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Assessing the Influence of Local Perception and Land Use Land Cover Dynamics on Vegetation Change in Katsina State, Nigeria

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Abstract

Vegetation degradation and land use land cover (LULC) change are major environmental challenges in the semi-arid regions of northern Nigeria, where increasing human pressure and climate variability threaten ecosystem stability and livelihoods. Katsina State, located within the Sudano–Sahelian zone, has experienced rapid changes in land use patterns over recent decades, making it a critical area for assessing vegetation dynamics and land degradation processes. The objective of this study was to evaluate the spatio-temporal dynamics of LULC and to examine how land use practices and human influences affect vegetation change in Katsina State, Nigeria, with particular attention to implications for land degradation and desertification. Multi-temporal Landsat (MSS, TM, ETM+, OLI) and Sentinel-2A imagery from 1989, 1999, 2009, and 2019 were analyzed using supervised classification and accuracy assessment based on the Kappa coefficient. Land Change Modeler (LCM) within IDRISI Selva was applied to assess LULC transitions, quantify gains and losses, and simulate future land use patterns using Markov Chain analysis, logistic regression, and multi-layer perceptron neural networks. Human drivers of change were assessed through a Human Influence Index (HII) integrating population density, infrastructure, and proximity variables. Field observations, household questionnaires (n = 400), and key informant interviews complemented the geospatial analysis. Results show a persistent decline in vegetation cover from 1989 to 2019, largely due to the expansion of farmland and built-up areas, while water bodies, bareland, and rock outcrops exhibited minor fluctuations. Vegetation loss intensified after 1999, particularly in areas of high population density and accessibility, and was more severe in northern Katsina. Future projections to 2050 indicate continued expansion of agriculture and settlements at the expense of natural vegetation, increasing vulnerability to land degradation and desertification. This study recommends strengthened land-use planning, promotion of sustainable agricultural practices, protection and restoration of natural vegetation, and continuous geospatial monitoring to support sustainable land management in Katsina State.

Keywords: land use/land cover change; vegetation dynamics; desertification; human influence index; Katsina State, Nigeria

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Introduction

Vegetation plays a crucial role in maintaining the balance and functioning of Earth's ecosystems, providing a wide range of ecological, social, and economic benefits (Dimoudi and Nikolopoulou 2003; Wyatt *et* *al*. 2011; de Lucena *et al*. 2012; Usman *et al*. 2016). However, the global vegetation landscape has undergone significant transformations over the past millennia due to various factors, including climate change, land use practices, and habitat loss (Mottl *et al*. 2021; Li *et al*. 2022). These changes have far-reaching consequences, yet the extent and patterns of vegetation change at a global scale remain inadequately understood (Chapin 2003; Mottl *et al*. 2021).

Land use land cover (LULC) change, encompassing the conversion of natural landscapes into built environments with diverse features such as agriculture, industrial areas, and residential settlements, has been recognized as a significant driver of environmental impacts at local, regional, and global scales (Kilic *et al.* 2006; Abbas *et al.* 2010; Yaro and Abdulrashid 2017; Felipe *et al*. 2021). Alterations in LULC are intricately linked to shifts in global environmental conditions, giving rise to changes in vegetation cover across different land uses (Song *et al.* 2018). Nigeria, in particular, has witnessed substantial vegetation loss due to LULC, human activities, and the impact of climate change. The country experiences an alarming annual loss of approximately 350,000 to 400,000 hectares of vegetation (Oyebo 2006; Akpu *et al.* 2017; Ojeh *et al.* 2022). Forests, in particular, have been significantly affecsted, with a staggering 21% loss between 1990 and 2005 (Aju *et al.* 2015). This has led to the expansion of cropland at an average rate of 554,657 hectares per year, while forested areas are diminishing at a rate of 105,865 hectares per year (Ogar *et al.* 2016).

The causes of vegetation loss in Nigeria are diverse, including deforestation driven by infrastructural development, fuel wood extraction, mineral exploration, and expansion of settlements (Akpu et al. 2017; Akpu *et al*. 2017). These activities have pushed many tree species to the brink of extinction, threatening the overall biodiversity and ecological integrity of the country (Soule *et al.* 2016). Unfortunately, the majority of LULC studies in Nigeria have focused on tropical deforestation, with limited attention given to areas beyond the tropical forests ((Mengistu Bahir *et al.* 2007; *Olokeogun et al.* 2014; Elijah *et al.* 2019; Olorunfemi *et al*. 2020; Njoku and Tenenbaum 2022).

Katsina State, situated in the Sahelian part of Nigeria, faces its unique set of challenges in terms of vegetation dynamics (Abaje et al. 2014; Mmaduabuchi et al. 2020). This region experiences significant rainfall variability and a rapid increase in population, exerting considerable pressure on the natural vegetation cover (Mmaduabuchi et al. 2020; Ibrahim and Abdullahi 2022). Understanding the factors influencing land use and vegetation change in Katsina State is crucial for effective environmental planning, policy-making, and conservation efforts. To address this gap, this study assessed the influence of local perceptions and land use/land cover (LULC) dynamics on vegetation change in Katsina State, Nigeria. Using remote sensing and Geographic Information System (GIS) techniques, this research mapped and detected spatio-temporal changes in LULC patterns while monitoring vegetation dynamics and conducting attribution analyses. Thus, by examining the interactions between human activities, local knowledge, and landscape change, this study provides critical insights into the processes driving vegetation degradation. The findings provide important evidence to support policymakers, geographers, environmentalists, and other stakeholders in promoting sustainable land-use practices, conserving vegetation cover, and strengthening environmental management for the benefit of both present and future generations.

Materials and Methods

The study area

The study area, Katsina state, is situated in the Northwestern region of Nigeria. It spans a geographical range between latitude 110 07' 49" and 130 22' 57" North of the equator and longitude 60 52' 03" and 90 09' 02" East of the Greenwich meridian. With a population of 5,801,587 people and covering a land area of 23,938 square kilometers. The state encompasses three distinct agroecological zones, namely the Sahel, Sudan, and the Northern Guinea Savanna, characterized by their unique environmental and ecological features. The soils prevalent in the area are predominantly Savanna and wet soils, creating diverse conditions for agricultural activities.

Katsina state experiences a tropical wet and dry climate, classified as AW and BS types, with semi-arid steppe characteristics. Annual rainfall ranges from 350mm to 1000mm, and temperatures fluctuate between 29^{0}C to 31^{0}C. The rainfall pattern exhibits high inter-annual variability, resulting in frequent and severe droughts that impact the region. The rainy season extends from April to October, accompanied by prevailing winds from the Southwest, while the dry season prevails from November to March, with Saharan winds dominating the area.

The climatic conditions in Katsina state give rise to four distinct seasons. The period between February and May is characterized by hot and dry weather. The rainy season, known as Damina, occurs from June to October and accounts for over 90% of the annual rainfall. The Cool Dry Season, referred to as Kaka, takes place between October and November, with less than 8% of the annual rainfall, and is marked as the harvest season. From November to February, the region experiences a dry season, devoid of rainfall but accompanied by the deposition of harmattan dust, enriching the soil with nutrients. This period is characterized by a significant level of dust circulation during the day and a cool breeze at night. The study area exhibits diverse soil textures, which impact agricultural practices and land use. Additionally, various major crops are cultivated in Katsina state, showcasing the agricultural significance of the State.

Reconnaissance survey

This was the first activity conducted for this research and served to familiarize the researcher with the study area. During the reconnaissance survey, systematic observations were made on the condition and spatial distribution of vegetation in order to assess vegetation changes driven by climatic factors and land use/land cover (LULC) dynamics. The field visit also enabled the identification of locations experiencing significant vegetation degradation and the selection of key informants with detailed knowledge of the area. These informants included individuals whose livelihoods depend directly on vegetation resources, such as farmers, charcoal sellers, and livestock producers.

