



Exploring the Normalized Difference Vegetation Index for Desertification Risk Mapping in Gombe State, Nigeria

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Abstract:

Desertification poses a growing environmental threat in Gombe State due to its ecological vulnerability and geographical proximity to the most affected areas. However, the interplay between natural and human factors has aggravated the susceptibility of the region to land degradation. Therefore, this study aimed to assess the extent and progression of desert encroachment in the Gombe State by analyzing vegetation cover between 2001 – 2022 using satellite-derived vegetation indices. The study employed a Moderate Resolution Imaging Spectroradiometer (MODIS) derived Normalized Difference Vegetation Index (NDVI) process and analyzed in ArcGIS. NDVI maps for 2001 and 2022 were classified using a standard threshold to determine vegetation conditions in the study area. Transition analysis was conducted to detect changes in vegetation class over time and determine stability, degradation, or potential recovery. The result revealed a consistent decline in vegetation health and density over the study period, with average NDVI values decreasing from 0.36 in 2001 to 0.32 in 2022. Areas with no vegetation slightly increased from 1.2% to 1.4%. While sparse vegetation expanded significantly from 95.7% to 98.1%. Conversely, areas with vegetation only declined from 3.1% to 0.5%. Approximately, 95.3% of the study area remained persistently under sparse vegetation throughout the study. It has been concluded that the findings indicated an increasing risk of desertification in the study area which is anticipated to further impact environment and socio-economic activities. The study recommends the need for integrated and sustained mitigation and restoration strategies to combat further degradation and enhance the ecological resilience of the study area.

Keywords: Desertification, Gombe, Remote Sensing, Vegetation Indices,

1.0 Introduction

Desertification has been one of the concerns of the world community in recent times. However, it is being underlined significantly in the global initiative named “Sustainable Development Goals” (SDGs). Specifically, SDG target: 15.3 aimed to “By 2030, *combats desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land degradation-neutral world*” [1]. This target was set as an instrument to measure the progress of SDG 15. The topic “Desertification” was defined by the United Nations Convention to Combat Desertification (UNCCD) “as a land degradation in arid, semi-arid and humid areas resulting from various factors, including climatic variations and human activities” [2]. It represents a persistent environmental threat that systematically diminishes the biological productivity of land, thereby reducing its inherent capacity to support ecosystem services. This irreversible soil degradation, as noted by [3], is self-perpetuating; once initiated, it perpetuates further degradation, as highlighted by [4]. This consequent loss of biodiversity poses a significant risk to global employment and economic stability. As a global issue affecting arid and semi-arid regions, desertification is primarily driven by natural processes but is exacerbated by anthropogenic activities. This environmental challenge significantly impacts the livelihoods of those dependent on these fragile ecosystems.

In Nigeria, desertification has been a long-standing issue, with records dating back to the 1920s. However, its effects became particularly evident during the 1971-1973 famine, which affected fifteen northern states and encompassed approximately one-fifth of Nigeria's total land area, as noted by [5]. This issue remains a critical environmental concern, particularly in the northern part of the country, according to [6]. The severity of desertification in Nigeria varies by region, generally intensifying from south to north. Approximately 75% of the northern states have been affected by various forms of desertification, as reported by [5]. In the foregoing, Borno and Yobe States experience severe desertification, while Bauchi, Gombe, Adamawa, and Taraba are considered vulnerable. However, even the Guinea Savannah region, traditionally less affected, is witnessing a decline in environmental resources, as noted by [7]. The delayed recognition/inconsistent monitoring and evaluation of desertification has led to a lack of comprehensive assessment of this phenomenon, particularly in the most affected areas, according to [2].

