African Journal of Environment and Natural Science Research
ISSN: 2689-9434
Volume 7, Issue 4, 2024 (pp. 102-118)
www.abjournals.org

GEOSPATIAL ANALYSIS OF CLIMATE CHANGE IMPACTS ON VEGETATION DYNAMICS IN OWERRI WEST, IMO STATE

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Cite this article:

Oyetunji, S. O., Popoola, I. B. (2024), Geospatial Analysis of Climate Change Impacts on Vegetation Dynamics in Owerri West, Imo State. African Journal of Environment and Natural Science Research 7(4), 102-118. DOI: 10.52589/AJENSR-64BQAK4M

Manuscript History

Received: 15 Aug 2024

Accepted: 13 Oct 2024

Published: 11 Nov 2024

ABSTRACT: *Climate change is a global phenomenon with profound effects on the environment, economies, and societies. It refers to significant changes in global temperatures and weather patterns over time. This study explores the impact of climate change on vegetation in Owerri West, Imo State, Nigeria, using geospatial techniques over a 20-year period (2003–2023). By analyzing satellite imagery and Normalized Difference Vegetation Index (NDVI) values alongside key climatic variables such as precipitation and land surface temperature (LST), the research seeks to quantify the extent of vegetation changes due to climate variability. The study uses Landsat 8 satellite data to evaluate spatiotemporal trends in vegetation health. NDVI values in 2003 ranged from a high of 0.45, indicating healthy and dense vegetation, to a low of -0.04, representing barren areas. By 2013, NDVI values had drastically declined, with a maximum of 0.12 and a minimum of -0.33, despite an increase in precipitation from 3300 mm (2003) to 3900 mm (2013). This decline suggests that other factors, such as extreme weather events or urbanization, contributed to vegetation stress. In 2023, NDVI values showed partial recovery, with a maximum of 0.28 and a minimum of 0.05, although precipitation levels dropped to a range of 600 mm to 540 mm. The broader temperature range in 2023, with a maximum of 32°C and a minimum of 17°C, likely reduced heat stress, allowing for vegetation recovery, though still below the 2003 levels, The findings highlight the complex interplay between climatic variables and vegetation health, where precipitation and temperature changes significantly influence vegetation dynamics. However, the NDVI decline in 2013, despite high precipitation, suggests that anthropogenic factors like urbanization and land use changes also play a critical role. This research emphasizes the importance of integrating remote sensing and GIS for monitoring vegetation responses to climate change. The study calls for sustainable land management practices and climate adaptation strategies to enhance vegetation resilience in the region.*

KEYWORDS: GIS, Climate Change, Remote Sensing, Sustainable development, NDVI, LST.

Article DOI: 10.52589/AJENSR-64BQAK4M
DOI URL: https://doi.org/10.52589/AJENSR-64BQAK4M

INTRODUCTION

Climate change is a global phenomenon with profound effects on the environment, economies, and societies. It refers to significant changes in global temperatures and weather patterns over time. While climate change is a natural process, scientific evidence shows that human activities have accelerated the rate of change. Among the many impacts of climate change, its effects on vegetation are particularly significant as they affect biodiversity, agricultural productivity, and ecological balance. Africa is considered one of the most vulnerable continents to climate change. Consistent rising temperatures and climate change have been linked to more prevalent drought, increased water scarcity, low harvests, and more extreme weather events. In Nigeria, droughts can indeed be attributed to climate change and changing weather patterns. Several factors contribute to the occurrence of droughts in the country, including Excessive Buildup of Heat, Decline in Precipitation, Increased Temperature, and Changes in Rainfall Patterns, El Niño, and La Niña Events.

Climate change is indeed one of the current crises that necessitate collective efforts and collaboration from various stakeholders around the world. e.g., climate advocates, government officials, industry leaders, institutions/academic experts, activists, media, international organizations, and business leaders.

Geospatial techniques, including remote sensing and Geographic Information Systems (GIS), have become invaluable tools in studying environmental changes. These technologies allow for the collection, analysis, and visualization of spatial and temporal data, providing insights into the dynamics of climate change and its impacts on vegetation.

Owerri West in Imo State, Nigeria, serves as a pertinent case study for examining the effects of climate change on vegetation. This region, characterized by its diverse ecosystems, has experienced noticeable climatic changes, making it an ideal location for this study. Owerri West is characterized by its tropical climate and diverse ecosystems. The area experiences significant seasonal variations in temperature and precipitation, making it an ideal study site for examining the impacts of climate change on vegetation.

The increasing variability and intensity of climatic conditions pose significant challenges to vegetation in Owerri West. Changes in temperature and precipitation patterns directly impact the health and distribution of vegetation. However, there is a lack of comprehensive studies using advanced geospatial techniques to analyze these impacts in this region.

This study aims to fill this gap by utilizing satellite imagery and geospatial analysis to assess the extent of climate change effects on vegetation in Owerri West.

The specific objectives are to:

i. Acquire the relevant satellite imagery such as Landsat 8 and preprocess the data.

ii. Assess changes in vegetation cover and climatic variables.

iii. Detect and analyze the spatiotemporal trend in vegetation dynamic

iv. Determine the impact of climate change on vegetation through regression analysis.

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This study is significant for several reasons:

It provides critical data for local and regional planning and decision-making.

It contributes to the body of knowledge on the impacts of climate change on vegetation.

It offers insights that can inform policy development and environmental management strategies.

This study focuses on Owerri West, Imo State, and covers the period from 2003 to 2023. It utilizes satellite imagery and geospatial analysis techniques. Limitations include potential data gaps, the resolution of satellite images, and the inherent uncertainties in climate models.

