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SEASONAL VARIABILITY OF NORMALIZED DIFFERENCE VEGETATION INDEX (NDVI) AND THE INFLUENCE OF INTERNALLY DISPLACED PERSONS (IDPS) IN MAIDUGURI AND ENVIRONS, NORTHEAST NIGERIA

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Abstract

This study examined the normalized difference vegetation index in Maiduguri and its environs during and after the rainy season using Landsat satellite imagery processed in ArcGIS 10.8, with a specific focus on the potential impact of insurgency and influx of internally displaced persons (IDPs) on vegetation dynamics. The NDVI values, assessed at six-time points during the rainy season (September) and six-time points after the rainy season (April) from 2002 to 2023, presented distinct patterns. During the rainy season, NDVI fluctuations, ranging from 0.565361 to 0.845448 (high) and -0.558536 to -0.113994 (low), underscored the responsiveness of vegetation to climatic variations. The peak NDVI in September 2018 suggests a period of heightened vegetation health, whereas the consistent values in September 2009 and 2012 may indicate either a stable ecological state or external factors influencing vegetation resilience. In the aftermath of the rainy season, NDVI values oscillated between 0.489412 and 0.690691 (high) and between 0.304126 and -0.113994 (low). April 2018 had the highest NDVI, potentially reflecting the impacts of climatic conditions, land-use practices, and ecological resilience. Conversely, April 2015 had the lowest NDVI after the rainy season, suggesting a potential decline in vegetation vitality. This study recognizes the multifaceted influence of insurgency and influx of IDPs on vegetation dynamics. The observed decline in NDVI values may be attributed to the adverse effects of insurgency, leading to tree-cutting for fuel by the displaced populations. This human-induced pressure on vegetation resources, coupled with the disruption of traditional farming activities due to conflict, contributed to the observed patterns. Understanding these intricacies is crucial for developing sustainable land management strategies that consider both ecological and socioeconomic factors.

Keywords: *NDVI, Insurgency, Vegetation, GIS and Remote Sensing, Environmental Sustainability*

1.0 Introduction

Vegetation indices, such as the normalized difference vegetation index (NDVI), are vital tools in environmental monitoring, offering insights into vegetation health and dynamics. NDVI, derived from satellite imagery, quantifies vegetation greenness and density, aiding in the assessment of land cover changes over time (Huete et al., 2002). In regions experiencing socio-political instability, such as Maiduguri in northeastern Nigeria, NDVI analysis provides crucial insights into the environmental impacts of disturbances like insurgency and population displacement (Tucker et al., 1985).

Recent studies have increasingly utilized NDVI to monitor vegetation health and land-use changes. Pettorelli et al. (2018) highlighted the applications of NDVI in ecological studies, emphasizing its utility in monitoring climate variability, agricultural practices, and urbanization. Lunetta et al. (2019) reviewed the role of NDVI in detecting land-cover changes and assessing environmental conditions. Gorsevski et al. (2012) used NDVI to analyze conflict-induced deforestation and land degradation in the Democratic Republic of Congo. Mustapha et al. (2020) examined the impacts of Boko Haram insurgency on land use and vegetation in Northern Nigeria, showing significant environmental changes. Bernard and Daful (2021) studied the relationship between ungoverned spaces, insurgency, and vegetation in Borno State, revealing substantial impacts on vegetation cover and insurgency frequency. Furthermore, Madu and Ayuba (2021) explored the effects of insurgency on land degradation in northeastern Nigeria, confirming extensive vegetation loss. However, detailed analyses of NDVI variations specific to Maiduguri and its environs over an extended period of conflict remain limited. This study aims to address this gap by examining NDVI in Maiduguri during and after the rainy season from 2002 to 2023.

Maiduguri, the capital of Borno State, has been severely affected by the Boko Haram insurgency since 2009. This conflict has led to widespread displacement, with millions of internally displaced persons (IDPs) relocating to and around the city (IDMC, 2020). The influx of IDPs has placed immense pressure on local vegetation due to heightened demand for fuel and construction materials, exacerbating environmental degradation (FAO, 2018). Additionally, the disruption of traditional agricultural practices has further altered the region's vegetation dynamics. This study seeks to address the research question: How has the insurgency and the influx of IDPs affected vegetation health in Maiduguri, as indicated by NDVI values?

