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RESEARCH ARTICLE

Geophysical Evaluation of Agricultural Potential of Orlu and Environs Using Landsat Imagery

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ABSTRACT

The scarcity of food afflicting third-world countries, particularly Nigeria, case study Orlu zone, Imo State, Nigeria, is intolerable, given the high rate of environmental degradation in the form of erosions, nation's poor economic state, insecurity, and extremely low per capita income of citizens, motivated this research. This research is tailored to a possible approach to combating the threat of food insecurity via geophysical investigation of agricultural potential areas and as well help in managing food insecurity ravaging the area, particularly in this post-COVID lockdown era. In this research, a geophysical approach—Landsat imagery and interpretation—was used to identify areas with high agricultural yielding potentials and how to exploit them for bumper agricultural harvests to sustain livelihood and alleviate the food crisis and food inflation ravaging the zone. Within the study area, the following data were collected: Normalized Difference Vegetation Index (NDVI) map, lineament map and drainage pattern map. They were interpreted, and areas with high agricultural yield potentials were mapped. Band ratios (3/4, 4/2, 3/1, 5/4) were generated to reduce the effects of shadowing and as well improve the features present. The NDVI values that indicate soil viability, generated within the study area range from –0.22 to 0.51.

1. Introduction

The use of the Landsat satellite has been consistent since the launching of the first satellite in 1972. The National Aeronautics and Space Administration (NASA), on March 1, 2022, launched the most recent Geostationary Operational Environmental Satellite (GOES-T), which

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will ensure and provide coverage of environmental and weather conditions and as well make predictions as it relates to weather. For about 50 years now, there has been a steady gathering of satellite imagery and this has led to the availability of the longest continuous archive of such imagery presently available [1].

Landsat can be applied in various aspects of life for different uses. Its benefits include ensuring water conservation and the safety of the public. It also provides a guide for field workers who are saddled with the decision of managing natural resources as it assists them in developing the proper developmental strategies and plans [2]. Irrespective of research carried out on Landsat imagery, the overall advantage of open access Landsat imagery is not so easy to predict as a result of many downstream and value-added uses.

Some analytical surveys were carried out in 2009 and 2012 to estimate the economic advantages of Landsat imagery employing the contingent method of assessment. There has been a series of case evaluations on Landsat by USGS in addition to the surveys Carried out by Miller and others [3]. A more quantitative approach was taken for these case studies, looking into the defined application of Landsat, its merit and demerit as appraised by the users. Specific examples of applications of imagery, advantages and drawbacks that arise from them give the details of users and uses as well.

The application of Landsat imagery in the investigation of agriculturally viable areas within Orlu and its environs, Nigeria is the focus of this research. Monitoring of agricultural production and food availability has become a major concern in Nigeria as the country's population continues to grow astronomically. According to the Food and Agriculture Organization (FAO) of the United Nations and the United Nations World Food Programme (WFP), Nigeria will face food insecurity and it is expected to last from June 2022 to August 2022 and possibly beyond. WFP and FAO [4] predicted a population of 19.4 million Nigerians across 21 States of the Federation including the Federal Capital Territory (FCT) to face food insecurity during the period, with 14.4 million people representing about 74.2% of the predicted population, already facing the crisis. It is worthy of note that tremendous improvements have been made in the last 50 years in agriculture with the practice of irrigation, crop rotation, fertilization, crop rotation and other technologies. These practices have contributed immensely to improving and increasing agricultural yield globally and Landsat imagery has played a huge role in informing management decisions, mostly at a global level in monitoring agricultural production or maximizing yield for a local field. This study investigates a number of agricultural applications and uses of Landsat imagery, unraveling both the merits and drawbacks, if any, with respect to the use of this technology.

Location Study Area

The study area Orlu and its environs as seen in Figure 1, are located in Imo state, Southeastern Nigeria and it is defined with Longitude 6°40'0" E-7°10'0" E and Latitude 5°10'0" N-6°0'0" N. There are two pronounced seasons within the study area: The dry season, which spans between November and March, and the wet or rainy season, which is primarily experienced between April and October, having its peak in June and July. The vegetation of the area is monsoon and tropical Savannah. Plants like Palm trees, yams, cassava, cocoyam, maize, and other crops are frequently grown in the area.

2. Materials and Method

The study area was geophysically mapped using geologic and topographic maps. Physical observations of the vegetation, drainage, and lineaments within the study area were also made. Geomorphological activities such as top soil weathering were also considered because they have an impact on agricultural practices.

The national space research and development center agency (NSRDA) provided a seven-band Landsat Enhanced Thematic Mapper (ETM) image of Orlu and its environs. The same area was also imaged by the shuttle radar topographic mission (SRTM). Ground control points (GCPs) and Satellite orbit transformation were employed for the correction of imagery. These Image corrections were performed with the aid of geo-coded Landsat multispectral scanner (MSS), SPOT (Satellite Pour l'Observation de la Terre) Multispectral data (image to image geo-coding) and the Universal Transverse Mercator (UTM) coordinate system. Radiometric amendments were also carried out on each scene. Band 1 Enhanced Thematic Mapper (ETM) data which permeates water for bathymetric mapping across the coastline was used to differentiate soil vegetation and types of forest [5]. ETM Band 2 was used in the estimation of green reflectance from healthy plants, while Band 3 estimated the chlorophyll assimilation in vegetation. ETM Band 4 was employed perfectly in spotting the peaks in near-infrared reflectance of healthy green vegetation including water bodies/land borders. Soil moisture and vegetation were analyzed using the two mid-Infrared bands (Bands 5 and 7). They were also employed in making distinctions between rock and mineral types. The thermal-Infrared Band on ETM Band 6 was also used in analyzing soil moisture and vegetation [6].