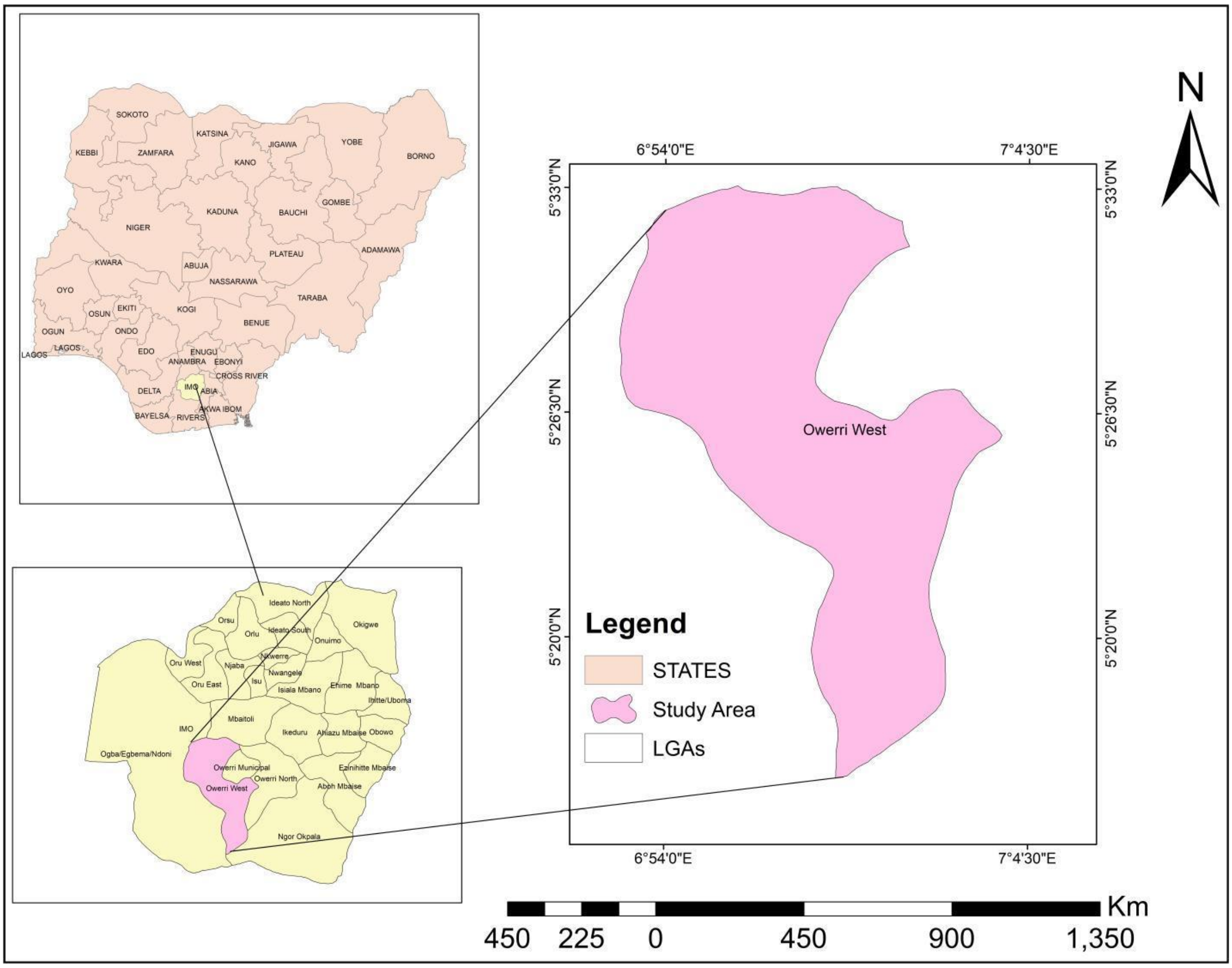

Fig 1: Map of the study area

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LITERATURE REVIEW

Climate change refers to significant changes in global temperatures and weather patterns over time. The Intergovernmental Panel on Climate Change (IPCC) has documented extensive evidence of climate change, highlighting rising temperatures, changing precipitation patterns, and increasing frequency of extreme weather events (IPCC, 2014). Regionally, in West Africa and Nigeria, studies have focused on the implications of changing climatic conditions on agriculture, water resources, and biodiversity (Odekunle, 2004; Salack et al., 2015).

Vegetation dynamics, which include changes in the distribution, composition, and health of vegetation over time, are significantly influenced by climate change. Studies have shown that increased temperatures and altered precipitation patterns directly impact vegetation health and productivity (Hickling et al., 2006). For instance, a study in East Africa linked changes in the Normalized Difference Vegetation Index (NDVI) with climate change and human activities, demonstrating a clear relationship between climatic variables and vegetation cover (Herrmann et al., 2005).

In Nigeria, research has indicated that climate change affects agricultural productivity and forest ecosystems. For example, the alterations in rainfall patterns and increased temperatures have led to shifts in the growing seasons and the health of crops and natural vegetation (Adejuwon, 2004). These changes have profound implications for food security and biodiversity conservation in the region. Geospatial techniques, including remote sensing and GIS, provide powerful tools for monitoring and analyzing environmental changes over large areas and long periods. Remote sensing involves the acquisition of information about the Earth's surface using satellite or airborne sensors, while GIS allows for the storage, manipulation, and visualization of spatial data (Campbell & Wynne, 2011). Remote sensing has been extensively used to monitor vegetation dynamics. For example, Landsat imagery has been employed to assess deforestation and reforestation patterns in various regions, providing valuable insights into land cover changes and their drivers (Hansen et al., 2013). Similarly, GIS techniques have been used to analyze spatial patterns and trends in vegetation cover, helping to identify areas most affected by climate change (Foody, 2002).