[8] Conducted a terrain analysis in Gombe State and reported that 30 gazetted forest reserves are located in different parts of the State, constituting about 9.1% of the total land area of the State. However, [9] stressed that these forest reserves only exist on a map of the state but in reality, most of the forests have been de-reserved. [10], [11], [12] in their studies reported a decline in vegetation cover in the study area. A downward vegetation growth rate was reported in the Dukku Local Government Area of the study area, using a normalized differential vegetation index which ranges from -0.722 low to 0.806 high in (2000); -0.150 low to 0.665 high in (2010); and very thin -0.133 low to 0.307 high in (2020), put in other words, the rate forest cover changed between 2000 and 2020, that none vegetated area had the larger percentage of about 3.5% annual rate and densely vegetation

decreased on a rate of -2.1 annually, consequently the rate of desert encroachment is on the rise in Dukku L.G.A [13], and the State at large. Persistent decline of vegetation cover deranges the meteorological balance resulting in increased heat and evaporation. Land degradation constitutes the most threatening factor to ecosystem changes in Gombe State affecting the livelihoods of the poor who rely on the biological or economic productivity of the land as a source of their basic living materials. However, continuous pressure on the environment exacerbates the existing vulnerabilities and contributes to desertification. Despite the growing concerns over desertification in northeastern Nigeria especially in ecologically sensitive areas like Gombe State, which is adjacent to the arid region to the north and Guinea Savannah to the south. There remains a significant inadequate of localized, data-driven assessments focusing specifically on vegetation transition over time. Therefore, this study seeks to fill that gap by conducting a detailed vegetation transition analysis using satellite-derived NDVI data to capture both the spatial and temporal dynamics of vegetation cover change, by focusing on how vegetation shifts across classes, such as from dense to sparse or bare. Therefore, the objective of this study is to assess the extent and spatial progression of vegetation degradation and desertification risk in Gombe State between 2001 to 2022 using NDVI-based analysis and to provide evidence-based recommendations for environmental monitoring, restoration planning, and policy interventions.

2.0 Materials and Methods

2.1 Study Area

Gombe State served as the study area for this research. It is one of the six northeastern states in Nigeria, established from the former Bauchi State on October 1, 1996. The study area is geographically situated between latitudes 9°30' and 12°30' N, and longitudes 8°45' and 11°45' East [14]. The state is situated at the center of the northeast geo-political region of the country. It is surrounded by Yobe State to the north, Borno State to the east, Adamawa and Taraba to the south, and Bauchi State to the west. The state covers an important geographical and ecological position within the Sudan savanna belt which is marked as a transit belt between the arid region to the north and the more humid regions to the southern part of the state. This transitional nature of the study area under review makes it a critical zone for studying, restoring, and mitigating the effect of vegetation changes influenced by natural and anthropogenic factors.

