FUDMA Journal of Earth and Environmental Sciences (FUDJEES), Vol. 3, No. 1, 2026
Print ISSN: 1595-9686
EISSN: 1595-9708

LAND USE AND LANDCOVER DYNAMICS AS SUSTAINABLE LAND MANAGEMENT AND MITIGATION STRATEGY FOR ECO-HYDROLOGICAL STRESS ON JIKWATHLAR SPRING, BIU PLATEAU REGION, NORTHEASTERN NIGERIA

[1]Rejoice P. Mbaya, [2]Ikusemoran Mayomi, [3]Muhammad Ali Bukar
[1&3] Department of Geography, Kashim Ibrahim University, Maiduguri, Borno State, Nigeria
[2] Department of Geography, University of Maiduguri, Borno State, Nigeria

Corresponding Author:rpmbaya@yahoo.com

https://doi.org/10/3303/jees.2026.0301/021

ABSTRACT
This study investigates the spatio-temporal dynamics of land use and land cover (LULC) change in the Garkida–Taula catchment of the Biu Plateau region, Northeastern Nigeria, and its implications for the hydrological sustainability of the Jikwathlar Spring. Landsat imagery from 1982–2022 was processed in ArcGIS 10.8, using mosaicking, subsetting, and supervised classification to delineate four LULC categories: Bare Surface, Grasses/Farmland, Woodland, and Dense Vegetation. LULC change detection was conducted using matrix analysis and ANOVA to quantify spatial transitions, magnitudes, and annual rates of change. Results revealed significant spatio-temporal variability in the catchment. Bare surface and grass/Farmland areas consistently expanded between 1982 and 2022, increasing by approximately 8% and 15%, respectively, largely due to agricultural intensification, grazing, and fuelwood extraction. In contrast, Woodland and Dense Vegetation declined from 34% and 24% in 1982 to 24% and 11% in 2022, reflecting deforestation pressures and climatic stress. Periodic vegetation recovery was observed in 2002 and 2022, attributed to improved rainfall and reduced anthropogenic activities during the Boko Haram insurgency, which rendered large portions of the catchment inaccessible. Spatially, over 58% of the catchment experienced LULC transformation during the study period, while 41.9% remained significantly static. The Jikwathlar Spring and its surrounding grove persisted within this stable zone, maintaining ecological integrity despite broader landscape alterations. The study concludes that sustained vegetation degradation poses long-term risks to groundwater recharge and spring discharge within the catchment. Effective watershed management, reforestation, and land-use regulation are therefore essential to safeguard the hydrological resilience of Jikwathlar Spring and ensure ecosystem stability in the Biu Plateau region.

Keywords: Hydrological Implications, Jikwathlar Spring, Land use and Land cover, Watershed Management.

INTRODUCTION
Land use and land cover (LULC) changes have become a major driver of environmental transformation, particularly in ecologically fragile regions such as the Biu Plateau in Borno State, where springs serve as critical freshwater sources for rural livelihoods and ecosystems. LULC dynamics such as deforestation, agricultural expansion, and urban encroachment directly alter hydrological processes, including infiltration, evapotranspiration, runoff generation, and groundwater recharge, which are essential for sustaining spring discharge. The conversion of natural vegetation into built-up or agricultural land reduces infiltration capacity and increases surface runoff, thereby

diminishing groundwater recharge and affecting the stability of spring systems (Odoh et al., 2024; Kumari, 2023). Similarly, LULC-induced changes in watershed characteristics have been linked to reduced water yield and altered eco-hydrological balance in comparable basins, underscoring the sensitivity of spring ecosystems to land-use change. Babaremu et al. (2024) observed that Nigeria have largely concentrated on urban hydrology, drainage density, or basin-scale water systems, with minimal attention to spring-specific eco-hydrological responses, especially in plateau environments.

The need for this study is therefore necessitated by the increasing anthropogenic pressures and climate variability in the region, which threaten the long-term Reliability of spring water resources. The implications of understanding LULC changes in the Biu Plateau are profound: it can inform integrated watershed management, enhance groundwater recharge strategies, and support ecosystem conservation efforts aimed at maintaining spring flow regimes. Moreover, according to Soleimani et al. (2024), such research contributes to broader sustainability goals by linking land management practices with water security, biodiversity conservation, and climate resilience. Without such targeted studies, continued LULC alterations may lead to progressive degradation of spring ecosystems, reduced water availability, and increased vulnerability of dependent communities.

The Biu Plateau region, characterized by volcanic geology, undulating terrain, and seasonal rainfall, is a notable site for several springs, which are recharged through surface and subsurface flow processes and greatly influenced by land cover conditions (Mohammed et al., 2020). The ecological and hydrological health of these springs is closely tied to the quality and distribution of vegetation, soil cover, and anthropogenic land use. Earlier land-cover analyses in parts of the Biu Plateau revealed significant conversion of woodland and grassland to agricultural and settlement areas, raising concerns about potential declines in spring recharge and water quality (Abu et al., 2020). These patterns suggest that, although Jikwathlar Spring remains active, it may be increasingly vulnerable to reduced flow and seasonal fluctuations if current land-use dynamics persist. Therefore, the study of the linkages between LULC and hydrological responses is essential for developing sustainable watershed management strategies for the Biu Plateau region.

This study, therefore, focused on the need for integrated, catchment-scale studies that holistically assess how land-cover changes affect the sustainability of spring-fed systems such as Jikwathlar Spring in the Biu Plateau region. Spatio-temporal analysis of LULC change and its hydrological implications for Jikwathlar Spring was conducted to support the sustainable management of vital freshwater resources in the Biu Plateau region and in similar semi-arid landscapes across northeastern Nigeria.

STUDY AREA

Garkida-Taula community is located in Mandaragirau District, one of the largest rural communities in the Biu Local Government Area of Borno State. Surrounding the community is a grove, and the Garkida Taula Spring, popularly known as the Jikwathlar Spring among residents, is situated there. The Garkida-Taula Spring lies on Latitudes 10° 37’ 36.53” and 10° 37’ 48.92 “N and Longitudes 12° 20’ 31.18” and 12° 20’ 43.76” E (Fig. 1). It is located within the larger Dambuwa catchment, which originates from the Biu Plateau and flows westward to the Babalwada community, where the river diverts southward to join the River Hawul in Hawul LGA. The catchment covers an area of about 72.69 km², with Garkida-Taula as one of its major settlements. A larger portion of the catchment lies in Askira/Uba and Hawul LGAs, while the section of the Biu Plateau that forms part of the catchment lies within Hawul LGA.

