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RESEARCH ARTICLE

Hotspots Mapping and Geoinformatics Analysis of Encroachment in Old Oyo National Park, Nigeria

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Abstract

This study identified, mapped, and analyzed the spatial dynamics and intensity of encroachment in Old Oyo National Park (OONP), Nigeria. Multi-temporal Sentinel-2 imagery (2017–2023) enabled land cover change assessment via geospatial techniques, including query, overlay, modeling, and derivative mapping. Geo-statistical analyses combined descriptive (frequency, percentage) and inferential methods: hotspot density (encroachment spots/km²) quantified intensity, while ANOVA tested differences across land cover classes. Results showed vegetation cover declining from 96.3% (2017) to 95.88% (2023), with increases in rangeland and cropland. Change detection revealed dominant vegetation-to-rangeland conversion in Marguba, Yemoso, and Oyo Ile Ranges. Marguba Range had the highest hotspot density (0.362 spots/km²). ANOVA confirmed significant land cover variations ($p < 0.00001$), driven by agricultural expansion and grazing. Encroachment in OONP is noticeable yet gradual. Recommendations include intensified monitoring and enforcement in high-risk zones, robust boundary demarcation, and community engagement to promote sustainable land use and preserve biodiversity.

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1. INTRODUCTION

In Nigeria and other developing countries, encroachment into protected areas poses a major conservation challenge (Watson et al., 2014). Parks like Old Oyo National Park (OONP) were established to preserve biodiversity and ecosystems, yet unauthorized agriculture, settlements, and resource extraction cause habitat fragmentation, degradation, and biodiversity loss (Adetoro et al., 2011). These pressures erode ecological integrity, underscoring the need for insights into encroachment patterns and drivers to inform mitigation strategies (Khazieva et al., 2022).

Remote sensing (RS) and geographic information systems (GIS) provide precise, consistent monitoring of such changes (Rane et al., 2023). Studies like Gao et al. (2020) used Landsat data to track forest degradation in OONP, revealing anthropogenic impacts, while Molere et al. (2016) applied GIS to map poacher routes and enhance resource management. However, prior research has emphasized general conservation and biodiversity, with limited spatial-temporal analysis of encroachment dynamics.

Although RS/GIS has detected hotspots elsewhere, systematic application in OONP remains underexplored. This study addresses this gap by using geospatial techniques to identify, map, and analyze encroachment's spatial dynamics and intensity, delivering decision-support tools for effective park management and conservation. .

2. MATERIALS AND METHODS

2.1 The study Area

Old Oyo National Park is one of Nigeria's seven national parks (Gashaka-Gumti, Kamuku, Okomu, Yankari Game Reserve, Cross River National Park and Kainji National Park), spanning an area of approximately 2,512 square kilometers. The park extends about 120 kilometers from southwest to northeast, with a width of up to 50 kilometers in its southern region, giving it a shape often likened to a saxophone. It straddles Oyo and Kwara States and is geographically situated between latitudes 8°10'–9°05' N and longitudes 3°00'–4°20' E.

The park's landscape features gently rolling hills, elevations ranging from 300 to 500 meters, and prominent geological formations such as Yemoso and Gbogun hills. Seasonal rivers and rocky outcrops add to its diverse topography. Old Oyo National Park is ecologically rich, hosting a variety of wildlife and over 300 bird species. For management purposes, the park is divided into six ranges: Yemoso, Sepeteri, Tede, Oyo-Ile, Marguba, and Tessi. To enhance protection, 12 ranger barracks are strategically located across the park as of 2024, ensuring effective monitoring and conservation of its biodiversity.

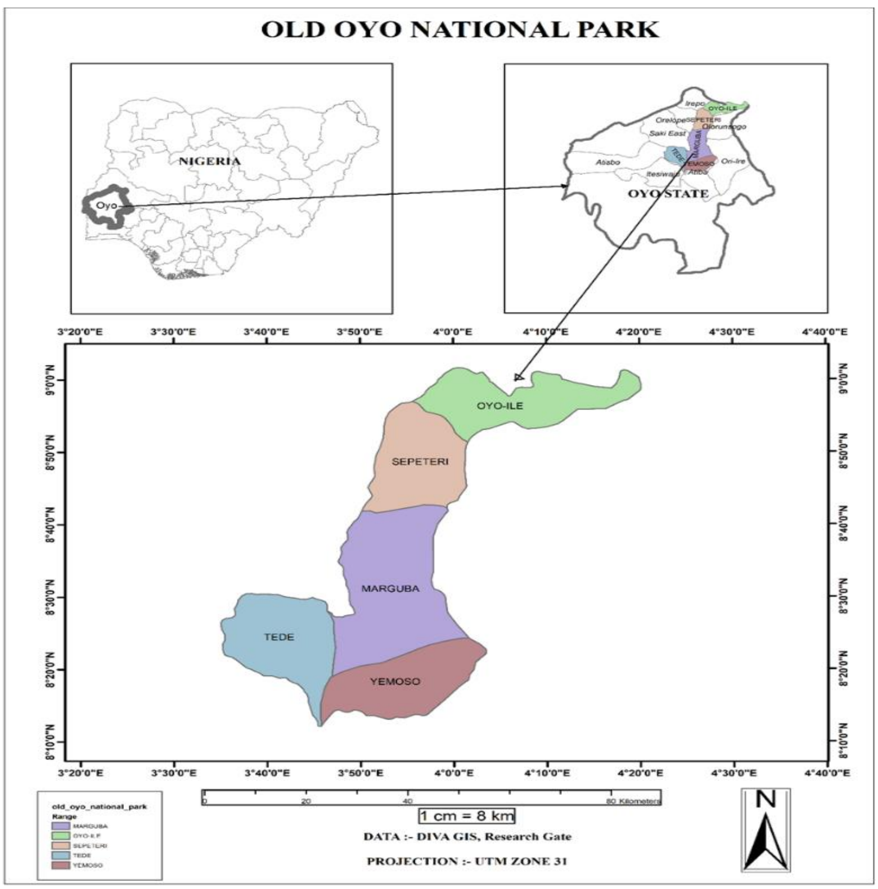

Figure 1. OONP in the context of Oyo state, Nigeria (Source: Author compilations 2024)

2.2 Method of Data Collection and Analysis

Secondary data were mainly used for the study. The data included Sentinel 2 imagery with a resolution of 10m; this remotely sensed image provided a consistent data coverage from 2017 to 2023 and was obtained from the Esri Living Atlas website. The already classified and rectified imagery projected to UTM zone 31 was reclassified to five classes (waterbodies represented by blue, vegetation as dark green, cropland in gold yellow, built-up in red and Rangeland in grey) for every year from 2017 to 2023 to align with Spatial Planning conventional colours for land uses and land cover on the map for clarity and standardization. Post-classification process was also employed using a classification to vector approach.