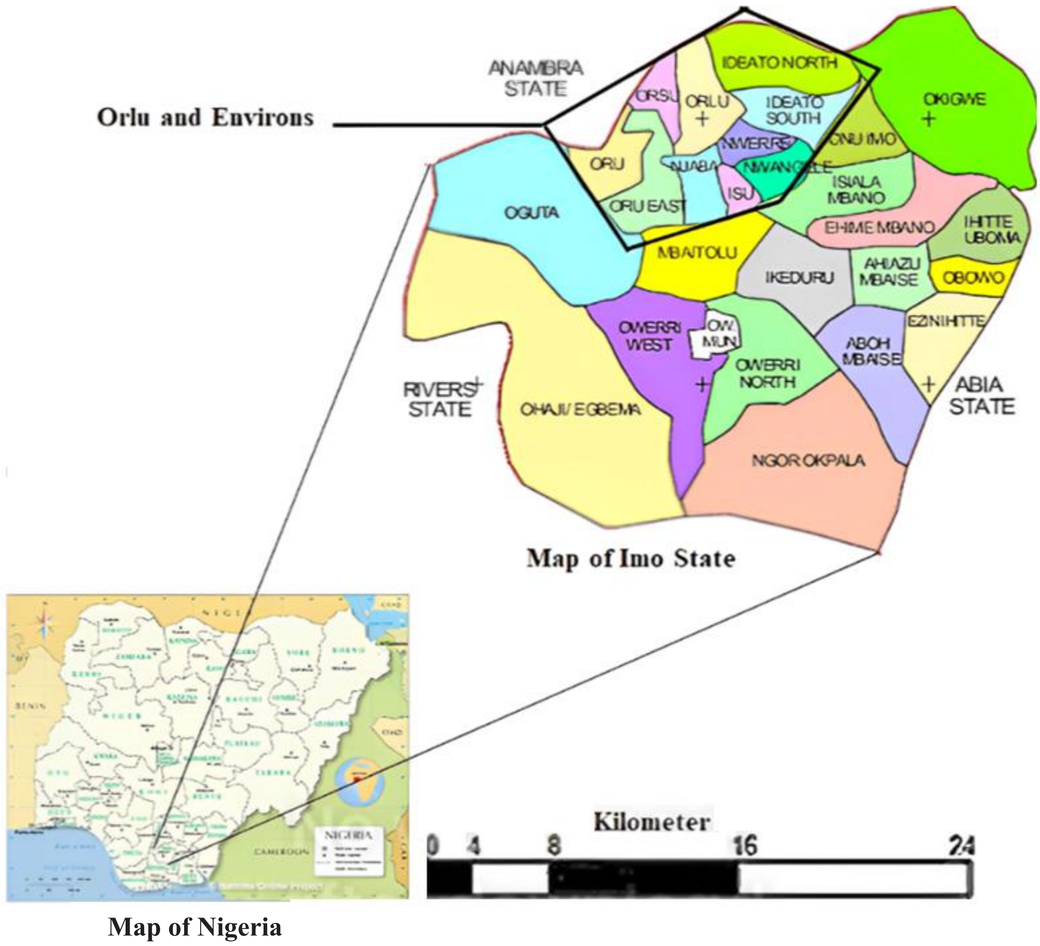

Figure 1. Location map of the study area.

Single band images, band ratio, colour composite and classified images of the study area were gotten by digital processing and enhancing the Landsat 5 ETM data of the area for the study area and these were supplemented by digitized geologic maps. Drainage configurations and surfaces, bare soils, and vegetated areas were boosted by enhancing the single-band images. A digital elevation model (DEM) was created via the use of SRTM data and it is beneficial in recognizing sands ridges. Colours were used as background data for both supervised and unsupervised image classifications.

3. Theoretical Background

3.1 Brief Review of Normalized Difference Vegetation Index (NDVI)

The Normalized Difference Vegetation Index (NDVI) is a numerical pointer that makes use of the visible and near-infrared bands of the electromagnetic spectrum in scrutinizing and analyzing remote sensing quantities and decides if the target being examined contains live green vegetation. To evaluate crop yields, field performance and capacities of rangeland in the study of vegetation, NDVI has been of immense help. It is also employed in studying some soil features like the percentage of ground cover, photosynthetic behaviour of plants, surface water, leaf area index and quantity of biomass [7]. NDVI information can be generated by aiming at satellite bands with more reliable facts about vegetation. This is aided as a result of already established behavioral attributes of plants across the electromagnetic (EM) spectrum (Near-Infrared and Red). The amount of vegetation within an area is determined by how large the difference between near-infrared and red reflectance is.

$$NDVI = \frac{NIR - RED}{NIR + RED} \quad (1)$$

NIR = Near Infrared, RED = Red Reflectance.

The NDVI expression implies that two similar vegetative covers may have discordant values especially if one is in bright sunlight and the other is under a cloudy sky. The digital number (DN) of its pixels under bright sunlight will be higher, thereby generating entirely a large difference between the bands. NDVI values are presented theoretically in the form of a ratio extending from –1 to 1. Practically, high negative values indicate water, values around zero show bare soil, and values higher than 0.6 signifies dense green vegetation.

3.2 Lineaments

Lineaments deduced from satellite images are usually employed in revealing major azimuth arrays whose alignment offers a clue of an area's regional fractured setting [8-10]. Geomorphologically, lineaments are described as mappable, common or complex linear surface attributes with fragments aligning rectilinearly or moderately in curvilinear form, having pronounced differences from adjacent patterns and apparently reflecting the subsurface peculiarities [11]. Hobbs [12] identified linear surface expressions as valleys, ridges, elevated area boundaries, rivers, coastlines, rock formation boundary lines, and fracture zones. The recognition of lineaments within an area is influenced by the types of outcrops observed within the area. The existence of thick vegetation, alluvial deposits, volcanic ashes, and human activities like landscape modification can pose some problems in the identification of lineaments.