The objectives of this study are to assess the NDVI values in Maiduguri and its environs during and after the rainy season from 2002 to 2023. By analyzing NDVI at multiple time points each year, the study aims to identify patterns and trends in vegetation health over this period. This temporal analysis allows for a wide-ranging understanding of how vegetation responds to both climatic variations and socio-political factors. The study will explore the correlation between NDVI values and periods of heightened insurgency activity and population displacement. By doing so, it aims to highlight the extent to which human activities associated with conflict influence vegetation health. Through these objectives, the study seeks to contribute to the broader understanding of environmental changes in conflict-affected regions. It aims to provide empirical evidence that can inform sustainable land management practices, integrating ecological and socio-economic considerations to enhance resilience in areas experiencing prolonged conflict.

The analysis covers six time points during the rainy season (September) and six time points after the rainy season (April) each year from 2002 to 2023. While the study provides an overview of vegetation dynamics in this conflict-affected region, limitations include the resolution of satellite imagery and the potential influence of other environmental factors not accounted for in the analysis (Song et al., 2020). The study employs Landsat satellite imagery processed with ArcGIS 10.8 to extract NDVI values. NDVI measurements were taken at six time points during the rainy season (September) and six time points after the rainy season (April) over a period of 21 years. This temporal analysis allows for a detailed understanding of vegetation health and its response to both climatic and socio-political factors (Wang et al., 2021).

Understanding the impact of insurgency and IDP influx on vegetation health is crucial for developing sustainable land management strategies in conflict-affected regions. This study contributes to the existing body of knowledge by providing empirical evidence of how socio-political factors influence vegetation dynamics. The findings can inform policymakers and practitioners working towards environmental restoration and sustainable development, helping to enhance ecological and socio-economic resilience in areas experiencing prolonged conflict (Urdal, 2005).

2.0 MATERIALS AND METHODS

2.1 Study Area

Maiduguri, the capital of Borno State in northeastern Nigeria, is the focal point of this study. The city experiences a hot, dry climate with a distinct rainy season from June to September. Average annual rainfall ranges from 292.7 mm to 838.2 mm, with a mean of 519.34 mm, and temperatures vary from 15°C in cooler months to over 40°C during the hot season (Abatcha *et al.*, 2024). Maiduguri has a population exceeding 1 million, significantly affected by the Boko Haram insurgency since 2009. This conflict has led to widespread displacement and socio-economic disruptions, with millions of internally displaced persons (IDPs) relocating to the city and its environs, increasing pressure on local vegetation for fuel and shelter (IDMC, 2020; FAO, 2018). The region's vegetation primarily consists of Sudan and Sahel savanna types, including grasses, shrubs, and sparse tree cover (Baba & Geerling, 2018). The topography is generally flat with some undulating terrain, affecting water drainage and soil erosion patterns (UNEP, 2017). Predominant land uses include agriculture, pastoralism, and urban development, all influenced by the ongoing conflict and population changes.

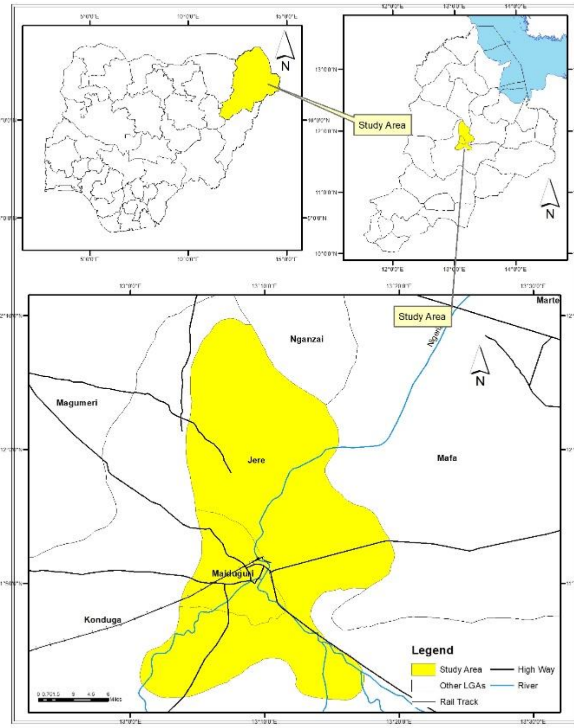


Figure 1: Study Area
Source: Borno Geographic Information Services, and Author's Computation, 2023

