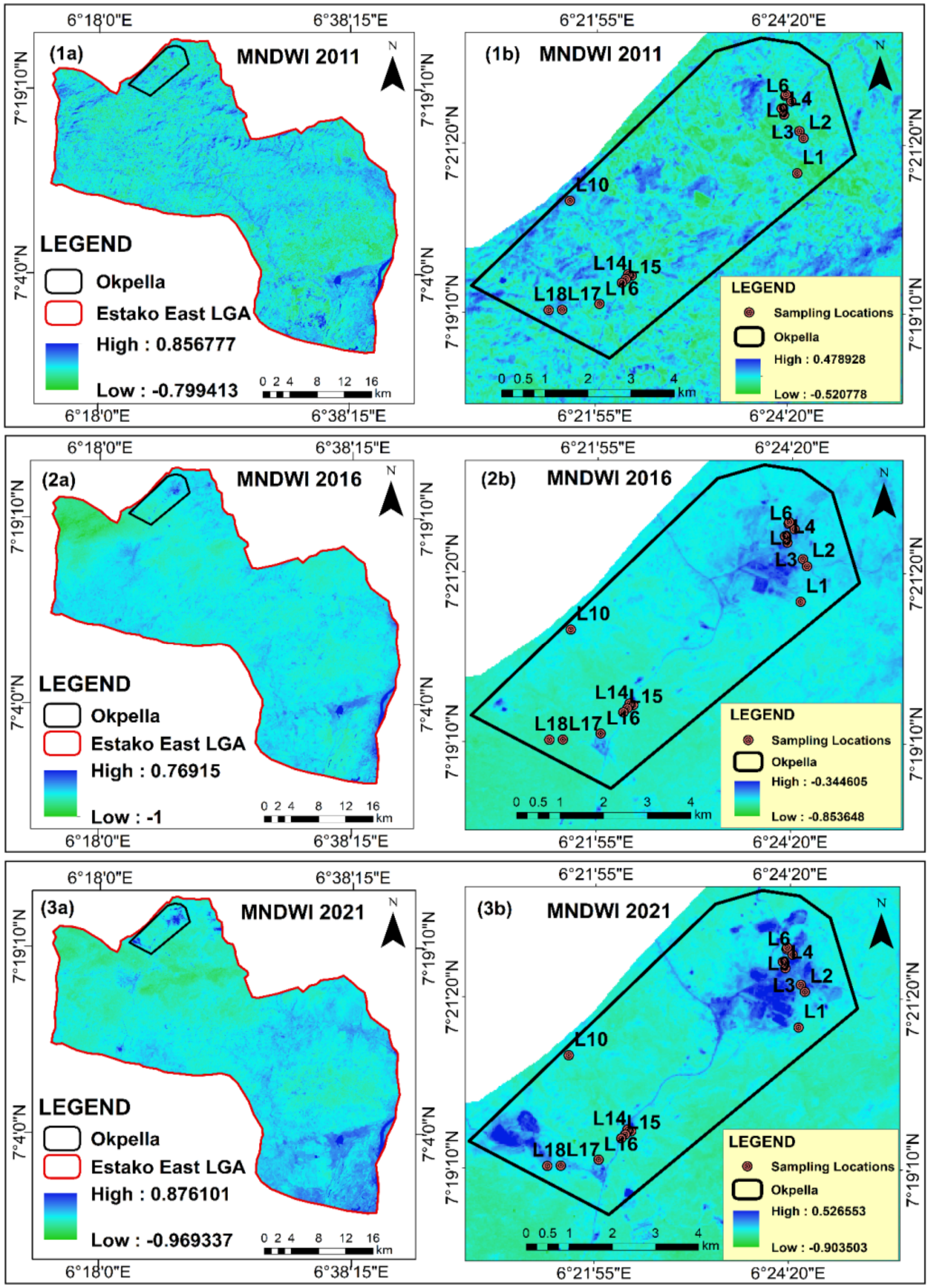

**Figure 3. Spatial distribution map of MNDWI in 2011, 2016, and 2021.**

**Table 2. Descriptive statistics of MNDWI.**

| Year | Minimum | Maximum | Mean | Standard deviation |
|---|---|---|---|---|
| 2011 | -0.85365 | 0.47893 | -0.32040 | 0.06405 |
| 2016 | -0.52078 | -0.34460 | -0.75125 | 0.04231 |
| 2021 | -0.90350 | 0.52655 | -0.64796 | 0.08152 |