Studies have demonstrated the effectiveness of these techniques in assessing the impacts of climate change on vegetation. For instance, a study in the Sahel region used remote sensing to monitor changes in vegetation cover and linked these changes to climatic variables such as rainfall and temperature (Anyamba & Tucker, 2005). Another study in the Mediterranean region utilized GIS to map the relationship between climate variability and vegetation dynamics, highlighting the role of geospatial techniques in environmental research (Gitas et al., 2004). The health and productivity of vegetation are critical indicators of environmental changes, and various studies have focused on the impact of climate change on these aspects. Vegetation health can be assessed using various indices derived from remote sensing data, such as the Normalized Difference Vegetation Index (NDVI) and the Enhanced Vegetation Index (EVI). These indices provide quantitative measures of vegetation greenness, which is an indicator of photosynthetic activity and overall plant health (Pettorelli et al., 2005).

Research has shown that increased temperatures and changes in precipitation patterns negatively impact vegetation health. For example, a study conducted in the Sahel region demonstrated that prolonged droughts, associated with climate variability, significantly

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reduced vegetation cover and productivity (Anyamba & Tucker, 2005). In contrast, increased CO_2 levels and higher temperatures in some temperate regions have led to enhanced plant growth and extended growing seasons, a phenomenon known as "CO_2 fertilization" (Keenan et al., 2014). The spatiotemporal analysis involves studying the changes in vegetation over both space and time, providing a dynamic view of environmental changes. This type of analysis is crucial for understanding the patterns and drivers of vegetation changes under the influence of climate change.

In a study by de Jong et al. (2011), Landsat imagery was used to analyze the spatiotemporal dynamics of vegetation in European forests. The study found that climate change, particularly changes in temperature and precipitation, was a significant driver of observed vegetation changes. Similar methodologies have been applied in other regions, such as the Amazon Basin, where deforestation and reforestation patterns were monitored using satellite data to understand the impact of climate policies and conservation efforts (Nepstad et al., 2004).

Remote sensing and GIS are indispensable tools in environmental studies, offering a wide range of applications from monitoring deforestation to assessing the impacts of climate change on various ecosystems. These technologies provide high-resolution, multi-temporal data that enable researchers to track changes in vegetation cover and health over time.

For instance, a study by Hansen et al. (2013) used Landsat data to create high-resolution global maps of forest cover change, revealing significant trends in deforestation and reforestation at a global scale. This type of analysis is essential for understanding the spatial distribution of vegetation changes and identifying areas that are most vulnerable to climate change. Extreme weather events, such as droughts, floods, and hurricanes, are becoming more frequent and intense due to climate change. These events have immediate and often severe impacts on vegetation, leading to changes in species composition, distribution, and overall ecosystem health (Allen et al., 2010). A study by van der Molen et al. (2011) examined the impact of the European heatwave of 2003 on vegetation. The research found that extreme heat and drought conditions led to a significant reduction in vegetation productivity, as evidenced by satellite-derived NDVI data. Similarly, in the aftermath of Hurricane Katrina, remote sensing was used to assess the damage to forested areas in the Gulf Coast, highlighting the utility of geospatial techniques in disaster impact assessment (Wang & Xu, 2009).

The findings from studies on climate change and vegetation dynamics have significant policy implications. Effective management strategies are needed to mitigate the adverse impacts of climate change on vegetation and ensure the sustainability of ecosystems. One approach is the development of climate adaptation strategies that enhance the resilience of vegetation to changing climatic conditions. For example, the implementation of sustainable land management practices, such as agroforestry and conservation tillage, can help maintain soil health and support vegetation growth under variable climate conditions (Lal, 2004). Additionally, policies aimed at reducing greenhouse gas emissions are critical for mitigating the long-term impacts of climate change on vegetation. Several case studies have shown the application of geospatial techniques in studying the impacts of climate change on vegetation. In the Amazon Basin, remote sensing has been used to monitor deforestation and its association with climate change, providing critical data for conservation efforts (Nepstad et al., 2004). In the Arctic, satellite data has revealed significant changes in vegetation cover linked to rising temperatures, underscoring the sensitivity of polar ecosystems to climate change (Jia et al.,

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2003). In West Africa, research using Landsat imagery and GIS has documented changes in vegetation cover over several decades, revealing the impacts of both climate change and human activities (Lambin & Ehrlich, 1997). These studies highlight the importance of integrating remote sensing and GIS for comprehensive environmental monitoring and assessment.

METHODOLOGY

The secondary data used in this study include Landsat 3satellite imagery with a spatial resolution of 30.0 m, Landsat 7 ETM+ (Enhanced Thematic Mapper Plus) satellite imagery with a spatial resolution of 30.0 m, Landsat 8 OLI (Operational Land Imager) satellite imagery with a spatial resolution of 30.0 m, Google Earth Imagery. The Landsat imageries covering the study area with the specified path (190) and row (055) for all the mentioned epochs were downloaded from the USGS Landsat download website (http://earthexplorer.usgs.gov/) using the Google Chrome web browser. Precipitation data (2003, 2013, 2023) datasets were acquired from the climate engine.

Satellite imagery from Landsat 8 was acquired for the years 2003, 2013, and 2023. The data underwent preprocessing steps, including radiometric and atmospheric correction, to enhance accuracy and reliability.

Vegetation cover was assessed using the Normalized Difference Vegetation Index (NDVI), which provides a measure of vegetation health and density. Climatic variables such as temperature and precipitation were analyzed using historical weather data and satellite-derived information.

Following the compilation of both primary and secondary data, the subsequent stage entails the utilization of acquired satellite data. This dataset is slated for a processing step commonly known as image clipping or subset, a procedure contingent on the specific software employed. Clipping or subset, in this context, involves the extraction of a designated section from a larger file. Specifically, it pertains to the isolation of the study area within the downloaded satellite imagery of Imo State, accomplished through the incorporation of the study area's shapefile. The execution of this task is slated to be carried out through the application of ArcGIS software, streamlining the process of isolating and focusing on the relevant geographical area for subsequent analyses.

To quantify the impact of urbanization on vegetation cover over the year in Owerri metropolis using NDVI.