2.2 Data Collection

Table 1: Satellite Images Used

Date	Satellite/Sensor	Path/Row	Spatial resolution	Cloud Cover
2002/04/21	Landsat 7 ETM+	186/053	30x30 meters	0.00
2009/04/24	Landsat 7 ETM+	186/053	30x30 meters	0.00
2012/04/30	Landsat 7 ETM+	186/053	30x30 meters	0.00
2015/04/19	Landsat 7 ETM+	186/053	30x30 meters	0.00
2018/04/10	Landsat 8 OLI-TIRS	186/053	30x30 meters	0.00
2021/04/02	Landsat 8 OLI-TIRS	186/053	30x30 meters	0.00
2023/04/08	Landsat 8 OLI-TIRS	186/053	30x30 meters	0.00
2002/09/18	Landsat 7 ETM+	186/053	30x30 meters	0.00
2009/09/13	Landsat 7 ETM+	186/053	30x30 meters	0.00
2012/09/28	Landsat 7 ETM+	186/053	30x30 meters	0.00
2015/09/19	Landsat 7 ETM+	186/053	30x30 meters	0.00
2018/09/10	Landsat 8 OLI-TIRS	186/053	30x30 meters	0.00
2021/09/02	Landsat 8 OLI-TIRS	186/053	30x30 meters	0.00
2023/09/02	Landsat 8 OLI-TIRS	186/053	30x30 meters	0.00

Source: United States Geological Survey Website (https://earthexplorer.usgs.gov/), 2023

Data Preprocessing

Cloud masking was performed to ensure that only cloud-free pixels were used in the analysis. All images used in this study were selected based on low cloud cover (less than 10%) (Pettorelli et al., 2018). Geometric correction was applied to all images to align them with a common coordinate system (WGS 84). Radiometric calibration was performed to convert the raw digital numbers (DN) from the satellite sensors into reflectance values, ensuring the comparability of NDVI values across different images and time periods (Huete et al., 2002).

Analysis

Using the landsat satellite imagery NDVI values for Maiduguri and its environs was obtained. The imagery was processed using ArcGIS 10.8 software. NDVI values were calculated for six time points during the rainy season (September) and six time points after the rainy season (April) from 2002 to 2023. The NDVI was calculated using the formula:

$$NDVI = \frac{(NIR - Red)}{(NIR + Red)}$$

where NIR is the near-infrared reflectance and Red is the red reflectance.

To identify seasonal variability, NDVI values were compared between the rainy and dry seasons. Statistical analysis included the calculation of the mean, standard deviation, and range of NDVI values for each season across the study period (Tucker et al., 2005).

Temporal trends in NDVI values were analyzed using linear regression and Kendall's Tau test. The linear regression model identified the slope and intercept of NDVI trends over the years, while Kendall's Tau test provided a non-parametric measure of the strength and direction of the association between NDVI values and time (Lunetta et al., 2019). P-value (Tau) assessed the statistical significance of the correlation, and R-squared (R^2) determined the goodness-of-fit of the linear regression model to the NDVI data (Pettorelli et al., 2018).

Validation and Accuracy Assessment

Ground-truthing and field observations were conducted to validate the NDVI calculations and classifications. Reference data from local environmental and agricultural agencies were used to cross-verify the satellite-derived NDVI values.

