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Effectiveness of Land Restoration in African's Great Green Wall (GGW): Insight from Nigeria's Frontline State

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Abstract

The Sahel region of Africa faces severe land degradation, compromising crucial ecosystem services vital for human well-being. In response, 11 African countries initiated the Great Green Wall (GGW) project to combat land degradation, with Nigeria, including Borno state, actively participating. This study focuses on evaluating GGW's effectiveness in Borno state using Landsat imagery from 1993 to 2022. Data from Landsat satellites, specifically Landsat 4, 5, 7, and 8, were utilized alongside GIS tools like ArcGIS 10.8 for image classification and analysis. Microsoft Office aided in data visualization and report generation, while Google Earth Pro facilitated area calculation and feature confirmation. The analysis, employing NDVI trends and a two-way repeated measures ANOVA, revealed a non-significant impact of GGW on greening in the region (F-value: 0.665, p>0.05). Despite the implementation of GGW in Borno state, findings suggest limited effectiveness in mitigating land degradation. This underscores the need for reassessment and potential recalibration of GGW strategies to achieve desired ecological restoration outcomes in the Sahel region.

1. Introduction

Land degradation, exacerbated by interconnected megatrends such as population growth, urban expansion, unsustainable land use, and climate variability, represents a critical global challenge [1]. According to the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) and the Intergovernmental Panel on Climate Change (IPCC), land degradation affects approximately 3.2 billion people worldwide, with annual economic losses exceeding 10% of global Gross Domestic Product (GDP) [2]. The IPCC has repeatedly underscored Africa's vulnerability, particularly in the IPCC Third Assessment Report (TAR3) and Sixth Assessment Report (AR6), highlighting the continent's heightened exposure to climate-induced risks such as desertification, water stress, food insecurity, and coastline vulnerability due to shifts in temperature and precipitation patterns [3].

In response to escalating land degradation and desertification pressures, several global and regional initiatives have emerged. Among the most prominent is the Great Green Wall Initiative (GGWI), launched in 2007 under the leadership of the African Union. Introduced by former Nigerian President Olusegun Obasanjo, the initiative seeks to restore ecosystems and livelihoods across the Sahara and Sahel by combatting the "social, economic, and environmental" effects of land degradation [4]. GGWI aligns with various multilateral environmental agreements (MEAs) and frameworks, including the United Nations Convention to Combat Desertification (UNCCD), the Convention on Biological Diversity (CBD), and the United Nations Framework Convention on Climate Change (UNFCCC) [5]. These frameworks are reinforced by the Sustainable Development Goals (SDGs) especially SDG 15, which aims to "protect, restore and promote sustainable use of terrestrial ecosystems" and achieve land degradation neutrality by 2030 [6].

In Nigeria, implementation of the GGWI began in earnest in 2012, culminating in the establishment of the National Agency for the Great Green Wall (NAGGW) in May 2015 under Act No. 3 of the Federal Government [7]. The NAGGW is tasked with coordinating national efforts to restore degraded land, halt desert encroachment, and build ecological resilience in eleven northern frontline states, stretching over a 1,500 km corridor from Kebbi to Borno State and spanning 15 km in width [8]. The agency's broader objectives include restoring 100 million hectares of land by 2030 and implementing a landscape mosaic approach encompassing afforestation, agroforestry, food and fuel resource generation, and climate adaptation through carbon sequestration.

The Great Green Wall is also a vehicle for achieving international climate commitments under the Paris Agreement, which requires countries to submit nationally determined contributions (NDCs) outlining their climate actions beyond 2020 [9]. Nigeria, facing one of the highest annual economic burdens from land degradation estimated at $1.4 billion has made significant investments in land rehabilitation [3]. Early GGW outcomes have demonstrated promise, with over 25,000 hectares restored and substantial improvements in local livelihoods. However, progress remains uneven, constrained by challenges such as outdated or insufficient land cover data, poor monitoring systems, and gaps in institutional coordination [10]. Given these dynamics, this study investigates the effectiveness of GGW implementation in Borno State, one of Nigeria's most vulnerable regions to desertification and ecological degradation

2. Methodology

2.1 Description of the Study Area

Borno State lies in the extreme north-east corner of Nigeria between latitudes 10° 30' and 13° 50' North and longitudes 11.00° and 13° 45' east (Figure 1). It occupies an area of 69.435 sq km sharing border with three states, Adamawa to the south, Gombe to the south west and Yobe to the west as well as three countries, namely, Republic of Niger, Chad and Cameroon to the north, north-east and east respectively. Borno is a small State in Nigeria but it was a great ancient nation in sub–Saharan Africa.

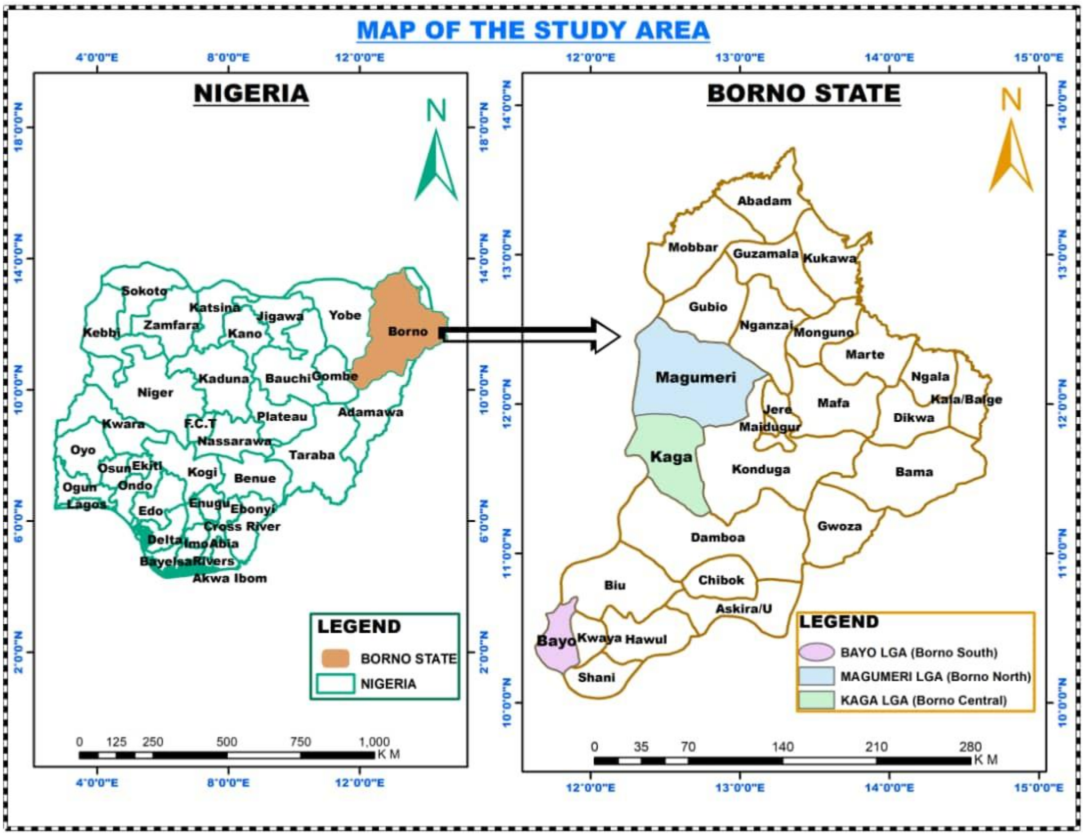

Fig. 1 *Study area*

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2.2 Sources of Data

Landsat 4, 5, 7 and 8 Imagery of 1993, 2002, 2003, 2012, 2013 and 2022 were downloaded from United State Geological Survey (USGS) earth explorer which was the secondary source of data. The land use and land cover raw data were acquired from the Landsat 8 Operational Land Imager (OLI) collected for the year 2022 and 2013, Landsat 7 Enhanced Thematic Mapper Plus (ETM+) imagery collected for the year 2002, 2003 and 2012, while both Landsat 4 and 5 were used to obtain imageries of 1993. Many preceding similar studies have used data from this source [11, 12, 13, 14].

2.3 Instrument for Data Collection

For the purpose of this study, the following software were used for data acquisition, processing, analysis and information presentation;
a) ArcGIS 10.8- This was used for the supervised maximum likelihood image classification of study area and the other GIS based functions that was carried out.
b) Microsoft Office software - This was used basically for plotting charts and report writing
c) Google earth pro – This software was used as a digital alternative to calculate the size of the study area and to assist in visualization for confirmation of certain features.

2.4 Sample and Sampling Procedure

The sampling population is the twenty-seven-local government area in Borno State, stratified into three senatorial districts. These are southern, central and norther senatorial district listed below.

Table 1 *Twenty-seven local government areas in Borno State, Nigeria*

S/N	Northern Senatorial District	Central Senatorial District	Southern Senatorial District
1	Bama	Abadam	skira/uba
2	Dikwa	Gubio	Bayo
3	Jere	Guzamala	Biu
4	Kaga	Kukawa	Chibok
5	Kala/ Balge	Magumeri	Damboa
6	Konduga	Marte	Gwoza
7	Mafa	Mobbar	Hawul
8	Maiduguri	Mongono	Kwayakusar
9	Ngala	Nganzai	Shani

The sample size is one local government from each senatorial district in Borno State. These local governments are Kaga in central Borno, Bayo in southern Borno and Magumeri in northern Borno (Table 1). This local government were selected as a result of research finding from the state desk officer about area of intensive intervention of the agency. Purposive sampling technique was used to select the local government that fall within the agency field area, this was done so as to measure the impact of the agency restoration effort on any change observed (Bayo, Kaga and Magumeri).

2.5 Image Pre-Processing

Pre-processing of remotely sensed data commonly comprises a series of operations which includes radiometric corrections and geometric corrections [15]. The acquired Imagery was preprocessed for the removal of distortion, degradation, and noise introduced during the imaging acquisition. Prior to the image pre-processing, the selected bands were stacked using the ArcGIS combine clipping was done, the procedures for this process are as follows: The boundary of the study area was imported into the ArcGIS environment by using the Add Data button, Then the extraction tool was launched using Arc Toolbox > Spatial Analyst Tool > Extraction > Extract by Mask [16].