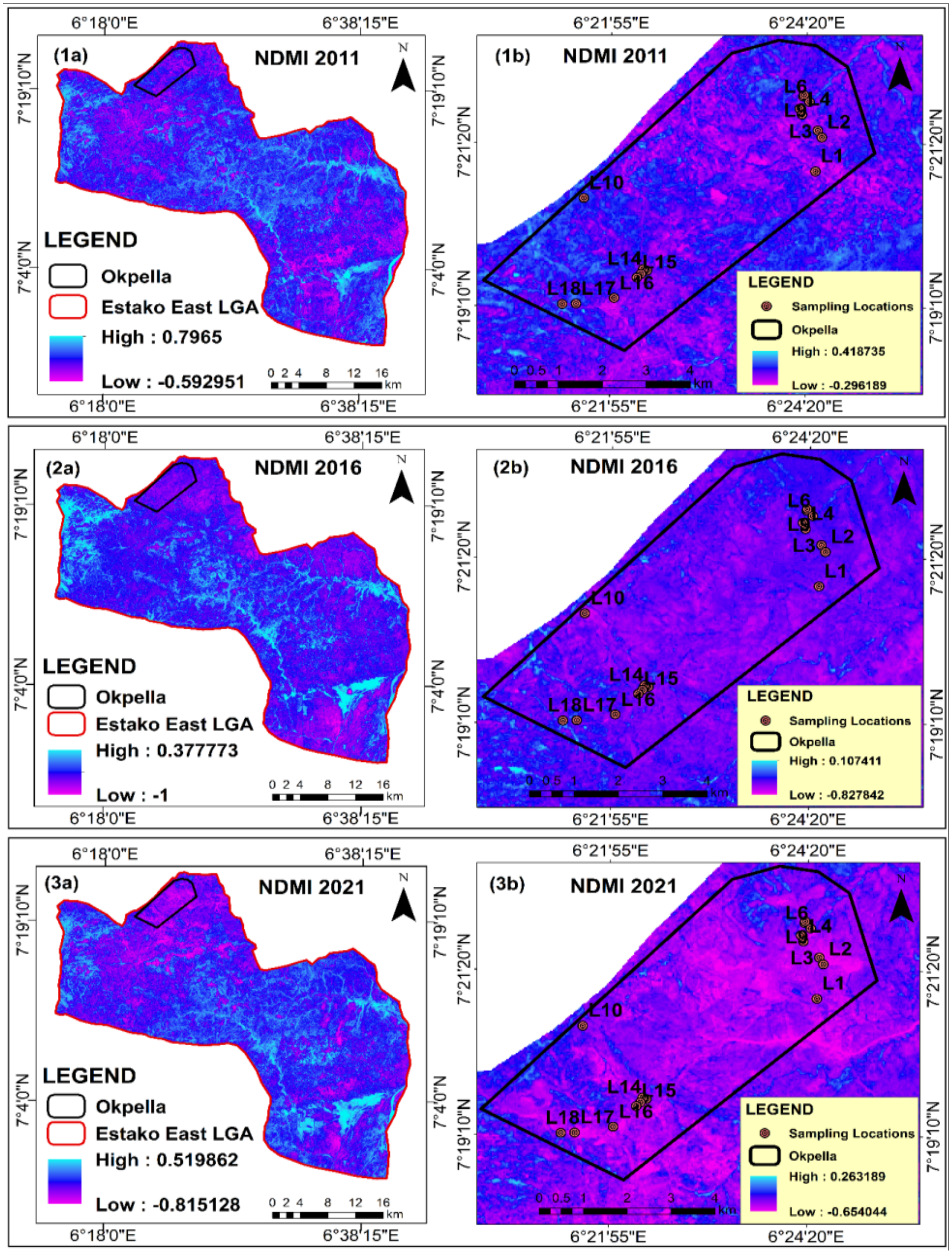

**Figure 4. Spatial distribution map of NDMI in 2011, 2016, and 2021.**

**Table 3. Descriptive statistics of NDMI.**

| Year | Minimum | Maximum | Mean | Standard deviation |
|---|---|---|---|---|
| 2011 | -0.29619 | 0.41873 | 0.01415 | 0.07888 |
| 2016 | -0.82784 | 0.10741 | -0.32949 | 0.06265 |
| 2021 | -0.65404 | 0.26319 | -0.15331 | 0.08447 |