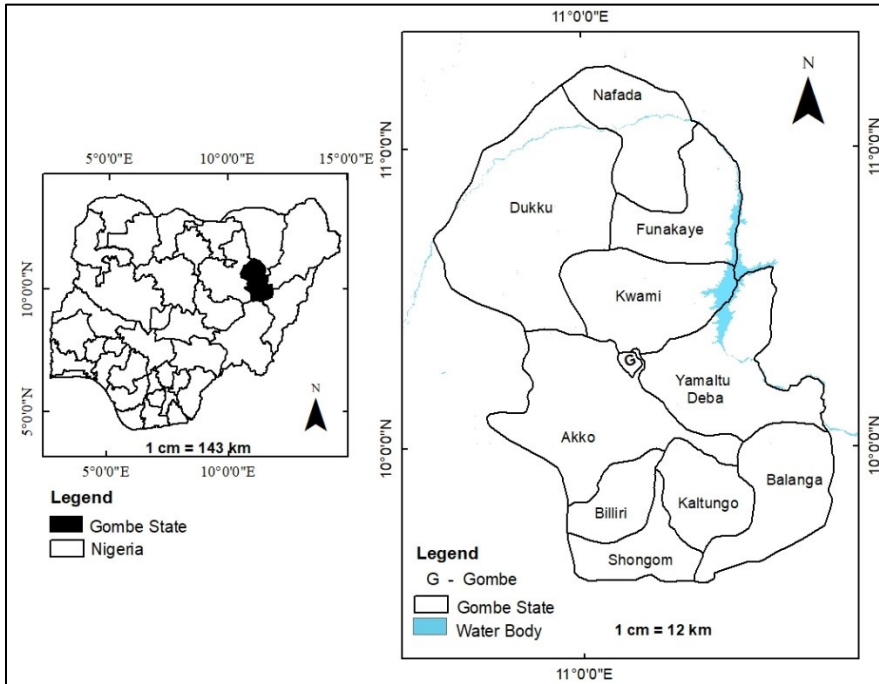


Fig. 1: Location of the Study Area

The state is characterized by a tropical savannah climate, which experiences two distinct seasons: a wet season from April to October, with an average rainfall of 850 mm, and a dry season from November to March, with an average annual temperature of 32°C [15]. The region is characterized by Sudan savanna vegetation, which includes unevenly distributed grasses, shrubs, and trees, and is significantly altered by anthropogenic activities such as bush burning, cultivation, grazing, and urban land use [16]. The elevation of the state ranges from 184 m to 1,184 m above sea level [8].

2.2 Data Acquisition

Normalized Different Vegetation Index (NDVI) a product of Moderate Resolution Imaging Spectroradiometer (MODIS) specifically the MOD13A3 was acquired from the NASA Earth Data portal [17], for the years 2001 and 2022, which represents the comparative baseline and endpoint for long-term desertification risk mapping. This product provides monthly composite NDVI data at a 1000m spatial resolution. NDVI is a widely used remote sensing index designed to quantify vegetation by exploring the distinct reflectance properties of vegetation in the red and near-infrared (NIR) portions of the electromagnetic spectrum. Healthy vegetation reflects more NIR and absorbs more red light due to chlorophyll activity, while non-vegetated surfaces reflect more Red light than the near-infrared wavelengths. It is calculated using the formula in Equation 1:

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

Where: NIR is the surface reflectance in the near-infrared band; Red is the surface reflectance in the Red band

NDVI values range from -1 to 1, where -1 indicates water bodies, values near zero represent bare soil or built-up areas, moisture-stressed or sparse vegetation, and 1 signifies healthy and dense vegetation.

[18], in their review paper, outlined remote sensing indices and respective thresholds used to assess the risk of desertification. The NDVI classification scheme proposed by [19] was adopted in this study because it provides an accepted, ecologically grounded framework for distinguishing vegetation density and degradation levels in dryland environments. These thresholds range from NDVI < 0.2 (bare soil), 0.2 - 0.5 (sparse vegetation), and > 0.5 (vegetation only/dense vegetation), has been applied in arid and semi-arid regions particularly, the Iberian Peninsula, where vegetation is typically discontinuous and seasonal.

In the context of Gombe State, which lies in Nigeria's continental climate (Aw), based on the Köppen's classification, characterized by distinct wet and dry seasons. Also lies within the Sudan Savannah belt characterized by open grasslands, shrubs, and scattered trees, often interspersed with bare soil. These semi-arid ecological features align with the conditions under which [19] thresholds were originally developed and validated. Moreover, field observations and ancillary data (e.g. land cover maps) support the appropriateness of these ranges in differentiating between healthy vegetation, degraded areas, and bare lands in the study area under review.

2.3 Data Preprocessing

Data preprocessing involves preparing satellite imagery for analysis to ensure consistency, accuracy, and geographic relevance. For this study, NDVI data were subjected to a number of preprocessing before analysis.

The satellite images were re-projected from the initial coordinate system to the Universal Transverse Mercator (UTM) projection, Zone 32N. This ensures that the imageries align accurately with local spatial datasets such as administrative boundaries, enabling precise spatial analysis. The resampling process was carried out to enhance the spatial resolution of the NDVI data. The original data, provided at 1km (1000m) spatial resolution, was resampled to 500m. This method was selected to preserve the continuous nature of NDVI values and improve the granularity of the vegetation distribution, allowing for more detailed spatial classification and change detection within the study area. Another essential preprocessing step involved adjusting the NDVI values. The NDVI data is provided in a scaled format, requiring the application of a scale factor of 0.0001 to convert digital numbers to real NDVI values within the valid range of -1 to 1. This transformation is necessary for meaningful interpretation and comparison across time and space. The monthly NDVI composites were aggregated to generate annual NDVI values for each study year. This was done by computing the mean of the twelve monthly values to

represent a single NDVI value for the year. This approach minimizes short-term fluctuations due to seasonality and provides a clear picture of long-term vegetation trends. Finally, the two annual datasets were clipped to the boundary of Gombe State using an administrative shapefile. This step focused the analysis solely on the study area, removing irrelevant data and reducing processing time. Clipping ensures that all subsequent analyses, including classification and transition detection, are strictly confined to the ecological and administrative context of the region under investigation.