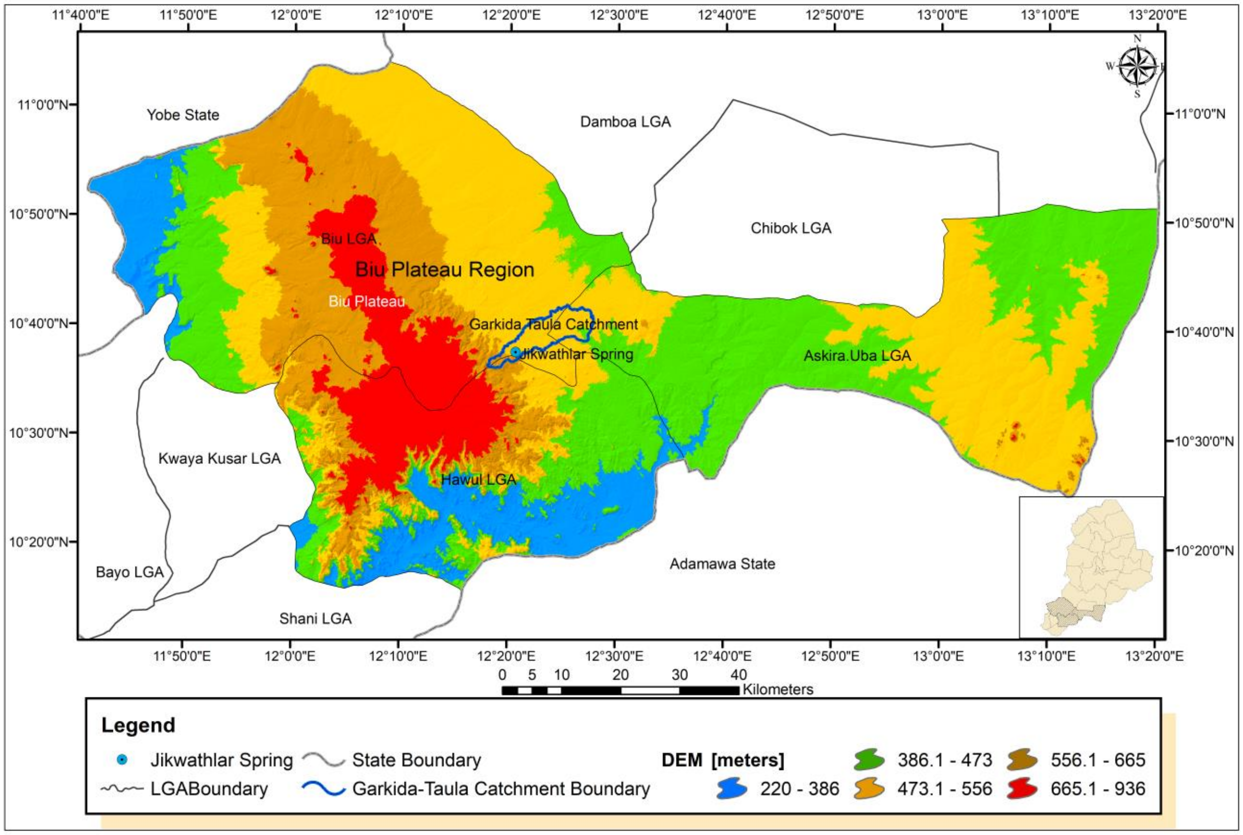

Figure 1: Study area

The spring itself emerges at the foot of the Mandaragirau volcanic outcrop and is primarily characterized by basaltic rock formations. The eco-climatic setting of Jikwathlar Spring within the Sudan Savannah zone of the Biu Plateau strongly governs its hydrological response through interactions among climate, geology, and land cover. The annual rainfall regime (600–1200 mm), concentrated within a short wet season, promotes intense groundwater recharge, particularly through the fractured basaltic formations of the Mandaragirau volcanic outcrop, which enhances infiltration and subsurface storage (Adane et al., 2023). However, the prolonged dry season, coupled with high evapotranspiration rates and harmattan-induced desiccation, leads to declining groundwater levels and reduced spring discharge, making the spring highly sensitive to climatic variability. Vegetation dynamics in the Sudan Savannah further influence this process, as wet-season plant growth enhances soil structure and infiltration, while dry-season vegetation loss and bush burning reduce soil cover, increase runoff, and limit recharge capacity (Tufa et al., 2024). These eco-climatic controls collectively result in a spring system characterized by pronounced seasonal flow fluctuations, with recharge-dependent sustainability that is vulnerable to both climate variability and land-use disturbances within the catchment.

FUDMA Journal of Earth and Environmental Sciences (FUDJEES), Vol. 3, No. 1, 2026
Print ISSN: 1595-9686
EISSN: 1595-9708

The geology and geomorphology of the Biu Plateau significantly influence the hydrological responses of springs due to their volcanic origin and structural characteristics (Bwala, 2011). According to Obiefuna & Orazulike (2023), the dominance of basaltic rocks, often highly fractured and weathered, enhances infiltration and promotes groundwater storage within secondary porosity systems, thereby sustaining spring discharge even beyond the rainy season. Furthermore, the plateau's elevated relief and dissected terrain facilitate orographic rainfall and drive subsurface flow from recharge zones at higher elevations toward lower-slope zones, where springs typically emerge. However, variations in rock permeability, slope gradient, and degree of weathering can lead to spatial differences in recharge efficiency and spring flow variability, making these systems highly sensitive to both geomorphic structure and external disturbances (Singh et al., 2022). The dominant economic activity in the community is farming, which sustains the livelihoods of most residents. Furthermore, residents around the Jikwathlar Spring actively garden, taking advantage of the spring's perennial water source. This interaction between the community's natural environment and its economic life highlights the importance of the Garkida Taula Spring, not only as a hydrological feature within the Dambuwa catchment but also as a central element of the community's ecological, cultural, and socioeconomic landscape.

METHODOLOGY

In examining the land use and land cover of the Garkida-Taula catchment from 1982 to 2022, the data types and sources used to generate the LULC are shown in Table 1.

Table 1. Data types and sources for the generation of LULC

Satellite Image	Path	Row	Date	Bands
Landsat 8 OLI	186	052	30/11/2022	Bands 5,4, & and 3
Landsat 8 OLI	186	052	16/11/2014	Bands 5,4, & and 3
Landsat 7	186	052	07/11/2002	Bands 4, 3, & 2
	186	053	07/11/2002	Bands 4, 3, & 2
Landsat 5	186	052	19/12/1992	Bands 4, 3, & 2
	186	053	19/12/1992	Bands 4, 3, & 2
Landsat 5	186	052	12/11/1982	Bands 4, 3, & 2
	186	053	12/11/1982	Bands 4, 3, & 2

Source: Earthexplorer.usgs.gov

Data Analysis

The obtained satellite imagery was mosaicked (especially Landsat 5 and 7, which contain two scenes), while the catchment shapefile was used to extract the area of the mosaicked scenes. A supervised classification method in ArcGIS 10.8 was used to classify each image into one of the following classes: Bare Surface, Grasses/Farmland, Woodlands, and Dense Vegetation (close to forest lands). Analysis of variance (ANOVA) was also used to show multiple Comparisons of land-use and land-cover changes in the Garkida-Taula catchment between 1982 and 2022.