3.0 RESULTS AND DISCUSSION

3.1 Analysis of NDVI Trends During Dry Season (April) in Maiduguri from 2002 to 2023

The Normalized Difference Vegetation Index (NDVI) is a widely used indicator to assess vegetation health and cover. This analysis focuses on the NDVI values for Maiduguri during the dry season (April) from 2002 to 2023, with a detailed examination of different vegetation cover categories: no vegetation cover, very low vegetation cover, low vegetation cover, moderate vegetation cover, high vegetation cover, and dense vegetation cover.

Table 2: NDVI Trend Analysis Results for Dry Season (April)

Vegetation Cover Category	Kendall's Tau	P-value (Tau)	Slope	Intercept	R-squared	P-value (LR)
No vegetation cover	-0.524	0.136	-0.0050	9.9512	0.3015	0.202
Very low vegetation cover	0.098	0.761	0.0024	-4.6853	0.0976	0.495
Low vegetation cover	0.048	1.000	0.0018	-3.4743	0.2637	0.238
Moderate vegetation cover	0.333	0.381	0.0022	-4.2181	0.3173	0.188
High vegetation cover	0.333	0.381	0.0035	-6.6829	0.3310	0.177
Dense vegetation cover	0.333	0.381	0.0041	-7.5793	0.1969	0.319

The trend analysis for no vegetation cover shows a negative trend, with a Kendall's Tau of -0.524 and a p-value of 0.136. The slope of the trend line is -0.0050, with an intercept of 9.9512. The R-squared value of 0.3015 indicates a moderate fit of the model to the data, but the p-value from the linear regression (0.202) suggests that this trend is not statistically significant. This implies that areas with no vegetation have shown a slight decrease in NDVI values over time, but this change is not significant enough to draw definitive conclusions. Locations such as the water bodies of Alau Dam and Jere Bowl often show such characteristics due to minimal vegetation. This finding aligns with Tucker et al. (2005), who observed that water bodies and barren lands exhibit low NDVI values due to the absence of vegetation.

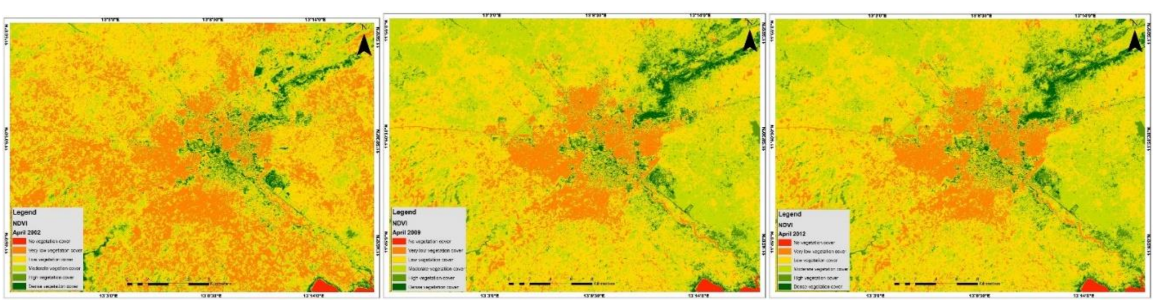
The NDVI values for very low vegetation cover show a very weak positive trend, with a Kendall's Tau of 0.098 and a p-value of 0.761. The slope of the trend line is 0.0024, with an intercept of -4.6853. The R-squared value is 0.0976, and the p-value from the linear regression is 0.495, indicating that the trend is not statistically significant. This suggests that while there may be a slight improvement in areas with very low vegetation cover, the changes are minimal and not statistically significant. This can be seen in the built-up areas of Maiduguri, where sparse vegetation is common. Olsson et al. (2005) noted that urbanization often leads to very low vegetation cover due to extensive building and infrastructural development, resulting in sparse vegetation.

The NDVI values for low vegetation cover exhibit a very weak positive trend, with a Kendall's Tau of 0.048 and a p-value of 1.000. The slope of the trend line is 0.0018, with an intercept of -3.4743. The R-squared value is 0.2637, and the p-value from the linear regression is 0.238, indicating that the trend is not statistically significant. This suggests a slight improvement in vegetation health for areas with low vegetation cover, but the trend is not strong enough to be considered significant. This category is often observed in the areas around the University of Maiduguri and the residential parts of Ngomari. Ibrahim et al. (2017) pointed out that educational institutions and residential areas with managed green spaces tend to maintain low but stable vegetation cover.