Types and Sources of Data

This study utilized multi-temporal satellite data, including Landsat Multispectral Scanner (MSS), Thematic Mapper (TM), Enhanced Thematic Mapper Plus (ETM+), Operational Land Imager (OLI), and Sentinel-2A imagery (2019) (Table 1). These datasets were obtained from the Global Land Cover Facility of the University of Maryland. Population data were sourced from the National Bureau of Statistics (NBS), Nigeria, to examine the relationship between population growth, and human activities such as wood extraction, infrastructure development, agricultural intensity and vegetation change.

$$Overall\ Accuracy = \frac{\text{Sum of diagonal tallied (correctly identified)}}{\text{total number of samples}} * 100$$

$$User's\ Accuracy = \frac{\text{Samples correctly identified in the row}}{\text{row total}} * 100$$

$$Producer's\ Accuracy = \frac{\text{Samples correctly identified in the column}}{\text{Column total}} * 100$$

$$Kappa\ Coefficient\ (k) = \frac{\text{Observed accuracy } (p_o) - \text{Expected Accuracy } (p_e)}{1 - \text{Expected Accuracy } (p_e)} * 100$$

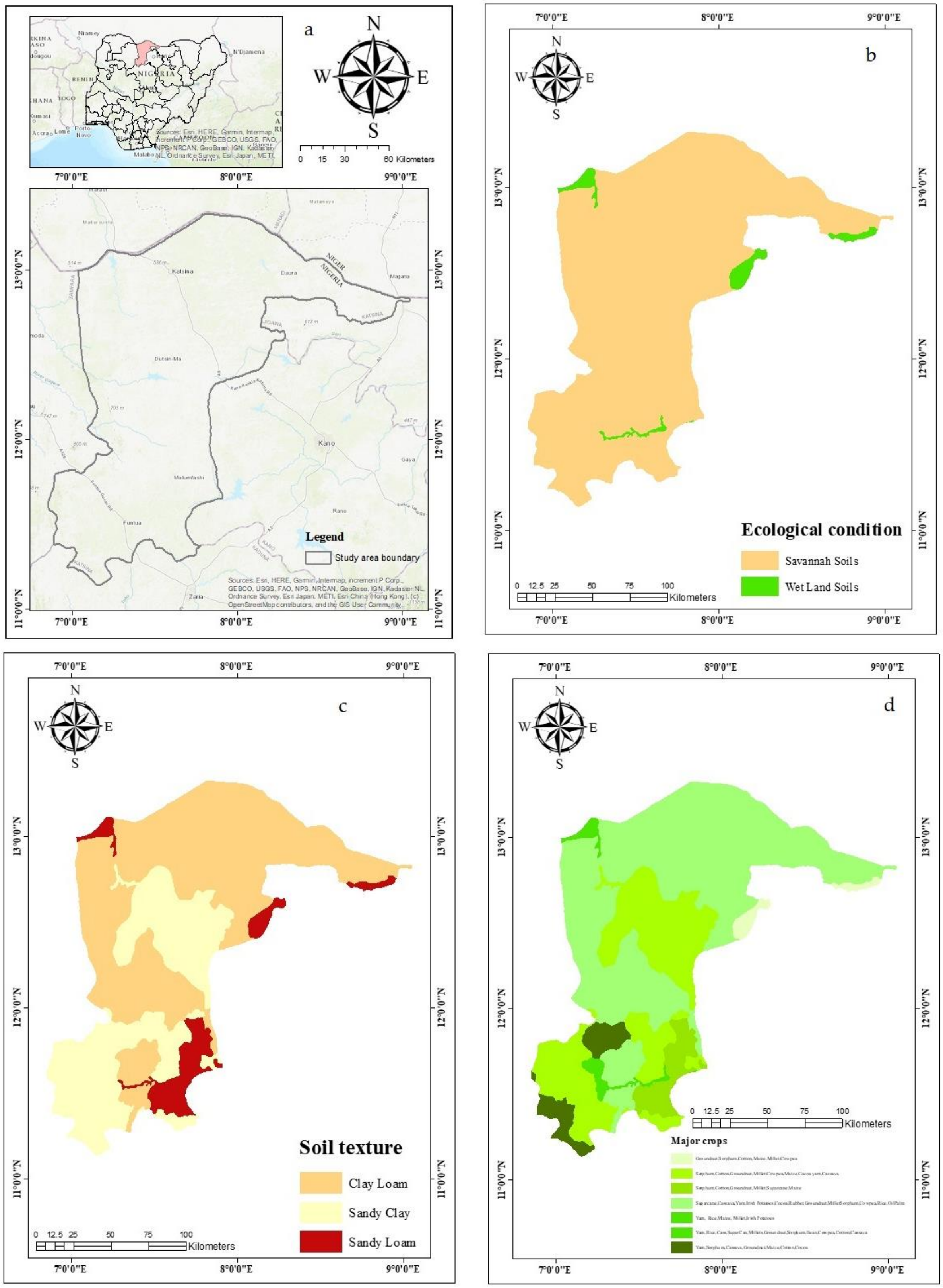

Fig. 1 (a) map of the study area, (b) ecological condition map, (c) soil texture, and (d) crop grown in the study area

Table 1 Satellite images with their acquisition dates, resolution, and cloud cover

Satellite ID	Sensor ID	Path/Row	Image Acquisition Date	Spatial Resolution	Cloud Cover
Landsat 4	MSS	188/51	1989-12-13	30m	9.00
Landsat 4	TM	189/51	1989-03-17	30m	5.20
Landsat 4	TM	189/52	1989-03-23	30m	0.00
Landsat 5	TM	188/51	1999-02-13	30m	4.23
Landsat 5	TM	189/51	1999-03-27	30m	3.20
Landsat 5	TM	189/52	1999-02-18	30m	0.00
Landsat 7	ETM	188/51	2009-11-17	30m	5.20
Landsat 7	ETM	189/51	2009-11-23	30m	10.0
Landsat 7	ETM	189/52	2009-11-02	30m	9.30
Landsat 8	OLI/TIRS	188/51	2019-11-12	30m	0.00
Landsat 8	OLI/TIRS	189/51	2019-11-18	30m	0.00
Landsat 8	OLI/TIRS	189/52	2019-11-29	30m	0.00

As a general guideline, kappas between 0.61-0.80 are generally considered substantial, while those over 0.81 are nearly perfect, although these divisions are obviously arbitrary (Palmieri *et al.* 2020).

An analysis of land cover changes, evaluation of land cover transitions, and simulations of future land changes were conducted in this study using LCM. It is a cutting-edge land planning and decision-making software tool used for conservation prioritisation and planning (Sahalu 2014). The software is included in IDRISI Selva Remote Sensing and GIS software. Therefore, to analyze and predict future changes in land cover, land cover maps classified from different dates are required in this study. This study uses three stages of land use change modeling:

Analyzing land use and land cover maps from 1989, 1999, 2009, and 2019 was done using image classifications.

i. Decadal changes (short-term changes) will be determined, i.e. (1989, 1999, 2009, and 2019).

ii. Changes between 1989 and 2019 are determined, which refers to long-term changes.

All the steps above were analyzed based on the principle of land change analysis, maps of gains and losses, contributions to net change, transitions of land cover classes between different categories, and spatial trend analysis both in the map and graphical form.

To run the actual modeling, future land use modeling with LCM was performed using potential transition maps of acceptable accuracy. This study explores the potential power of explanatory variables by transitioning from a group model to a set of sub-models. The lists of all transitions between the two lands cover maps (1985) and (2019). The transitions specify which factors must be taken into account in order to generate the transition potential (Nuissl et al. 2009). This study examined all of the land cover classes between 1989 and 2019, and then identified transitions between the various land cover classes over the time period. These selected transitions in LCM were modeled using Logistic Regression and Multi-layer Perceptrons. The multilayer perceptron neural network is capable of running multiple transitions at the same time. After modeling transition potentials, maps of transition potentials were generated. As a result, future land use changes can be predicted using the potential maps.

We used Markov Chain analysis to determine how much land cover changed between 1989 and 2019. We calculate the amount of land that will transition between 2009 and 2019 using future transition potentials. In the

Change Allocation panel, it has been possible to generate a vulnerability change map using soft prediction (Sahalu 2014). A map of the land cover of the study area for 2019 was simulated for comparison. This was done in order to compare it with the actual map of land cover for the same year. This was done by running a 3-way cross-tabulation between the later land cover map (a map of 2019), the prediction map (simulated map of 2019), and a map of reality (actual map for 2019). See figure 2 for the methodology flow chart.