2.6 Image Classification

Image classification was done using maximum likelihood method while also taking 20 training samples per land use Land cover class, the training samples were then converted to KM format for ground truthing on google earth application [17].

2.7 Data Analysis

Analysis was done using Microsoft Excel to compare land use land cover classes and generate charts. Further analysis on Normalized Difference Vegetation Index (NDVI) and image-based analysis was done on ArcGIS 10.8 [18]. Analysis of Variance (ANOVA) was used to quantify vegetation greenness in the area between the period of 1993 to 2022 at 0.05 level of significant using Zach Bobbit's One-way Repeated Measures ANOVA Calculator.

2.8 NDVI Determination

Traditionally, the NDVI is calculated using a combined operation between the red band and Near-Infrared (NIR) band as follows:

$$NDVI = (R\text{NIR} - R\text{Red}) / (R\text{NIR} + R\text{Red}) \quad (1)$$

Where: – *R*NIR represents the spectral reflectance in the b NIR band, – *R*Red represents the spectral reflectance of the red band.

3. Results and Discussion

3.1 Land Use Land Cover (LULC) Changes Under Three Different Epochs

3.1.1 LULC of Bayo LGA

The land cover distribution presented in Table 2 reflects the spatial variations in land use and land cover (LULC) across Bayo Local Government Area (LGA) of Borno State from 1993 to 2022. The analysis shows that in 1993, water bodies occupied approximately 1.3%, while vegetation, bareland, and rock outcrops covered 1.2%, 50.7%, and 46.8% respectively of the 947.5 km^2 study area (Figure 2). These findings align with regional observations in the

Table 2 *Temporal distribution of land use land cover changes in Bayo LGA*

S/N	LULC CLASS	1993		2002		2003		2012		2013		2022	
		KM^2	%	KM^2	%	KM^2	%	KM^2	%	KM^2	%	KM^2	%
1	Water Body	12.5	1.3	10.8	1.1	8.5	0.9	10.5	1.1	10.8	1.1	7.5	0.8
2	Vegetation	11.0	1.2	38.3	4.0	15.0	1.6	65.3	6.9	23.0	2.4	27.3	2.9
3	Bareland	480.7	50.7	478.4	50.5	483.7	51.1	455.7	48.1	443.9	46.6	460.3	48.6
4	Rock Outcrop	443.4	46.8	420.1	44.3	440.4	46.5	416.1	43.9	470.5	49.7	452.1	47.7
Total		947.5	100	947.5	100	947.5	100	947.5	100	947.5	100	947.2	100

Nigerian drylands, which report a predominance of bare surfaces and rapid land degradation driven by desertification and anthropogenic pressures [19].

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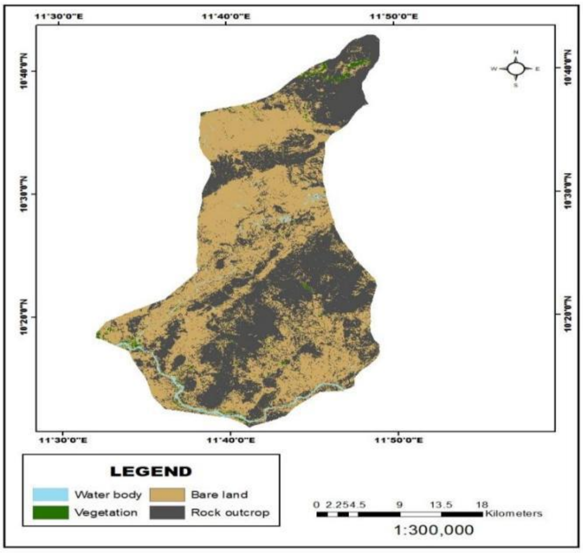

Fig. 2 *LULC of Bayo LGA in 1993*

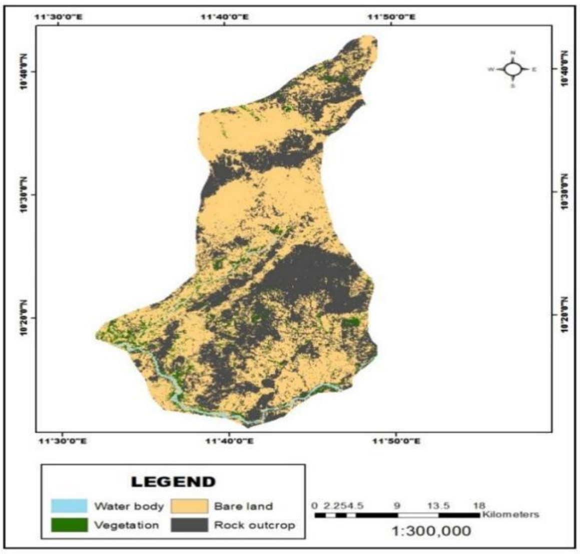

Fig. 3 *LULC of Bayo LGA in 2002*

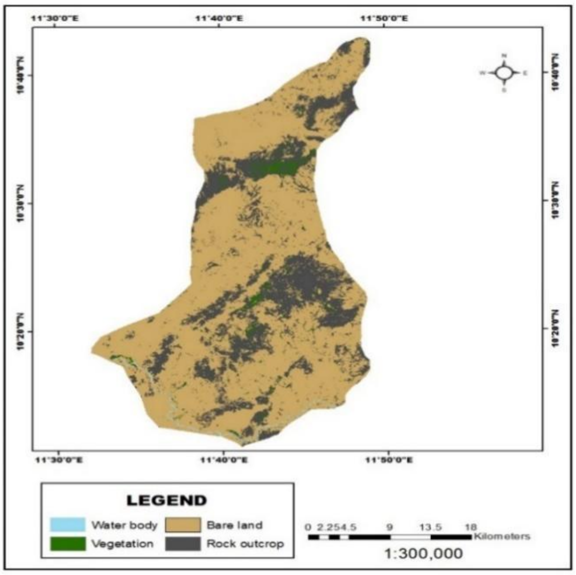

Fig. 4 *LULC of Bayo LGA in 2003*

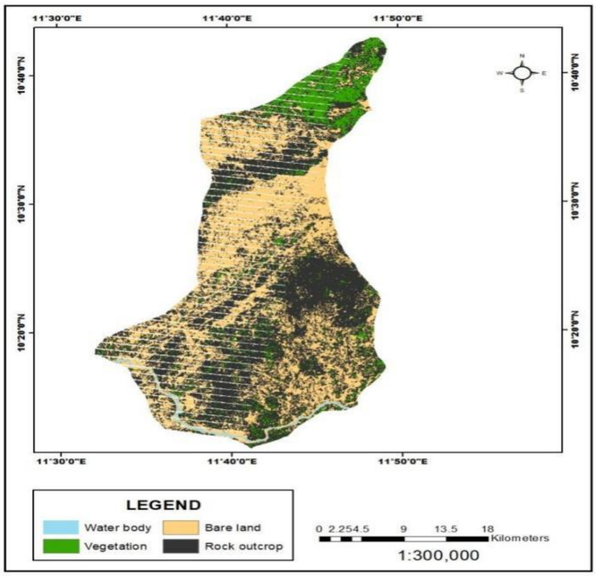

Fig. 5 *LULC of Bayo LGA in 2012*

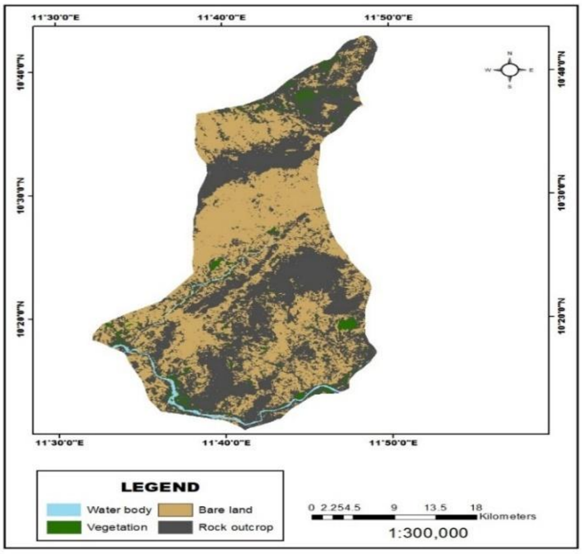

Fig. 6 *LULC of Bayo LGA in 2013*

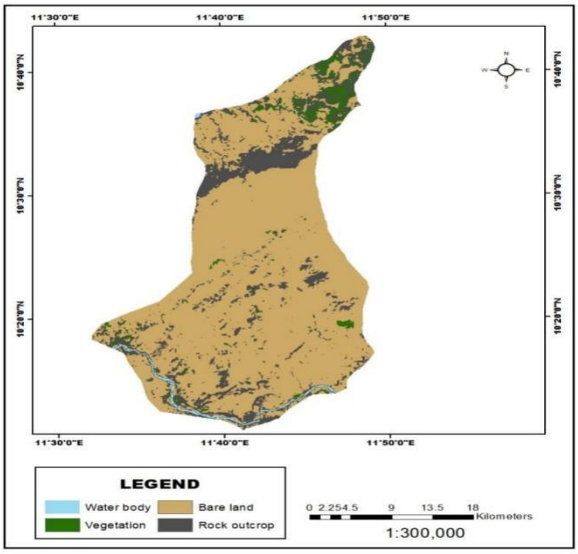

Fig. 7 *LULC of Bayo LGA in 2022*

By 2002, water bodies reduced to 1.1%, while vegetation increased to 4.0%, occupying about 38.3 km^2 (Figure 3), suggesting recovery linked to seasonal hydrology or vegetative restoration efforts [20]. Concurrently, bareland and rock outcrop experienced modest reductions to 50.5% and 44.3%, reflecting potential early responses to environmental interventions or land use dynamics [21].