3.3 Drainage Patterns

Howard [13] postulated that examination and analysis of drainage expose the details of structural attributes and lithology. The fundamental knowledge is that rivers flow from areas of high elevation to areas of low elevation along the maximum regional topographic gradient. There are different drainage forms and they include Dendritic, parallel, trellis, rectangular, radial/centrifugal, annular, and contorted [14,13]. Drainage irregularities are described as unconformities from a dendritic pattern circumlocutory to the regional topographic gradient. These deviations result from structural or lithological incoherence [15].

4. Results and Discussion

The Landsat 5-ETM data were treated and analyzed using different types of image boosting and modification processes. Band ratios for image modification and transformations were generated using IDRISI 32 calculator module [16]. These ratios (3/4, 4/2, 3/1, 5/4) were generated to reduce the effects of shadowing and to improve the detection of particular features. IDRISI 32 composite module was also in use to generate three band Red, Green, and Blue (RGB) color composites for image enhancement. The spectral qualities of images were improved via this method. Composites were generated in the following forms: RGB 357, RGB 751, RGB 752, and NDVI composite. These ratios generated were carefully analyzed alongside with digital elevation model to extract information and subsequently attribute the color patterns observed to that of color composites.

IDRISI 32 was used to generate a digital elevation model as seen in Figure 2 from Shuttle Radar Topographic

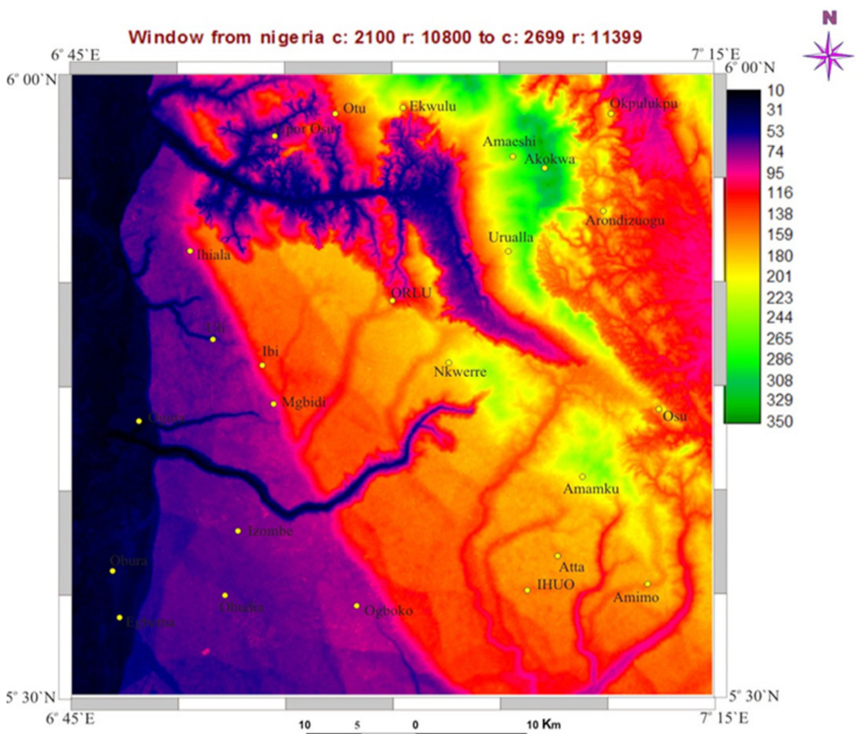

Figure 2. Digital elevation model (DEM) map.

Mission (SRTM) data using a color-shaded operation. Using the ERDAS and ArcView software, the DEM was converted into a contour map. Geomorphic units in the study area were identified using the DEM [17]. Based on the image texture and tone, three geomorphic units were identified: A portion of Orlu and Environs, a scarp slope, and a low-lying plain. The highest elevations are represented as green patches and are thought to be sandy ridges. This feature, visible in the upper right corner of Figure 2, is thought to be part of the Awka-Orlu Cuesta, which runs NE-SW. The scarp gradient of the ridge was recognized by the close packing of light green, yellow, and red colors, demonstrating an abrupt alteration in topography from 116 to 201 meters. There are numerous streams, gullies, and rivers on the slope. The interpretation of topographic high areas as characterized by top soil will be correct. Similarly, the highest elevation of the study area is depicted as green contours on the topographic map (Figure 3), which corresponds to the green patches on the DEM map in Figure 2. The study area's low-lying plain is depicted in blue on the DEM and topographic map. The ridge slope is similar to the one interpreted from the DEM imagery.

Linear features with a length of 1km or more were considered. The longer lineaments have the greatest potential for further development into gullies, limiting the amount of land available for agriculture. Lineaments reveal three distinct groups of linear features. The most common direction is NE-SW, while others are N-S, E-W, and NW-SE. Figure 4 depicts the drainage map of the study area superimposed on the lineament map.

To prove the affiliation between geological formations and structural attributes, the interpreted lineaments (Figure 5) were submerged on the edge-enhanced map with a lineament density map (Figure 6) indicating a high-density fracture area east of Urualla and Orlu town. These lines indicate that the top soils used for agriculture have been weakened and therefore are carried away by runoff due to their loose nature, causing soil erosion. This consequently leads to non-availability of topsoil used for agriculture and its nutrients.