2.4 Transition Analysis

This was employed to quantify and interpret changes in vegetation cover between the years 2001 and 2022. This process involved overlaying the NDVI-derived classified maps from both periods to detect spatial and categorical shifts in vegetation status. By comparing the pixel-based classifications, the analysis captured transitions across three vegetation classes: bare soil, sparse vegetation, and vegetated areas, based on thresholds established by [19]. The transition assessment identified the spatially stable areas where vegetation class remained unchanged over the study period, and the degraded areas, represented by a shift from vegetated to less vegetated or sparsely vegetated areas to bare soil. Conversely, areas of potential recovery were identified where NDVI values improved, indicating transitions from bare or sparse vegetation to more vegetated classes.

3.0 Result and Discussion

Between 2001 and 2022, NDVI analysis revealed significant changes in vegetation within Gombe State. The data indicate that the average NDVI value was approximately 0.36 in 2001, which declined to 0.32 by 2022, suggesting a reduction in vegetation health and density. Despite this decline, both the mean values were categorized as sparse vegetation based on the vegetation classification scheme by [20]. In the foregoing, previous studies have highlighted factors degrading vegetation in the study area. For instance, [12] attributed the decline to the expansion of agricultural activities and human settlement, Musa et al, 2018, associated the issue with population growth which led to the conversion of natural habitat to farmlands and residential areas, resulting in fragmentation or loss of vegetation, [11], reported unsustainable grazing, and cutting down of trees for making timber and fuel wood have contributed greatly in the destruction of vegetation, [21] reported that climate change affect vegetation wellbeing due to increased temperature and rainfall variability. This research suggests that this land quality degradation results from the interplay between climate change and human activities that directly or indirectly damage vegetation, leaving soil exposed and vulnerable to the loss of its physical, chemical, and biological properties, thereby compromising some of its essential functions.

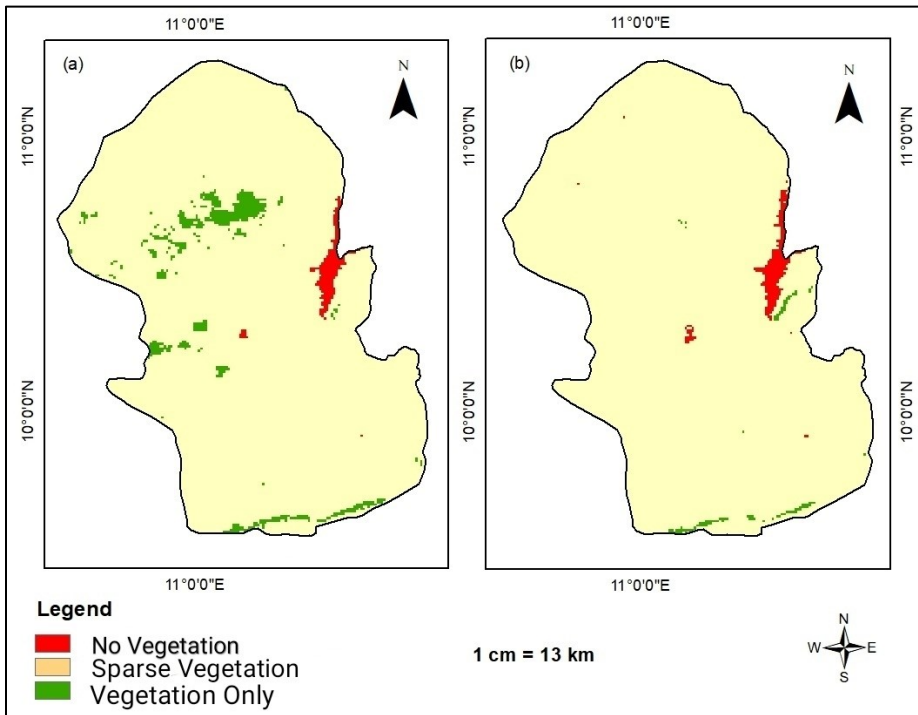


Fig. 2: Classification of vegetation in Gombe State using the adopted thresholds by Julien et al., [19], (a) 2001, (b) 2022.