To quantify the impact of urbanization on vegetation cover over the years in Owerri metropolises using NDVI, we compared the NDVI values between 2003 and 2023 by:

1. Calculating the difference in NDVI values between 2003 and 2023 for each pixel or area within the study area.

2. Aggregating these differences to determine the overall change in NDVI associated with urbanization.

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3. Interpreting the results to understand the magnitude and direction of the impact of urbanization on vegetation cover.

1. Calculate the difference in NDVI values:

$$\Delta NDVI = NDVI\_2023 - NDVI\_2003$$

2. Aggregate the differences to determine the overall change in NDVI:

$$\text{Total Change in NDVI} = \Sigma(\Delta NDVI)$$

Interpolation methods were used to generate continuous precipitation surfaces from point data collected at meteorological stations. These methods help estimate precipitation values at unsampled locations, providing a comprehensive spatial representation of rainfall patterns.

Spatiotemporal analysis was conducted using GIS software to detect and analyze changes in vegetation over time. This included mapping vegetation cover and identifying trends and patterns.

RESULTS

NDVI Analysis

The NDVI is a widely used vegetation index that provides information about vegetation health and cover. Higher NDVI values indicate healthier and denser vegetation, while lower values suggest sparse or stressed vegetation. In 2003, the NDVI range was high at 0.451792, indicating areas with dense and healthy vegetation, while the low value of -0.0491556 indicated regions with little to no vegetation cover, potentially bare soil or urban areas. By 2013, the maximum NDVI value had reduced to 0.121622, and the significant drop in the minimum value to -0.328947 indicated a decline in vegetation health and density over the decade, suggesting increased vegetation stress or loss. In 2023, NDVI values showed some recovery compared to 2013, with a higher maximum value of 0.280021 and a minimum value of 0.0519259, indicating an improvement in vegetation health and density, though not reaching the levels observed in 2003.

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Figure 2: Spatial Distribution of Normalized Difference Vegetation Index **in 2023**

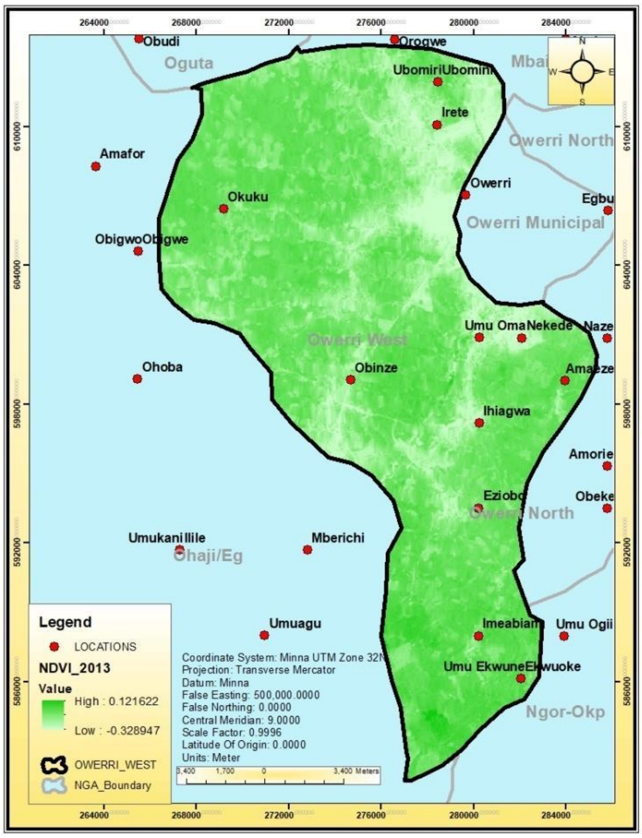

Figure 3: Spatial Distribution of Normalized Difference Vegetation Index **in 2023**

Figure 4: Spatial Distribution of Normalized Difference Vegetation Index **in 2023**

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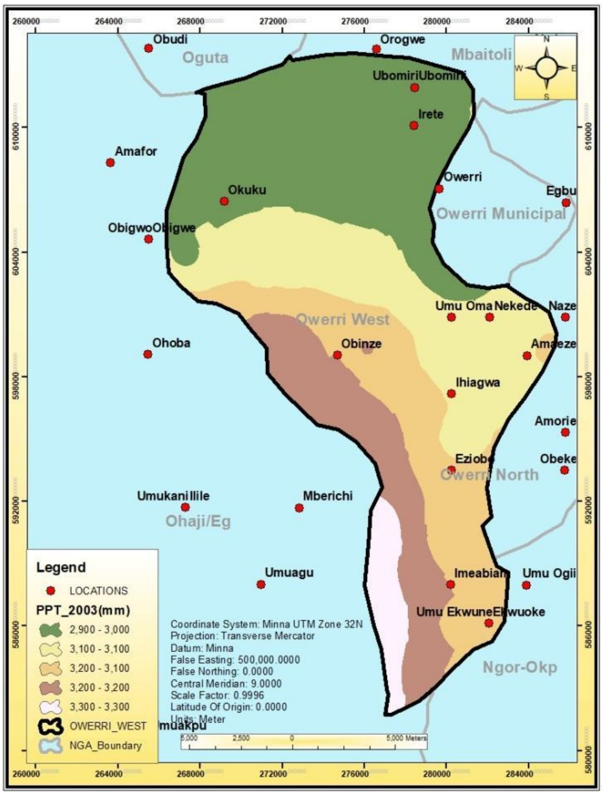
Precipitation Analysis

Precipitation is a critical factor influencing vegetation growth and health. Changes in precipitation patterns can directly impact vegetation cover and productivity. In 2003, the precipitation range was high at 3300 mm and low at 2900 mm, supporting dense vegetation as indicated by the high NDVI values. Despite an increase in precipitation to a high of 3900 mm and a low of 3300 mm in 2013, the NDVI values indicated a decline in vegetation health. This anomaly suggests that other factors, possibly extreme weather events or human activities, may have negatively impacted vegetation. In 2023, the significant drop in precipitation, with a high of 600 mm and a low of 540 mm, correlated with a decline in vegetation health compared to 2003. However, an improvement was noted compared to 2013, indicating that reduced precipitation levels may have limited vegetation recovery despite some improvement in NDVI values.