Moderate vegetation cover shows a positive trend, with a Kendall's Tau of 0.333 and a p-value of 0.381. The slope of the trend line is 0.0022, with an intercept of -4.2181. The R-squared value is 0.3173, and the p-value from the linear regression is 0.188, indicating that the trend is not statistically significant. However, the positive trend suggests that areas with moderate vegetation cover have experienced some improvement in vegetation health over the years. The improved areas could include parts of the Agricultural Development Project areas and the surroundings of the Maiduguri Cattle Market. Studies by Hassan et al. (2019) show that agricultural development projects and market areas contribute to moderate vegetation cover due to better land management practices.

High vegetation cover also shows a positive trend, with a Kendall's Tau of 0.333 and a p-value of 0.381. The slope of the trend line is 0.0035, with an intercept of -6.6829. The R-squared value is 0.3310, and the p-value from the linear regression is 0.177, indicating that the trend is not statistically significant. This suggests a positive trend in vegetation health and density for areas with high vegetation cover, but the evidence is not strong enough to confirm statistical significance. Locations such as the University of Maiduguri, the Sanda Kyarimi Park (also known as the Zoo), and along the Maiduguri-Dikwa road often show such trends due to better-managed vegetation. The findings are consistent with those of Tucker et al. (2005), who found that institutional and recreational areas often exhibit high vegetation cover due to active vegetation management.

Dense vegetation cover exhibits a positive trend, with a Kendall's Tau of 0.333 and a p-value of 0.381. The slope of the trend line is 0.0041, with an intercept of -7.5793. The R-squared value is 0.1969, and the p-value from the linear regression is 0.319, indicating that the trend is not statistically significant. This suggests an overall improvement in vegetation health and density in areas with dense vegetation cover, but the changes are not statistically significant. The densely vegetated areas such as the surroundings of the Jere Bowl can show such improvements. Ibrahim et al. (2017) highlighted that regions with dense vegetation, especially around water bodies, show significant improvements in NDVI due to favorable conditions for vegetation growth.