Geospatial analyses used for manipulation included query, overlaying, modelling, and change detection analysis to assess the shifts in encroachment activities over time. The geostatistical analyses employed were descriptive and inferential techniques. The descriptive method included frequency and percentage to summarize findings. For inferential analysis, a hotspot density approach was adopted, in which the number of encroachment spots was normalized by the area of each range (spots/km²) to accurately estimate the intensity of encroachment across the park. This method allowed for a more objective comparison of encroachment pressure across ranges of varying sizes. Additionally, Analysis of Variance (ANOVA) was also conducted to examine significant differences among various land cover classes, helping to assess the impact of encroachment on vegetation, cropland, and other land use types.

Database design was created to take into consideration all the objects and their interrelationship within the spatial unit of the park. The design was carried out in such a way that maximum benefit could be derived from the result of the database. The database design was taken through four different levels of abstraction as diagrammatically expressed below in Figure 2. Having designed a generic data structure and procedures, the actual database implementation follows by inculcating the designed data structure into the internal data model of the GIS software. Then Database created was populated by inputting the data collected. Phases through which the database was taken are diagrammatically adapted after (Kufoniyi 1998) model as shown in Figure 2, with the explicit explanations thereafter to each level on how the database was created and implemented to achieve the aim of this study.

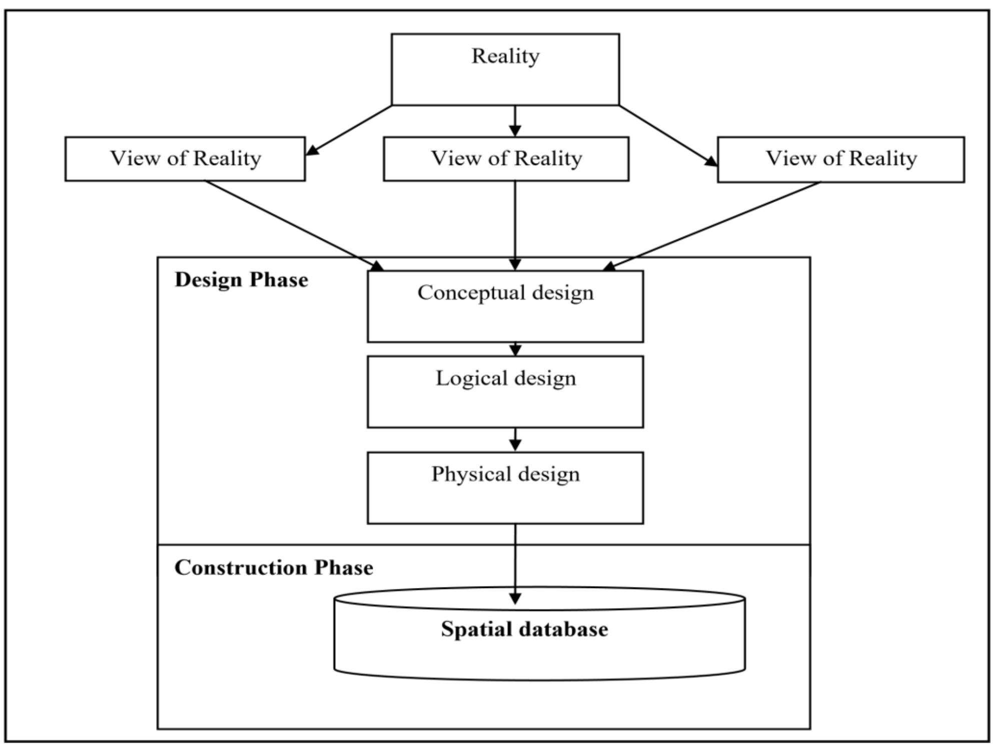

Figure 2. Design and construction phases of a Database. **(**Source: Kufoniyi 1998.)

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View of Reality

After a careful thought of the problems for which the system was required and identifying all entries that took up the spatial unit of interest, the following entities were identified as 'actual reality' i.e as they exist in Old Oyo National Park. A road was viewed as roads, encroachment spot as encroachment spot, boundary as boundary and ranges as ranges, rangers barrack was viewed as park administration station and stream is viewed as stream