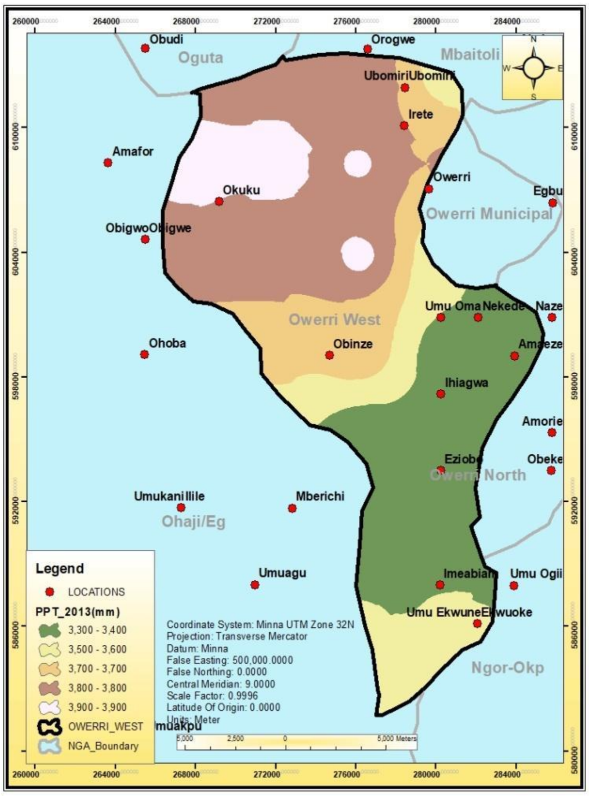


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Figure 5: Spatial Distribution of Precipitation in 2023

Land Surface Temperature (LST) Analysis

LST is another crucial factor affecting vegetation health. Higher temperatures can increase evapotranspiration rates, leading to water stress in plants. The moderate temperature range in 2003, with a high of 32°C and a low of 24°C, supported healthy vegetation growth, as reflected in the NDVI values. In 2013, a slight increase in maximum temperature to 33°C and a decrease in minimum temperature to 20°C, coupled with high precipitation, did not translate to healthier vegetation, suggesting possible heat stress or other negative impacts on vegetation. In 2023, the lower minimum temperature of 17°C, coupled with a maximum temperature of 32°C, indicated a broader temperature range. While the maximum temperature remained similar to 2003, the overall cooler minimum temperatures might have mitigated some heat stress on vegetation, contributing to the observed improvement in NDVI values compared to 2013.

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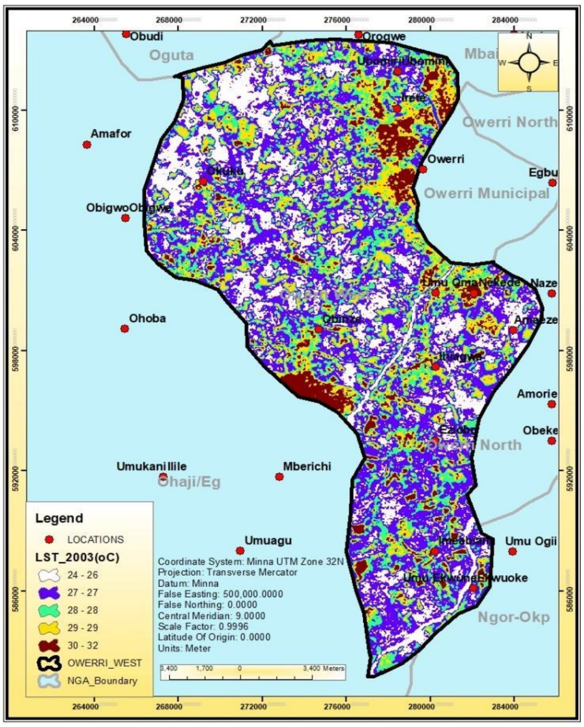