In 2003, the water body slightly decreased to 0.9%, while vegetation saw a modest increase (Figure 4). By 2012, vegetation expanded to 6.9% (~65.3 km^2), indicative of natural regeneration or improved climatic conditions (Figure 5). Bareland exposure declined from 51.1% to 48.1%, while rock outcrops reduced from 46.5% to 43.9%, consistent with other Sahelian zone studies reporting soil cover stabilization and sand redistribution [22]. Table 2 further shows that between 2012 and 2022, the water body reduced from 1.1% to 0.8%, while vegetation slightly increased from 2.4% to 2.9% (Figure 5 and 7). However, bareland exposure rose again from 46.9% to 48.6%, suggesting fluctuating degradation-recovery dynamics linked to climatic variability and land use. Rock outcrops also declined to 47.7%, likely influenced by erosional processes and vegetation encroachment [19].

3.1.2 LULC of Kaga LGA

Table 3 depicts the area distribution of land use and land cover (LULC) in square kilometers (km^2) within Kaga Local Government Area (LGA) and presents percentage variations (%) from 1993 to 2022. Based on Table 3, LULC analysis for the year 1993 reveals that water bodies occupied approximately 0.0% of the study area, while vegetation**,** bareland**,** and rock outcrop covered 1.4%**,** 52.9%**,** and 45.6% respectively within a total land area of 7325 km^2**.** These land use characteristics reflect widespread bare surface dominance common in semi-arid regions of northern Nigeria [23].

Table 3 *Temporal distribution of land use land cover changes in Kaga LGA*

S/N	LULC CLASS	1993		2002		2003		2012		2013		2022	
		KM^2	%	KM^2	%	KM^2	%	KM^2	%	KM^2	%	KM^2	%
1	Water Body	0.5	0.0	0.9	0.0	3.0	0.04	0.0	0.0	4.8	0.1	4.8	0.1
2	Vegetation	103.0	1.4	127.4	1.8	33.3	0.45	302.4	4.1	34.0	0.5	85.6	1.2
3	Bareland	3881.6	52.9	5452.9	75.7	4853.8	66.24	3629.5	49.6	4485.7	61.2	5520.4	75.4
4	Rock Outcrop	3339.9	45.6	1626.5	22.6	2437.9	33.27	3393.1	46.3	2800.5	38.2	1714.3	23.4
Total		7325	100	7207.7	100	7328	100	7325	100	7325.	100	7325.1	100

By 2002, water bodies remained at 0.0%**,** whereas vegetation and bareland increased to 1.8% and 75.7%**,** translating to 127.4 km^2 and 5452.9 km^2 respectively (Figure 9). This suggests possible vegetative encroachment and sand redistribution, while the slight reduction in rock outcrops points to erosion and vegetative expansion. In 2003, vegetation sharply declined to 0.5%, while bareland dropped from 75.7% to 66.2% (Figure 10). Simultaneously, rock outcrops rose from 22.6% to 33.3%, likely due to surface exposure from reduced vegetation.

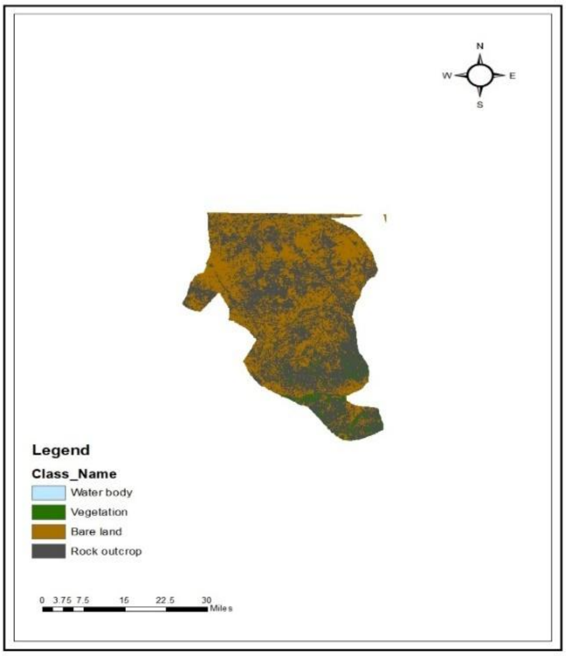

Fig. 8 *LULC of Kaga LGA in 1993*

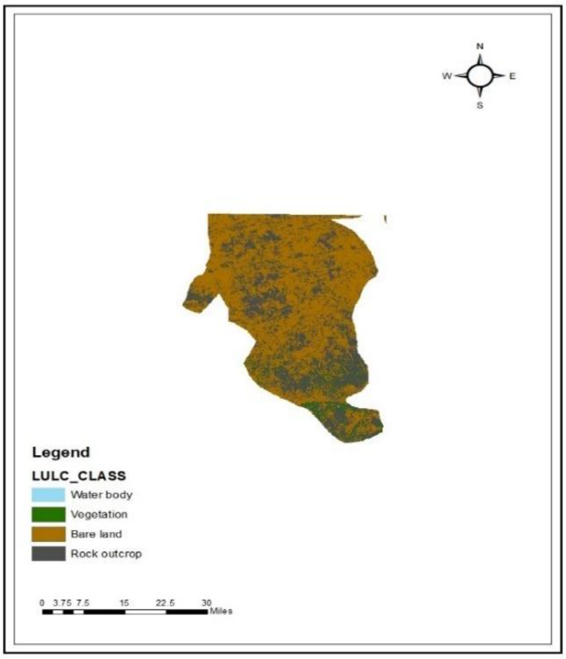

Fig. 9 *LULC of Kaga LGA in 2002*

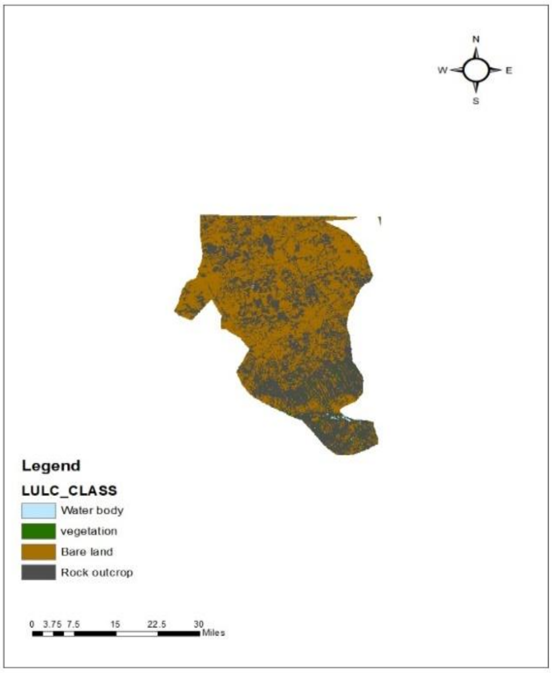

Fig. 10 *LULC of Bayo LGA in 2003*

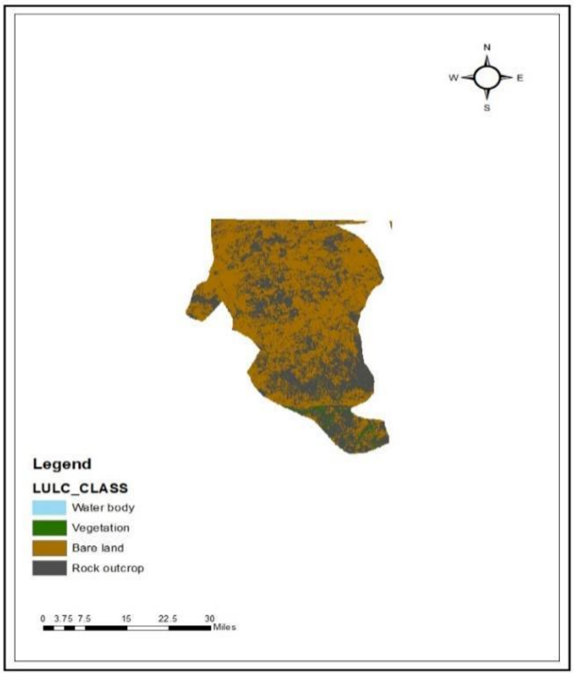

Fig. 11 *LULC of Bayo LGA in 2012*

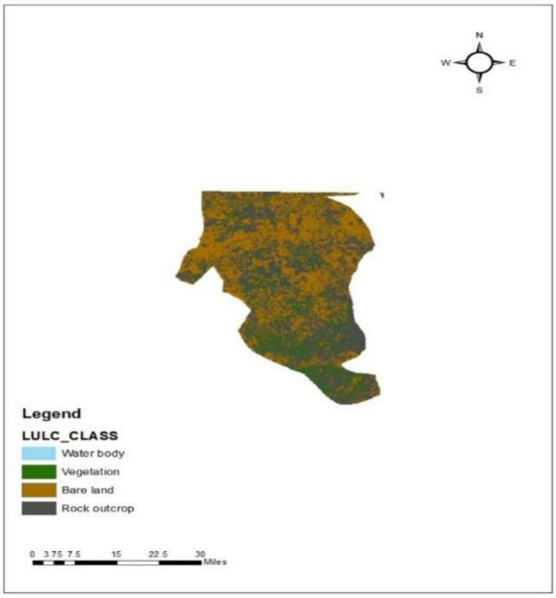

Fig. 12 *LULC of Bayo LGA in 2013*

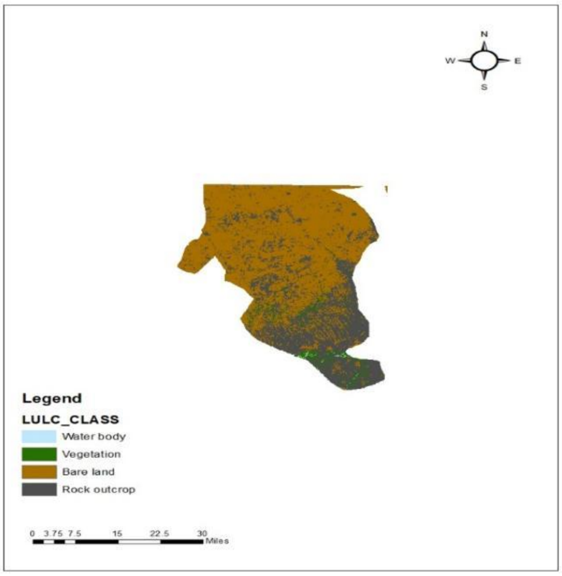

Fig. 13 *LULC of Bayo LGA in 2022*

By 2012, vegetation rebounded to 4.1% (302.4 km^2), reflecting re-greening likely driven by climatic factors and agro-ecological shifts. Bareland dropped further to 49.6%, and rock outcrop increased to 46.3%, suggesting dynamic landform changes. In 2013, a minimal increase in water coverage (from 0.0% to 0.1%) was recorded. By 2022, the water body stabilized, vegetation increased to 1.2%, bareland surged to 75.4%, and rock outcrop declined to 23.4%, all indicating fluctuating land surface processes due to vegetation cycles and sand deposit transformations [23].