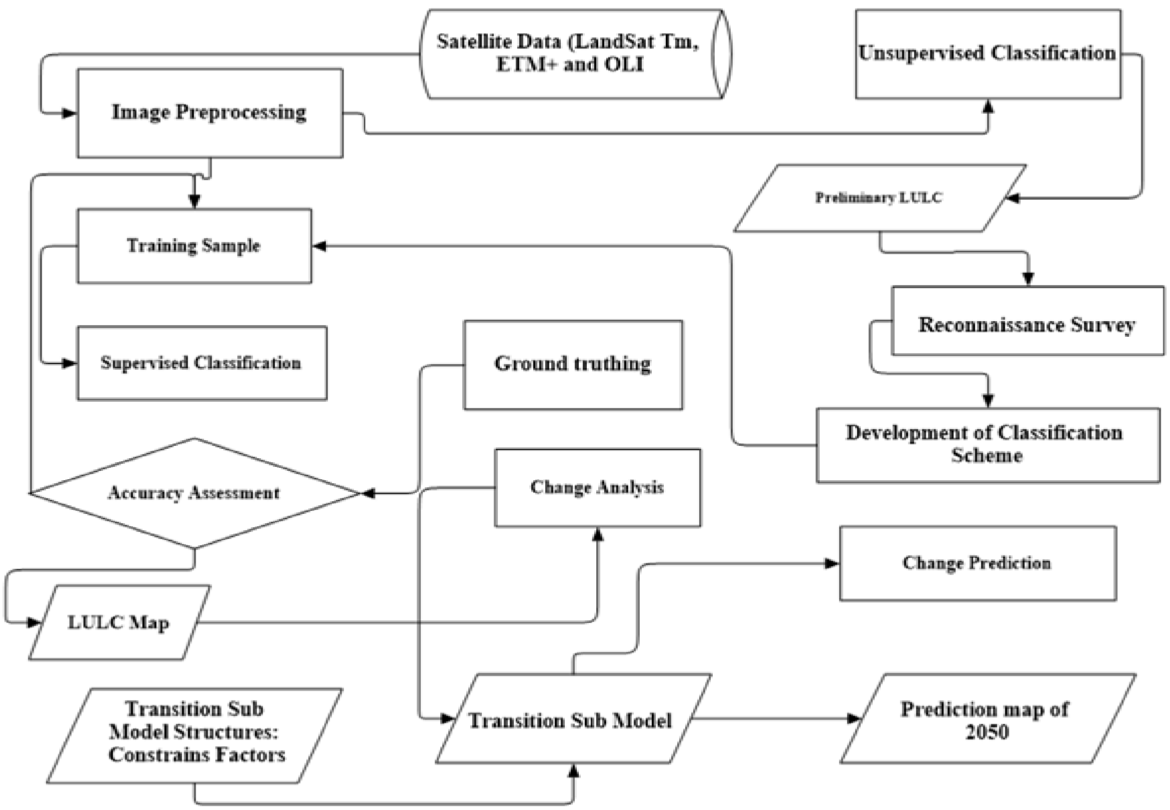

Fig. 2 Diagrammatic presentation of the methodology

Human Influence Index (HII) was determined using Land Use, buildings, urban polygon, road networks, population density, and protected areas variables etc. Variables were projected into the same projection, same processing extent, and same cell size for consistency of the analysis. Population density is scaled continuously from 0 to 10 within each cell. Land cover types in every cell are used to value buildings, urban polygons, and protected areas. Roads, rivers, and streams are scored according to direct and indirect effects; 500 m on either side of a road is given a score of 8, with a score of 4 exponentially decaying from 500 m away from the road out to 15 km. Rivers and streams are assigned a pressure score of 4, exponentially decaying to 15 km. HII values range from 0–50 for each cell. A raster calculator from Arcmap 10.8 was used to add all the variables and produce an HII map of the katsina state.

Sample size

According to the National Population Commission (2006) census, the study area's population is 1,081,703. People's views on the driving forces behind vegetation change were captured using a Key Informant Interview (KII) and semi-structured questionnaire. People's experience is necessary because the area in the extreme north is more prone to drought, land degradation, and desertification. The projection of the population is based on the population growth rate of 2.0% (Federal Republic of Nigeria 2009) using the formula:

$$P_{t+n} = P_t e^{rn}$$

Where:

Pt + n = future population (2019)
Pt = base year population (2006); r = growth rate (3%); n = interval between future population and base year population (2019 – 2006) = 13years and e = exponential

$$P_{t+n} = P_t e^{0.03*13}$$
$$P_{t+n} = P_t e^{0.39}$$
$$P_{t+n} = 1{,}081{,}703 e^{0.39}$$
$$P_{t+n} = 1{,}597{,}655$$

Based on the projected population of the study area 2019 (1,597,654) Yamane (Yamane 1967) formular for sample size determination was used to get the number of respondents for questionnaire administration:

$$\boldsymbol{n = \frac{N}{1 + Ne^2}}$$

The formula was simplified and adjusted to be more accurate than Cochran's sample size formula

$$\boldsymbol{\frac{\frac{Z^2(p)(1-p)}{e^2}}{\frac{1 + Z^2(p)(1-p)}{Ne^2}}}$$

Where n = Number of samples
N = number of populations under study
e = error tolerance (level) or margin error at a proportion of population given as 0.05%

399.998, rounded up to 400 respondents, were selected for the questionnaire administration. The questionnaire was randomly administered to the selected household in the study area. However, the sample size for each ward varied with its population size through the use of:

$$\boldsymbol{\frac{nQ}{N}}$$

Where: N= total population of the study area; Q= total sample size and n= population of LGA.

Sampling technique

The cross-sectional study was carried out in six (6) LGAs selected from the entire state through purposive sampling. The selected LGAs are located at the extreme north in consideration of the three vegetation zones within the study area. The sample locations are Baure, Jibia, Kaita, Mai Adua, Mashi and Zango LGAs. Random and systematic sampling techniques were used to administer questionnaires on household heads per housing unit which comprises farmers and non-farmers (aged 40 and above) who lived in the area and or have cultivated land in the study area for at least 10 years or more, the first house was picked randomly from the selected areas to determine the starting point of questionnaire administration, and others are then picked at regular intervals predetermined by the research team. Four hundred (400) questionnaires were distributed to the sampled rural dwellers in the study area, and four hundred questionnaires (400) were dully completed and returned. Based on the objective, a scheduled interview was prepared to collect relevant information from the respondents. An interview schedule was used to conduct personal interviews with the respondents. Information about historical environmental changes was obtained through interviews with elderly people (heads of the village) in the study area. Table 2 presents the sampling size of the selected LGAs.

Table 2 Sample size by the population of the selected LGAs in Katsina State

S/N	LGAs	Population of the selected LGAs (2006)	Projected population (2019)	Sample size of selected LGAs
1	Jibia	167,435	247,298	62
2	Kaita	182,405	269,409	67
3	Mashi	171,070	252,667	63
4	Mai Adua	201,800	298,055	75
5	Zango	156,052	230,486	58
6	Baure	202,941	299,740	75
	Total	1,081,703	1,597,655	400

Key Informant Interview (KII)

Information about historical changes on the driving forces behind vegetation was obtained through interviews held with people that have first-hand knowledge about the community vegetation and climate change, elderly people (heads of village and community leaders) and agency representatives, community residents, and local business owners were chosen with the help of traditional rulers (Silva and McDill 2004).

KII discussion was held with twelve key informants and two informants from each local government area using an open-ended interview schedule to respond to key informants of the study (see Appendix II). The key informants were identified during questionnaire administration. However, the researcher and research assistants were assisted by the villagers in translation and description during interviews with the key informants. The Key Informant Interviews was conducted at Baure, Jibia, Kaita, Mai Adua and Mashi LGAs. The responses of the interviewees were recorded, refined, and analyzed using descriptive statistics of frequency, percentages Principal Component Analysis (PCA) and regression analysis in the IBM SPSS Statistics 20 environment.

Results

Land Use Land Cover on Vegetation Dynamics

In order to evaluate vegetation change drivers, land use and land cover datasets were used over the course of the study period. The analysis of land use and land cover shows how vegetation cover changes over time in Katsina state. Due to human-induced conversion to other land uses, semi-natural vegetation has been converted into farmland in the study area. Results were verified during field research in October 2020 and March 2021.

Land Use Land Cover of Katsina State Estimated from Landsat Data

In this section, we broadly examine the changes in the LULC of Katsina state in four phases. The LULC changed from 1989, 1999 to 2009 and 2019. As a result of over-cultivation, deforestation, overgrazing, industrialization, and urbanization, vegetation, farmland, and other land use changed in Katsina state. One of the main focuses of carrying out this study is to prompt the investigation of land degradation leading to desertification. The supervised classification for 1989, 1999, 2009, and 2019 was carried out for the study area, using six land use classes: bare land, farmland, built-up area, vegetation, rock outcrop, and waterbody.

Table 3 Area and Percentages of Land Use Land Cover Change of Katsina State (1989 – 1999)

Land Use Land Cover Class	Period							
	1989		**1999**		**Area change (km^2)**	**% Cover change**	**Annual rate of change (km^2/year)**	**% Annual rate of change (%/year)**
	Area (km^2)	**%**	**Area (km^2)**	**%**				
Built-up area	16013.12	0.68	22564.95	0.95	6551.83	0.28	655.18	0.03
Vegetation	1873611.65	79.14	1690503.60	71.41	-183108.05	-7.73	-18310.81	-0.77
Water body	1497.42	0.06	1098.09	0.05	-399.33	-0.02	-39.93	0.00
Farmland	456650.62	19.29	638788.98	26.98	182138.36	7.69	18213.84	0.77
Bare land	11385.89	0.48	8576.83	0.36	-2809.06	-0.12	-280.91	-0.01
Rock outcrop	8173.25	0.35	5799.12	0.24	-2374.13	-0.10	-237.41	-0.01
Total	**2367331.95**	**100.00**	**2367331.57**	**100. 00**				

The Landsat data were used to evaluate variations in LULC patterns between 1989 and 2019 using the Maximum Likelihood Supervised Classification (MLSC) algorithm (Figures 3, 4, 5, and 6). In the study area, the period 1989–1999 exhibited relatively minor changes in LULC classes (Table 3). During this period, farmland expanded at an annual rate of 0.77%, while built-up areas increased at 0.03% per year (Table 3). In 1989, vegetation was the predominant land cover across the study area (Figure 3), interspersed with built-up areas and farmland concentrated in the southern and central regions. The higher proportion of farmland in southern LGAs such as Funtua, Dandume, Sabuwa, Bakori, and Danja is attributed to fertile soils and a predominantly farming population. Water bodies in the study area are seasonal, flowing primarily during the wet season. Seasonal rivers include Marigo, Damari, Maikategi, Magajin Dutse, and Kara. LULC analysis indicates that built-up areas are gradually encroaching on other land uses (Figure 3). Consequently, detecting and predicting LULC changes has become critical for a variety of applications, including vegetation modeling, rural and urban planning (Paul, 2021), identification of changing landscapes (Hussain et al., 2020), conservation planning, and the study of desertification dynamics and urban expansion at watershed and regional scales.