Figure 6: Spatial Distribution of Land Surface Temperature in 2003

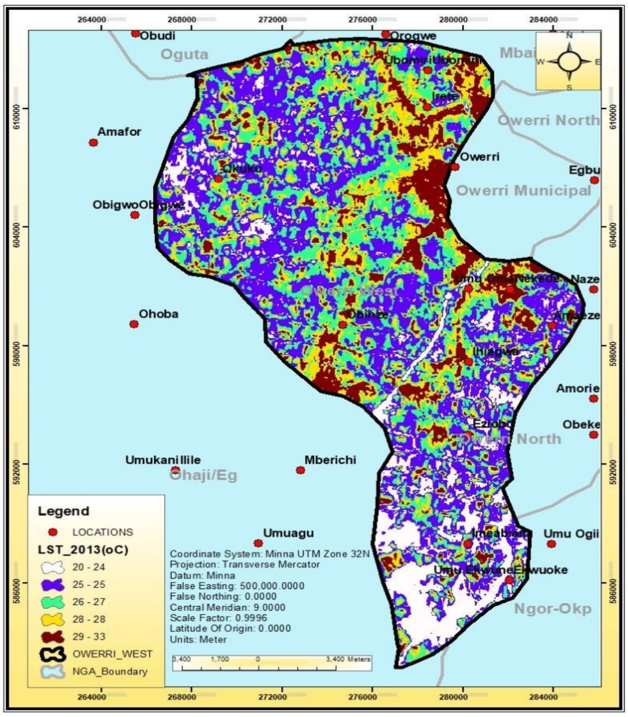

Figure 7: Spatial Distribution of Land Surface Temperature in 2003

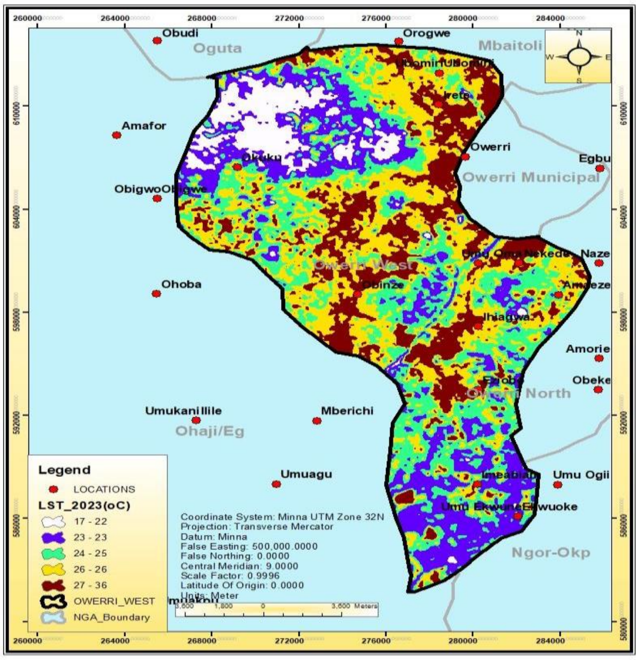

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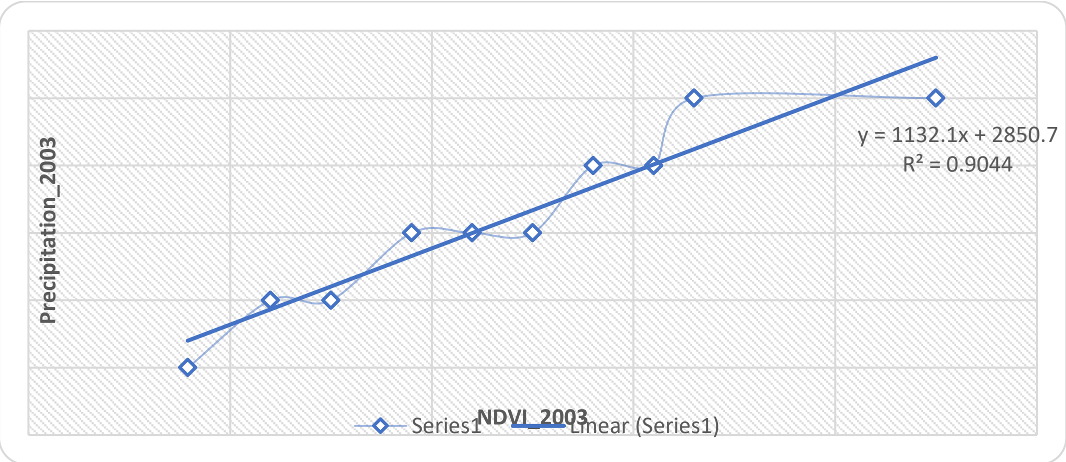
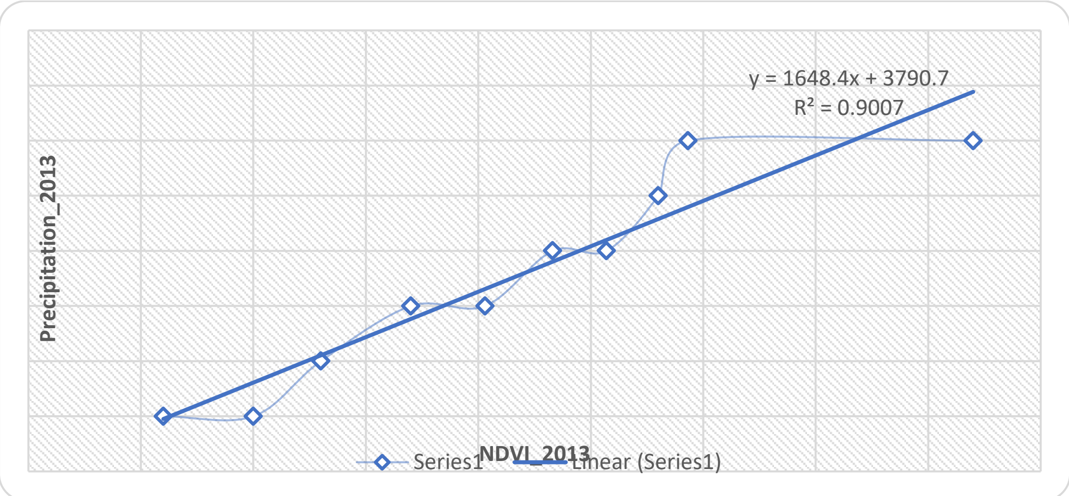
Table 1: Analysis Table

NDVI_2003	2013	2023	ppt_2003	ppt_2013	ppt_2023	LST_2003	LST_2013	LST_2023
0.1	-0.24	0.079	2,900	3,400	550	25	23	20
0.12	-0.2	0.12	3,000	3,400	550	26	24	21
0.14	-0.17	0.15	3,000	3,500	560	26	24	22
0.16	-0.13	0.19	3,100	3,600	570	27	25	23
0.18	-0.097	0.22	3,100	3600	570	28	26	25
0.19	-0.067	0.25	3,100	3,700	580	28	27	26
0.21	-0.043	0.28	3,200	3,700	580	29	28	28
0.22	-0.02	0.31	3,200	3,800	590	30	29	29
0.23	-0.0068	0.33	3,300	3,900	590	31	30	32
0.28	0.12	0.45	3,300	3,900	600	32	33	36