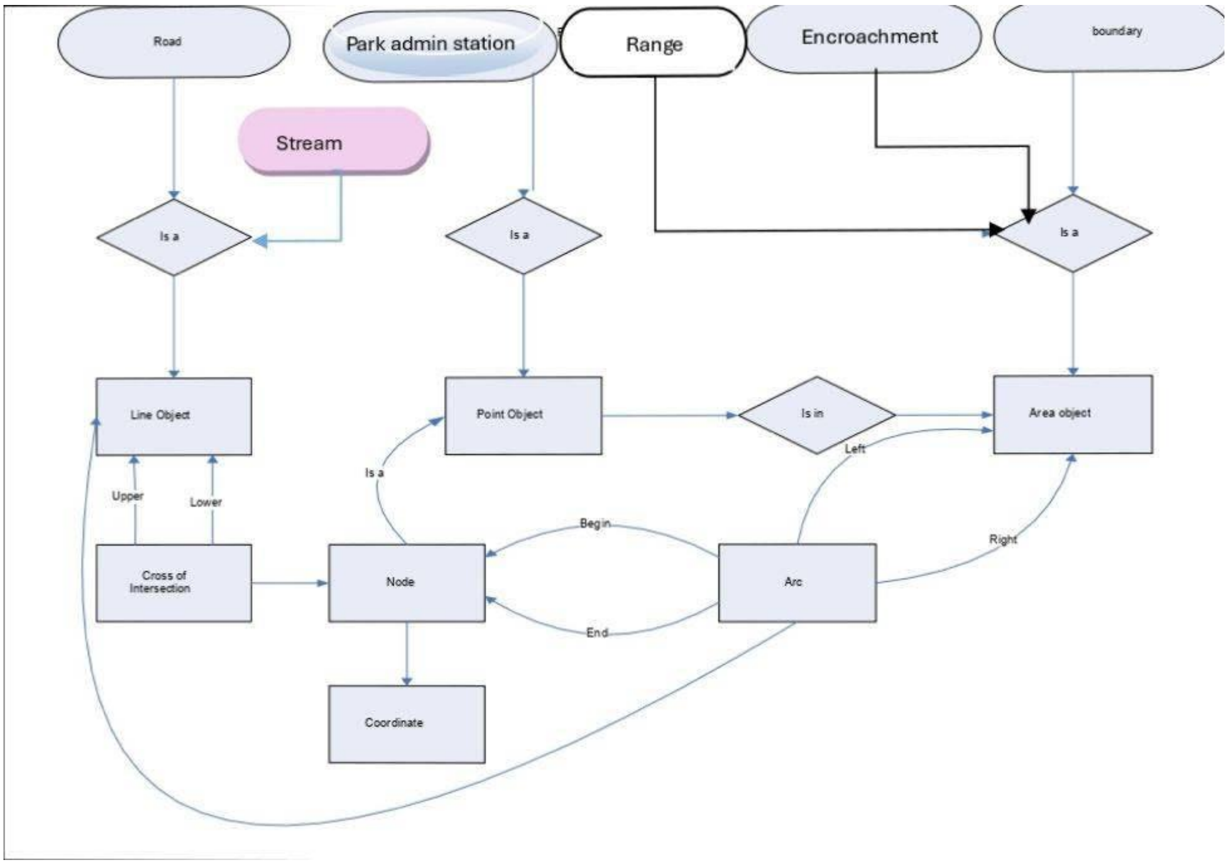

Figure 3. Geometric representation of the study area. Source: Authors' work (2024).

Conceptual Design

The view of reality was represented in a simplified form for conceptual design. This is the human representation of the various views of reality. The entities identified were laid out and all their interrelationships were mapped by using the extended Entity Relationship (E-R) diagram. An ER diagram is a modelling technique in the framework of a relational database management system (RDMS). Figure 4 shows an example of the conceptual design of an encroachment management database using an E-R diagram, based on a vector (topologic) data model. In the E-R diagram, a rectangle represents an entity and a diamond represents a relationship. Relationships were linked to their constituent entity types by arcs and the degree of relationship is indicated on the arc.

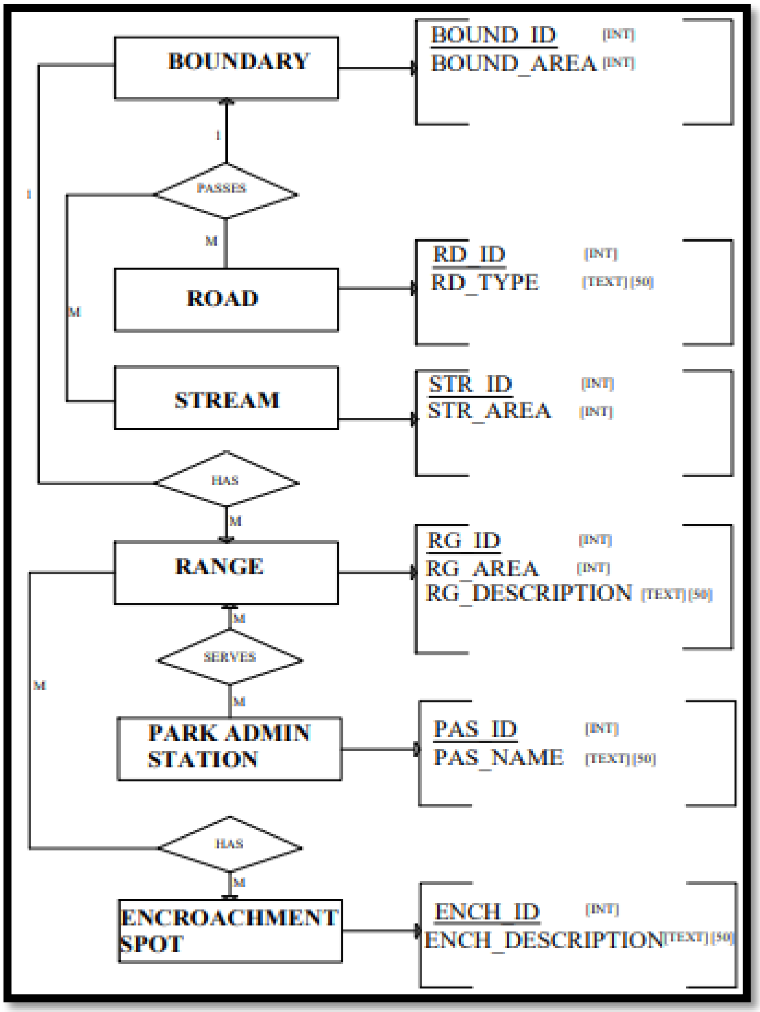

Figure 4. Entity Relationship Diagram (Source: Authors' work, 2024).

Definition of Entity

Boundary: A line that marks the limits of an area. In this context, it is the coverage area of the park.
Range: A division of the park for easy management.
Park Administration Station: A facility, a barrack located within the park, often used for administrative or management purposes. It serves as operation hub for park staff and rangers.
Encroachment spot: A specific location in the park where illegal or unauthorized activities have occurred.

Enterprise Rules

Enterprise rules define the relationship between the entities and these rules are derived from the legislation, regulations and rules of best practice (Paresi, 2000). These rules are also derived from the norms of the organization. Enterprise rules are the underlying rules governing how data elements in a system work together. These rules are usually determined from an in-depth understanding of how the data elements relate in the real world and these define how the data is going to be managed. For the encroachment monitoring database, the enterprise rules are given below.

Spatial Enterprise Rules

A boundary contains many ranges.
One or more roads and streams may pass through the boundary.
A range has many park administration stations
The park administration station serve encroachment spot
One range contains one or many encroachment spots
One or more park admin stations serve one or many encroachment spots.