Table 1: Classification of Desertification Maps

	2001		2022	
	Area (km ²)	%	Area(km ²)	%
No Vegetation	203.1	1.2	245.5	1.4
Sparse Vegetation	16,771.2	95.7	17,190.5	98.1
Vegetation Only	544.4	3.1	84.5	0.5

Table 1 provides a comparative assessment of desertification in Gombe from 2001 to 2022. The results showed that the area with no vegetation increased from 203.1 km² (1.2%) in 2001 to 245.5 km² (1.4%) in 2022. The sparse vegetation class, which includes areas with a mix of bare soil and vegetation, expanded from 16,771.2 km² (95.7%) in 2001 to 17,190.5 km² (98.1%) in 2022, indicating an increase in bare soil and a reduction in vegetation. Conversely, the vegetation-only class, representing areas with healthy vegetation cover, decreased significantly from about 544.4 km² (3.1%) in 2001 to 84.5 km² (0.5%) in 2022. These findings demonstrate a substantial increase in bare surfaces and a corresponding decline in vegetation cover, suggesting a rising risk of desertification in the study area. This trend points to land degradation, due to a combination of human activities and climate change. The significant reduction in vegetation cover from 3.1% in 2001 to 0.5% in 2022 raises concerns about potential biodiversity loss and ecosystem disruption. This

aligns with [13], who reported a decrease in vegetation cover in the Dukku Local Government Area of the current study region, from 72.1% in 2000 to 40.4% in 2010 and 24.03% in 2020. [13], further noted that the non-vegetated area was increasing at an alarming rate, from 27.87% in 2000 to 59.56% in 2010 and 75.95% in 2020.

Table 2 presents the transition analysis for vegetation cover and the risk of desert encroachment in Gombe State. Approximately 195.1 km² (1.1%) remained unchanged as no vegetation class, indicating no vegetation regeneration throughout the period. A transition of about 7.4 km² (0.04%) was observed from no vegetation to sparse vegetation, indicating minimal vegetation regeneration. There was no conversion from no vegetation to the vegetation-only class. The results further show that about 16,691.7 km² (95.3%) remained unchanged as sparse vegetation. About 49 km² (0.3%) of sparse vegetation converted to no vegetation, which indicates a continuous decline. Of the 26.8 km² (0.2%) of the sparse vegetation area was converted into vegetation only, indicating recovery from degradation. A conversion of 486.1 km² (2.8%) was observed from vegetation only to sparse vegetation, with this loss of vegetation having far-reaching effects, including reduced biodiversity, decreased ecological resilience, and increased soil erosion, which are clear pointers of potential risk of desertification. Only 57.6 km² (0.3%) of vegetation remained unchanged during the period under review. There was no transition from the vegetation-only class to the no-vegetation class.

The findings presented above indicate that 95.3% of the study area remained unchanged as sparse vegetation, lacking a continuous vegetative cover. This indirectly suggests that the soil has been exposed to its natural vegetative cover during the period under review. Although this area remains stable, it is vulnerable, reflecting the impact of climate change and anthropogenic activities. However, human activities exacerbate the situation due to population growth, increased demand for vegetative and agricultural products, and land use, including urbanization, agriculture, and the collection of firewood. The widespread low-density vegetation suggests a gradual deterioration of the land, increasing its carrying capacity and contributing to the expansion of desert conditions. Consequently, sparse vegetation exacerbates desert encroachment due to inadequate soil protection, increased soil temperature, low infiltration rates, high runoff, and soil erosion.