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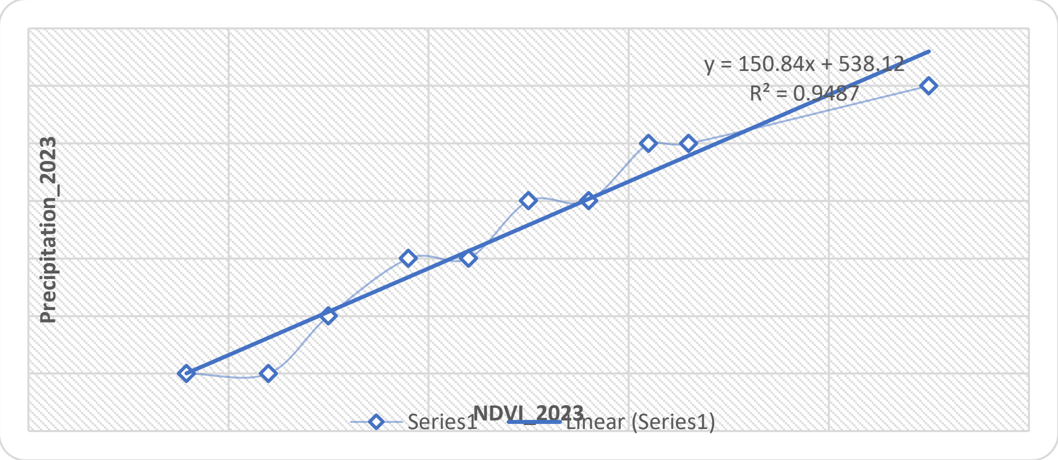

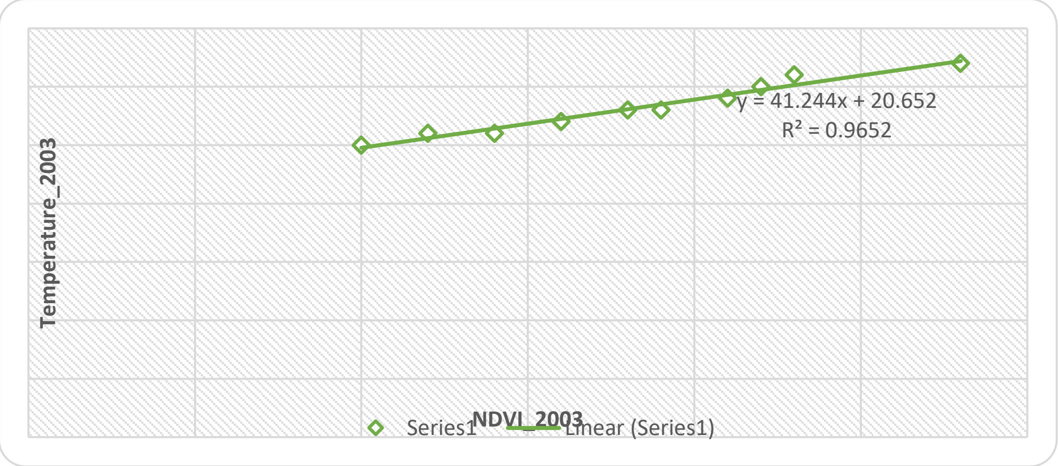

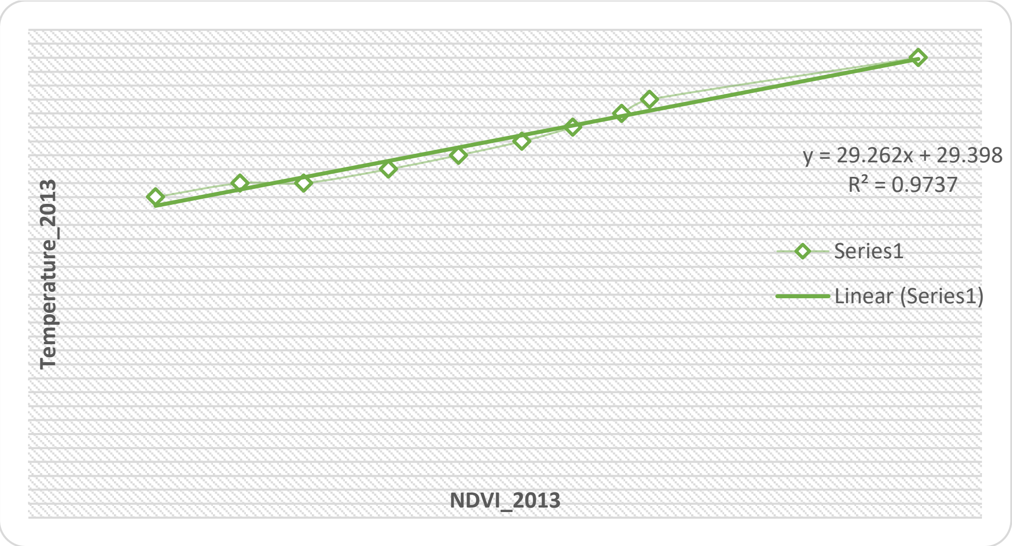

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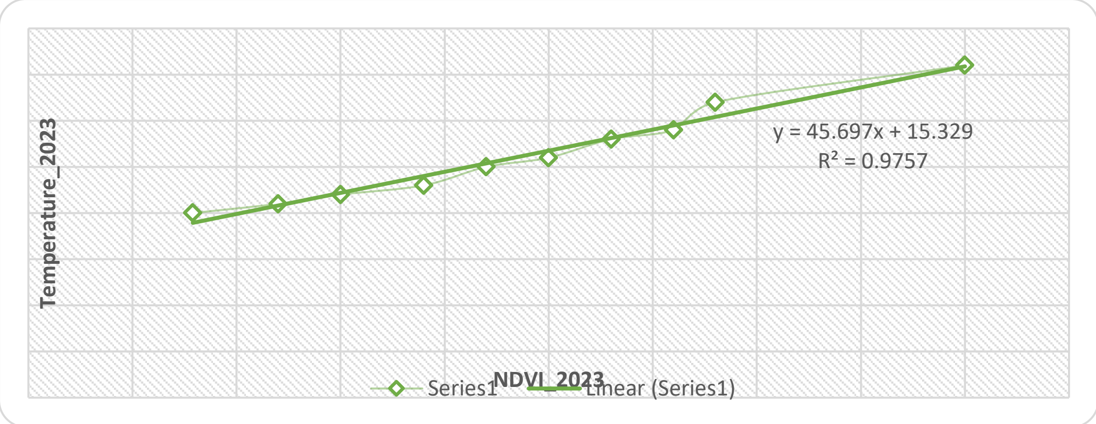