Logical Design

The conceptual data model was transformed into a data structure (tabular and spatial) upon which the database system was implemented. The relational data model was used. A relational data Model represents the database as a collection of relations. A relational data model is one in which facts (real-world concepts) are represented at a logical or abstract level. When the relation was created, it was given a name. The type of attributes it has and what their respective domain was also indicated. This type of declaration of a relation is known as a relational schema. From the entity relationship diagram, skeleton tables of the relational data structure are derived. The logical design stage was defined during physical design. The structure of these tables is presented below in Table 1. In the skeleton table drawn, the symbol ***** refers to the primary key, while **'f'** refers to the foreign key.

Table 1. Skeleton Table

Boundary	Bound_ID*	Bound_area	STR_ID^f	RD_ID^f	RG_ID^f
Road	RD_ID*	RD_area	Bound_ID^f		
Stream	STR_ID*	STR_area	Bound_ID^f		
Range	RG_ID*	RG_area	RG_Description	PAS_ID^f	Ench_ID^f
Park admin station	PAS_ID*	PAS_name	RG_ID^f		
Encroachment spot	Ench_ID*	Ench_Description	RG_ID^f		

Source**:** Authors' work (2024).

Physical Design

At this stage, the data structure presented in logical design was presented in the language of the implementation software. The attribute tabular structured data generated in the logical design stage was actualized in the format of the implementation software. This includes the definition of fields (numeric, text and string), record, length and type of record, etc., and setting some integrity rules that must be obeyed before data is accepted into the records. This aspect also includes the data preparation and actual population of the database. The map data was geo-referenced and digitized in ILWIS 3.0 for the creation of different required layers. The spatial products of data format in ILWIS were thereafter converted to the ArcMap (ESRI) shapefile for use and adding a database. Spatial acquisition of this research is depicted in Table 2.

Table 2. Collection of Dataset and their Format Type

Feature	Spatial type	Format
Boundary	Polygon	Shape file
Road	Line	Shape file
Road	Line	Shape file
Stream	Line	Shape file
Range	Polygon	Shape file
Park admin station	Point	Shape file
Encroachment spot	Polygon	Shape file

Source: Authors' work (2024).

3.0 RESULTS AND DISCUSSION

3.1 Spatial Extent and Patterns of Old Oyo National Park

The analysis of land cover distribution in the study area for the years 2017, 2020, and 2023 reveals notable shifts in land use patterns and the extent of human-induced changes. The results are summarized in Table 3, while Figures 5(A–C) provide visual representations of the spatial distribution for each year. In 2017, the study area was predominantly covered by vegetation, which accounted for 96.3% of the total area. This indicates that the natural environment remained largely intact, with minimal evidence of human encroachment. Water bodies made up 0.51%, while cropland and built-up areas were virtually absent, occupying just 0.0041% and 0.0001%, respectively. Rangeland constituted 3.18%, suggesting limited grazing activities. Overall, the land cover in 2017 reflected a relatively undisturbed natural landscape (see Figure 5A).

By 2020, a significant change was observed. Vegetation cover increased further to 97.74%, reversing the prior trend of gradual decline and suggesting natural regeneration or effective conservation efforts. Water

bodies remained unchanged at 0.51%. However, cropland expanded slightly to 0.015%, pointing to ongoing but minimal agricultural activities. Built-up areas remained negligible at 0.000%, and rangeland decreased significantly to 1.74%, indicating a reduction in grazing pressures. These changes suggest a temporary retreat in encroachment activities and improved vegetation cover across the landscape (see Figure 5B).
In contrast, the 2023 land cover data shows a reversal of the previous gains. Vegetation cover declined to 95.88%, signalling renewed disturbance. Water bodies remained consistent at 0.51%, while cropland expanded further to 0.048%, indicating an increase in agricultural encroachment. Notably, built-up areas, although still limited, increased to 0.006%, reflecting emerging urban development. Rangeland also rose sharply to 3.56%, suggesting a resurgence of grazing activity. Collectively, the 2023 data indicate a renewed wave of encroachment driven by agricultural expansion, grazing, and minor urban development (see Figure 5C).
These findings highlight dynamic land cover transitions within the study area over the six-years. The temporary recovery in 2020 contrasts sharply with the encroachment pressures evident in 2023, underscoring the need for continuous monitoring and sustainable land management strategies.

Table 3. Old Oyo National Park land cover analysis

	2017		
SN	Classification	Area	%
1	Waterbodies	13.56677	0.5099
2	Vegetation	2562.169	96.3071
3	Cropland	0.109734	0.0041
4	Built-up	0.002334	0.0001
5	Rangeland	84.56771	3.1787
	Total	2660.416	100
	2020		
1	Waterbodies	13.62469	0.512
2	Vegetation	2600.17	97.736
3	Cropland	0.409236	0.015
4	Built-up	0.000626	0
5	Rangeland	46.20562	1.737
	Total	2660.411	100
	2023		
1	Water bodies	13.50238	0.508
2	Vegetation	2550.73	95.877
3	Cropland	1.266845	0.048
4	Built-up	0.160347	0.006
5	Rangeland	94.75731	3.562
	Total	2660.417	100

Source: Authors' work, (2024).