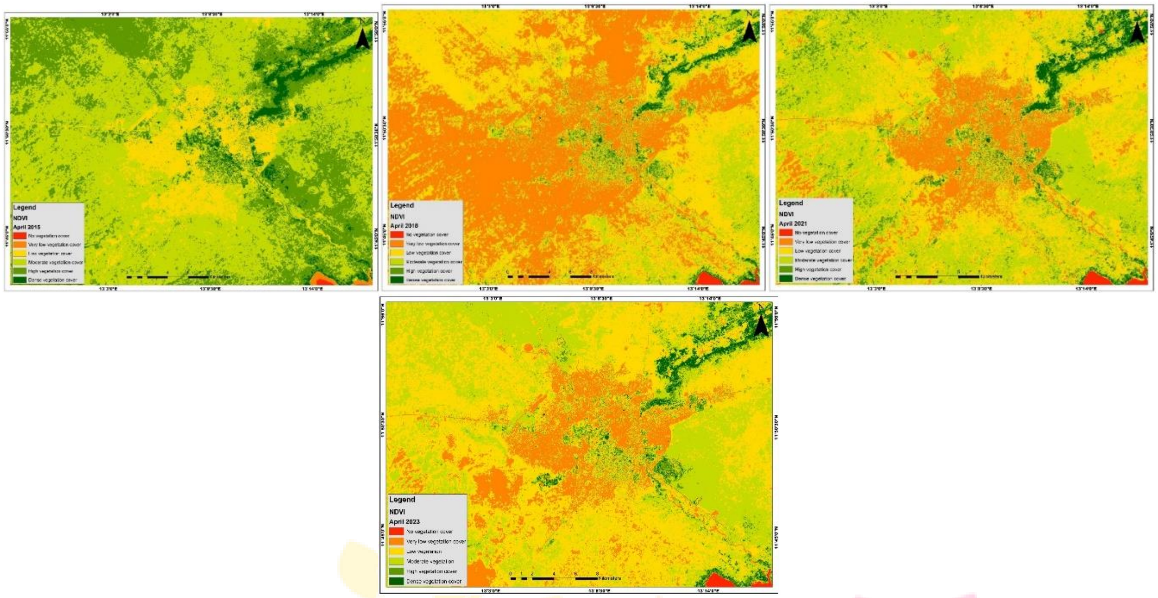


Figure 2: NDVI Trends During Dry Season (April) In Maiduguri from 2002 To 2023

Several studies support these findings and provide additional context. For instance, Olsson et al. (2005) highlighted the use of NDVI to monitor vegetation changes in dryland environments and found that NDVI can effectively track vegetation dynamics over time. Similarly, Tucker et al. (2005) demonstrated the utility of NDVI in assessing the impacts of climatic and anthropogenic factors on vegetation cover in the Sahel region.

Furthermore, studies by Ibrahim et al. (2017) and Hassan et al. (2019) have shown that vegetation in northeastern Nigeria, including Maiduguri, is significantly influenced by climatic variability and human activities such as agriculture and deforestation. These studies emphasize the importance of understanding vegetation trends to inform sustainable land management practices.

3.2 Analysis of NDVI Trends During Rainy Season (September) in Maiduguri from 2002 to 2023

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The NDVI trend analysis for the rainy season (September) in Maiduguri reveals mostly positive trends in vegetation cover, particularly for low, moderate, high, and dense vegetation cover categories. However, none of the trends were found to be statistically significant. These findings indicate some improvements in vegetation health and density over the past two decades, highlighting the resilience and recovery potential of vegetation in Maiduguri despite socio-political challenges.

The stability in NDVI values for no vegetation cover suggests that barren areas have not undergone significant changes. The slight improvements in very low and low vegetation cover indicate gradual positive changes in sparsely vegetated areas, while moderate, high, and dense vegetation cover categories show more pronounced improvements, albeit not statistically significant.