Accuracy Assessment
The Accuracy Assessment of the classified image is shown in Table 2.

Table 2: Accuracy Assessment

Reliability (Users Accuracy)	Accuracy (Producer's Accuracy)	Average Accuracy
Bare Surface	0.91	0.86
Grasses/Farmlands	0.88	0.78
Woodlands	0.90	0.83
Dense Vegetation	0.86	0.82
Total	3.55	3.29

Source: Calculated using the Error Matrix module of ArcGIS 10.8

Average Accuracy for User's Accuracy = 3.55/4 = 88.75%
Average Accuracy for Producer's Accuracy = 2.52/4 = 82.25%

The high User's accuracy of 88.75% and the Producer's accuracy of 82.25% indicate good classification, which was accepted for the study.

Formular for LULC analysis
The following formular was used (Padma & Srinivas, 2015; Usman *et al.,* 2016; Yigez *et al.,* 2018)

(i) Trends: The values of the mean annual climatic data from 1982 to 2022

(ii) Magnitudes: The value of the current year of study (1992, for instance, minus the previous year (1982, for example and divide by the value of the previous year)

(iii) The annual rate of change was derived by dividing the percentage change by 100 and multiplying by the number of years in the study (such as 10 years between 1982 and 1992)

Finally, matrix tables with three categories were generated. (a) static (no change) areas; (b) areas that were lost to other land use/land cover types; (c) areas that gained from other LULC types, as presented in Table 3.

Table 3: Matrix for Landuse and Landcover Change Detection

Landuse/Landcover	A	B	C	D	E	Total
Bare Surface	♦	♦	♦	♦	♦	TR
Grasses/Farmland	♦	♦	♦	♦	♦	TR
Woodland	♦	♦	♦	♦	♦	TR
Dense Vegetation	♦	♦	♦	♦	♦	TR
Total	TC	TC	TC	TC	TC	GT

`♦: Area in km^2 of the pixels in LULC classes within a study period.

Diagonal: Area (km^2) of LULC that did not record any change (static) within a study period

Rows: LULC class of land areas that were lost to other LULC classes

Columns: The gained land area (km^2) of a particular vegetation class from other types.

TC/TR: Total of the land areas (km^2) of Columns and Rows

GT: Grand Total of both rows and columns

→ Previous year of study

→ Current year of study

Sources: Padma & Srinivas (2015), Yigez et al (2018)

The values in the matrix table help to identify the LULC classes that have lost/gained to/from other classes, the period when the classes were lost/gained, the total land areas that were lost/gained and the land areas that were yet to change, that is, static areas. The obtained satellite imagery was mosaicked (especially Landsat 5 and 7, which contain two scenes), while the catchment shapefile was used to extract the area of the mosaicked scenes. A supervised classification method in ArcGIS 10.8 was used to classify each image into one of the following classes: Bare Surface, Grasses/Farmland, Woodlands, and Dense Vegetation (close to forest lands). Methods of LULC analysis formular were used (Padma & Srinivas, 2015; Usman *et al.,* 2016; Yigez *et al.,* 2018)**.**