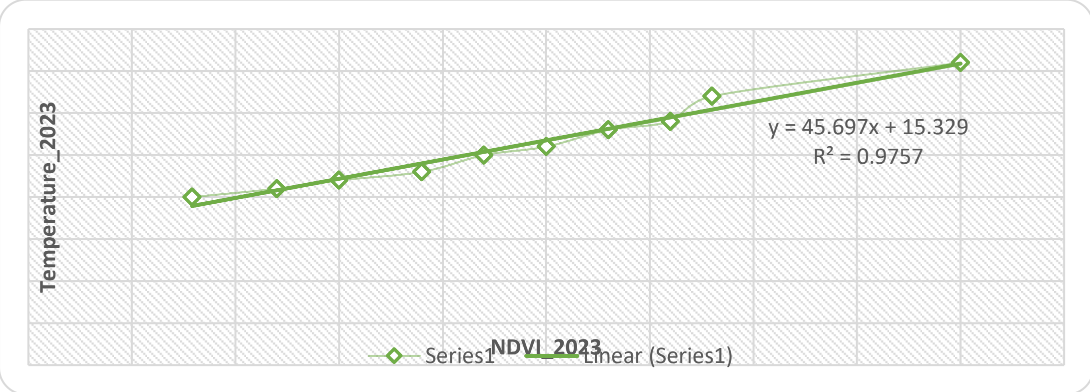

DISCUSSION

The analysis shows significant temporal changes in vegetation health as measured by NDVI values over the 20-year period. The highest vegetation health was recorded in 2003, followed by a notable decline in 2013, and a partial recovery by 2023. These changes highlight the complex interactions between precipitation, temperature, and vegetation dynamics. Precipitation levels showed a dramatic decline from 2013 to 2023, which correlates with a reduction in vegetation health. Despite higher precipitation in 2013 compared to 2003, the NDVI values suggest other factors influenced vegetation negatively. The drop in precipitation in 2023, although substantial, saw a slight recovery in vegetation, indicating other mitigating factors at play. The LST analysis indicates that temperature fluctuations, particularly increases in maximum temperatures, can have adverse effects on vegetation health. The broader temperature range in 2023, with lower minimum temperatures, may have contributed to the observed improvement in NDVI values despite lower precipitation levels. The discrepancy between high precipitation and low NDVI values in 2013 suggests that factors such as extreme weather events, land use changes, and human activities might have played significant roles in vegetation dynamics. It underscores the importance of considering multiple factors when analysing vegetation health in the context of climate change.

The results indicate that while precipitation and temperature are crucial determinants of vegetation health, their impacts are modulated by a range of other factors. The study highlights the importance of integrated approaches combining geospatial techniques and ground

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observations to understand the complex dynamics of climate change and vegetation interactions. The observed trends call for more detailed studies to unravel the underlying causes and inform effective management and conservation strategies.

CONCLUSION

This study aimed to assess the impact of climate change on vegetation dynamics by analyzing NDVI values, precipitation, and land surface temperature (LST) over the periods of 2003, 2013, and 2023. The findings highlight significant temporal changes in vegetation health, as well as the complex interactions between climatic variables and vegetation dynamics.

The highest vegetation health, indicated by the NDVI values, was recorded in 2003, supported by relatively high precipitation and moderate temperatures. By 2013, despite an increase in precipitation, vegetation health declined significantly, suggesting the influence of other factors such as extreme weather events or human activities. The year 2023 showed some recovery in vegetation health, although precipitation levels dropped dramatically. The broader temperature range, with cooler minimum temperatures, may have mitigated some heat stress on vegetation, contributing to the observed improvement in NDVI values compared to 2013.

The results underscore the importance of considering multiple factors when analyzing vegetation health in the context of climate change. Precipitation and temperature are crucial determinants, but their impacts are modulated by other factors, including land use changes and extreme weather events. This complexity highlights the need for integrated approaches that combine geospatial techniques, ground observations, and robust statistical analyses to understand the full scope of climate-vegetation interactions.

Based on the findings of this study, several recommendations are proposed to enhance the understanding and management of vegetation dynamics in the context of climate change:

1. Enhanced Monitoring and Data Collection:

Continuous and high-resolution monitoring of climatic variables and vegetation indices is essential. Efforts should be made to improve the spatial and temporal resolution of satellite imagery and ground-based observations.

2. Integrated Climate and Vegetation Models:

Develop and utilize integrated models that incorporate climatic variables, land use data, and vegetation indices to predict future changes and assess potential impacts on vegetation health. These models should consider the interactions between different climatic factors and human activities.

3. Mitigation and Adaptation Strategies:

Implement strategies to mitigate the adverse effects of climate change on vegetation. This includes promoting sustainable land use practices, reforestation, and conservation of existing green spaces. Adaptation measures should also be designed to enhance the resilience of vegetation to climatic stressors.

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4. Research on Extreme Weather Events:

Conduct detailed studies on the impact of extreme weather events, such as droughts and heatwaves, on vegetation dynamics. Understanding these impacts will help in developing targeted interventions to protect and restore vegetation health.

5. Community Engagement and Education:

Engage local communities in monitoring and managing vegetation health. Educational programs should be designed to raise awareness about the importance of vegetation in mitigating climate change and promoting environmental sustainability.

6. Policy and Governance:

Formulate and enforce policies that promote the sustainable management of natural resources and reduce human activities that negatively impact vegetation. Collaboration between government agencies, non-governmental organizations, and local communities is crucial for effective policy implementation.

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