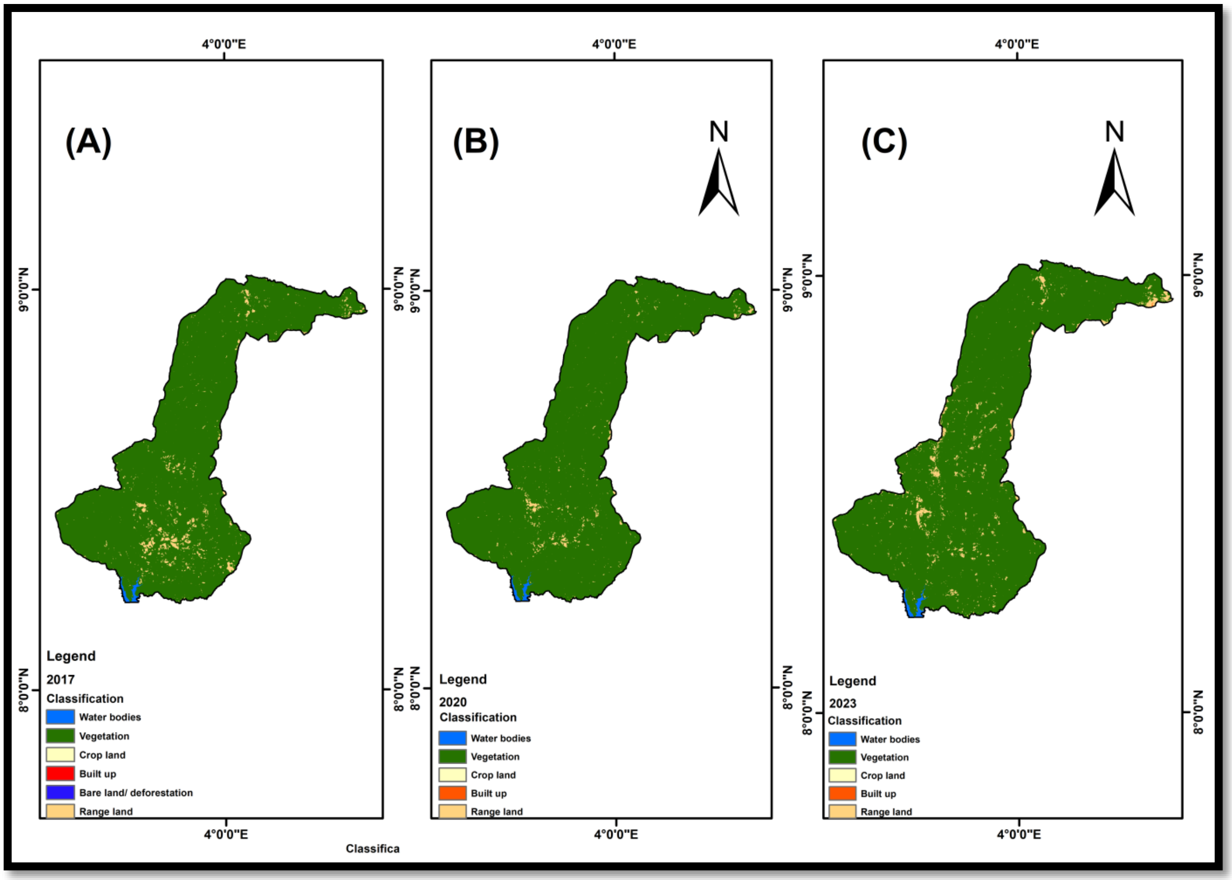

Figure 5. Land cover maps of Old Oyo National Park for 2017 (A), 2020 (B), and 2023 (C) showing temporal changes. Source: Author design (2024)

Change detection

The change detection analysis of 2017 and 2023, across all the ranges (Yemoso, Marguba, Tessi, Tede, Oyo Ile and Sepeteri) revealed vegetation to range land change is the most significant form of change detected across all the range which account to averaging 25-40%, Sepeteri Range recorded the highest percentage of vegetation to rangeland conversion (37.97%), indicating intense, Persistent rangeland ranged between 1–22%, reflecting ongoing human activity, The Oyo-Ile Range had the highest persistent rangeland (22.59%) Vegetation recovery from range land accounted for 5–7% in most ranges. The Yemoso Range recorded the highest vegetation recovery (4.55%), Persistent cropland (cropland to cropland) was generally minimal.

The Sepeteri Range had the highest cropland persistence (0.19%), Persistent built-up areas (built-up to built-up) were negligible across all ranges, Vegetation to Cropland/Built-up areas these conversions were minor, averaging less than 1% across the ranges, but they highlighted localized impacts of agriculture and settlement expansion, Changes in waterbodies and other land cover transitions were negligible (<0.1%) and largely influenced by natural dynamics. The Sepeteri Range experienced the most severe encroachment from vegetation to range land. The Oyo-Ile Range had the highest persistent rangeland, while the Yemoso Range demonstrated the highest vegetation recovery. Cropland persistence was most significant in the Sepeteri Range, though still minimal (see Appendix 1)

Relationship between different land cover classes across the years

The ANOVA results (Table 5 and 6) revealed significant differences in land use categories within Old Oyo National Park, indicated by a high F-ratio of 20,349.74 and a p-value of less than 0.00001. These findings suggest that encroachment activities are impacting specific areas of the park, particularly through the increase in cropland and the decline in vegetation. This shows the urgency for enhanced monitoring strategies to track encroachment dynamics, particularly in zones experiencing agricultural expansion, which

threatens biodiversity and natural habitats.Rangeland shows a trend of increasing significance as it has the highest p value when compared with both cropland and built-up, indicating a clear and growing distinction from both other land types. This distinction suggests that rangeland is becoming increasingly important in the context of land use dynamics.
This can be attributed to several factors, including its ecological value, economic uses, and its role in supporting biodiversity. Built-up shows less pronounced differences compared to cropland and rangeland, indicating it is not increasing significantly in terms of its relevance or distinctiveness. This suggests that built-up may be more susceptible to encroachment, as it often represents land that has been cleared or degraded, making it more vulnerable to conversion for agricultural or urban development.

Table 5. Land use classification Area (km) from 2016-2023
WB=Waterbodies, V=Vegetation, CL=Cropland, BA= Built-up, RG= Rangeland

Year	WB	V	CL	BA	RG
2017	13.56677	2562.169	0.109734	0.002334	84.56771
2018	13.64494	2543.594	0.093822	0.002985	103.08
2019	13.65081	2542.39	0.18277	0	104.1923
2020	13.62469	2600.17	0.409236	0.000626	46.20562
2021	13.58066	2611.178	0.808763	0	34.85075
2022	13.51933	2619.29	0.99423	0.002436	26.61004
2023	13.50238	2550.73	1.266845	0.160347	94.75731

Source: Authors' work, (2024).

Table 6. ANOVA result detail for variation land use classes

Result Details				
Source	SS	Df	MS	
Between-treatments	36564924	4	9141231	F = 20349.73893
Within-treatments	13476.19	30	449.2063	
Total	36578401	34		

Source: Authors' work, (2024).