RESULTS AND DISCUSSION

Spatial Patterns of LULC of Garkida Talau Catchment from 1982 to 2022

Fig. 2 shows the LULC of the Garkida Taula catchment in 1982

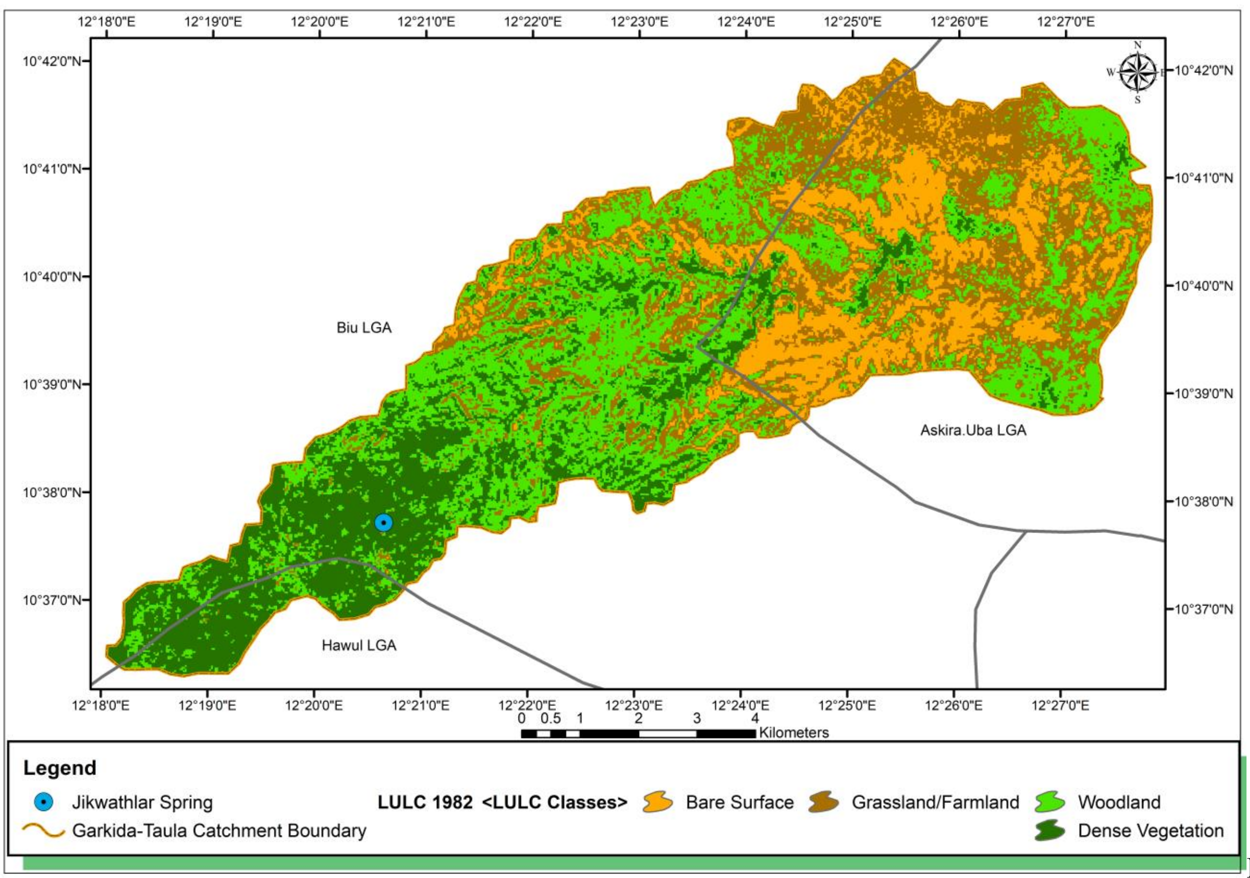

Figure 2: LULC of Garkida Taula catchment in 1982

Fig. 2 shows that bare surfaces and grassland/farmland mainly covered the Askira/Uba LGAs in the catchment, while major parts of Biu and Hawul were covered by woodland and dense vegetation. The relief of the Askira/Uba LGA, as discussed in this study, revealed that the entire area is a floodplain, which is conducive to agriculture. Therefore, the agricultural areas become bare during the dry season, when the images of the area were captured for this study. The woodland and dense vegetation areas, especially in the Hawul area, are part of the Biu Plateau, with rugged terrain that poses accessibility challenges and helps preserve the area's woodland and dense vegetation. It must be stated that the Garkida Taula Spring is located in the Dense vegetation parts of the catchment.

Fig. 3 shows the LULC of the catchment in 1992

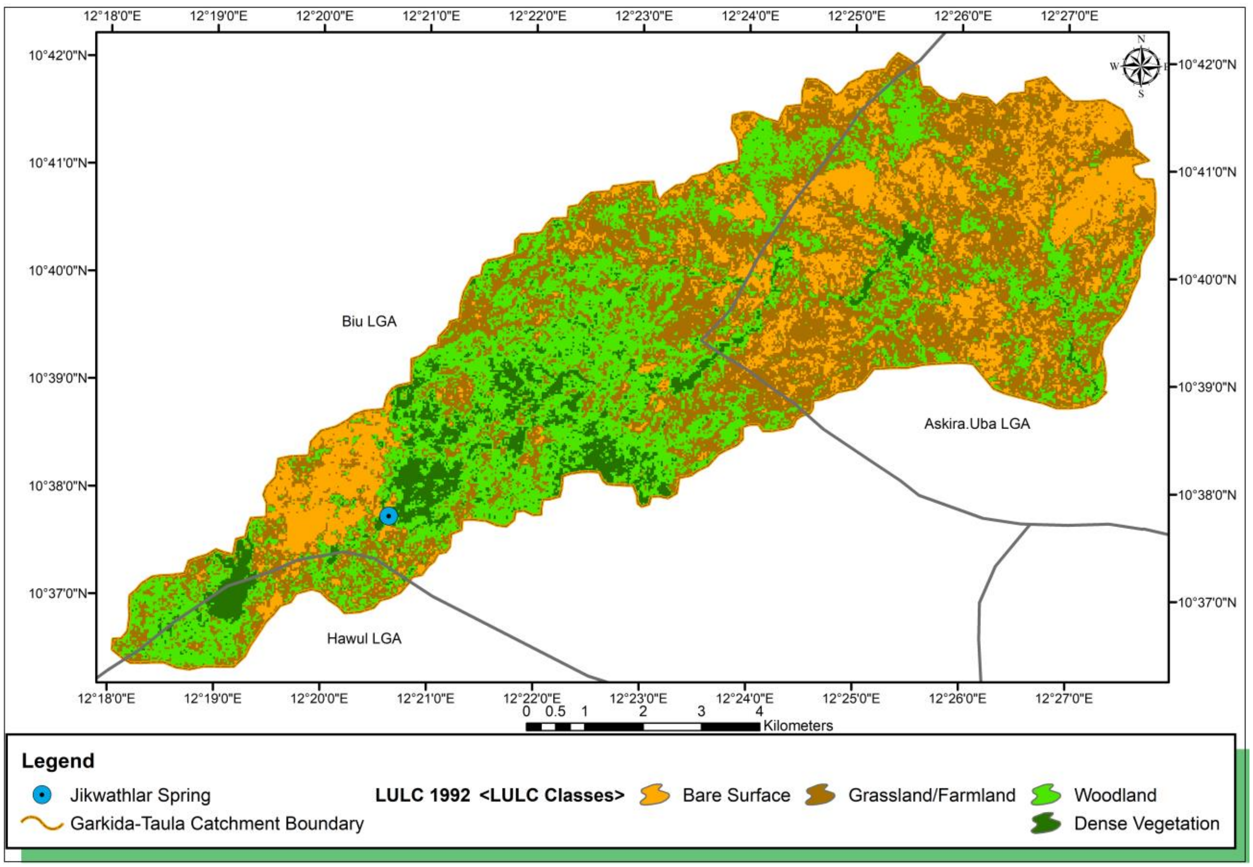

Figure 3: LULC of Garkida Taula catchment in 1992

The observed LULC pattern for 1992 indicates a substantial decline in dense vegetation within the catchment between 1982 and 1992, suggesting significant environmental stress and landscape transformation. This reduction can be linked to the combined effects of climatic variability and human activities. Notably, the late 1980s and early 1990s were characterized by widespread drought across the region, which likely contributed to vegetation loss by reducing soil moisture availability and impairing plant regeneration (Baba et al., 2024). This is further supported by the rainfall trend reported by Mbaya (2025), which shows a prolonged period of low rainfall between 1988 and 1993. Such climatic conditions would have intensified vegetation degradation, particularly in the Sudan Savannah ecosystem, where vegetation is highly sensitive to rainfall fluctuations.

In addition to climatic factors, anthropogenic pressures appear to have influenced the observed decline in vegetation. Rapid population growth within the region has been associated with increased demand for land, fuelwood, and other natural resources, leading to deforestation and land conversion (Yakubu, 2009; Abdullahi, 2014; Musa, 2023). These human-induced changes likely compounded the effects of drought, accelerating the reduction of dense vegetation cover within the catchment. Despite this decline, it is noteworthy that, as of 1992, the Garkida-Taula (Jikwathlar) Spring was still located in an area classified as dense vegetation. This suggests that, at the time, the immediate spring environment retained some level of ecological integrity, which may have helped sustain its hydrological function. However, the loss of surrounding vegetation raises concerns about the spring's long-term sustainability, given vegetation's critical role in enhancing infiltration, reducing runoff, and maintaining groundwater recharge.