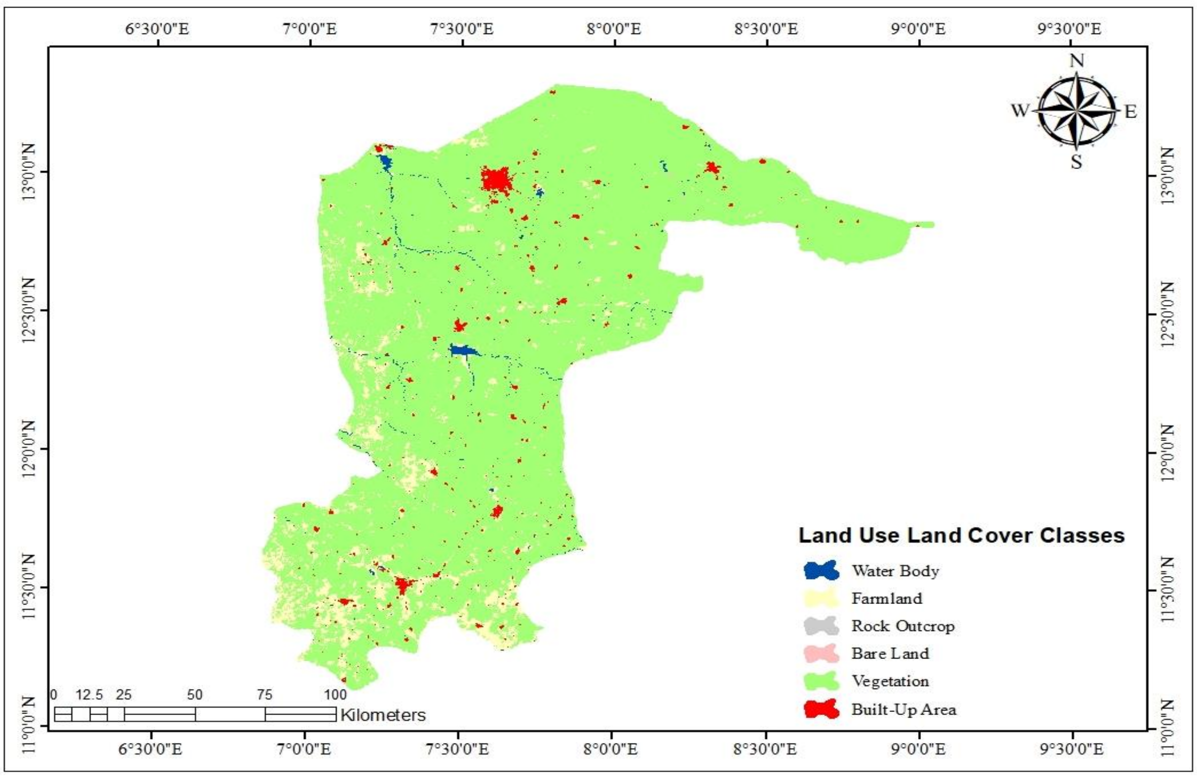

Fig. 3 Land Use Land Cover Map of Katsina for 1989

By 1999, built-up areas began to expand due to population growth, although the annual rate of change remained low at 0.03% per year. This expansion occurred largely at the expense of vegetation (Table 3, Figure 4). During the same period, forested areas began to decline as farmland expanded. Other LULC classes, including water bodies, bare land, and rock outcrops, also experienced reductions in spatial coverage (Table 3, Figure 4).

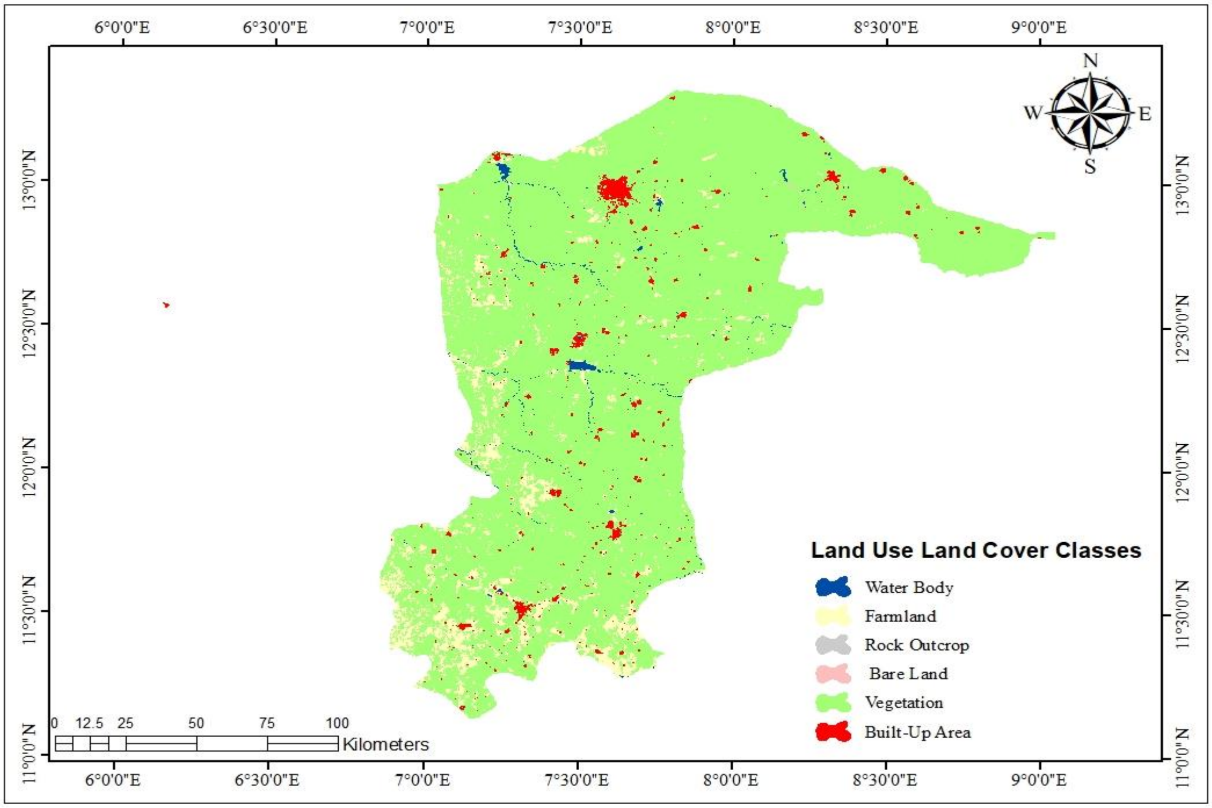

Fig. 4 Land Use Land Cover Map of Katsina for 1999

Table 4 Area and Percentages of Land Use Land Cover Change of Katsina State (1999 – 2009)

Land Use Land Cover Class	Period				Area Change (km^2)	% Cover Change	Annual Rate of Change (km^2/year)	% Annual Rate of Change (%/year)
	1999 Area (km^2)	%	2009 Area (km^2)	%				
Built-Up Area	22564.95	0.95	39295.04	1.66	16730.09	0.71	1673.01	0.07
Vegetation	1690503.60	71.41	1538099.21	64.97	-152404.39	-6.44	-15240.44	-0.64
Water Body	1098.09	0.05	1973.51	0.08	875.42	0.04	87.54	0.00
Farmland	638788.98	26.98	768800.18	32.48	130011.20	5.49	13001.12	0.55
Bare Land	8576.83	0.36	10183.47	0.43	1606.64	0.07	160.66	0.01
Rock Outcrop	5799.12	0.24	8980.88	0.38	3181.76	0.13	318.18	0.01
Total	**2367331.57**	**100.00**	**2367332.29**	**100.00**				

The percentage changes in land use classes between 1999 and 2009 were calculated (Table 4). Figure 5 and Table 4 indicate that the composition of LULC classes in the study area varied significantly over time. The data suggest that the decline in vegetation cover during this period was primarily driven by the expansion of both built-up areas and farmland. Consequently, the spatial extent of built-up areas and farmland increased noticeably between 1999 and 2009 (Table 4, Figure 5).