Spatial Variation and Intensity of Encroachment in Old Oyo National Park
The spatial distribution of encroachment across the various ranges within Old Oyo National Park was assessed using encroachment density values. These were derived by dividing the total area affected by encroachment (in km²) by the total land area of each range (in km²). The results, presented in Table 7 and visualized in Figure 6, reveal significant variation in the intensity of encroachment among the different ranges.

Marguba Range recorded the highest encroachment density at 0.362, indicating that approximately 36% of its total area is encroached upon. This range, therefore, represents the most severely affected section of the park, likely due to its proximity to human settlements or accessibility that facilitates illegal activities. Yemoso Range follows closely with a density of 0.250, also reflecting a considerable level of disturbance that may necessitate urgent conservation intervention.

Moderate encroachment densities were observed in Oyo Ile Range (0.119) and Tessi Range (0.058), suggesting that while these areas are affected, the pressure is less intense compared to Marguba and Yemoso. On the other hand, Tede Range and Sepeteri Range reported the lowest encroachment densities of 0.036 and 0.025, respectively. These lower values may be attributed to more effective protection measures, difficult terrain, or reduced human activity within and around these ranges.

The findings highlight the need for range-specific conservation strategies. Marguba and Yemoso Ranges should be prioritized for intensive anti-encroachment actions such as increased surveillance, boundary demarcation, and community sensitization programs. Meanwhile, although Tede and Sepeteri are less impacted, ongoing monitoring and preventative measures remain essential to ensure that encroachment levels do not rise in the future. Overall, these patterns underscore the importance of targeted management and resource allocation in protecting the ecological integrity of Old Oyo National Park.

Table 7. Encroachment hotspot density

Range name	Encroachment spot km^2	Range Area km^2	Density
Yemoso Range	149.0401	595.6668	0.250207
Tede Range	14.1169	397.3514	0.035527
Marguba Range	186.0038	513.5187	0.362214
Tessi Range	20.7161	358.7221	0.05775
Sepeteri Range	11.3936	453.9166	0.025101
Oyo ile Range	40.8543	342.2232	0.119379

Source: Authors' work, (2024).

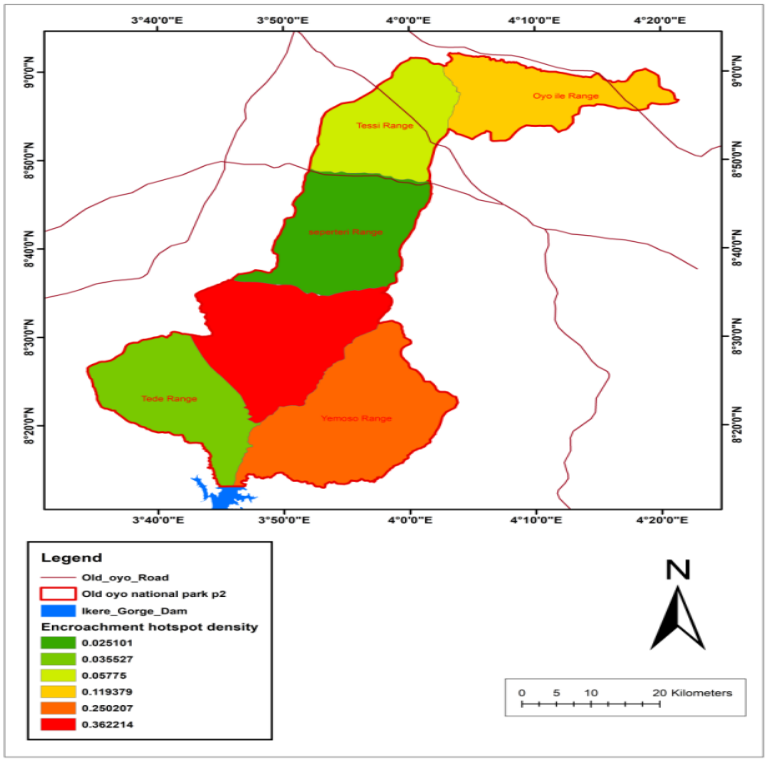

Figure 6. Encroachment hotspot density map across the six park ranges. Source: Author design (2024)

Database extraction (spatial query)

A spatial database allows users to store, query and manipulate collections of spatial data and also a query is a computer program that extracts data from the database that meet the conditions indicated in the query (Güting, 1994). The results generated from these queries according to them are tables that are shown to the user who executed the queries. That is the reason why whenever the user closes the view on the query result, that result is lost. The single criterion and multiple criteria queries were issued to answer some generic questions about the entities that made up the application being carried out, Figure 7 shows the composite map of Old Oyo National Park indicating encroachment spot and other features.

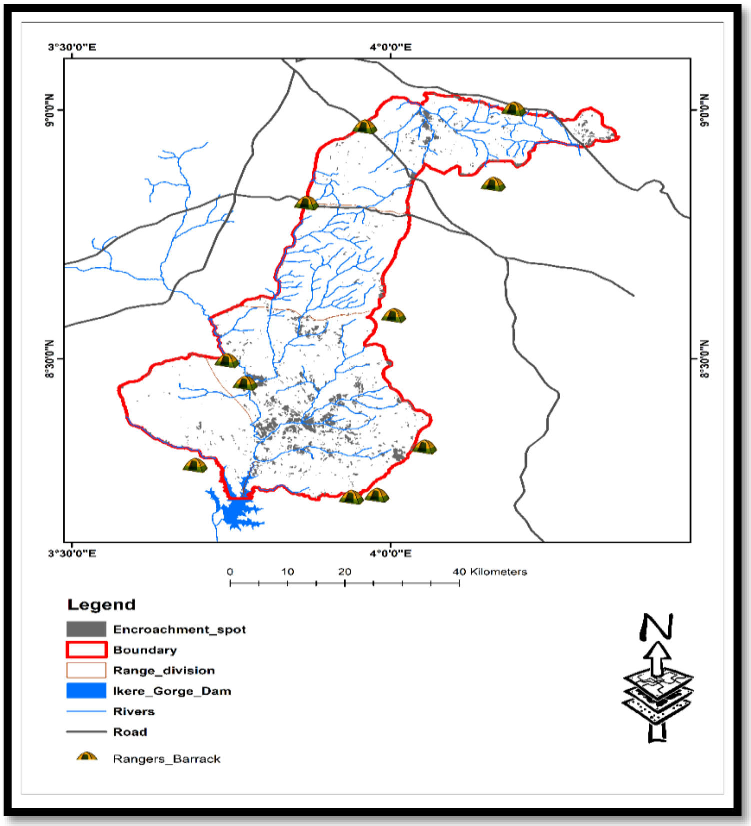

Figure 7. Composite map of the study area. Source: Author design (2024*)*

Single criterion query one:

This is when a condition is applied to the query. One of the fields I the tables created was used to query the database; in this case, the condition used is to query for the Rangers barrack located within the ranges in the study area.