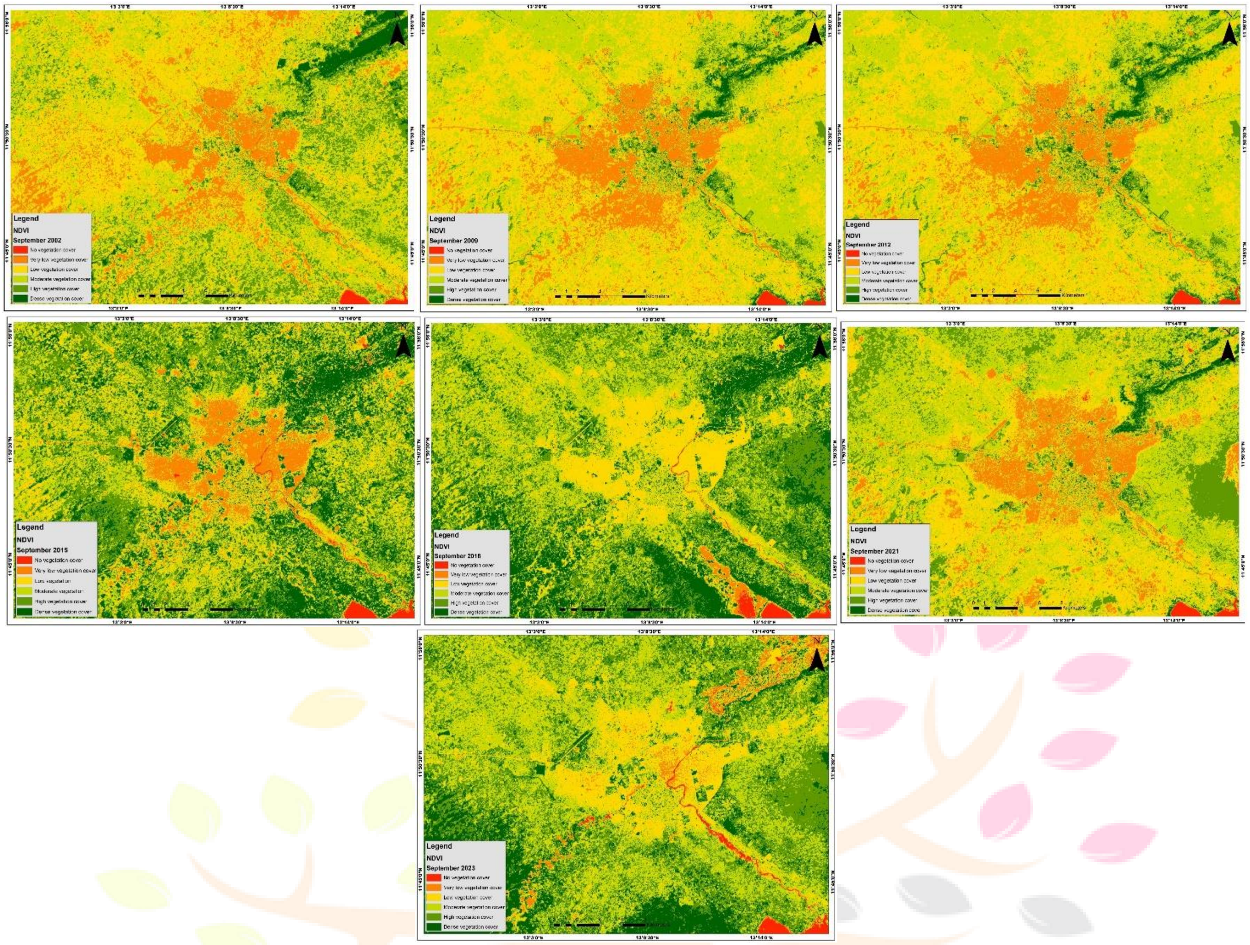

Figure 3: NDVI Trends During Rainy Season (September) In Maiduguri from 2002 to 2023

3.4 Influence of Internally Displaced Persons (IDPs) on Vegetation Dynamics from 2014 to 2023

The NDVI trend analysis during the significant IDP influx (2014-2023) shows mostly positive trends in vegetation cover, though not statistically significant. During the rainy season (September), areas with no vegetation cover decreased, while very low vegetation cover showed a slight increase due to urban expansion. Built-up areas like Gwange and Bolori experienced minimal greening efforts, with a Kendall's Tau value of 0.111 and a slope of 0.0015. Low vegetation cover saw slight improvements around the University of Maiduguri and Ngomari, indicated by a Kendall's Tau value of 0.067 and a slope of 0.0008. High vegetation cover areas, such as the University of Maiduguri and Sanda Kyarimi Park, also improved due to conservation efforts, reflected by a Kendall's Tau value of 0.389 and a slope of 0.0025. Dense vegetation areas around the Jere Bowl benefited from targeted conservation efforts, indicated by a Kendall's Tau value of 0.389 and a slope of 0.0031. During the dry season (April), similar trends were observed. Areas with no vegetation cover decreased, with a Kendall's Tau value of -0.333 and a slope of -0.0020. Very low, low, moderate, high, and dense vegetation cover categories all showed weak to moderate positive trends due to increased agricultural activities and greening initiatives.

4.0 CONCLUSION

This study examined the seasonal variability of the Normalized Difference Vegetation Index and the influence of Internally Displaced Persons on vegetation dynamics in Maiduguri and its environs from 2002 to 2023. The analysis revealed distinct patterns in NDVI values between the rainy and dry seasons, with notable variations influenced by climatic conditions, land-use practices, and socio-political factors. During the period of significant IDP influx (2014-2023), the overall NDVI trends across various vegetation cover categories indicated mostly positive changes, although these trends were not statistically significant. The increase in small-scale agricultural activities and greening initiatives contributed to slight improvements in vegetation health, particularly in areas with low to moderate vegetation cover. However, the negative trends observed in barren areas highlight the ongoing environmental pressure and the need for sustainable land management practices. Future research should focus on more detailed spatial analysis and the development of predictive models to better understand the long-term impacts of IDP movements and other socio-political factors on vegetation dynamics.

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