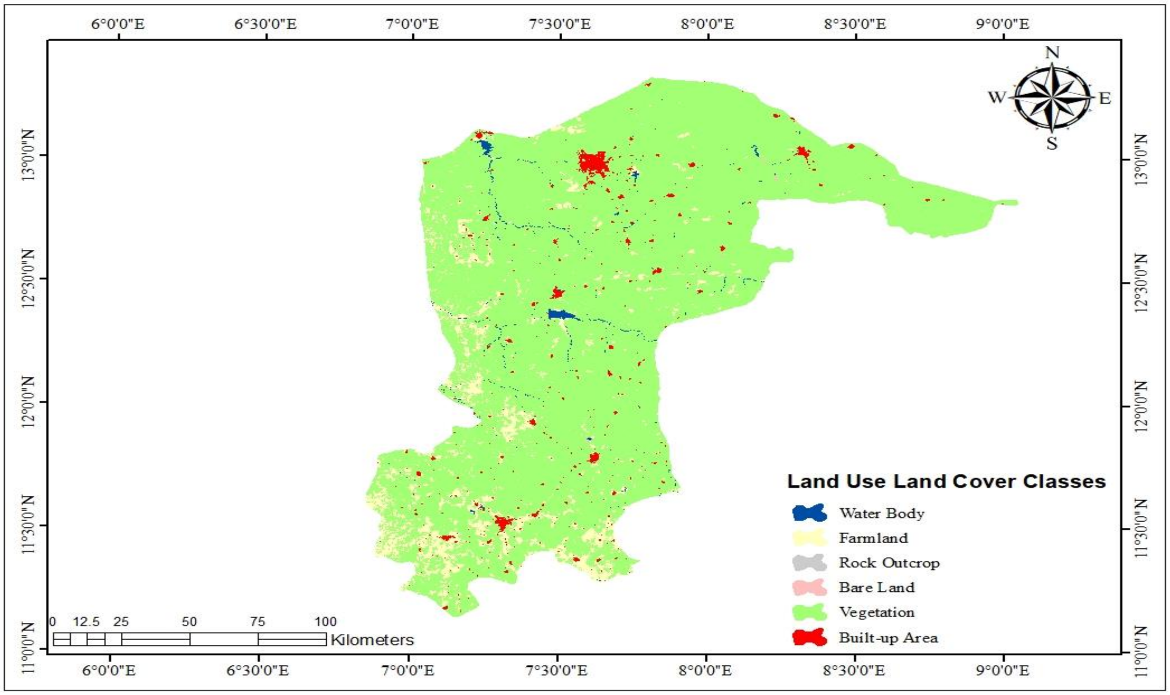

Fig. 5 Land Use Land Cover Map of Katsina for 2009

Table 5 Area and Percentages of Land Use Land Cover Change of Katsina State (2009 – 2019)

Land Use Land Cover Class	Period				Area Change (km^2)	% Cover Change	Annual Rate of Change (km^2/year)	% Annual Rate of Change (%/year)
	2009 Area (km^2)	%	2019 Area (km^2)	%				
Built-Up Area	39295.04	1.66	53098.77	2.24	13803.73	0.58	1380.37	0.06
Vegetation	1538099.21	64.97	1366899.37	57.74	-171199.84	-7.23	-17119.98	-0.72
Water Body	1973.51	0.08	1429.81	0.06	-543.70	-0.02	-54.37	0.00
Farmland	768800.18	32.48	928535.76	39.22	159735.58	6.75	15973.56	0.67
Bare Land	10183.47	0.43	9369.87	0.40	-813.60	-0.03	-81.36	0.00
Rock Outcrop	8980.88	0.38	7998.07	0.34	-982.81	-0.04	-98.28	0.00
Total	**2367332.29**	**100.00**	**2367331.65**	**100.00**				

Table 4 highlights the patterns and trends in LULC changes. By 2019, built-up areas had become dominant, not only in Katsina city but also in smaller, scattered settlements that expanded into adjacent local government areas such as Daura, Funtua, Dutsin-Ma, and Malumfashi. Figure 6 and Table 5 show that between 2009 and 2019, forested areas declined significantly. In the absence of adequate infrastructure and planning, LULC changes have accelerated. The observed trends indicate a gradual increase in built-up areas accompanied by a corresponding decline in vegetation over the study period. Farmland and built-up areas largely replaced natural vegetation, driven by unplanned population growth and migration (Khan et al., 2014). A key finding of this study is that urban expansion is influenced by both economic and geopolitical factors (Oyeleye, 2013). Predicting future LULC change, the transition assessment among different LULC is a critical aspect (Leta et al. 2021). Urbanization triggered the LULC change in the study region in the last few decades.

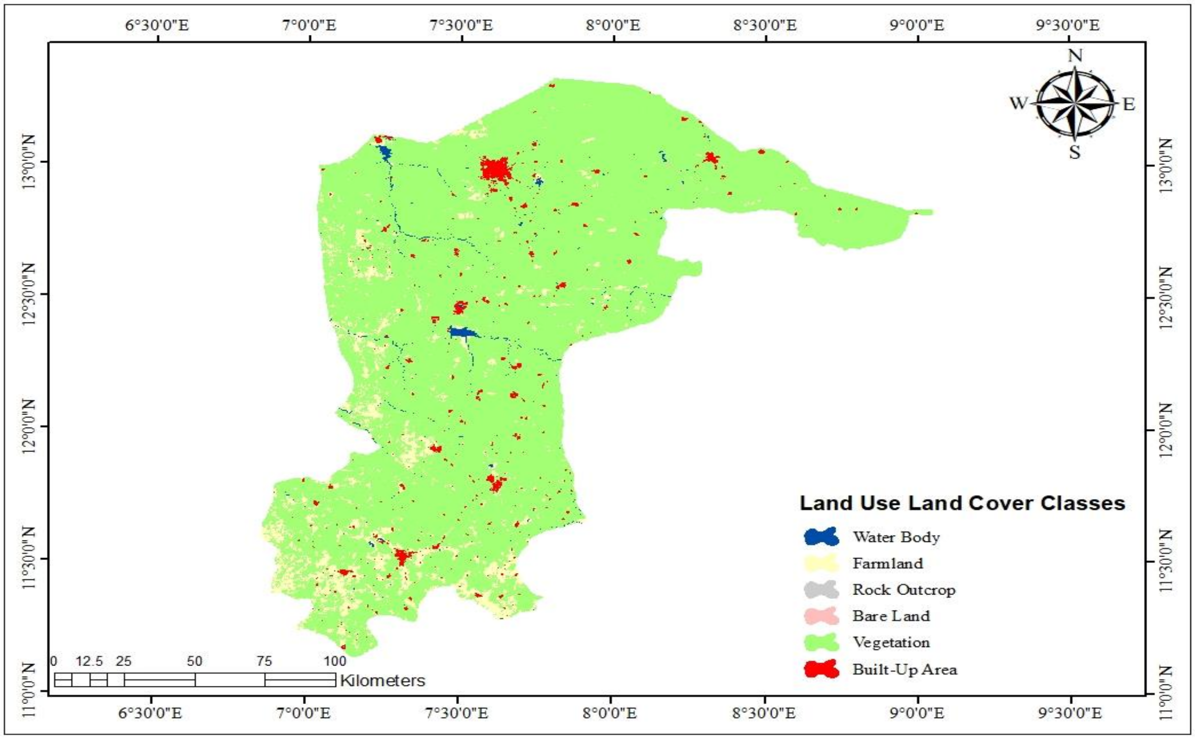

Fig. 6 Land Use Land Cover Map of Katsina for 2019

Table 6 Area and Percentage of Predicted LULCC of Katsina (2050)

Land Use Land Cover Type	Area (hectare)	Percentage (%)
Built-Up Area	1235808.70	5.17
Water Body	48214.30	0.20
Farmland	5063540.80	21.17
Rock Outcrop	100224.10	0.42
Bare Land	2049604.30	8.57
Vegetation	15420727.20	64.47
Total	**23918119.40**	**100.00**

Table 6 presents the predicted land use and land cover (LULC) changes in Katsina State for 2050. The projections indicate that built-up areas, water bodies, farmland, and bare land will expand at the expense of natural vegetation (Table 6, Figure 7). Continuous reduction of vegetation and its protective role in the landscape, driven by human activities, increases the region's vulnerability to desertification. These findings align with Garba and Al-Amin (2014) and Idris et al. (2019), who reported that deforestation and land degradation are driving the expansion of farmland and settlements, thereby accelerating desertification. The changes are influenced by both climatic and socio-economic factors, with southern Katsina exhibiting higher vegetation cover and more intensive agricultural activities compared to the drier northern regions (Figure 7). Proper monitoring and management of land use are essential to safeguard natural resources, maintain ecosystem stability, and support sustainable livelihoods. Effective land use monitoring can detect and mitigate land degradation, enabling informed planning and management of resources to benefit both humans and the environment.