### 3.1.4. SMI

The Soil Moisture Index (SMI) is a critical indicator for assessing the availability of moisture in the soil, which directly affects vegetation growth, agricultural productivity, and ecological stability. Table 4 and Figure 5 present the spatial and temporal distribution in soil moisture levels in Okpella for the years 2011, 2016, and 2021. The SMI values in the Okpella range from 0.47828 to 0.91733 in 2011, 0.34479 to 0.79410 in 2016, and 0.25564 to 0.84897 in 2021. The mean SMI values for these years are 0.73682 for 2011, 0.58690 for 2016, and 0.58897 for 2021. These figures suggest a noticeable reduction in soil moisture from 2011 to 2016, followed by a slight but insignificant recovery in 2021. The decrease in the soil moisture levels over this period indicates a potential reduction in the soil's capacity to support healthy vegetation and crop growth. This indicates that the amount of moisture required by the soil for crop production and vegetation growth declined, but remained at an average scale with SMI ranging from 0 to 1.

The reduction in soil moisture correlates with land-use changes including mining activities, and highlights the need for sustainable soil and land management practices. The low soil moisture levels can hinder vegetation growth, reduce agricultural yield, and disturb the natural water cycle [37, 38]. These findings are aligned with SDG 15 (life on land), as the declining soil moisture levels can disrupt local ecosystems and biodiversity. To address these challenges, interventions like soil conservation techniques and water retention strategies are essential for restoring soil moisture levels. Such efforts will not only enhance soil health and crop production but also help to ensure the long-term sustainability of the region’s agricultural and ecological systems.

## 3.2. Spatial distribution of surface temperature

### 3.2.1. LST

Table 5 and Figure 6 present the spatial distribution of Land Surface Temperature (LST) in the Okpella area for the years 2011, 2016, and 2021. The LST values range from 23.918 ºC to 35.360 ºC in 2011, 25.750 ºC to 34.724 ºC in 2016, and 27.455 ºC to 39.020 ºC in 2021. The average LST values indicate a progressive increase over time, with an average of 28.623 ºC in 2011, 29.889 ºC in 2016, and 32.525 ºC in 2021. This upward trend suggests that surface temperatures in Okpella have been rising steadily over the years, which may have significant implications for the local climate, ecosystem health, and agricultural productivity. Increasing land surface temperatures can lead to accelerated evaporation rates, reduced soil moisture, and heightened stress on vegetation [18]. These changes, if sustained, could exacerbate the challenges related to water availability and land degradation, potentially hindering efforts to achieve environmental sustainability.

The observed increase in LST aligns with broader concerns about the global climate change, as well as local land-use practices such as mining, which may contribute to heat retention in the land surface. Climate adaptation measures and land-use strategies that mitigate the impact of rising temperatures in the region are needed in the studied area.