The spatial pattern of LULC in 2002 is presented in Fig. 4

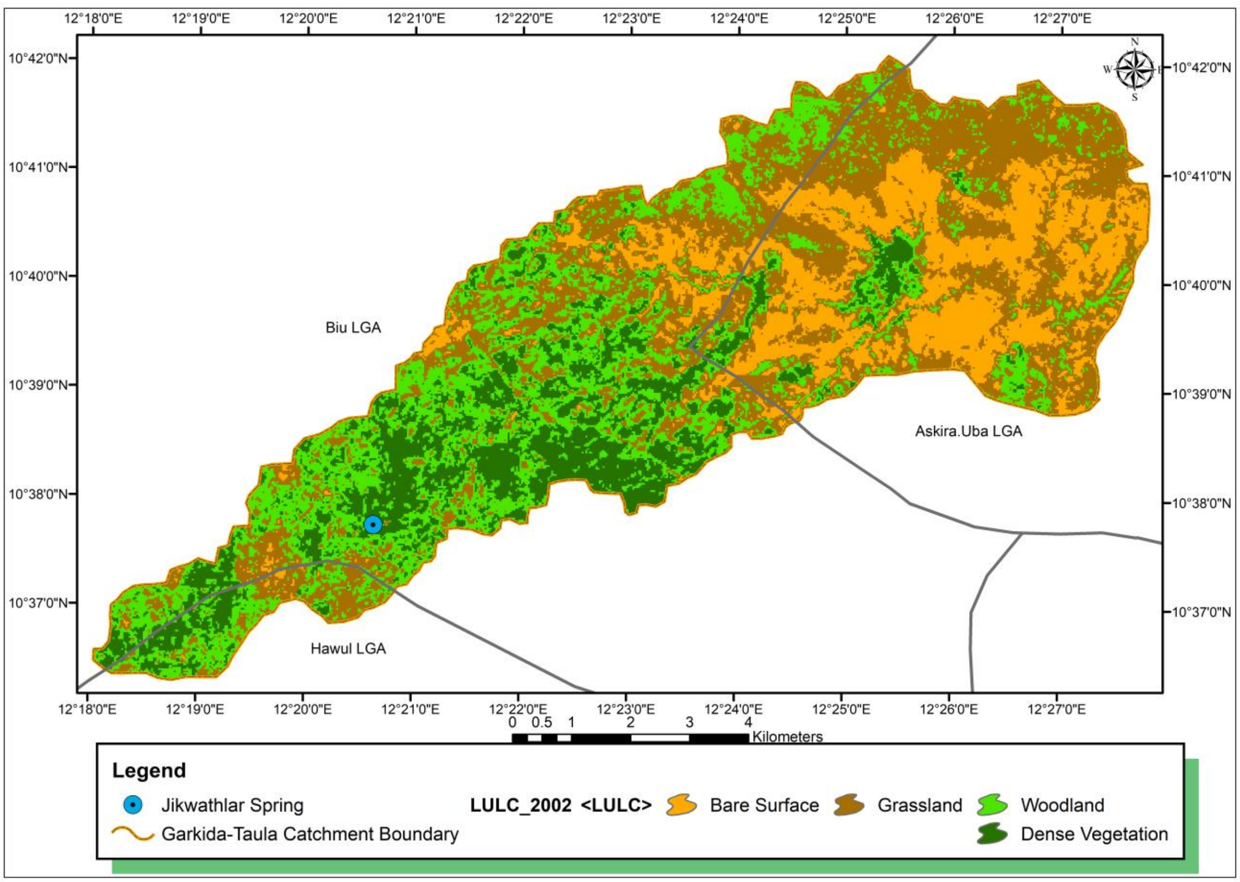

Figure 4: LULC of Garkida Taula catchment in 2002

In 2002, dense vegetation that had almost disappeared in 1992 resurfaced, especially in the plains of Biu LGA. However, the parts of the dense vegetation area that had disappeared in 1992 had yet to be recovered in 2002, possibly due to the thin soil layer on the plateau. The Garkida Taula spring, as of 2002, was still within the dense forest area.

Fig. 5 shows the spatial pattern of LULC in the Garkida Taula catchment in 2014.

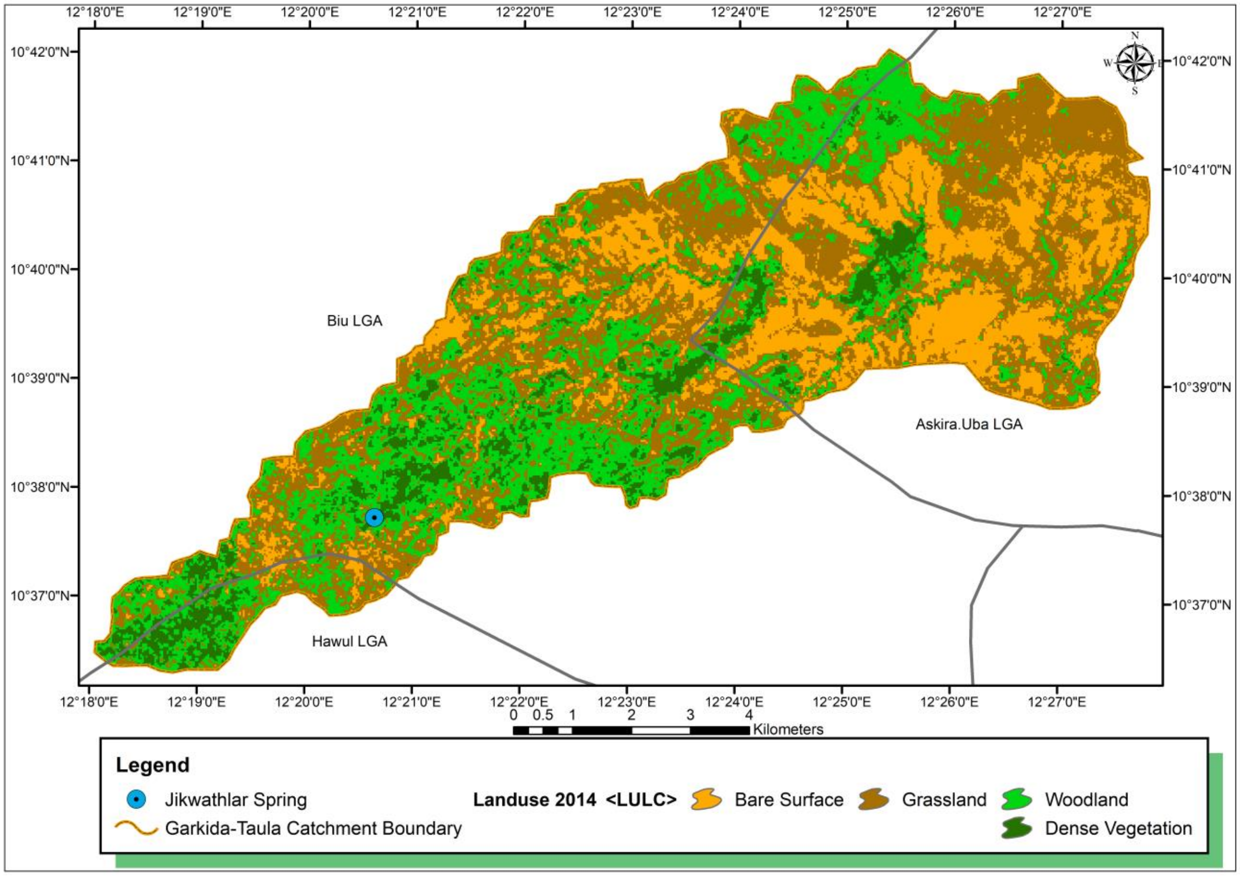

Figure 5: LULC of Garkida Taula catchment in 2014

Dense vegetation began regenerating on the Biu Plateau in Hawul LGA, part of the catchment, in 2014. However, during this period, most parts of the floodplains in Askira/Uba LGA have become bare due to human activities, except for patches of woodland along streams and in the northern part of the catchment. The spatial pattern of LULC in 2022, as presented in Fig. 6, revealed that dense vegetation has almost disappeared in the Biu Plateau area of Hawul LGA within the catchment, as well as in the floodplains of Askira/Uba LGA, where farming activities are dominant. However, dense vegetation increased in the Plains of Biu LGA within the catchment from what it was in 2002