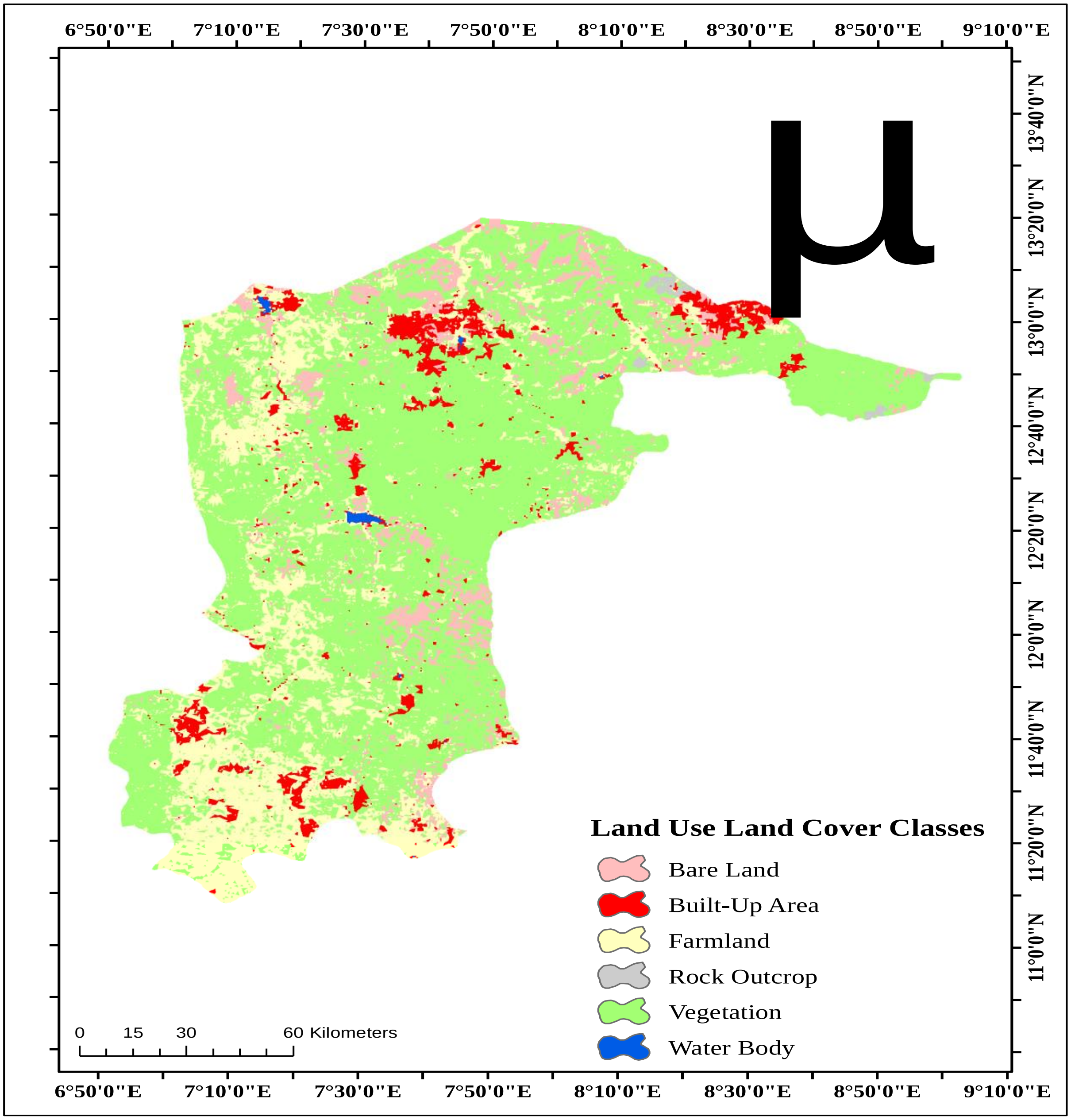

Fig. 7 Predicted LULC Map of Katsina State 2050

Figure 8 presents key environmental and anthropogenic factors influencing land use and land cover (LULC) dynamics in Katsina State. The elevation layer (Figure 8a) shows that the study area ranges from 379 m to 755 m above sea level, with higher elevations in the south and lower areas in the north, influencing vegetation distribution and land use suitability. The slope layer (Figure 8b) indicates terrain steepness, with gentle slopes favored for agriculture and settlement, while steeper areas are more prone to erosion and less intensively used. The aspect layer (Figure 8c) depicts slope orientations ranging from -1^0 to 359^0, affecting microclimatic conditions such as solar radiation and soil moisture, which in turn influence vegetation growth. Finally, the distance-from-protected-areas layer (Figure 8d) highlights the protective effect of conservation zones, showing that areas closer to protected sites experience lower human pressure, whereas more distant areas face higher anthropogenic disturbance. Together, these layers illustrate how topography and proximity to protected areas interact to shape LULC patterns, vegetation distribution, and susceptibility to degradation, providing critical input for land change modeling, sustainable land management, and conservation planning

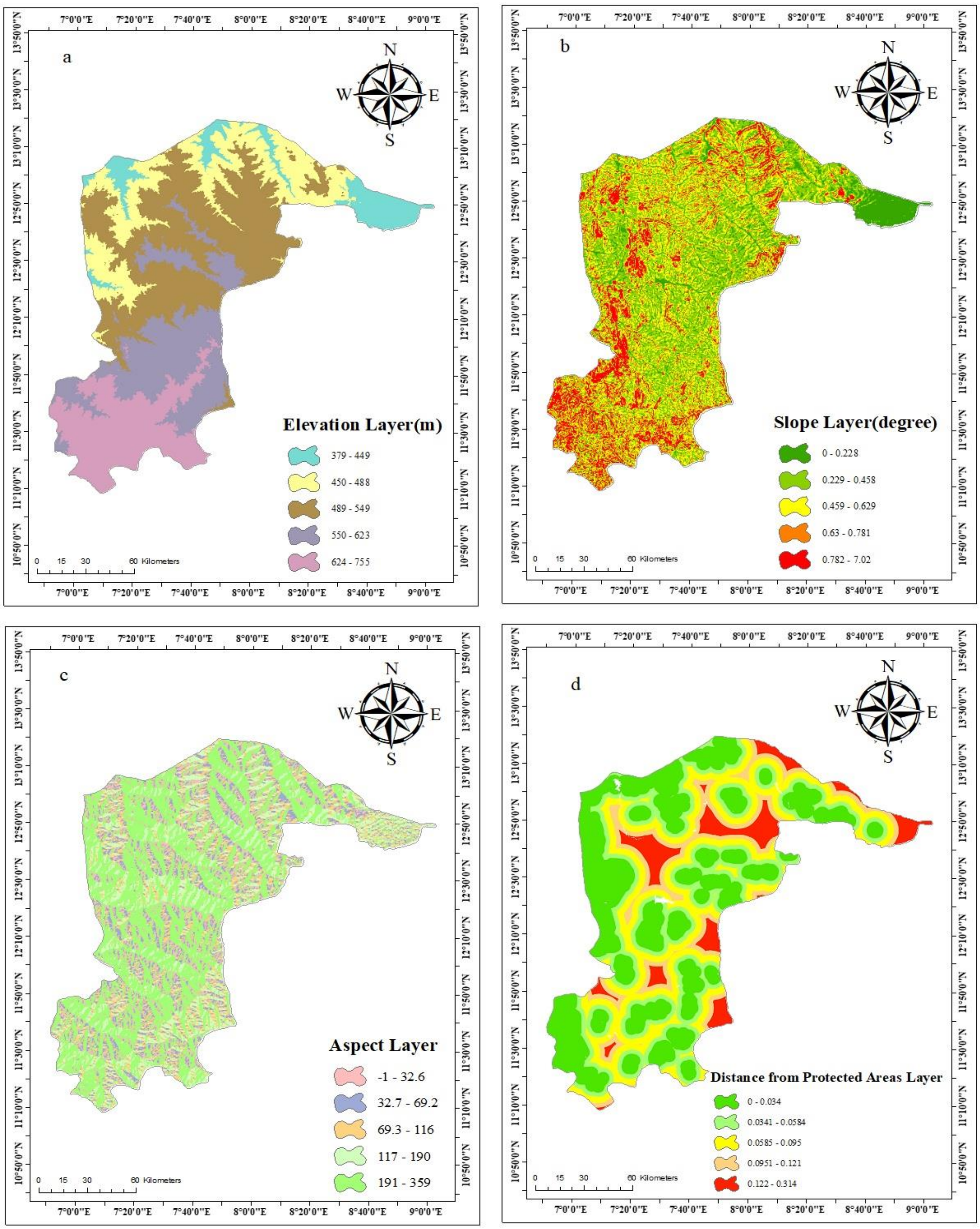

Fig. 8 Contributing factors to land use and land cover change a) elevation, b) slope layer, c) aspect layer, d) distance from protected

Figure 9 presents the spatial patterns of key proximity-based drivers used in modelling vegetation change and land use transitions in Katsina State. Figure 9a illustrates the distance from major and minor roads, showing dense networks of accessibility corridors where areas closest to roads (in green) dominate the central and southern parts of the state, indicating strong potential for human disturbance and land conversion. Figure 9b maps the distance from rivers, revealing clustered zones of high accessibility around major river channels, particularly in the central and northeastern regions, where proximity to water resources often encourages agricultural expansion and settlement activities. Figure 9c displays the distance from streams, showing a more dispersed pattern of hydrological influence across the landscape, with several stream-buffered zones in green and yellow that correspond to areas of intensive land use due to water availability. Figure 9d represents the distance from urban areas, highlighting concentrated zones of settlement influence around major towns, especially in the south-central and eastern regions, where urban expansion radiates outward. Collectively, these layers depict the spatial gradients of human and environmental influence incorporated into the Land Change Modeler (LCM), demonstrating how proximity to infrastructure, water bodies, and urban centres shapes land use decisions and contributes to vegetation loss and land degradation across the state.