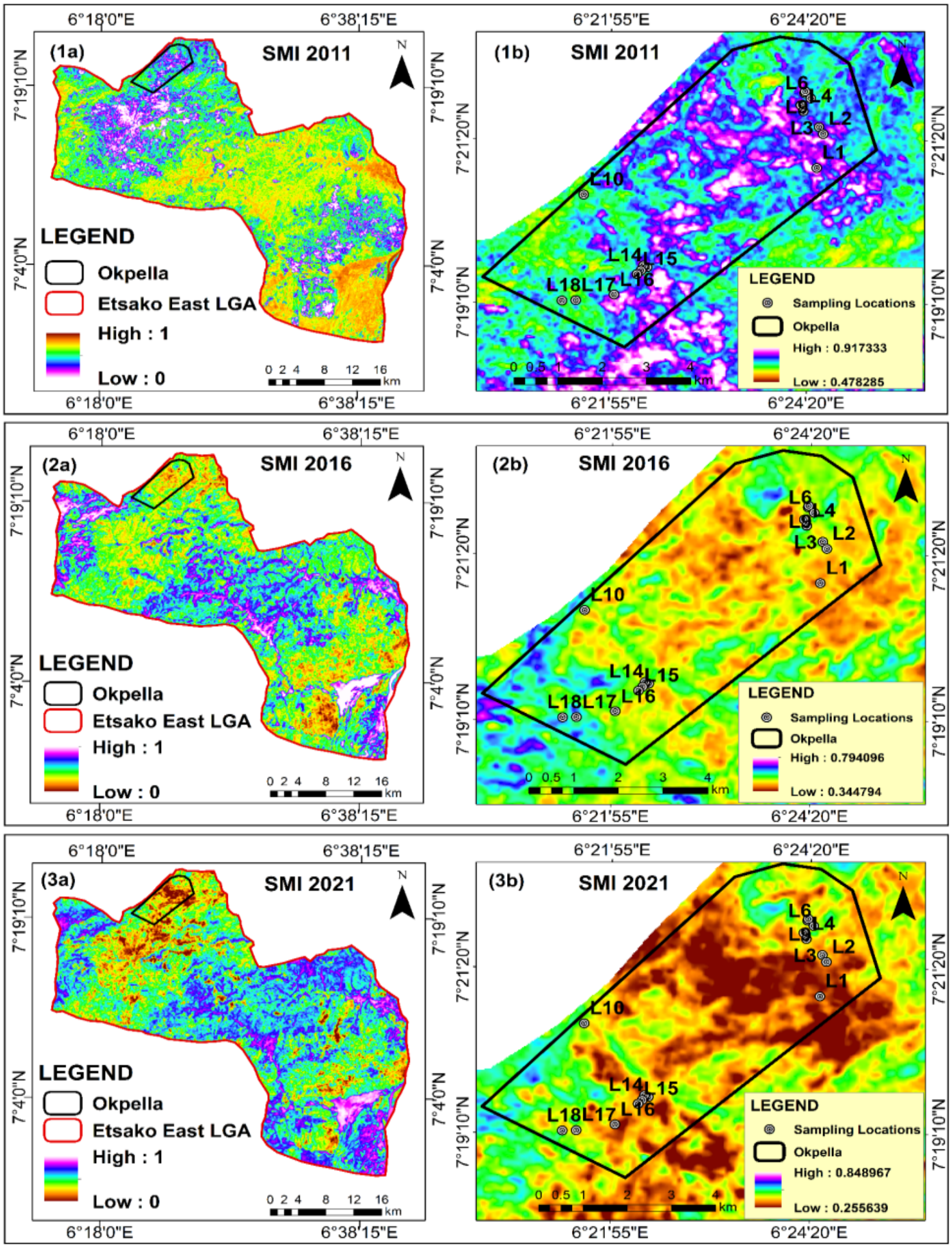

Figure 5. Spatial distribution map of SMI in 2011, 2016, and 2021.

Table 4. Descriptive statistics of SMI.

| Year | Minimum | Maximum | Mean | Standard deviation |
|---|---|---|---|---|
| 2011 | 0.47828 | 0.91733 | 0.73682 | 0.06428 |
| 2016 | 0.34479 | 0.79410 | 0.58690 | 0.05759 |
| 2021 | 0.25564 | 0.84897 | 0.58897 | 0.08063 |