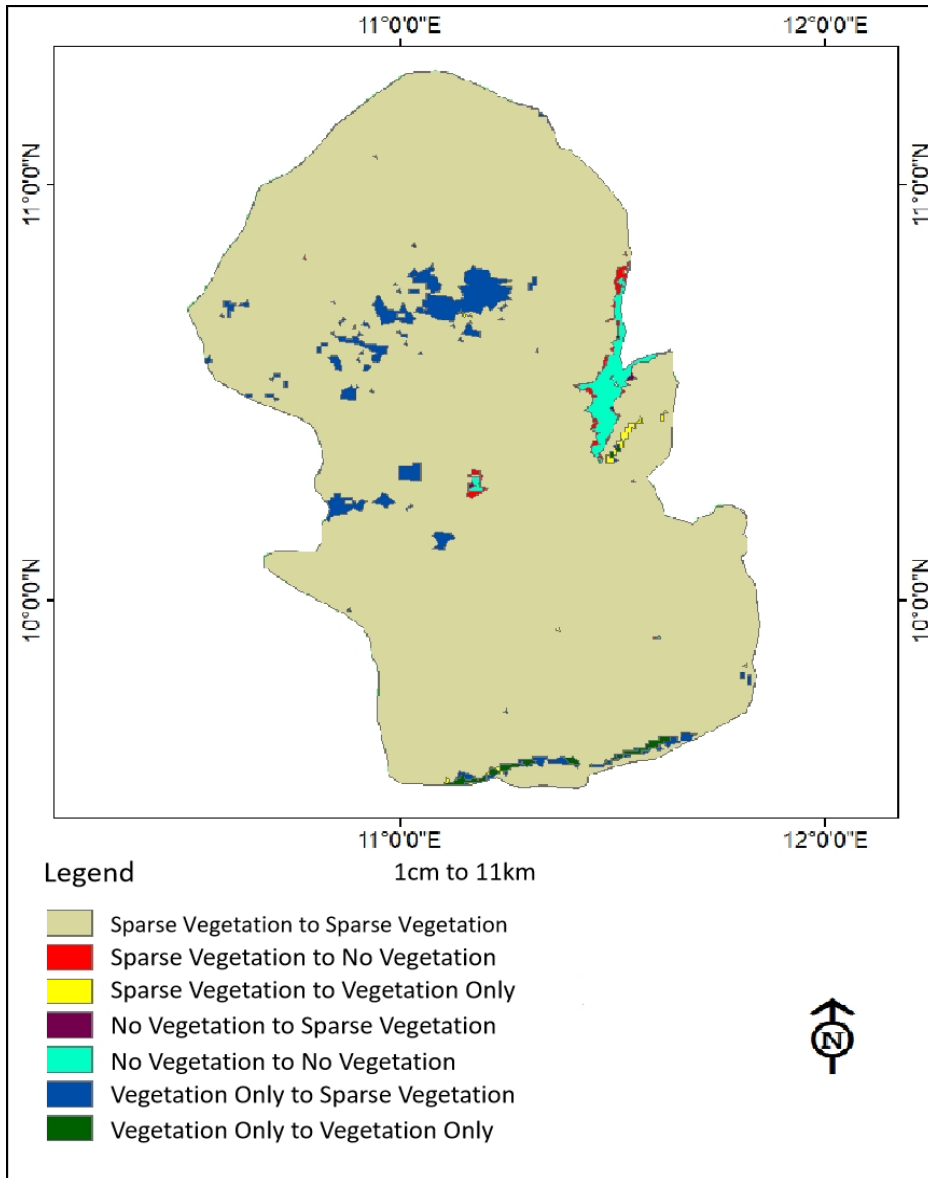


Figure 3: Vegetation transition analysis using the adopted thresholds by Julien et al., [19], for exploring the risk of desertification in Gombe State between 2001 and 2022.