3.1.3 LULC of Magumeri LGA

Table 4 describes the spatial distribution of land use and land cover (LULC) in square kilometers (km^2) within Magumeri Local Government Area (LGA) and outlines percentage variations from 1993 to 2022. Based on the provided data, in 1993, water bodies occupied approximately 0.0054%, while vegetation, bareland, and rock outcrop covered 0.4%, 57.2%, and 42.4% respectively of the total 5,000 km^2 area. These findings are consistent with broader dryland dynamics reported in northern Nigeria, where rocky substrates and arid soil surfaces dominate land use trends [24].

Table 4 *Temporal distribution of land use land cover changes in Magumeri LGA*

S/N	LULC CLASS	1993		2002		2003		2012		2013		2022	
		KM2	%	KM2	%	KM2	%	KM2	%	KM2	%	KM2	%
1	Water Body	0.3	0.0054	0.2	0.0038	0.0	0.0059	0.0	0.00052	0.4	0.0082	0.2	0.0044
2	Vegetation	18	0.4	22.9	0.5	1.1	0.0	67.9	1.4	3.9	0.6	2.8	0.08
3	Bareland	2860.5	57.2	4139.4	82.7	3471.5	69.4	2684.9	53.7	3254.6	65.1	4122.9	82.4
4	Rock Outcrop	2121.2	42.4	838.6	16.7	1529.6	30.6	2248.4	44.9	1742.2	34.8	875.6	17.5
	Total	7325	5000	100	5001.1	100	5002.2	100	5001.2	100	5001.1	100	5001.5

By 2002, water bodies slightly declined to 0.0038%, while vegetation increased to 0.46% (22.9 km^2), and bareland surged to 82.77% (4,139.4 km^2), compared to 18.0 km^2 and 2,860.5 km^2 respectively in 1993 (Figure 14 and 15). During this period, rock outcrops declined from 42.4% to 17.8%, likely due to increasing sediment deposition and vegetation encroachment. By 2003, the water body declined further to 0.00059%, and by 2012 it dropped again to 0.00052%. Vegetation plummeted to 0.0% in 2003, but later expanded to 1.4% (67.9 km^2) in

2012. These variations suggest seasonal or climatic influence over ground cover and land use. Bareland exposure declined from 82.8% to 69.4%, while rock outcrops increased from 17.8% to 30.6%, possibly due to decreased surface soil and vegetation stability [24].

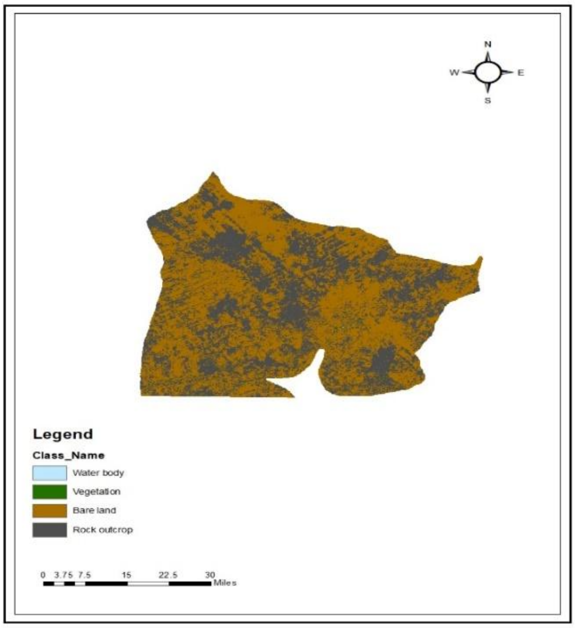

Fig. 14 *LULC of Magumeri LGA in 1993*

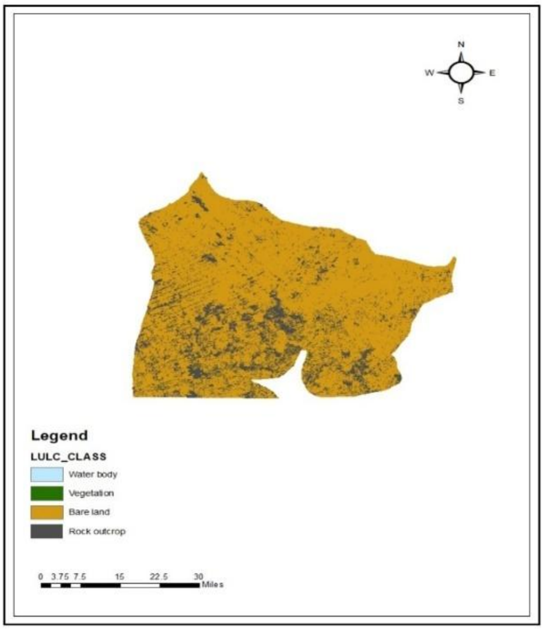

Fig. 15 *LULC of Magumeri LGA in 2002*

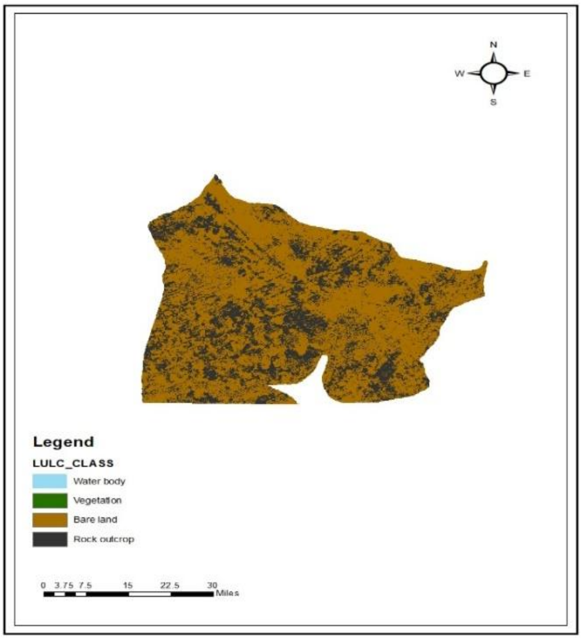

Fig. 16 *LULC of Magumeri LGA in 2003*

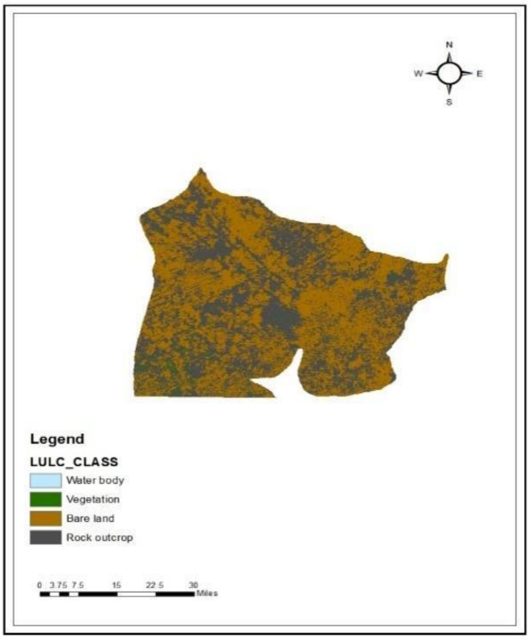

Fig. 17 *LULC of Magumeri LGA in 2012*

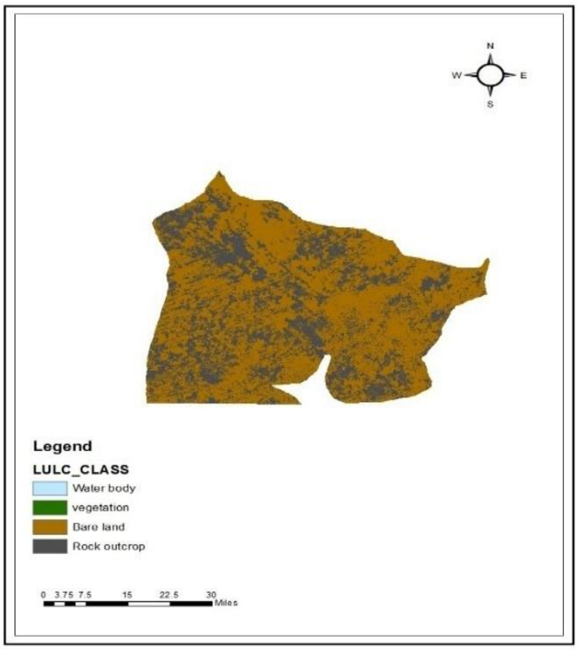

Fig. 18 *LULC of Magumeri LGA in 2013*

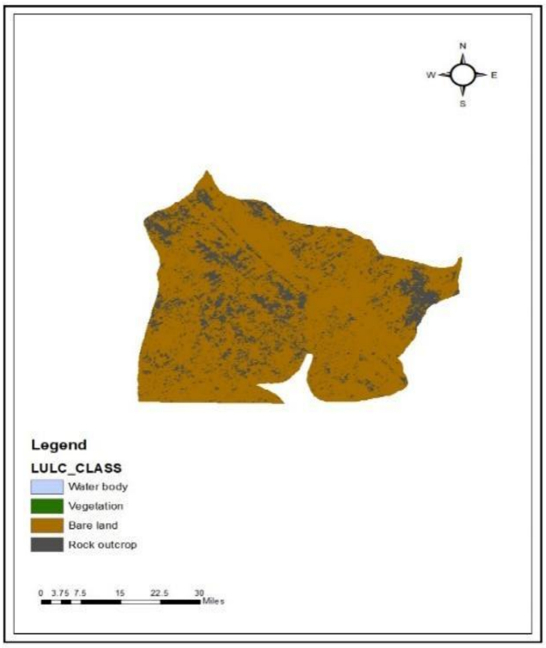

Fig. 19 *LULC of Magumeri LGA in 2022*

From 2013 to 2022, the water body showed a marginal rise to 0.0082% before stabilizing at 0.0044%, while vegetation decreased from 0.6% to 0.08%, and bareland expanded from 65.1% to 82.4% (Figure 18 and 19). Conversely, rock outcrop declined from 34.8% to 17.5%, likely due to increased land pressure, erosion, and the cyclical nature of land degradation and recovery processes in dryland ecologies [24].