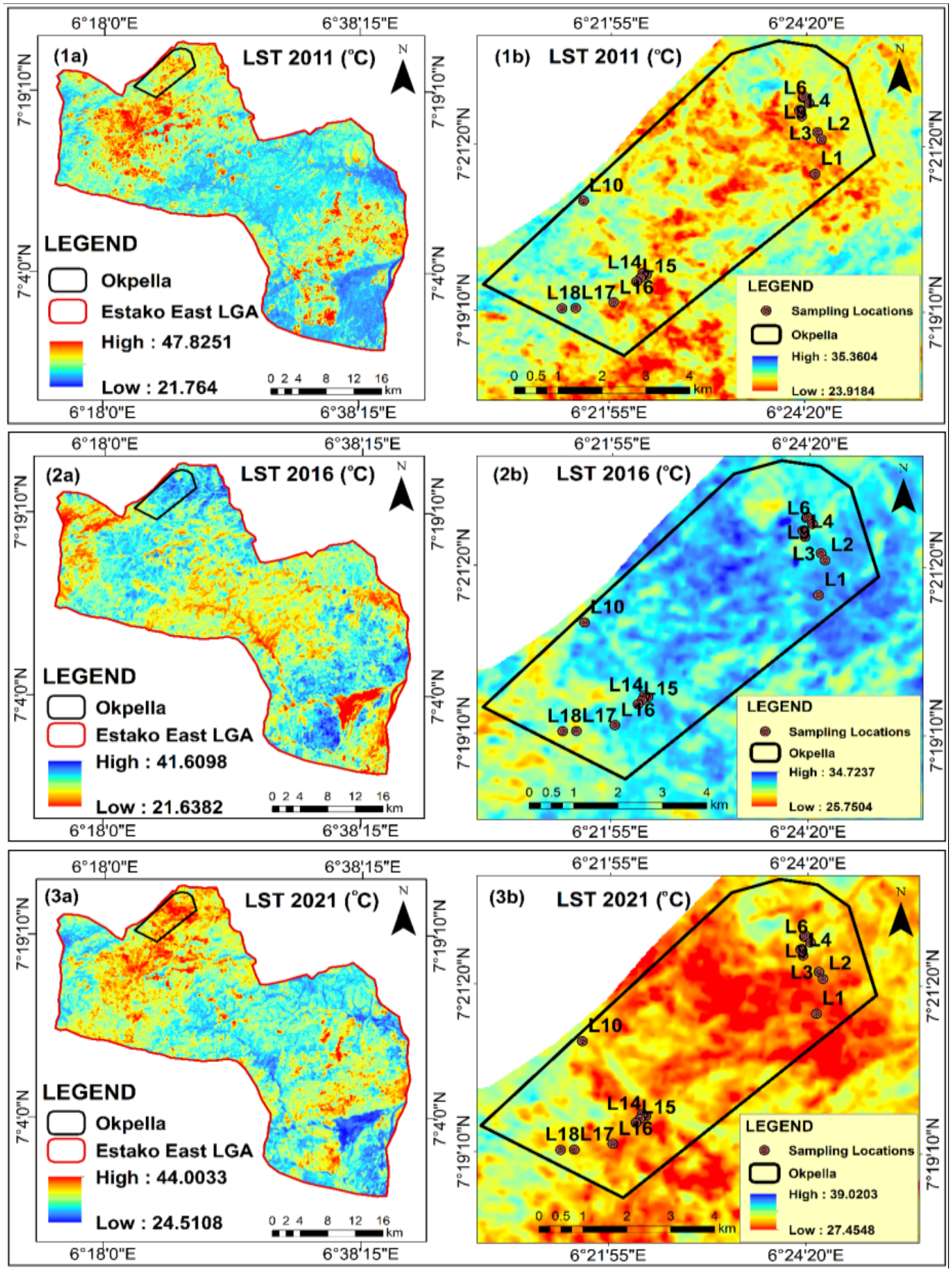

**Figure 6. Spatial distribution map of LST in 2011, 2016, and 2021.**

**Table 5. Descriptive statistics of LST.**

| Year | Minimum (°C) | Maximum (°C) | Mean (°C) | Standard deviation |
|---|---|---|---|---|
| 2011 | 23.918 | 35.360 | 28.623 | 1.675 |
| 2016 | 25.750 | 34.724 | 29.889 | 1.150 |
| 2021 | 27.455 | 39.020 | 32.523 | 1.572 |

## 4. Conclusions

The geographical distribution of vegetation, water, soil moisture, vegetation-moisture, and land surface temperature were evaluated using a combination of Geographic Information Systems (GISs) and Remote Sensing (RS). The distribution of spatial patterns and trends made possible by the geospatial analysis, which also contributed to the understanding of the spatial variability of vegetation, water, soil moisture, vegetation-moisture, and land surface temperature between 2011 (the pre-mining era) and 2021. These results showed that grasslands and bushes predominate in Okpella, not densely populated woods 7 years after mining began, mapped, and shown. Even still, there is more vegetation now than there was when it was first found in the pre-mining era (2011). Apart from the mining and extractive industries, there exist other factors that could potentially cause the deforestation such as population growth, climate change (primarily due to greenhouse gas emissions), increased agricultural and animal production, infrastructure development, illicit logging, and insufficient forest management. It is crucial to remember that these variables are frequently related to one another, and that, prior to mining, a number of factors had to be acting in concert to cause forest degradation in the studied area. In comparison to the year prior to mining (2011), soil moisture and vegetation levels were lower in 2016 and 2021 after mining commenced, although the values stayed average. Since a lack of soil moisture enhances the impact of warmth and inhibits evaporative cooling, it is evident that the decline in soil moisture has contributed to the rising LST.