The syntax is given as:

SELECT * FROM Rangers barrack WHERE “Range” = Oyo Ile

Figure 8 shows that 3 out of 12 ranger barracks serve the Oyo-Ile range

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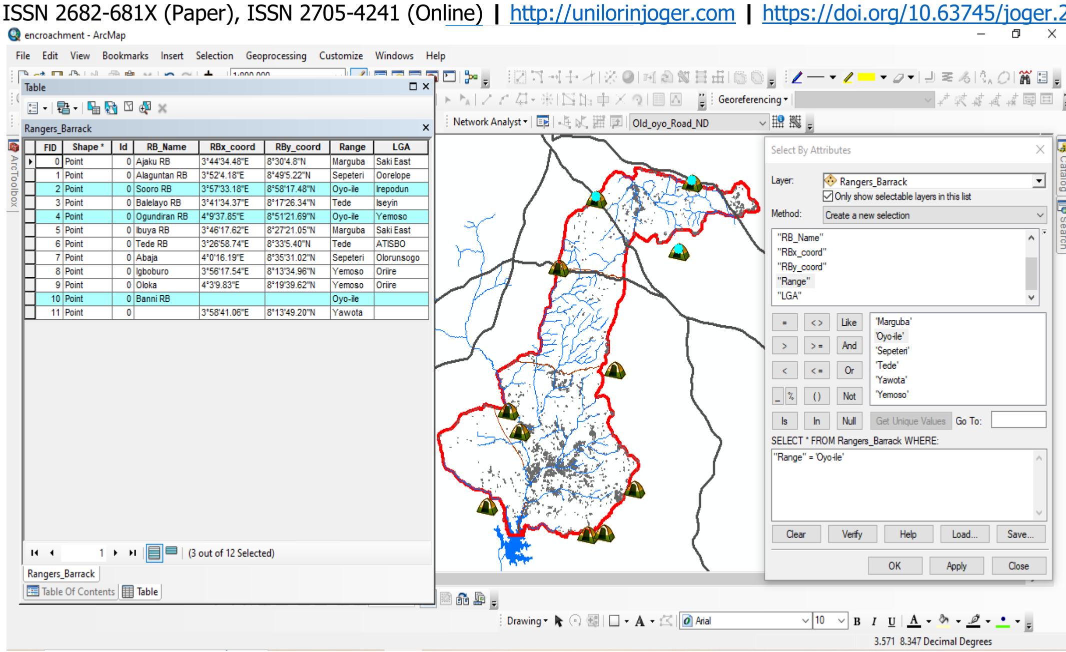

Figure 8. Single query for range in Oyo-Ile. Source: Author design (2024)

Multiple criterion query one:

This is when more than one condition is applied to the query. More than one of the fields in the tables created was used to query the database. In this case, the condition used is to query for encroachment spots that are located within each range in the study area.

The syntax is given as:

SELECT * FROM encroachment spot WHERE “Range” = Sepeteri range

Figure 9 shows that 196 out of 3492 encroachment spots are located inside the Sepeteri range

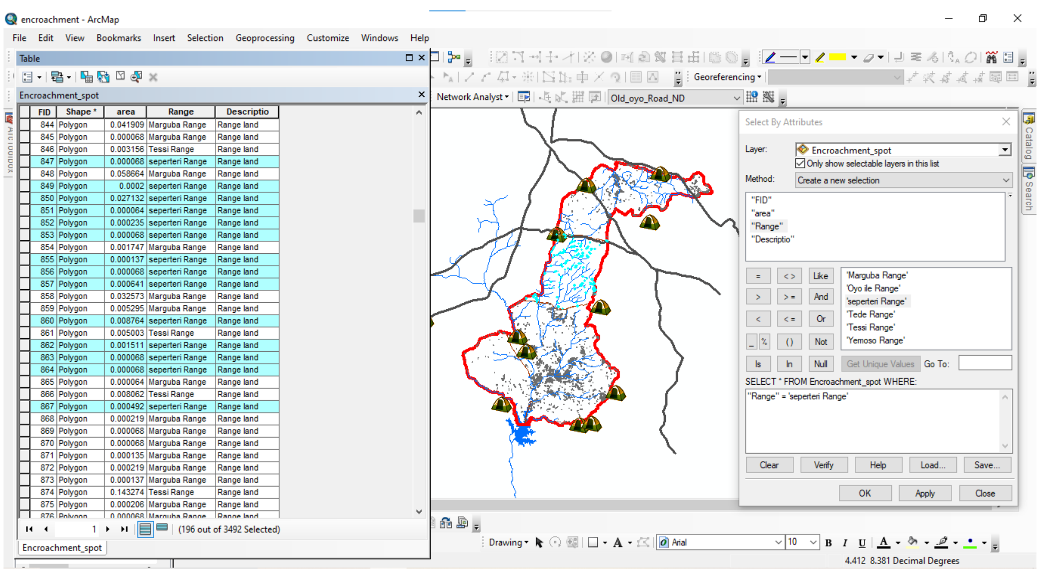

Figure 9. Multiple query for Sepeteri range. Source: Author design (2024)

Query two: This is when more than one condition is applied to this query. The condition used is to query for encroachment activities that are built up with is located within the Sepeteri range in the study area.
The syntax is given as:
SELECT * FROM encroachment spot WHERE “Range” = Sepeteri range AND “description” = built-up

Figure 10 shows that 1 out of 196 encroachment spots is located within the Sepeteri range, which is built-up