The Normalized Difference Vegetation Index (NDVI) is based on a plant's chlorophyll content, which indicates the amount of nutrients in the soil. The higher the chlorophyll content of plants, the more there are nutrients in the soil, implying that the area is very viable for agriculture [18]. Areas with low chlorophyll content have low soil nutrients or have been eroded as top soil used for agriculture has been washed away. NDVI was established to demarcate areas of vegetation and bare soil. Healthy plants were seen to have higher NDVI values due to their high reflectance

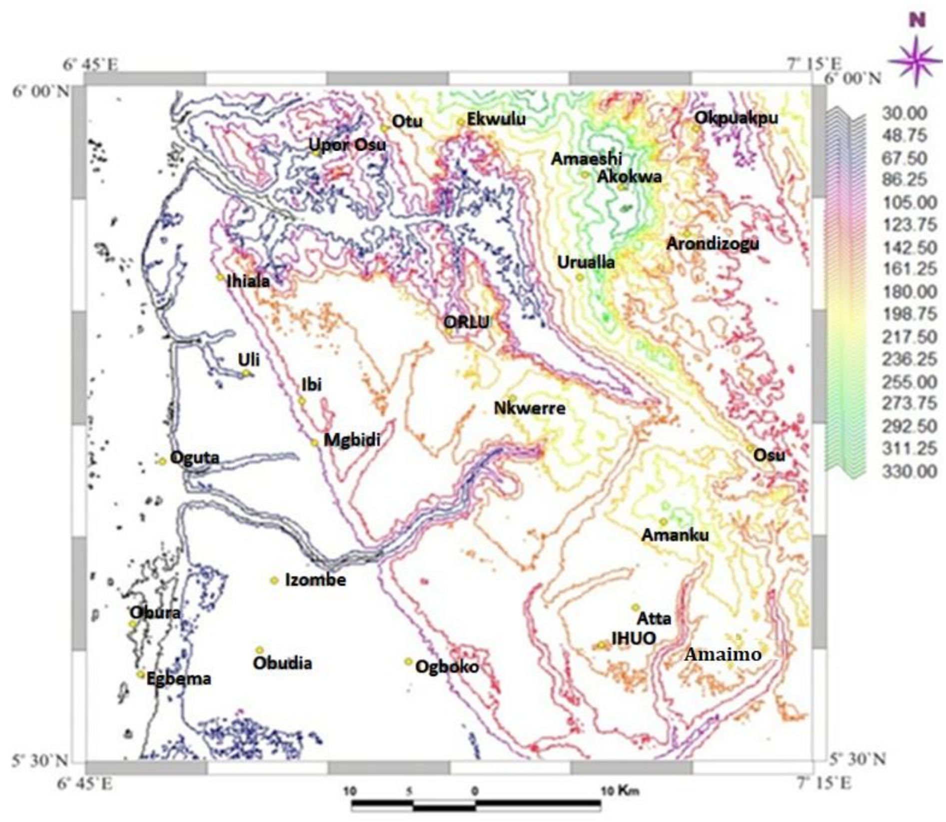

Figure 3. Topographical map of Orlu and Environs.

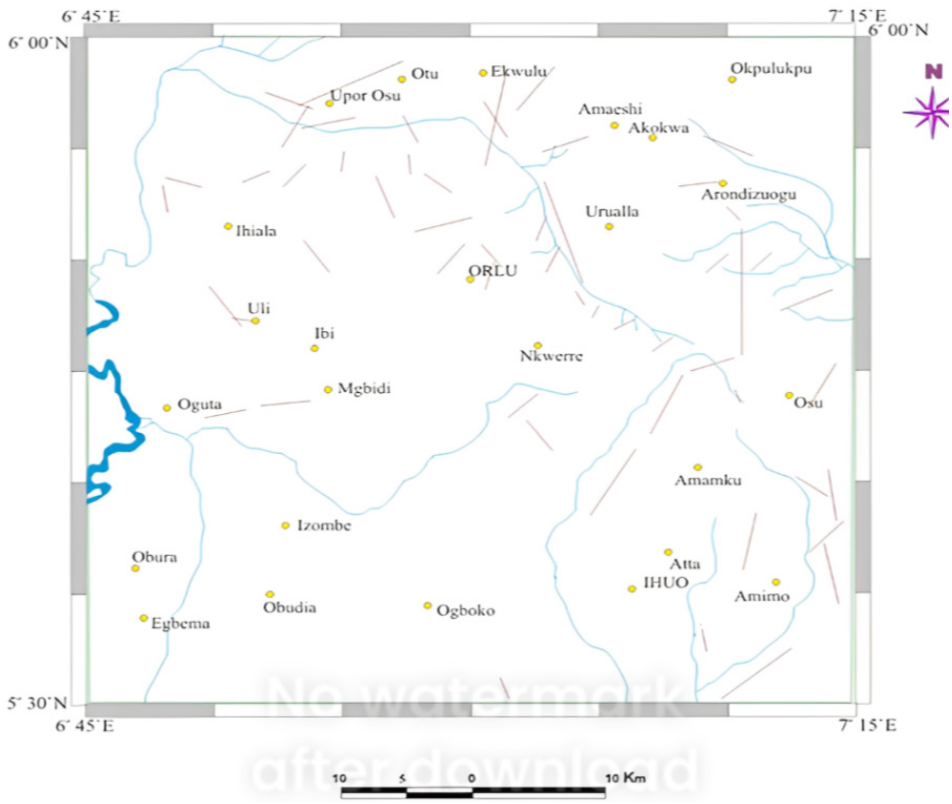

Figure 4. Lineament on drainage map.