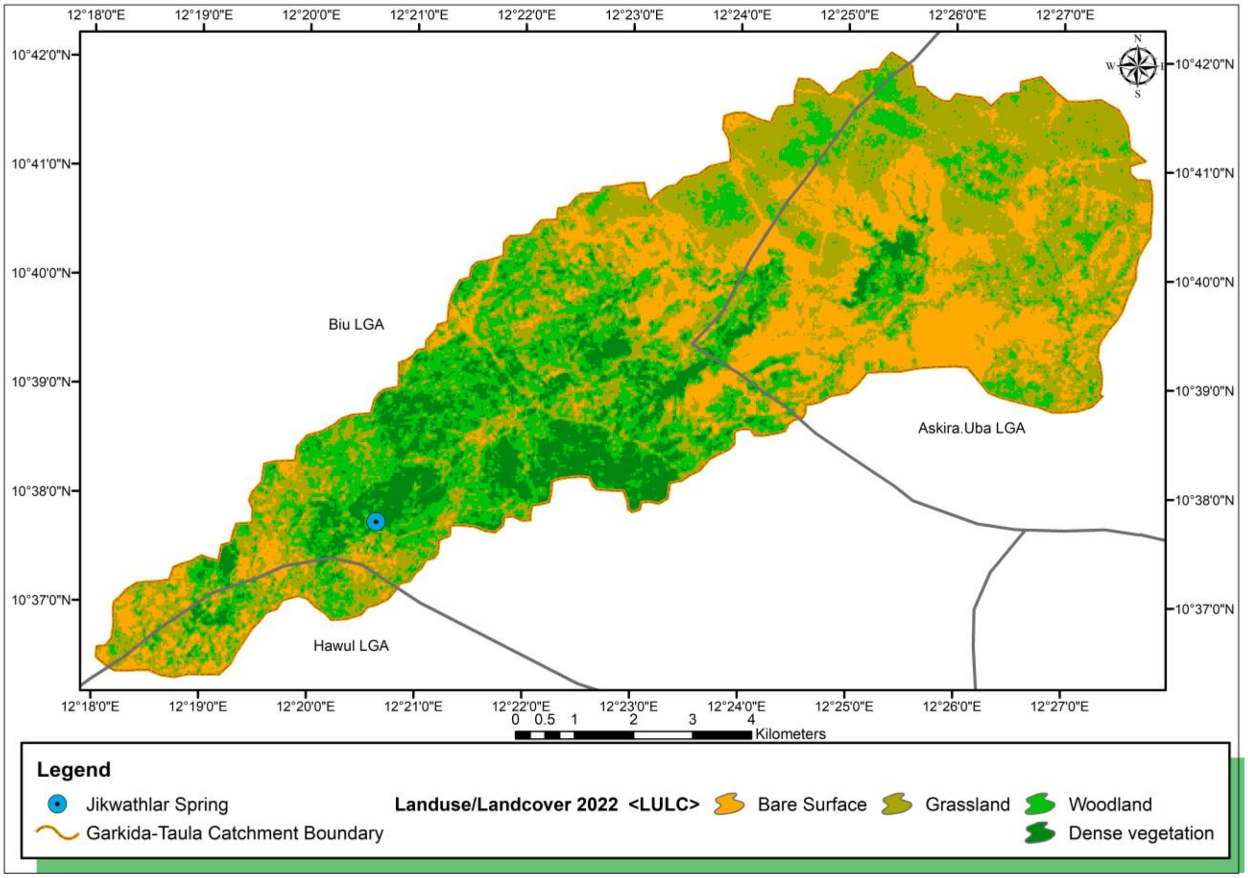

Figure 6: LULC of Garkida Taula catchment in 2022

The Garkida Taula groove, as well as the spring, were still within a dense area of vegetation until 2022. In 2022, the almost completely bare surface region of Askira Uba is now covered by vegetation, especially grasses and woodland, which could be attributed to the fact that the catchment area of Askira/Uba has been almost inaccessible because of the Boko Haram insurgency since 2014. Therefore, there have been little to no human impacts in the area, which stabilizes vegetation growth in the catchment within the LGA.

Trends in LULC of Garkida Taula catchment (1982-2002)

Table 4 shows the trends and percentage changes in LULC changes in the Garkida Taula catchment between 1982 and 2022.

Table 4. Trends in LULC of Garkida Taula catchment (1982-2022)

LULC	1982	%	1992	%	2002	%	2014	%	2022	%
Bare Surface	10.82	14.89	13.74	18.90	14.25	19.60	16.13	22.19	16.69	22.96
Grassland/Farmland	19.59	26.95	24.72	34.01	27.56	37.91	29.95	41.20	30.68	42.21
Woodland	24.96	34.34	25.99	35.75	19.26	26.50	19.53	26.87	17.38	23.91
Dense Vegetation	17.32	23.83	8.24	11.34	11.62	15.99	7.08	9.74	7.94	10.92
Total	**72.69**	**100**	**72.69**	**100**	**72.69**	**100**	**72.69**	**100**	**72.69**	**100**

Source: Calculated from the 1982-2022 Landsat images (Researcher, 2024)

The LULC trends (Table 4) in the Garkida-Taula catchment reveal a progressive increase in bare surfaces and grassland/farmland, alongside a marked decline in dense vegetation and woodland, with significant eco-hydrological implications for the spring system. The expansion of bare surfaces likely enhances surface runoff and reduces infiltration, thereby limiting groundwater recharge that sustains the spring (Woldeyohannes et al., 2022). Similarly, the conversion of woodland and dense vegetation to farmland reduces canopy cover and root structure, which are essential for maintaining soil moisture and promoting percolation (Berihun et al., 2023). The sharp decline in dense vegetation between 1982 and 2022 suggests a weakened capacity of the catchment to regulate hydrological flows, leading to increased variability in spring discharge. Furthermore, the dominance of grassland/farmland indicates intensified human activity, which may further disrupt soil structure and hydrological pathways (Dibaba et al., 2021). Collectively, these changes indicate reduced recharge efficiency, increased runoff, and a greater susceptibility of the spring to seasonal drying and long-term flow decline. Similar findings on LULC trends in the region have been reported by Ikusemoran et al. (2017), Abu et al. (2020), and Dibal et al. (2020).