Table 2: Transition of Desertification Risk Mapping (2001 - 2022)

	No Vegetation		Sparse Vegetation		Vegetation Only	
	km ²	%	km ²	%	km ²	
%						
No Vegetation	195.1	1.1	7.4	0.04	-	-
Sparse Vegetation	49 0.3	16691.7	95.3	26.8	0.2	
Vegetation Only	-	-	486.1	2.8	57.6	

0.3

Table 3 presents an analysis of vegetation cover changes in the study area between 2001 and 2022, revealing a trend towards desertification. The results indicate a negative change in vegetation cover of approximately 535.1 km² (3.1%), highlighting the risk of desertification and reflecting a significant loss of biodiversity, ecosystem services, and local livelihoods. To mitigate this trend, it is imperative to address the major drivers of desertification, such as overgrazing, deforestation, and climate change. Conversely, a minimal positive change of approximately 34.2 km² (0.2%) was observed, indicating signs of vegetation regeneration and emphasizing the challenges of revegetation and desertification. This suggests that current land management practices and conservation efforts are insufficient to enhance ecological resilience. Furthermore, a significant portion of the study area, totaling 16,944.4 km² or 96.7% (out of which 1.1% no vegetation, 95.3% sparse vegetation, and 0.3% vegetation only), remained unchanged during the period under review. This vast area remained stable yet vulnerable to the continuous pressures of drought and desert encroachment.

Table 3: Classification of the Vegetation Transition

Transition Classes	Area (km ²)	%
Negative Change	535.1	3.1
Unchanged	16,944.4	96.7
Positive Change	34.2	0.2

4.0 Conclusion and Recommendations

4.1 Conclusion

This study has demonstrated that desertification is an ongoing and intensifying threat in Gombe State, largely driven by its proximity to the affected areas, and a combination of natural and anthropogenic factors such as overgrazing, deforestation, and climate variability. Analysis of MODIS-derived NDVI data from 2001 to 2022 revealed a persistent dominance of sparse vegetation cover, indicating limited ecological recovery and continued land degradation. These findings highlight the vulnerability of the region's ecosystems and the potential socio-economic impacts on communities dependent on land resources.

However, the use of MODIS NDVI data, while effective for long-term and large-area monitoring, is constrained by its spatial resolution and limited sensitivity to specific vegetation types and small-scale land cover changes. Consequently, localized degradation patterns and subtle vegetation dynamics may not be fully captured.

Future research should consider integrating higher-resolution remote sensing data (e.g., Sentinel or Landsat imagery) alongside field-based ground truthing to improve accuracy and contextual interpretation. Additionally, incorporating socio-economic data and land

use history could provide a more holistic understanding of the drivers and impacts of desertification. Such approaches would enhance the reliability and applicability of findings for targeted land management and policy intervention.

4.2 Recommendations

In response to the decreasing trend of vegetation and desertification risk in Gombe State, a multi-dimensional intervention strategy is essential. The following recommendations are proposed based on the study's findings:

1. Enhancing Community Engagement and Environmental Education

Awareness campaigns and targeted training programs should be developed to sensitize local communities on the implications of desertification and the importance of sustainable land use. Promoting alternative livelihood options will help reduce the overdependence on natural resources, thereby mitigating human-induced pressures on fragile ecosystems.

2. Fostering Community-Based Initiatives and Securing Sustainable Funding

The establishment of local cooperatives and stakeholder-driven interventions can enhance the success of restoration efforts. Adequate and consistent funding—both from government sources and international development partners—is critical to support long-term mitigation and adaptation strategies.

3. Promoting Sustainable Land Management Practices

Findings indicating persistent sparse vegetation highlight the need to adopt land restoration practices such as afforestation, agroforestry, rotational farming, introduction of drought-tolerant species, and regulated grazing. These practices will help rehabilitate degraded land and improve vegetation cover over time.

4. Improving Water Resource Management

Given the semi-arid conditions of the study area, efficient water use through techniques like rainwater harvesting and the development of low-cost irrigation systems is vital for sustaining both agriculture and vegetation health during prolonged dry seasons.

5. Strengthening Policy Frameworks and Environmental Governance

To support the above measures, strong institutional frameworks are required. This includes enforcing regulations against deforestation, incentivizing sustainable land use practices, and integrating desertification risk monitoring into local and regional development planning.

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