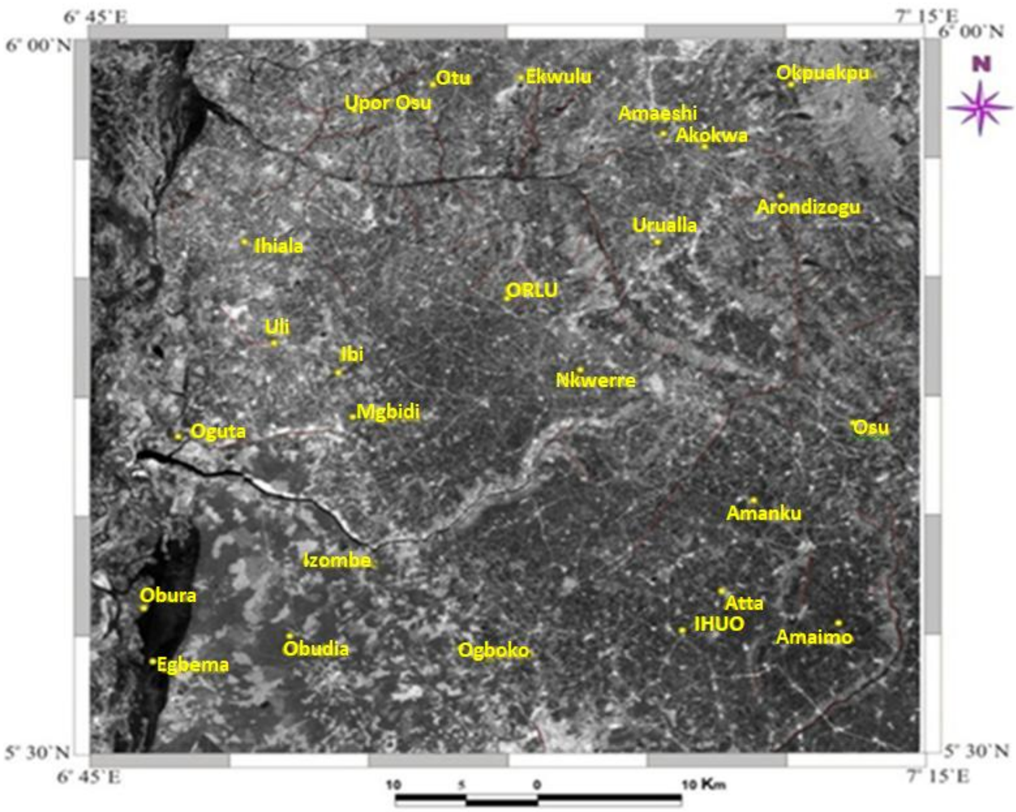

Figure 5. Lineament on edge enhanced band 5 map.

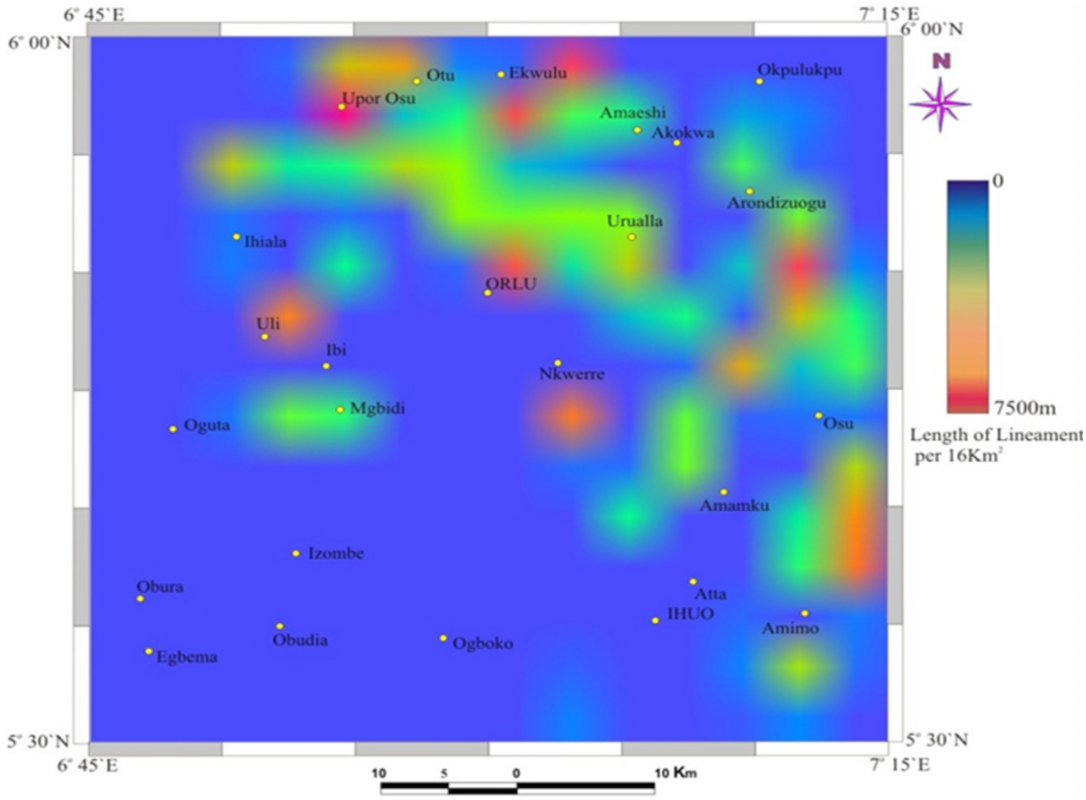

Figure 6. Lineament density map.

of infrared (band 4) light and relatively low reflectance of red (band 3) light. The NDVI is calculated using the formula in Equation (1).