3.2 Trend in Vegetation Cover Between Pre-GGW (1993–2012) and Post-GGW (2013-2022)

Trends of vegetation cover during pre-GGW and post-GGW period is presented in Figure 20. It was observed that across all 3 local government areas the highest coefficient of vegetation was recorded in 2012 (in Kaga local government, table 3) with area coverage of 302.4 Km^2 which could be indicative of a rainy or wet year in specific regions of the study area. Although, it was also observed that the distribution of the vegetation was not even but skewed across the study area.

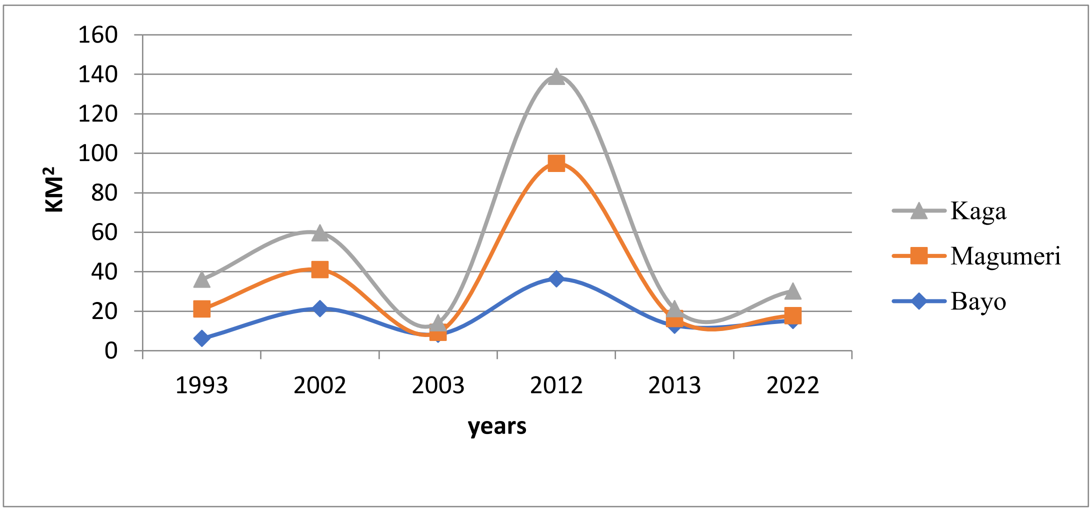

Fig. 20 *Trends of vegetation cover during pre-GGW and post-GGW period*

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In Bayo Local government area, vegetation profile shows that the vegetated areas were least in 1993 and highest in 2012, asides the years 2002 and 2012 where there was a spike in vegetation growth, the vegetation size shown in the other years (2003 and 2013) are below the average mark of 30.0km^2 which indicates that the region for the other years have suffered poor vegetation. But between the years of 2013 and 2022 the vegetation improved when compare directly with 1993 and 2002 with 2022 having the highest vegetation coefficient in terms of area coverage. In Kaga Local government area vegetation profile shows that the vegetated areas were least in 2003 and highest in 2012 with values of 33.3 km^2 and 302.4 km^2 respectively.

In Magumeri local government area the vegetation profile also shows that the vegetated areas were least in 2003 and highest in 2012 with 1.1 km^2 and 67.9 km^2 respectively. In the study area vegetation appears to be more in previous years than in more recent years especially in 1993 and 2002, but again there was growth in vegetation area coverage between 2013 and 2022, showing that there is an improvement in curbing vegetation loss. Figure 20, indicate that in 1993 that was little difference in vegetation cover between the three-local government with Kaga having the highest vegetation cover and Bayo with the least vegetation cover likewise in 2002 but in 2013 Kaga and Magumeri vegetation cover decreases massively and the three locals were at equilibrium. In 2012 there was a significant difference in vegetation cover between the three-local government with Kaga local government at its peak followed by Magumeri and Bayo with the least. 2013 shows no significant difference and 2022 also shows little differences. Therefore, the period with significant difference within the study area is the year 2012.

3.3 Analysis of Normalized Difference Vegetation Index (NDVI) from 1993-2022

3.3.1 NDVI for Bayo LGA (1993-2022*)*

The NDVI values of Bayo LGA from 1993 to 2022 are depicted in Figure (21-26). In 1993, the NDVI value ranged between -0.225 – 0.43, the highest positive NDVI values were recorded in the more vegetated areas and the least values in the non-vegetated area or low vegetation areas.