The land surface temperature has been rising due to various factors like population growth, the increase in built-up areas, the Urban Health Island (UHI) effect, the bare land and exposed rock phenomenon, and the direct consequence and reaction of flora (found to be grasses and shrubs) and water to mining activities in Okpella. The study's findings shed important light on the historical, and present environmental circumstances in the Okpella mining region. An extensive assessment of the quality and quantity of water and soil in the Okpella mining area was made possible by the integrated method, which made it easier to bridge the gap between laboratory analysis, field data collecting, and GIS analysis.

Finally, future studies in the subject area may be conducted using higher spatial resolution satellite data such as WorldView-2, WorldView-3, WorldView-4, GeoEye-1, Quick Bird, Ikonos, SPOT-6, and SPOT-7 to gain a better understanding of the factors driving land cover stress.

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# ارزیابی اثرات معدن سنگ آهک بر روی پوشش زمین در اوکپلا، نیجریه

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## چکیده:

توسعه پایدار، توسعه‌ای است که نیازهای نسل فعلی را بدون به خطر انداختن توانایی نسل‌های آینده برای برآوردن نیازهای خود برآورده کند. رویکرد جغرافیایی برای ارزیابی درجه پایداری عملیات معدن در Okpella، نیجریه استفاده شد. ۲۰۱۱، ۲۰۱۶ و ۲۰۲۱. شاخص تفاوت عادی شده گیاهی (NDVI) به ترتیب مقادیر میانگین ۰.۳۶۵۵۷، ۰.۳۲۹۶۱ و ۰.۴۱۶۷۴ را نشان داد. این پوشش گیاهی از بوته‌ها، مراتع و پوشش گیاهی نسبتاً سالم پس از فعالیت‌های معدنی در منطقه تحقیقاتی باقی ماند. آب‌های سطحی در این منطقه به دلیل فعالیت‌های انسان‌زایی مانند استخراج معادن، تحت تنش قرار دارند، که مشخص است به مقدار زیادی آب برای بازیافت و فرآوری مواد معدنی نیاز دارد. علاوه بر این، شاخص تفاوت نرمال شده رطوبت (NDMI) نشان داد که مقادیر میانگین برای سال‌های ۲۰۱۱، ۲۰۱۶ و ۲۰۲۱ به ترتیب ۰.۰۱۴۱۵، -۰.۳۲۹۴۹ و -۰.۱۵۳۳۱ بوده است. NDMI منطقه تحقیقاتی تنش آبی کمی را نشان داد. شاخص رطوبت خاک (SMI) برای سال‌های ۲۰۱۱، ۲۰۱۶ و ۲۰۲۱ میزان رطوبت متوسطی را در خاک نشان داد (به ترتیب ۰.۷۳۶۸۲، ۰.۵۸۶۹۰ و ۰.۵۸۸۹۷). داده‌های دمای سطح زمین (LST) نشان داد که سطوح LST (از ۲۸.۶۲۳ درجه سانتیگراد به ۳۲.۵۲۵ درجه سانتیگراد) در حال افزایش بوده است. در طول سه سال مورد مطالعه، اجسام آبزی کمترین مقدار LST را داشتند، در حالی که زمین های برهنه و مناطق پرجمعیت بیشترین مقادیر LST را داشتند. بر اساس نتایج بررسی‌های NDVI، NDMI و MNDWI، این افزایش به دلیل سطح پوشش گیاهی متوسط و آب‌های سطحی بسیار کم بوده است. تدوین یک سیاست زیست محیطی برای کاهش پیامدهای منفی استخراج معادن بر روی پوشش زمین ضروری است.

**کلمات کلیدی:** پوشش زمین، پوشش گیاهی، آب، دمای سطح زمین.