A closer examination of the NDVI imagery (Figure 7) revealed that the brown areas with NDVI values between –0.22 and –0.01 correspond to bare or eroded soils. It is not recommended to conduct agricultural activities in such areas because crops will barely survive, let alone yield results. Yellow areas (0.01-0.19) correspond to sparsely vegetated areas. The lack of vegetation within the zones may indicate a lack of soil nutrients; though agricultural activities may be permitted only within the said area if significant soil remedial interventions can take place. This intervention to improve soil nutrients will undoubtedly be capital intensive, as crop yield may not justify the capital invested to make the soil viable, so agricultural activities are not recommended. Dense vegetation areas with NDVI values between 0.19 and 0.51 indicate high chlorophyll content. These are invariably natural agricultural viable areas, as indicated by the color green in Figure 7.

The dendritic configuration indicates that the underlying sediment is a single unit. Also, the dendritic pattern shows that the top lithology of the soil is soft and most likely suitable and less energy-consuming during cultivation. Overburdens, sand, and other materials are included in this litho-unit. The RGB752 composite in Figure 8 is very descriptive because it distinguishes between the patterns. In Figure 2, the bare soil area, interpreted as a sandy ridge from the DEM, is rendered in lavender and magenta, while urban areas are represented in a lavender form.

The areas with vegetation are represented by green shades in RGB 357 and 752 as seen in Figures 10 and 8, indicating potentially agricultural high yield areas, which is consistent with NDVI as seen in Figure 7. Shades of blue indicate vegetated areas in RGB 751 (Figure 9), while light brown and light yellow indicates areas with no or little vegetation.

The unsupervised classification which is primarily based on image classification was carried out using ArcGIS. This classification depends on tonal differences as seen in Figure 11. Nine tonal features were observed in the study area. The blue and green colors in Figure 11 represent areas with mixed vegetation. Yellow areas were discovered in Orlu, Urualla, and Umueshi. This was previously interpreted as sand based on the DEM and color composites.

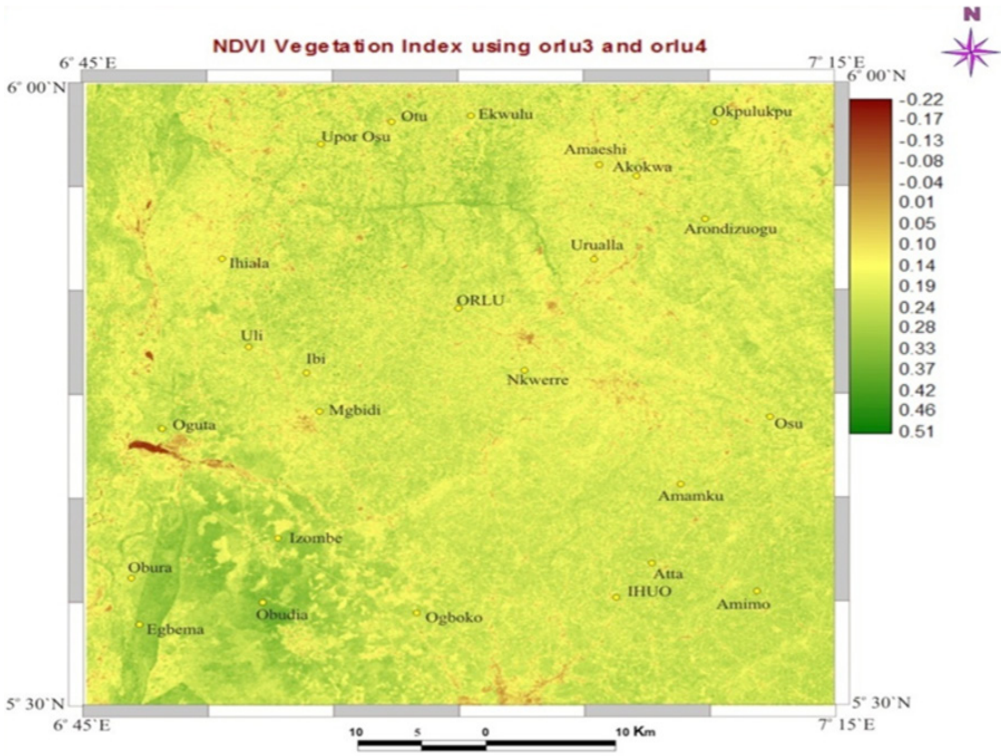

Figure 7. Normalized Difference Vegetation Index (NDVI).