Magnitudes, Percentage Change and Annual Rate of Changes in LULC in Garkida Taula catchment

Table 5 revealed that between 1982 and 1992, all the LULC classes except dense vegetation recorded positive changes, that is, an increase in their initial land area in 1982. For instance, Grassland/Farmland, which had the largest change in magnitude, recorded an additional 5.13 km2 in its land area as of 1982. However, Dense Vegetation areas (the only LULC class that decreased during the period) decreased by 9.08 km^2 between 1982 and 1992. During the same period (1982 and 2022), Bare surface recorded the highest percentage change, while Dense Vegetation recorded the lowest. Therefore, while Bare Surface gained an additional 2.92 $km^{2,}$ which was a rate of 2.70% per annum (annual rate of change), Dense vegetation lost 9.08 km^2 within the period, amounting to 5.22% negative annual rate of change

Between 1992 and 2002, Dense Vegetation, which had been decreasing between 1982 and 1992, increased by 11.71 km2 at an annual rate of change of 1.71%. The increase in dense vegetation, however, affected the size of the woodland, which dense forest can easily capture. During the period, woodland lost a total land area of 6.73 km^2, at an annual rate of -0.26%. The period between 2002 and 2014 was unique in this study because it was the period when almost 5 km2 of dense vegetation was converted to other LULC classes. It was the same period when the annual rate of change was also almost 5% per annum.

Table 6a: Magnitudes, Percentage Change and Annual Rate of Changes in LULC in Garkida Taula catchment (1982-2002)

LULC	1982	1992	Magnitude (km^2)	Percentage Change	Annual Rate (%)	1992	2002	Magnitude (km^2)	Percentage Change	Annual Rate (%)
Bare Surface	10.82	13.74	2.92	26.99	2.70	13.74	14.25	0.51	3.71	0.37
Grassland/Farmland	19.59	24.72	5.13	26.19	2.62	24.72	27.56	2.82	11.49	1,15
Woodland	24.96	25.99	1.03	4.13	0.14	25.99	19.26	-6.73	-2.59	-0.26
Dense Vegetation	17.32	8.24	-9.08	-52.42	-5.22	8.24	11.62	3.02	17.11	1.71
Total	**72.69**	**72.69**	**18.6**	**109.73**	**10.68**	**72.69**	**72.69**	**13.08**	**34.9**	**2.34**

Source: Computed by the researcher based on the generated LULC from Landsat images (1982-2002)

Table 6b: Magnitudes, Percentage Change and Annual Rate of Changes in LULC in Garkida Taula catchment (2002-2022)

LULC	2002	2014	Magnitude (km^2)	Percentage Change	Annual Rate (%)	2014	2022	Magnitude (km^2)	Percentage Change	Annual Rate (%)
Bare Surface	14.25	16.13	1.88	13.19	1.58	16.13	16.69	1.03	3.47	0.28
Grassland/Farmland	27.56	29.95	2.39	8.67	0.56	29.95	30.68	0.73	2.44	0.20
Woodland	19.26	19.53	0.27	1.40	0.03	19.53	17.38	-2.15	-11.01	-0.88
Dense Vegetation	11.62	7.08	-4.54	-39.07	-4.69	7.08	7.94	0.86	12.15	0.97
Total	**72.69**	**72.69**	**9.08**	**62.33**	**6.86**	**72.69**	**72.69**	**4.77**	**29.07**	**2.33**

Source: Computed by the researcher based on the generated LULC from Landsat images (2002-2022)

The 2014 to 2022 period was the period when insurgency was rampart in the area but now declining. The Dense Vegetation at this period increased because of the facts that restriction of people within few kilometers buffer of their domain for fear of being captured by the insurgents. Based on the findings of Musa (2023), due to the relative safety of the people in the area, many people that were displaced from nearby communities like Askira/Uba, Gwoza and other parts of Borno State moved to such areas and thereby increased the human activities in the area which led to slight increase in farmland and bare surface but decrease in woodland vegetation mainly because of farming and fuel wood harvesting activities.

The LULC dynamics of the Garkida-Taula catchment from 1982 to 2022 reveal significant transformations in both magnitude and composition, with important implications for the sustainability of Jikwathlar Spring. Between 1982 and 1992, bare surfaces and grassland/farmland increased sharply by 26.99% and 26.19% (annual rates of 2.70% and 2.62%, respectively), while dense vegetation declined dramatically by 52.42% (−5.22% annually), reflecting severe ecological degradation likely driven by both climatic and anthropogenic pressures (Berihun et al., 2023). Although there was some recovery of dense vegetation between 1992 and 2002 (17.11%), woodland continued to decline (−6.73 km²), indicating ongoing habitat loss and disruption of hydrological regulation. From 2002 to 2022, the expansion of bare surfaces and farmland persisted, while dense vegetation experienced continued fluctuation, including a sharp decline between 2002 and 2014 (−39.07%, −4.69% annually), highlighting the persistent vulnerability of the catchment to land degradation (Woldeyohannes et al., 2022). These LULC changes reduce soil infiltration, lower groundwater recharge, and increase runoff, all of which directly threaten spring discharge and hydrological stability. To mitigate these impacts, sustainable land management strategies—such as reforestation, preservation of remnant vegetation, and implementation of soil and water conservation practices—are critical for restoring hydrological function, enhancing groundwater recharge, and securing the long-term eco-hydrological sustainability of the spring.

Nature of LULC Change

The what-changed-to-what, where and when were analyzed in this section. That is, what LULC class to what LULC? Where does the changes take place? During which period? that all constitute the nature of LULC were presented in Tables 7 to 10.