Figure 10 illustrates key socio-environmental variables incorporated into the assessment of vegetation change and land degradation in Katsina State. Figure 10a shows the spatial distribution of population density, revealing clusters of high and very high population concentrations in the central and eastern urban corridors, where human pressure on land resources is most intense. Figure 10b depicts the distance from urban areas, highlighting zones of strong urban influence concentrated around major towns and radiating outward, which correspond to regions where land conversion and vegetation loss are more pronounced. Figure 10c presents the annual mean temperature pattern, showing an increasing northward temperature gradient, with the northern zones experiencing higher thermal stress that can exacerbate vegetation decline and reduce ecological resilience. Figure 10d displays the mean annual rainfall distribution, demonstrating a clear transition from higher rainfall in the southern parts of the state to markedly lower rainfall in the north, aligning with the broader Sudano–Sahelian climatic gradient. Together, these variables provide critical insights into how population pressure, urban expansion, temperature variability, and rainfall patterns interact to shape vegetation dynamics and drive land degradation processes across Katsina State.

Table 7 Perceived drivers of vegetation changes in Katsina using PCA

Component	**Perceived Driver**	**Rotation Sums of Squared Loadings**			
		Rotated Component Matrix	Eigenvalues	% of Variance	Cumulative %
1	Firewood Collection	0.831	5.703	28.516	28.516
2	Charcoal Production	0.762	3.709	18.545	47.061
3	Agricultural expansion	0.795	2.297	11.485	58.545
4	Climate Variability	0.851	1.849	9.247	67.793
5	Overcultivation	-0.845	1.412	7.059	74.851

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.

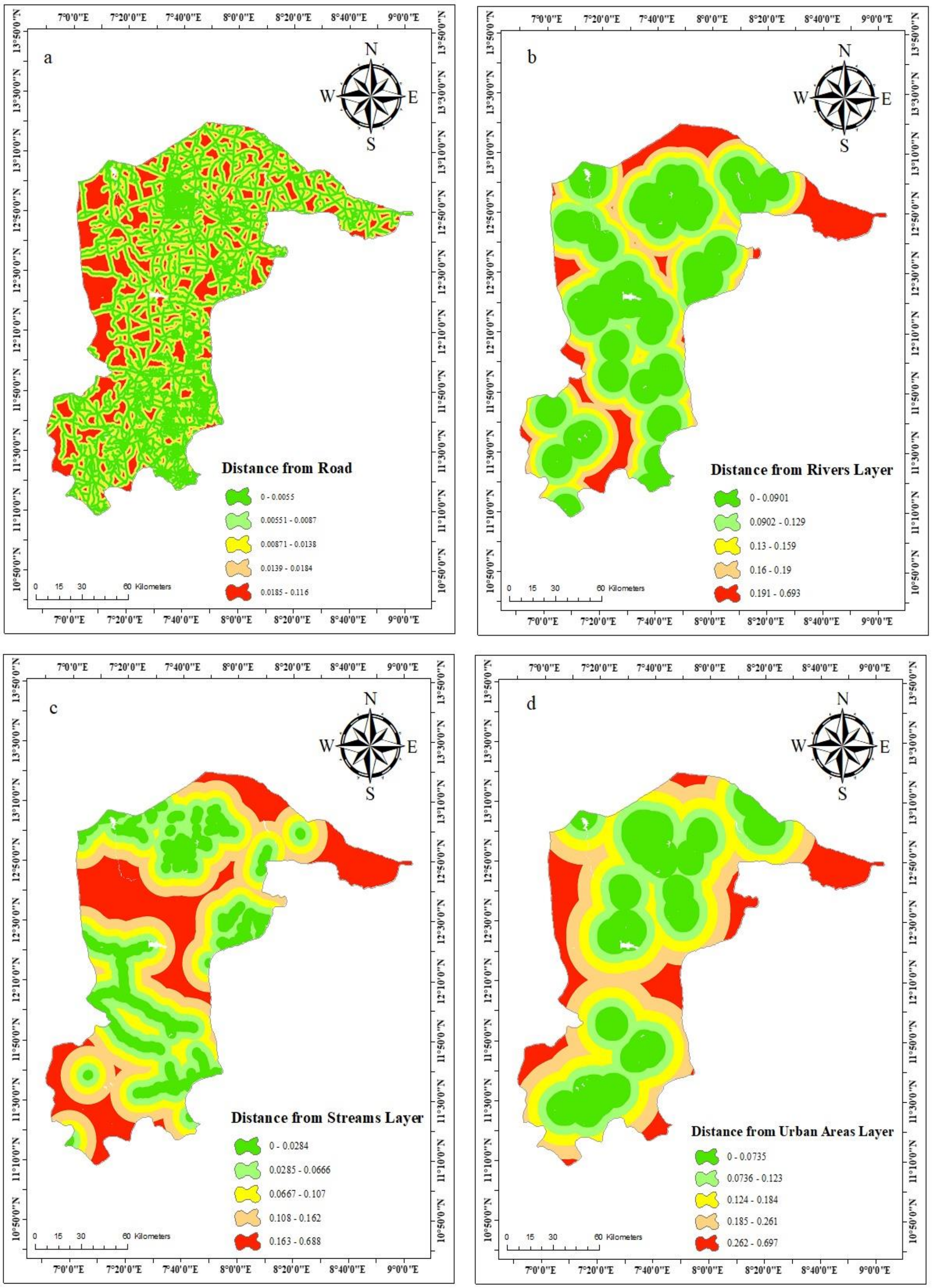

Fig. 9 Contributing factors to land use and land cover change and HII a) distance from road, b) distance from river, c) distance from stream and d) distance urban areas

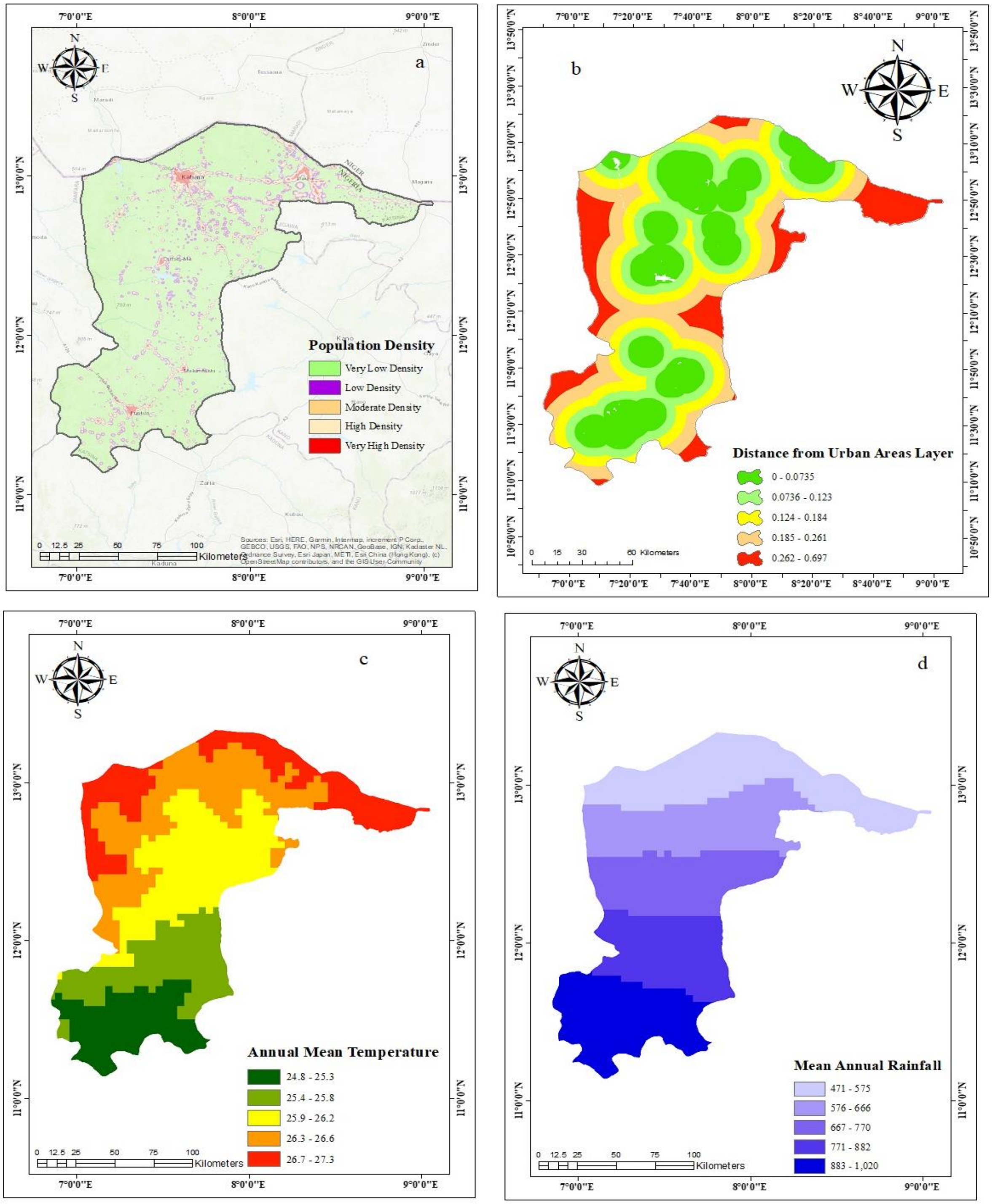

Fig. 10 Contributing factors to land use and land cover change and HII a) population density, b) distance from urban area, c) mean annual temperature, and d) mean annual rainfall

Discussion

Perceived Drivers of Vegetation Change

Table 7 shows the result obtained from Principal Components Analysis (PCA) of the drivers behind vegetation changes in Katsina state. Five components were identified from the PCA results accounting for a cumulative variance of 74.851% in original variables using a cut-off point value (Eigenvalues) of 1. The first PCA contributed 28.516% of the total variance, while the second, third, fourth, and fifth contributed 18.545%, 11.485%, 9.247%, and 7.059%, respectively. The five PCA components are named based on their loadings in relation to the original variables. This result implies that the new model variables to explain the driving forces behind vegetation change in Katsina are the five resulting components of the PCA, named to identify the groups of states with which they are most closely associated (firewood collection, charcoal production, agricultural expansion, climate variability, and over-cultivation).