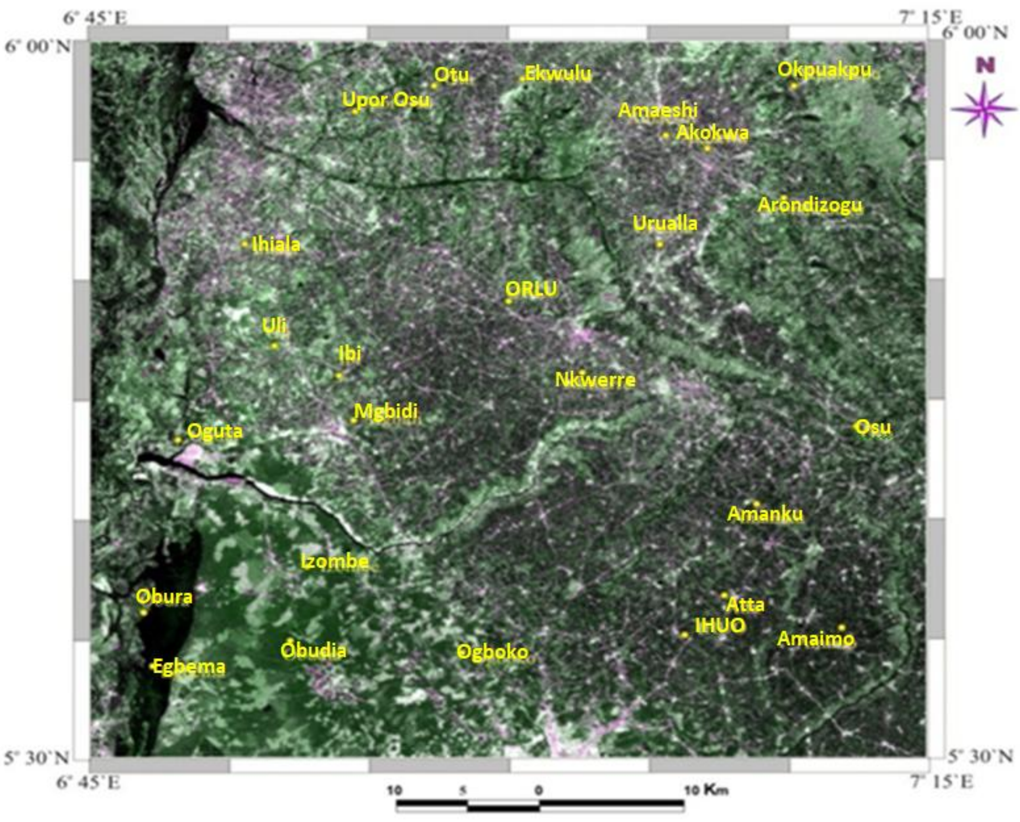

Figure 8. Colour composite RGB 752 map.

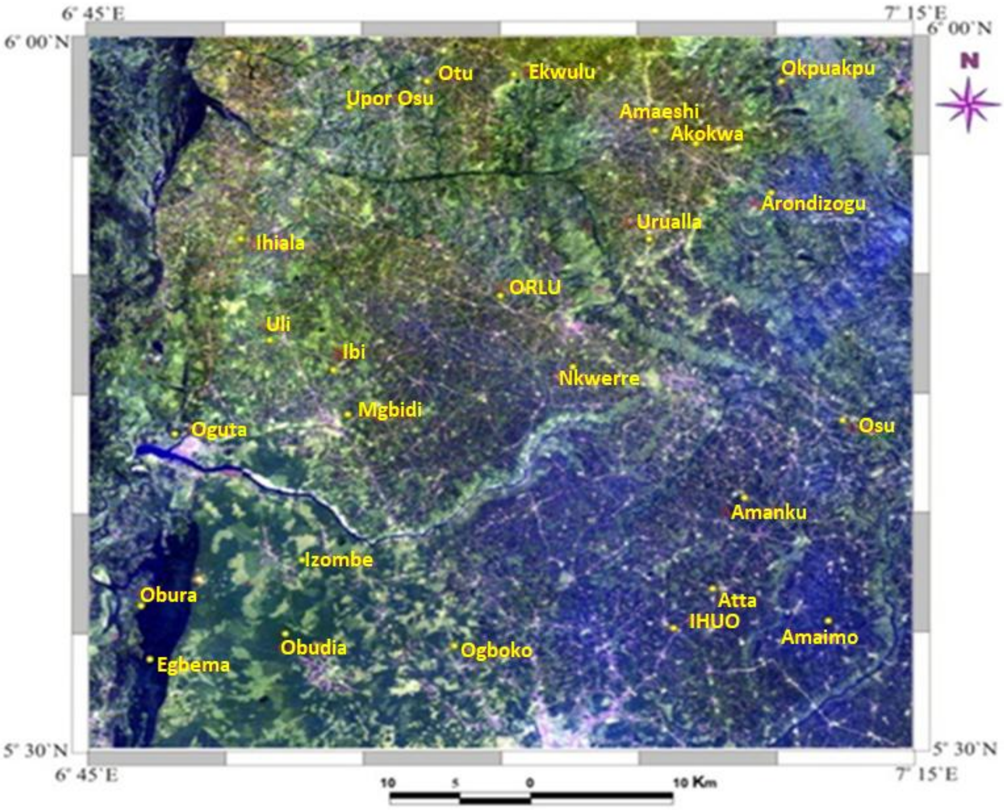

Figure 9. Colour composite RGB 751 map.

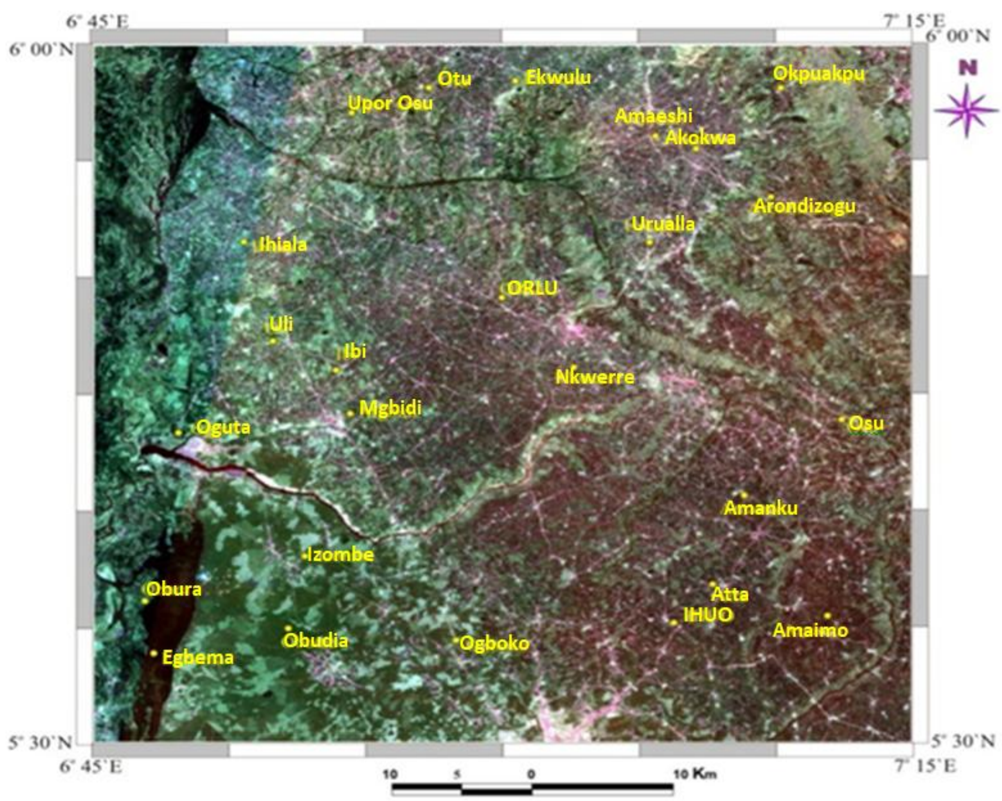

Figure 10. Colour composite RGB 357 map.