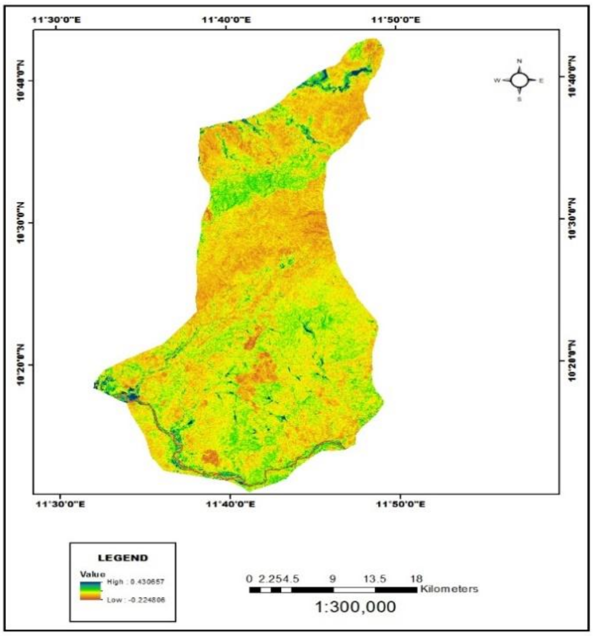

Fig. 21 *NDVI of Bayo LGA in 1993*

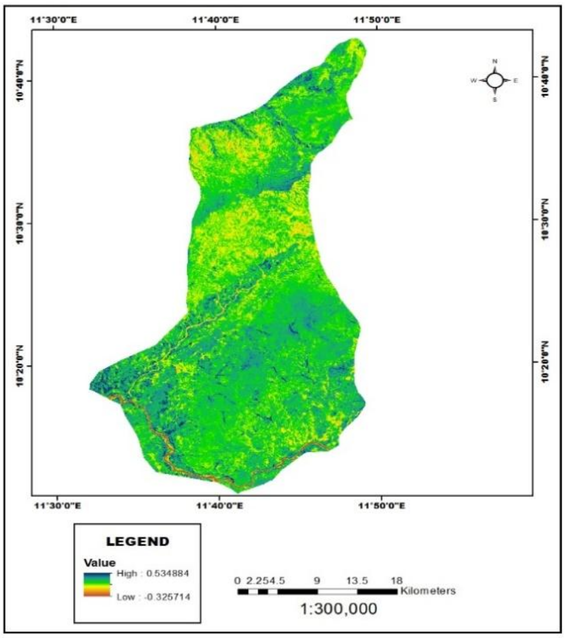

Fig. 22 *NDVI of Bayo LGA in 2002*

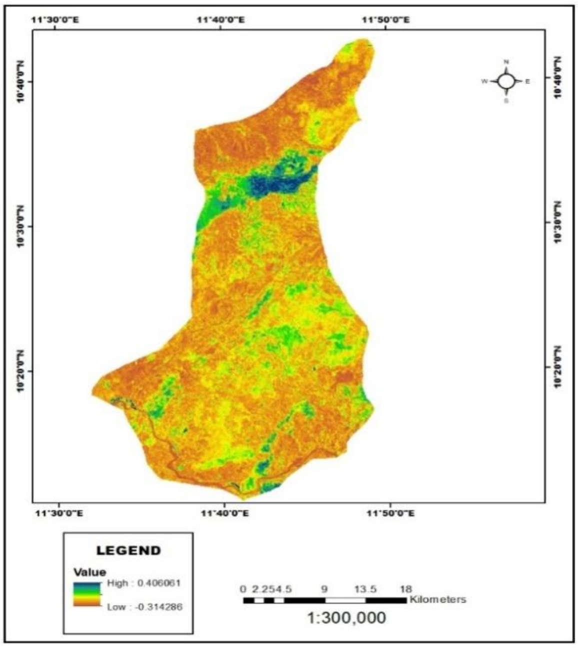

Fig. 23 *NDVI of Bayo LGA in 2003*

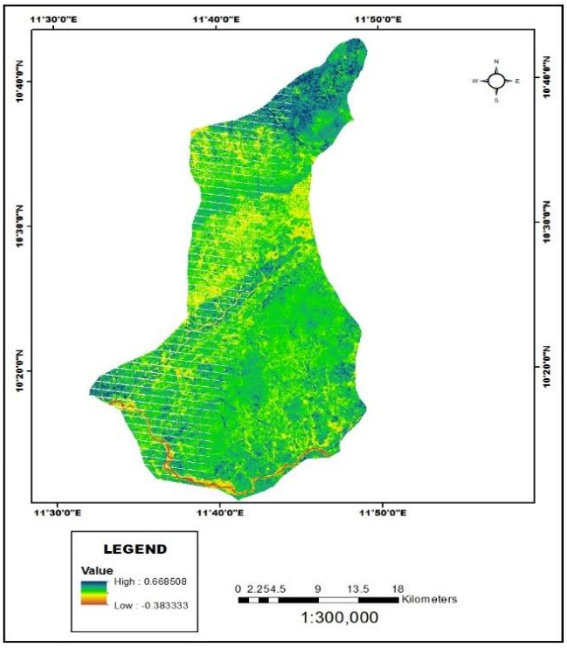

Fig. 24 *NDVI of Bayo LGA in 2012*

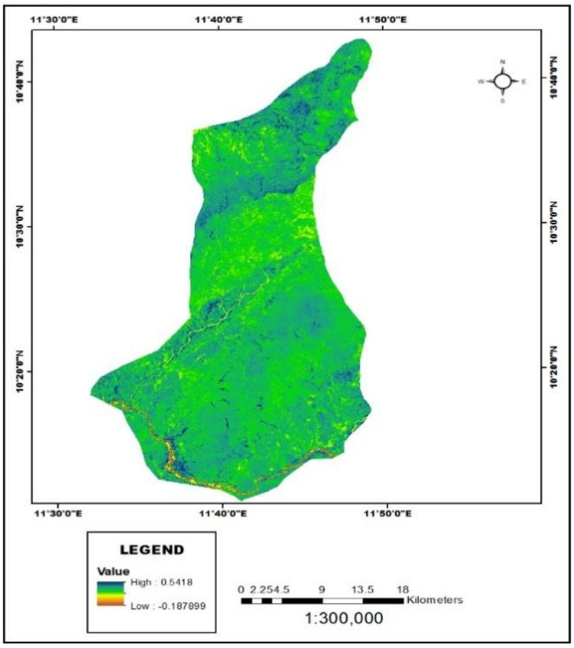

Fig. 25 *NDVI of Bayo LGA in 2013*

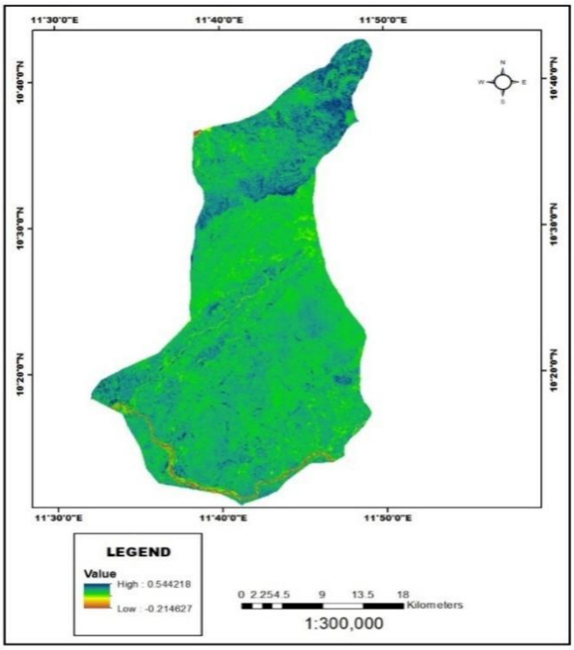

Fig. 26 *NDVI of Bayo LGA in 2022*

The regions with values closer to -0.225 are associated with Bareland or surfaces with minimal vegetation; generally, in the study area the rock surfaces hold more vegetation than the bare surfaces. In essence this NDVI range suggests that the region has varieties of land cover like grassland and shrub land but not the type of vegetation present in forest areas. In 2002 the NDVI values increased across the study area with a range of -0.3257 – 0.535 for low and high respectively. The NDVI values closer to -0.32 suggest areas with no vegetation or very limited vegetation while values closer to 0.535 suggests healthier vegetation but not dense. While in 2003 NDVI values decreased when compared with NDVI of previous years with a moderate value range of -0.314 to 0.406, this suggests that the area is made up of scrubs, grasslands and patches of vegetation. In 2012 the NDVI values ranges from-0.38 to 0.668 across the study area.

In summary, the NDVI range of -0.38 to 0.668 suggests a mixture of land covers and vegetation conditions. While there is some vegetation present, it's important to note that this range spans a wide variety of scenarios, from areas with sparse or stressed vegetation to areas with moderate levels of vegetation health. The NDVI values of Bayo LGA for 2013 ranged between -0.187 – 0.5418, The vegetation near the 0.5418 regions exhibits a healthier density compared to the lower end of the range. The interpretation of these NDVI values should be considered in conjunction with the specific characteristics of the location being assessed. The diverse range of NDVI values indicates a landscape with both less vegetated and moderately vegetated areas. In 2022 the NDVI values had a value range of -0.21 – 0.544 for low and high respectively. When compared to the NDVI in 2013 it has a slight edge in the health of the vegetation in the study area in 2022 over the vegetation health in 2013.

3.3.2 NDVI for Kaga LGA (1993-2022)

The NDVI values of Kaga from 1993 to 2022 are illustrated in Figure (27-32). In 1993, the NDVI ranged between -0.507 – 0.452, the highest positive NDVI values were recorded in the vegetated areas and the least values in the non-vegetated area or low vegetation areas such as bareland and other surfaces with minimal vegetation. In essence this NDVI range suggests that the region has varieties of land cover like grassland and shrubland but not the type of vegetation present in forest areas.