Figure 11 presents the spatial distribution of the Human Influence Index (HII) across Katsina State, illustrating the varying intensity of human pressure on the landscape. Areas classified as having maximum human influence (shown in red) are concentrated around major towns, transportation corridors, and densely populated agricultural zones, particularly in the central, southern, and eastern parts of the state. These hotspots correspond to regions where land conversion, vegetation clearing, and resource extraction are most intense. Zones with moderate to high influence (orange and light orange) form transitional belts surrounding the high-impact clusters, indicating expanding human footprints driven by farming, grazing, and settlement growth. In contrast, areas of low or no human influence (light green and dark green) are predominantly located in the northern and northwestern fringes, where population density is lower and accessibility is limited. The spatial patterns depicted in this figure highlight the strong relationship between human proximity and environmental pressure, providing important insights into how anthropogenic activities drive vegetation degradation and increase susceptibility to land degradation and desertification across the state. The maximum influence of humans on vegetation in the study area covers an area of (436835.59 ha), considerable human influence (697665.45 ha), medium influence (686878.09 ha), small human influence (383662.48 ha) and no influence (168036.57 ha) (See appendix V).

Respondents identified five key factors as the major drivers of vegetation change in Katsina State during the study period (1989–2019). These include agricultural expansion, firewood collection, charcoal production, climate variability, and over-cultivation. Among these, firewood collection and charcoal production were perceived as the most dominant drivers (Table 7). Key informant interviews reinforced these findings, emphasizing firewood collection, charcoal production, over-cultivation, population growth, poverty, and agricultural expansion as the principal causes of vegetation decline in the study area. Overall, evidence from both the household surveys and key informant interviews indicates that local communities perceive firewood collection, charcoal production, agricultural expansion, climate variability, and over-cultivation as the critical drivers of vegetation change. High poverty levels, rapid population growth, weak enforcement of environmental regulations, and the rising cost of agricultural inputs were identified as factors that intensify these pressures.

Influence of Socioeconomic Variables on the Perceived Drivers of Vegetation Change

The socioeconomic variables influencing vegetation change are summarized in Appendix 1. Several socioeconomic characteristics were examined using a logistic regression model, including age, sex, education level, marital status, monthly income, livelihood source, number of dependents, and farming experience. The results show that education level had a negative and statistically significant effect ($p < 0.05$) on perceptions of firewood collection, climate variability, and over-cultivation as drivers of vegetation change in Katsina (Appendix 1).

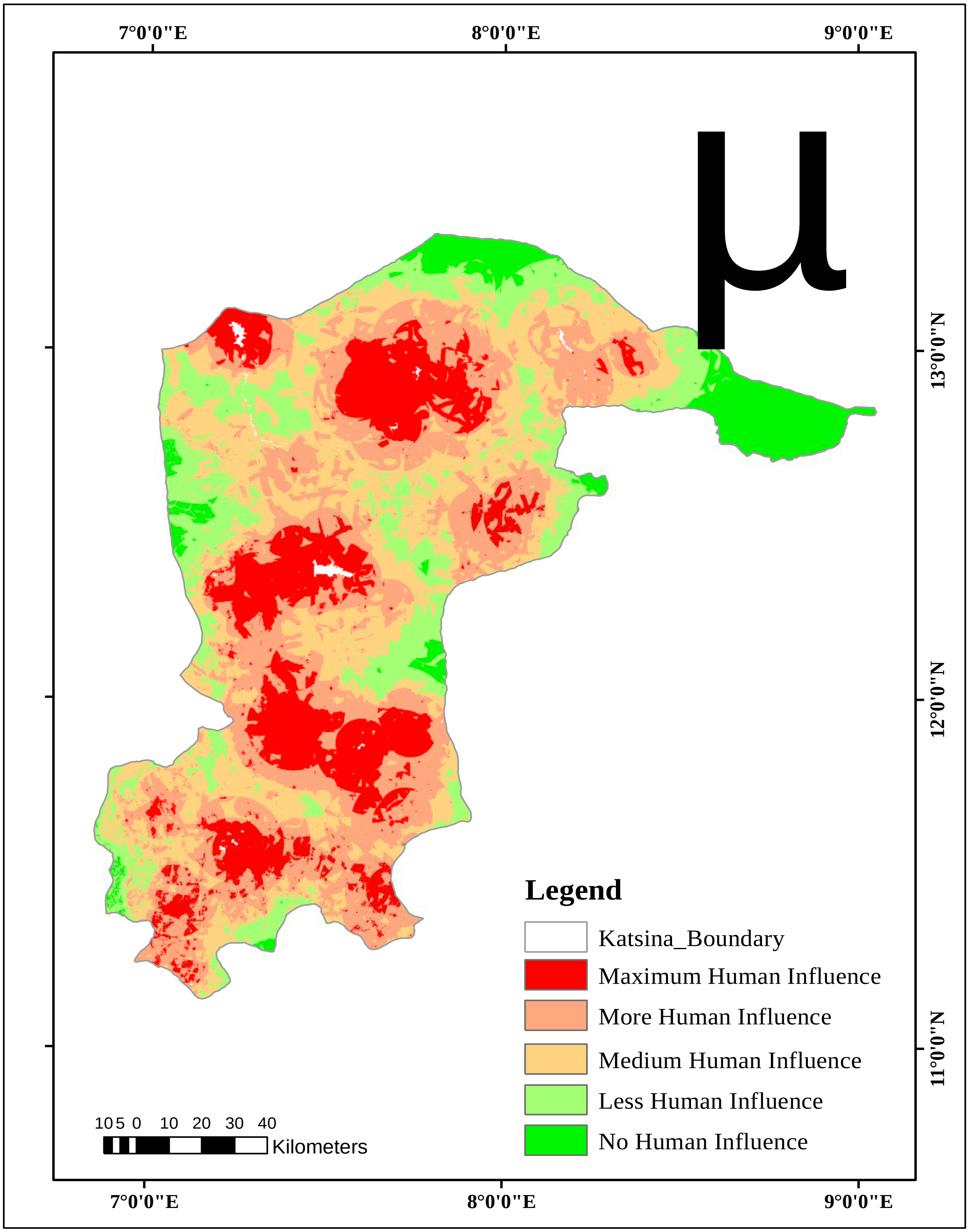

Fig. 11 Human influence index on vegetation

Charcoal production and agricultural expansion were not significantly influenced by any of the socioeconomic variables considered. Positive regression coefficients for age, farming experience, and marital status indicate that increases in these variables raise the likelihood of perceiving climate variability as a major driver of vegetation change. This implies that older, more experienced farmers and married respondents are more aware of or more affected by climate-related stressors, which increases their perception of climate variability as a cause of vegetation degradation. Conversely, negative regression coefficients for education level, livelihood source, and sex indicate an inverse relationship. Higher levels of education, for example, are associated with greater awareness of sustainable resource management practices; thus, educated individuals may be more inclined toward environmentally friendly agricultural and land-use practices.

Conclusion

This study aimed to evaluate the spatio-temporal dynamics of land use and land cover (LULC) and to assess how land use practices influence vegetation change in Katsina State, Nigeria. Using multi-temporal Landsat imagery, supervised classification, field validation, and future LULC prediction, the results revealed a consistent and substantial decline in natural vegetation from 1989 to 2019, largely driven by the expansion of farmland and built-up areas. Vegetation loss was most pronounced in areas experiencing rapid population growth, agricultural intensification, and unplanned urban expansion, while climatic factors such as rainfall and temperature further influenced the spatial distribution of vegetation. Future projections to 2050 indicate continued increases in farmland, settlements, and bare land at the expense of natural vegetation, heightening the risk of land degradation and desertification, especially in northern Katsina State. These findings highlight significant implications for ecosystem stability, food security, and sustainable livelihoods in this region. Consequently, this study recommends the integration of effective land-use planning policies, promotion of sustainable farming and afforestation practices, protection of ecologically sensitive areas, and the institutionalization of regular geospatial monitoring to guide sustainable land management and mitigate ongoing land degradation.

Declaration

Ethics approval and consent to participate

This study does not involve human or animal participation. It has no experiments and does not involve human data and/or tissue.

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