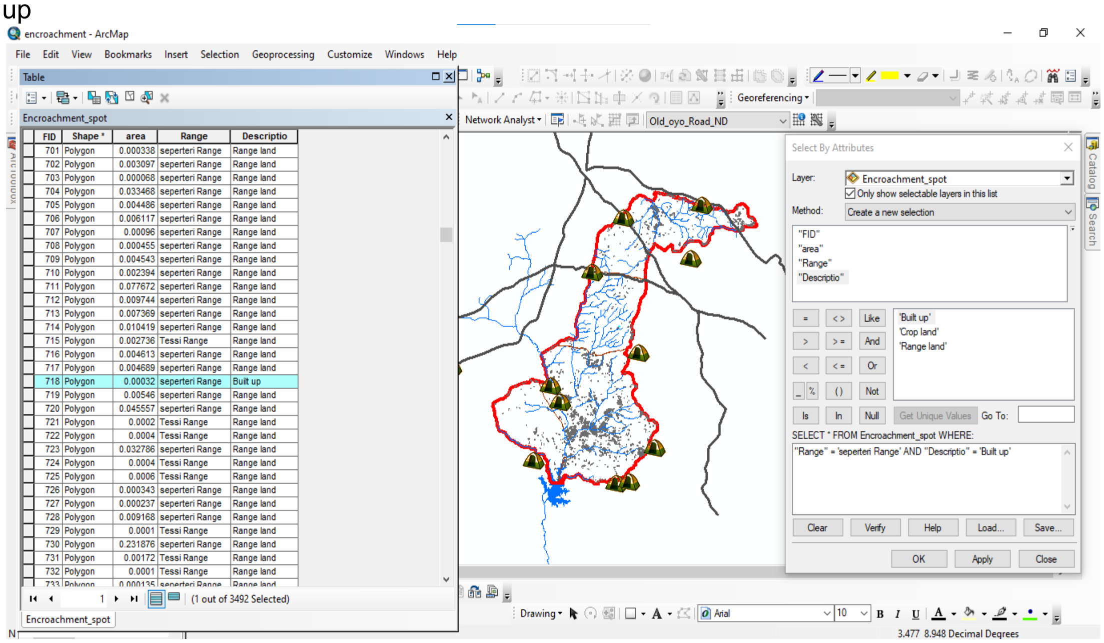

Figure 10. Multiple queries for encroachment activities within Sepeteri range that built-up Source: Author design (2024*)*

4.0 CONCLUSION AND POLICY REMARK

The study concluded that encroachment in Old Oyo National Park is noticeable, but the occurrence is not spontaneous. Immediate management intervention is crucial to mitigate encroachment in the hotspot areas and support conservation efforts. Effective and immediate management interventions are essential to curb further encroachment, especially within identified hotspot areas. These interventions must have to do with enhancing monitoring and enforcement in high-risk areas, prioritizing conservation programs in vulnerable ranges, and strengthening the involvement of local communities in sustainable land use practices to curb encroachment activities. By adopting these policy measures, park authorities and stakeholders can promote long-term ecological sustainability, preserve biodiversity, and mitigate the adverse impacts of human encroachment within Old Oyo National Park.

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APPENDICES

Appendix 1: Change Detection across the ranges from year 2017 and 2023

SN	Change detection	Area (m^2)
Marguba Range		
1	vegetation –vegetation	464902121.5
2	vegetation -rangeland	21512703.07
3	rangeland –vegetation	18695929.76
4	rangeland -rangeland	8374727.348
5	vegetation -cropland	5594.160792
6	waterbodies -waterbodies	4432.629868
7	waterbodies -rangeland	3276.324002
8	waterbodies –vegetation	1225.649692
9	vegetation -waterbodies	389.937187
10	rangeland -waterbodies	47.78795
Sepeteri Range		
1	vegetation –vegetation	433706084.1
2	vegetation -rangeland	17230161.32
3	vegetation -cropland	15758.53533
4	rangeland –vegetation	818579.1558
5	rangeland -rangeland	2099860.584
6	rangeland -cropland	5972.186885
7	cropland –vegetation	3227.56336
8	cropland -rangeland	949.72414
9	cropland -cropland	8523.51099
10	Built-up -rangeland	319.88706
Tessi Range		
1	vegetation –vegetation	351242282.7
2	vegetation -rangeland	1309769.563
3	vegetation -cropland	28268.05649
4	rangeland –vegetation	2323612.546
5	rangeland -rangeland	3577412.895
6	rangeland -cropland	223744.6478
7	cropland –vegetation	877.982243
8	cropland -cropland	3106.782601
Yemoso Range		
1	vegetation –vegetation	547231927.5
2	rangeland –vegetation	27112284.33
3	vegetation -rangeland	8210197.512
4	rangeland -rangeland	8053426.868
5	waterbodies -waterbodies	4720477.444

6	water bodies –vegetation	106210.1187
7	rangeland -cropland	63621.61786
8	vegetation -waterbodies	37367.2775
9	cropland -rangeland	33517.13781
10	cropland -cropland	21588.99134
11	vegetation -crop land	15489.42563
12	waterbodies -rangeland	5639.917198
13	cropland –vegetation	4521.630492
14	Built-up -rangeland	1396.265539
15	waterbodies -cropland	516.430396
16	rangeland -waterbodies	148.01063
17	Built-up –vegetation	52.648614
	Oyo Ile Range	
1	vegetation –vegetation	319415247.4
2	vegetation -rangeland	11833507.62
3	vegetation -cropland	258850.7492
4	vegetation -built-up	42515.02729
5	rangeland –vegetation	2279703.79
6	rangeland -rangeland	7611357.823
7	rangeland -cropland	583250.0093
8	rangeland -built-up	117832.4488
9	cropland -rangeland	10155.38069
10	cropland -cropland	20616.13996
11	built-up –vegetation	546.93632
12	built-up -rangeland	18.68968
	Tede Range	
1	vegetation –vegetation	381836481.4
2	waterbodies -waterbodies	9136422.4
3	vegetation -rangeland	3475686.437
4	rangeland -rangeland	1359003.101
5	rangeland –vegetation	1257330.005
6	vegetation -waterbodies	126250.411
7	waterbodies –vegetation	114571.7017
8	rangeland -cropland	2555.906577
9	rangeland -waterbodies	2370.220033
10	vegetation -cropland	1863.661621
11	waterbodies -rangeland	573.931827

Source: Authors' work, (2024).