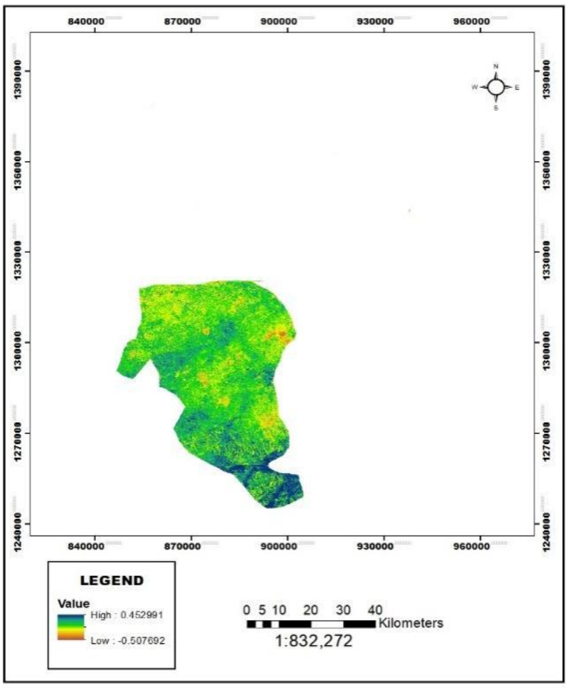

Fig. 27 *NDVI of Kaga LGA in 1993*

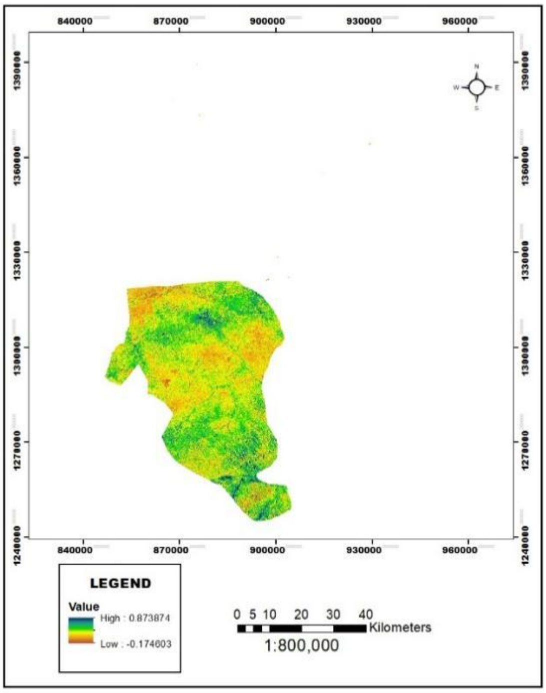

Fig. 28 *NDVI of Kaga LGA in 2002*

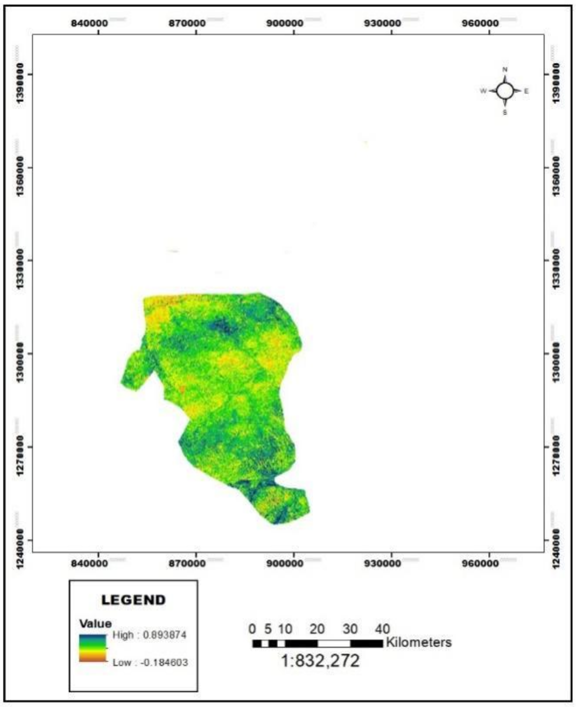

Fig. 29 *NDVI of Kaga LGA in 2003*

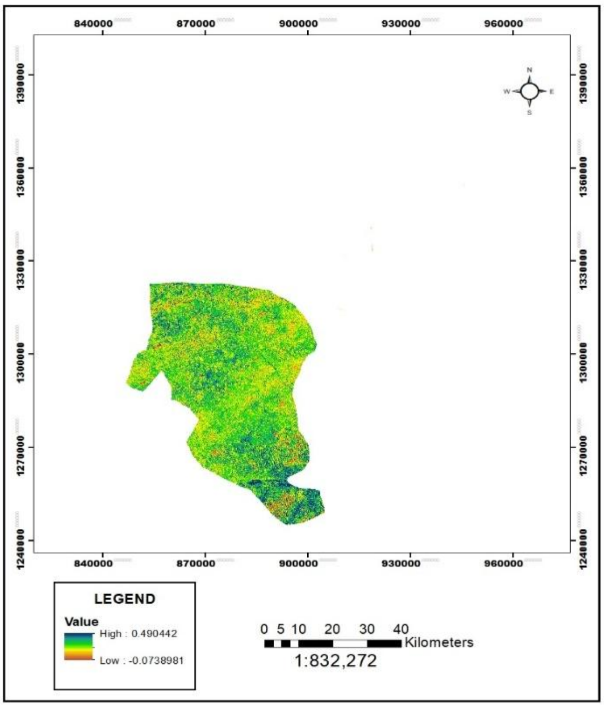

Fig. 30 *NDVI of Kaga LGA in 2012*

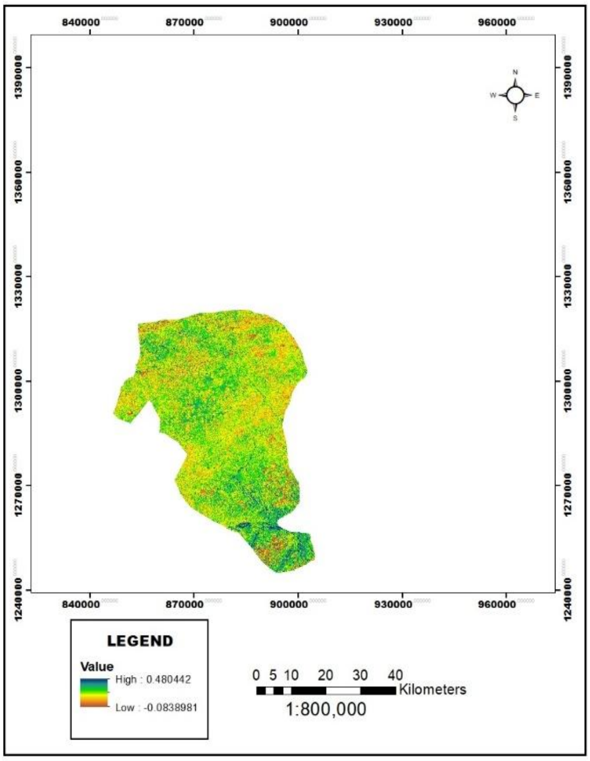

Fig. 31 *NDVI of Kaga LGA in 2013*

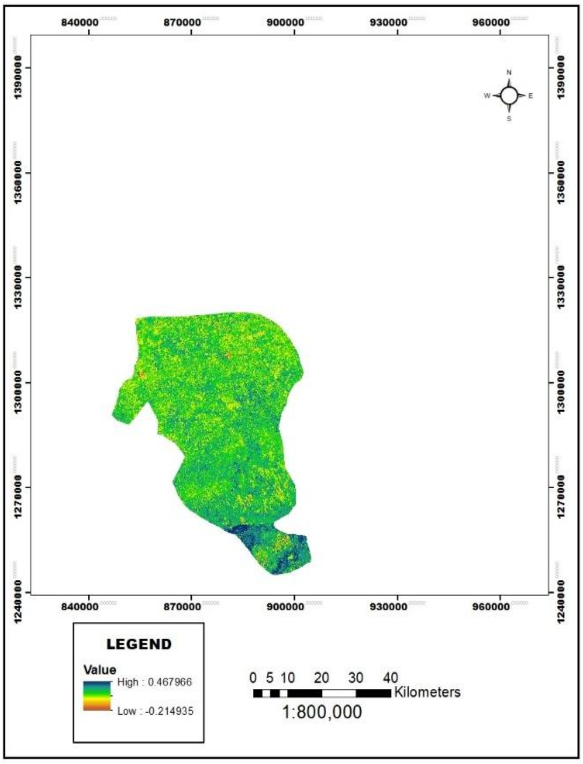

Fig. 32 *NDVI of Kaga LGA in 2022*

In 2002 the NDVI values ranges from -0.174 to 0.873 across the study area. This suggests that, at the low end of the range, the NDVI values point to areas with very limited or sparse vegetation cover. These areas might include barren land, urban zones, or bodies of water where vegetation is notably absent or minimal. As the NDVI values climb higher up this range, the presence and health of vegetation become more pronounced. This suggests a variety of land cover scenarios, such as grasslands, shrublands, forests, and other vegetated areas. These regions

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exhibit a more substantial and healthier density of vegetation compared to the lower end of the range. When compared to 1993 this shows a significant change in vegetation health suggesting that in 2002 the vegetation was much healthier. The NDVI values of Kaga Local government area for 2003 ranged between -0.184 – 0.893 across the study area. This suggests that, at the low end of the range, the NDVI values point to areas with very limited or sparse vegetation cover. These areas might include barren land, urban zones, or bodies of water where vegetation is notably absent or minimal. The NDVI values for 2012 ranged between -0.073 - 0.490, Although from the low end of the range the vegetation health in the less vegetated regions improved, but in the vegetated regions the NDVI reduced drastically when compare to 2003. The NDVI values of Kaga Local government area for 2013 ranged between -0.083 – 0.480. The NDVI values ranges between -0.214 – 0.467 in 2022, when compared with the year 2013, the range is wider and the vegetation health is lower.

3.3.3 NDVI for Magumeri LGA (1993-2022)

The NDVI values of Magumeri from 1993 to 2022 are demonstrated in Figure (33-38). In 1993, the NDVI ranged between -0.507 – 0.452, the highest positive NDVI values were recorded in the vegetated areas and the least values in the non-vegetated area or low vegetation areas sure as bareland and other surfaces with minimal vegetation. In essence this NDVI range suggests that the region has varieties of land cover like grassland and shrubland but not the type of vegetation present in forest areas. In 2002, the NDVI values ranges from -0.174 to 0.873 across the study area. This suggests that, at the low end of the range, the NDVI values point to areas with very limited or sparse vegetation cover. These areas might include barren land, urban zones, or bodies of water where vegetation is notably absent or minimal. As the NDVI values climb higher up this range, the presence and health of vegetation become more pronounced. This suggests a variety of land cover scenarios, such as grasslands, shrublands, forests, and other vegetated areas. These regions exhibit a more substantial and healthier density of vegetation compared to the lower end of the range. When compared to 1993 this shows a significant change in vegetation health suggesting that in 2002 the vegetation was much healthier.

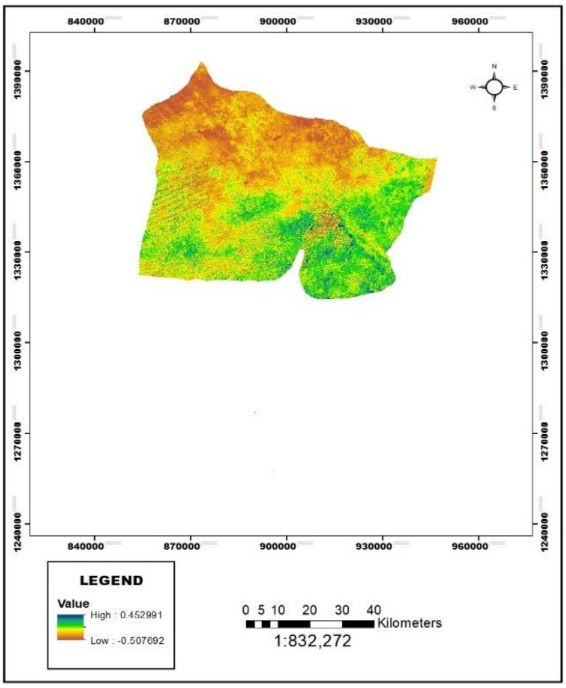


Fig. 33 *NDVI of Magumeri LGA in 1993*

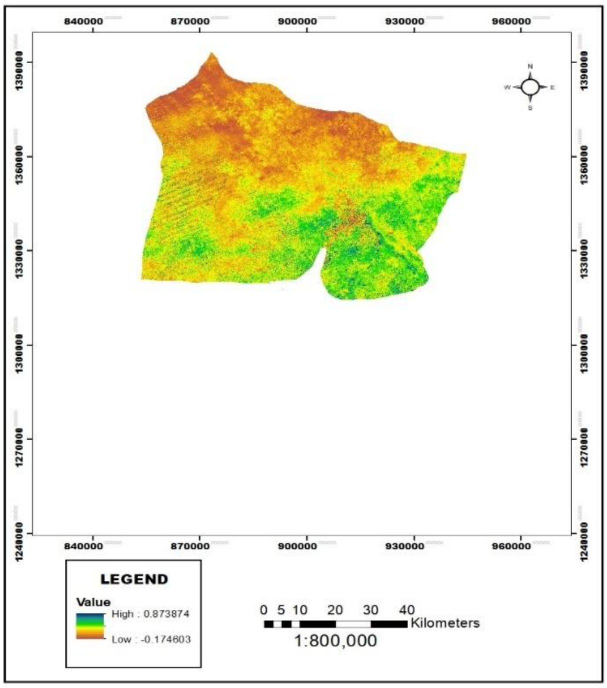
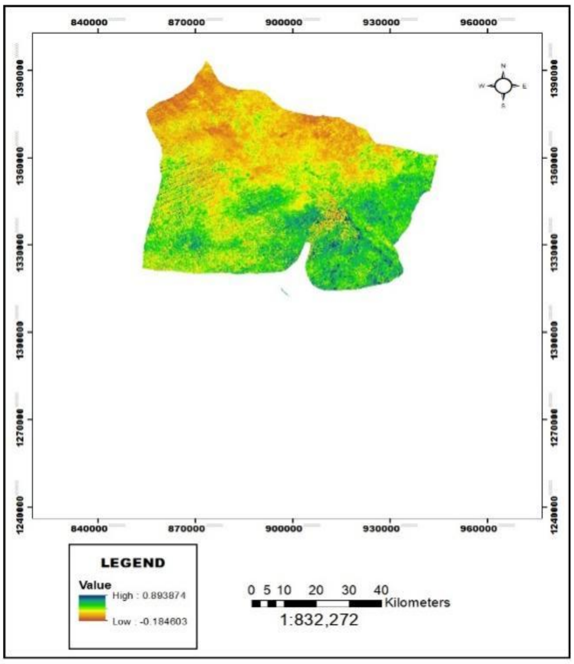