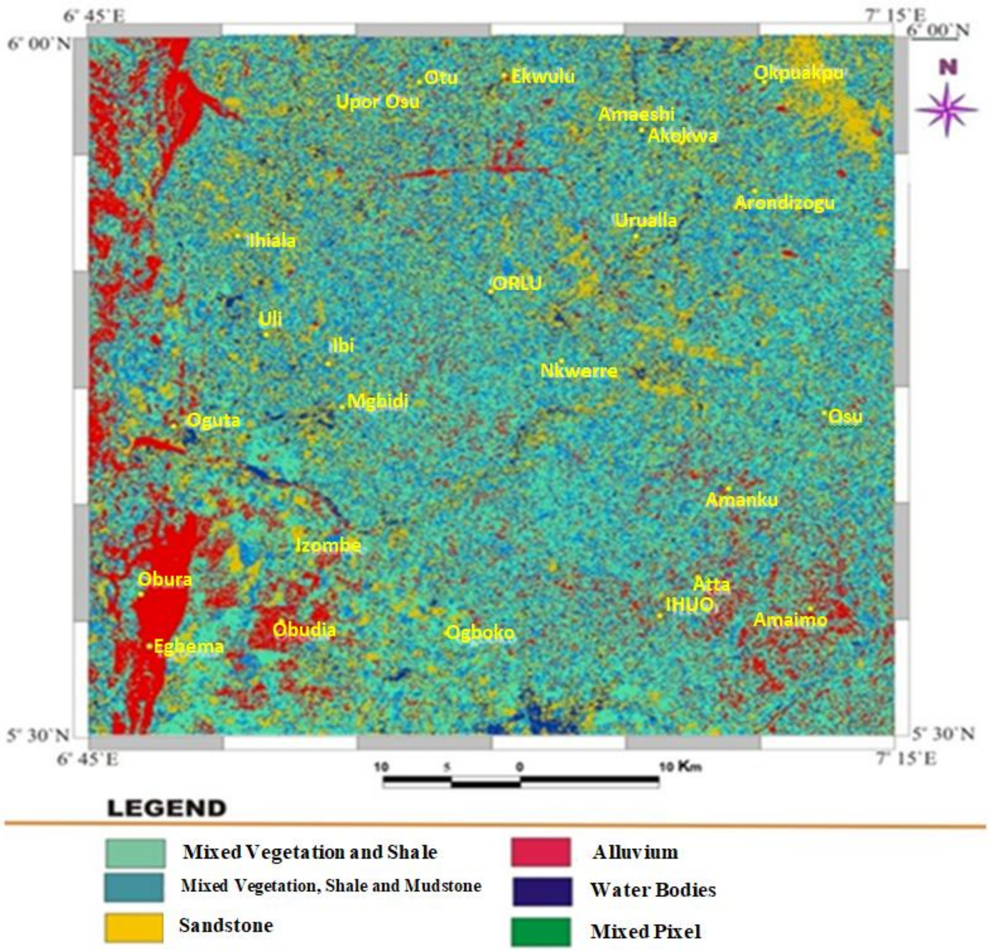

Figure 11. Unsupervised classification map.

5. Conclusions

Figures 2 and 3 from this study revealed the presence of a topographic high, which can easily aid runoff or washing away of top soil meant for agricultural activities. The presence of lineaments concentrating in the north-eastern part of the study area, as shown in Figures 4 and 6 respectively, revealed that erosion, which is a major factor affecting agricultural practices within the area, is structurally and lithologically controlled. It's possible that the lineaments provided a path for the top soil to migrate. This could also imply that the rivers and streams that serve as a source of water and irrigation in the area are structurally controlled. Hence agricultural practices should be discouraged in these areas to limit waste. Should agriculture be practiced in such locations, proper control measures must be put in place to ensure sustenance and preservation of agricultural input for appropriate yield. The study's findings also validate the existence of significant relationships between NDVI and crop yield, as shown in Figure 7, and which Figures 8, 9, and 10 agree with. Areas with high NDVI values are areas best fit for agricultural practices as they are areas of high soil nutrients with minimal or no erosion threats as a result of topography or even lineaments.

To contribute to the resolution of Nigeria's impending food crisis, it is critical to take note of these areas identified as viable for agriculture and make proper use of them for crop yield while investing limited resources.

Author Contributions

Chukwuebuka N. Onwubuariri conceptualize this research and is the main editor of the manuscript; Chidimma O. Ikeme and Chukwuebuka N. Onwubuariri gathered all the data used for this research and as well interpreted them after they were being processed; Lebe A. Nnanna and Boniface I. Ijeh supervised the entire research; Chidiebere C. Agoha and Cynthia C. Nwaeju processed the acquired data; Obinna C. Dinneya and Festus U. Nwaneho did the literature review. All authors have read and agreed to the published version of the manuscript.

Data Availability Statement

Data will be made available on request.

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Conflict of Interest

There is no conflict of interest.

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