Fig. 34 *NDVI of Magumeri LGA in 2002*



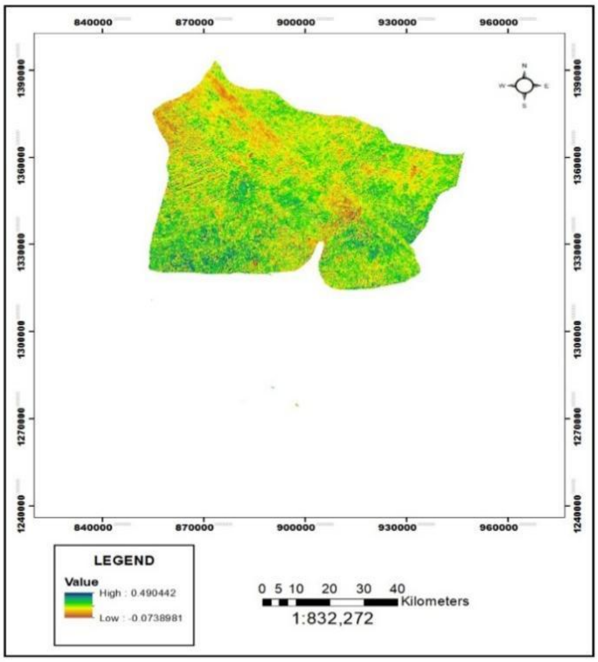
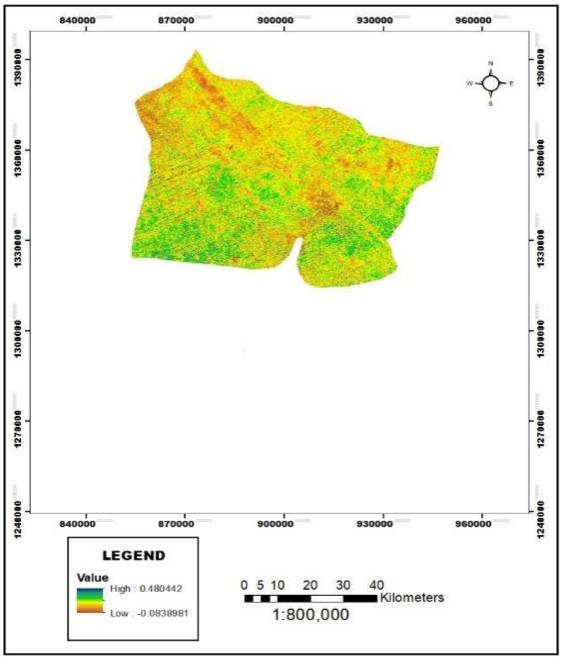


Fig. 35 *NDVI of Magumeri LGA in 2003* **Fig. 36** *NDVI of Magumeri LGA in 2022*



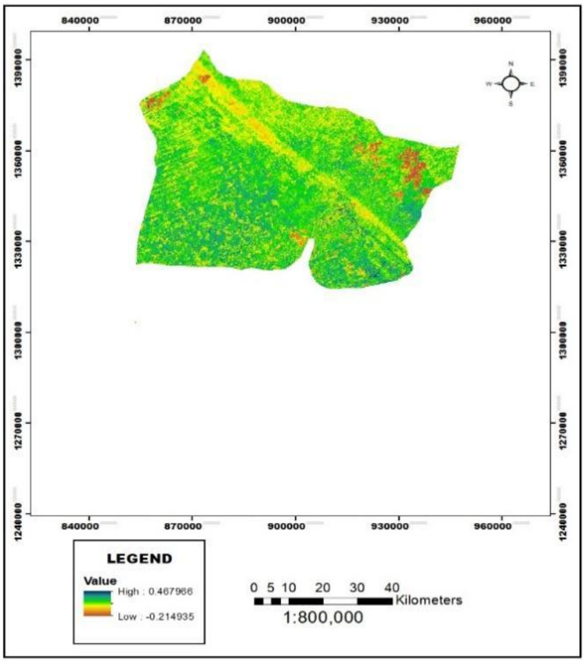


Fig. 37 *NDVI of Magumeri LGA in 2013* **Fig. 38** *NDVI of Magumeri LGA in 2022*

The NDVI values of Magumeri Local government area for 2003 ranged between -0.184 – 0.893 across the study area. This suggests that, at the low end of the range, the NDVI values point to areas with very limited or sparse vegetation cover. These areas might include barren land, urban zones, or bodies of water where vegetation is notably absent or minimal. The NDVI values for 2012 ranged between -0.073 - 0.490, Although from the low end of the range the vegetation health in the less vegetated regions improved, but in the vegetated regions the NDVI reduced drastically when compare to 2003. The NDVI values of Magumeri Local government area for 2013 ranged between -0.083 – 0.480 The NDVI values ranges between -0.214 – 0.467 in 2022, when compared with the year 2013, the range is wider and the vegetation health is lower.

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3.4 Level of Vegetation Greenness Between the Period of 1993-2022

In an attempt to quantify the level of vegetation greenness before and after the intervention of Nigeria's Great Green Wall, positive NDVI of the three-study areas were compared to test the hypothesis (Table 5 and 6). Outcome of the two-way repeated measures ANOVA carried out, indicates the F value (0.665), and P value of (0.5356). Since the p value is greater than 0.05 level of significant, we accept the null hypothesis and reject the alternative hypothesis.

Table 5 *NDVI trend from 1993-2022*

S/N	LGA	1993		2002		2003		2012		2013		2022	
		+	-	+	-	+	-	+	-	+	-	+	-
1	Bayo	0.43	0.225	0.535	0.3257	0.406	0.314	0.668	0.38	0.5418	0.187	0.544	0.214
2	Kaga	0.452	0.507	0.873	0.174	0.893	0.184	0.490	0.073	0.480	0.083	0.467	0.214
3	Magumeri	0.452	0.507	0.873	0.174	0.893	0.184	0.490	0.073	0.480	0.083	0.467	0.214

Note: the (+) sign means positive trend while the (−) means negative trend

Table 6 *One-way repeated measures ANOVA of vegetation greenness between pre-GGW (1993–2012) vs. post-GGW (2013-2022)*

Source	SS	DF	MS	F	P
Between	0.0	2	0.0	0.665	0.5356
Subject	0.3	5	0.1		
Error	0.2	10	0.0		

The result of this findings indicated that vegetation cover has undergone changes over the last three decades in the study areas as a result of climate change, anthropogenic activities between the years 1993 and 2002 as indicated in table 5, vegetation increased by 247.14%, during the same time period NDVI increased with its positive values increasing from 0.43 to 0.54, between 2003 and 2012 vegetation increased by 335.26% and so did NDVI with positive values increasing from 0.406 to 0.668 within the two years. Also, between the years 2013 and 2022 there was 18.77% rise in vegetation cover with positive NDVI values maintaining a constant unit of 0.54, which shows that there is no major improvement in the quality of vegetation between 2013 and 2022 even with increased vegetation cover. While in Kaga and Magumeri local government area between the years 1993 and 2002 vegetation increased 23.5% while positive values of NDVI increased from 0.435 to 0.87 within the period. Likewise, between the years 2003 and 2012 the vegetation cover increased by 508.17% but positive values of NDVI decreased from 0.89 to 0.49 in 2012 which indicates a poorer health of vegetation or vegetation quality. Also, between the years 2013 and 2022 vegetation increased by 151.58% but NDVI values remain constant with approximately a unit of 0.48 which indicates that the vegetation quality hasn't had any major improvement between the periods.

The information obtained with NDVI trends and the one-way repeated measure ANOVA reveal that the establishment of the GGW had no significant impact on the greening of most of this zone. It would also be interesting to know if the greening is due to an increase in agricultural activity in the region rather than other types of restoration interventions. Therefore, there is still great work to be done in other to mitigate the effect of climate change within the study area as the result shows that the impact of the intervention has not been felt as expected in the area, only little changes on the vegetation improvement was observed, though there was increased on the area coverage of vegetation but the health of the vegetation becomes a thing to be worried about as the area is prone to loss this vegetation due to continuous changes in climate most especially in precipitation received in the region if proper and adequate irrigational practices is not employed. This finding agrees with the research work carried out by [26].

4. Conclusion

Desertification and changes in land use land cover are indicators of land degradation and regeneration which can trace to climate change, this study attempted to determine changes in vegetation cover in the great green wall of Nigeria, Borno state (Bayo, Kaga, and Magumeri) over the period 1993-2022. The regional GGWI domesticated by Nigeria and implemented through the National Agency for the Great Green Wall Nigeria is regarded as an audacious intervention program to improve or solve land degradation challenges caused by desertification and other anthropogenic actions. The initiative was Analysis of Normalized Difference Vegetation Index (NDVI) explicitly targeted at arresting soil/land degradation, conserve biodiversity, improve agricultural productivity, and mitigate the impact of climate variability with a strategic action plan (SAP). The SAP is aimed at transforming the degraded land established that land restoration process by the NAGGW though in phases for a period of five years is moving in a snail-like mode, though the implementation in the study area started ten years behind the regional commencement and two years behind the national commencement of the implementation and there was a big gap between the launch of the initiative and the implementation process.

Plantation should be intensified in the study area to hasten the restoration of the degraded land. Proper irrigation practice should be done regularly as the areas are prone to loss of water bodies due to little precipitation received within the study areas. Further studies should be carried out in other local government to ascertain the effectiveness of the agency in afforestation effort. Land-truth should be done to be sure that the little changes observed in the study area are the result of the afforestation effort of the agency.

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Conflict of Interest

The authors declare that there is no conflict of interest regarding the paper's publication.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Paul Idowu Oyemomi, Abdullahi Chado Salihu, Ayuba Musa Mshelia;* ***data collection:*** *Paul Idowu Oyemomi;* ***analysis and interpretation of results:*** *Paul Idowu Oyemomi, Abdullahi Chado Salihu, Ayuba Musa Mshelia and Danbaba Goma;* ***draft manuscript preparation:*** *Paul Idowu Oyemomi, Abdullahi Chado Salihu, Danbaba Goma, Ayuba Musa Mshelia . All authors reviewed the results and approved the final version of the manuscript.*

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