Table 7: Matrix Table of LULC changes between 1982 and 1992

	1992 →				
LULC **1982**	Bare Surface	Grasses/Farmland	Woodland	Dense Vegetation	Total
Bare Surface	**11**	21	31	41	
	4.31	5.63	0.88	0	**10.82**
Grasses/Farmland	12	**22**	32	42	
	3.69	**9.49**	6.18	0.23	**19.59**
Woodland	13	23	**33**	43	
	3.18	6.81	**12.06**	2.91	**24.96**
Dense Vegetation	14	24	34	**44**	
	2.56	2.79	6.87	**5.10**	**17.32**
Total Land Area	**13.74**	**24.72**	**25.99**	**8.24**	**72.69**

Source: Generated from SRTM DEM data (2011)

*Static area (Land areas that did not change during the study period (1982-1992) are the values in the diagonal. Addition of the values was 30.96 = 42.59%
*Changed areas (values in rows excluding the diagonal was 41.73 = 57.41%

Taking Bare Surface for example in Table 7, all pixel eleven (11) are the areas that were Bare Surface in 1982 and still maintain the Bare Surface in 1992, that is, bare surface areas that have not changed to other landuse classes between 1982 and 1992. The bold 4.31 was the total land area of all pixels with number eleven 11, that is, the total land areas that remain Bare Surface. All the bold pixel numbers and figures at the diagonal are the static (LULC classes that have not changed) values. That is, pixel 11 and value 4.31 for Bare Surface, 22 and 9.49 for grasses/farmland, 33 and 12.06 for Woodland and 44 and 5.10 for Dense Vegetation. Between 1982 and 1992, Bare Surface lost 3.69 km^2 to Grasses/Farmland, 3.18 km^2 to Woodland and 2.56 km^2 to Dense Vegetation (all red values under the column of Bare Surface are the land areas that were lost to other LULC classes). During the same period (1982-1992), Bare Surface gained 5.63 km^2 to Grasses/Farmland, 0.88 km^2 to woodland and zero (0) to Dense vegetation. The zero-record means that no part of Dense Vegetation became bare Surface within the period. All other LULC of what changed to are discussed in the same way. The static areas between 1982 and 1992 collectively covered 42.59% of the total catchment, while 57.41% of LULC of the catchment have changed to LULC classes within the period.

Table 8 shows the Matrix of LULC changes between 1992 and 2002. During this period, the static land areas covered 41.74% which was just about 1% less than that of 1982-1992. The land areas that have changed collectively was about 58.26% which was also closed to that of the period between 1982 and 1992. During this period (1992-2002) Grasses/Farmland lost 10.35 km^2 to woodland, while Bare Surface also lost 7.68 km^2 to Grasses/Farmland. The LULC with the largest gain was Woodland which gained 10.35 km^2 from Grasses/Farmland and bare Surface that gained 5.26 km^2 from Grasses/Farmland.

Table 8: Matrix Table of LULC changes between 1992 and 2002

		2002			
LULC **1992**	Bare Surface	Grasses/Farmland	Woodland	Dense Vegetation	Total
Bare Surface	**11**	21	31	41	
	5.28	5.29	2.52	0.65	**13.74**
Grasses/Farmland	12	**22**	32	42	
	7.68	**11.46**	4.37	1.21	**24.72**
Woodland	13	23	**33**	43	
	1.28	10.35	**9.1**	5.26	**25.99**
Dense Vegetation	14	24	34	**44**	
	0.01	0.46	3.27	**4.5**	**8.24**
Total Land Area	**14.25**	**27.56**	**19.26**	**11.62**	**72.69**

Source: Generated from SRTM DEM data (2011)
*Static area (values in diagonal) was 30.34 = 41.74%
*Changed areas (values in rows excluding diagonal) was 42.35 = 58.26%

FUDMA Journal of Earth and Environmental Sciences (FUDJEES), Vol. 3, No. 1, 2026
Print ISSN: 1595-9686
EISSN: 1595-9708

The LULC change matrix between 2002 and 2014 is presented in Table 8 when unchanged land area of Dense Vegetation that was 8.24km^2 between 1982 to 1992 has reduced to just 4.47 km^2 between 2002 and 2014. The 2002 to 2014 period was the period when the highest static area within the catchment recorded the highest land area of 40.5.km^2 (55.72%). During this period Grasses/Farmland recorded the highest lost area of 8.08 km^2 to Woodland, while Dense Vegetation gained 5.25 km^2 from Woodland. Therefore, this period recorded relatively positive changes because substantial portion of grasses/farmland became woodland areas, and also large woodland areas turned to dense vegetation.

Table 9: Matrix Table of LULC changes between 1992 and 2002

	2014				
LULC **2002**	Bare Surface	Grasses/Farmland	Woodland	Dense Vegetation	Total
Bare Surface	**11**	21	31	41	
	10.83	3.25	0.16	0.01	**14.25**
Grasses/Farmland	12	**22**	32	42	
	4.27	**16.95**	5.87	0.47	**27.56**
Woodland	13	23	**33**	43	
	0.8	8.08	**8.25**	2.13	**19.26**
Dense Vegetation	14	24	34	**44**	
	0.23	1.67	5.25	**4.47**	**11.62**
Total Land Area	**16.13**	**29.95**	**19.53**	**7.08**	**72.69**

Source: Generated from SRTM DEM data (2011)
*Static area (values in diagonal) was 40.50 = 55.72%
*Changed areas (values in rows excluding diagonal) was 32.19 = 44.28%

Between 2014 and 2022, large land area covering 55.26% of the catchment area were static, that is, did not change. It was also the period when an increase in Dense Vegetation was recorded because 5.83 km^2 of woodland area were converted into Dense vegetation within the period. About 7 29 km^2 of Grasses/Farmland also turned into woodland within the period. It was the period when Dense Vegetation that lost only 2.94 km^2 of land to woodland also benefited 7.29 km^2 from the same woodland landcover classes.

Table 10: Matrix Table of LULC changes between 1992 and 2002

	2022				
LULC **2014**	Bare Surface	Grasses/Farmland	Woodland	Dense Vegetation	Total
Bare Surface	**11**	21	31	41	
	11.37	2.01	0.77	0.1	**14.25**
Grasses/Farmland	12	**22**	32	42	
	3.79	**17.8**	4.71	1.26	**27.56**
Woodland	13	23	**33**	43	
	0.81	7.29	**8.22**	2.94	**19.26**
Dense Vegetation	14	24	34	**44**	
	0.16	2.85	5.83	**2.78**	**11.62**
Total Land Area	**16.13**	**29.95**	**19.53**	**7.08**	**72.69**

Source: Generated from SRTM DEM data (2011)
*Static area (values in diagonal) is 40.17 = 55.26%

*Changed areas (values in rows excluding diagonal) is 32.52 = 44.74%

Static and Changed Areas of Garkida Taula Catchment Between 1982 to 2022

The static and changed areas from 1982 to 2022 as examined in this section is presented in Fig. 7. Major land areas of the Biu Plateau within Hawul LGA of the catchment have been subjected to changes. The static areas were calculated to be 30.48 km^2 representing 41.93% of the catchment, which means only 30.48 km^2 out of the catchment area of 72.69 kms maintained their LULC from 1982 to 2022. The remaining land area covering 58.07% have been subjected to changes within the 40-year period (1982-2022). One important finding to be noted here is that the Garkida Taula Groove and the Spring were located in the static area, which means that the LULC of the Groove and the Spring has not changed to any other LULC type within the 40 years of study.

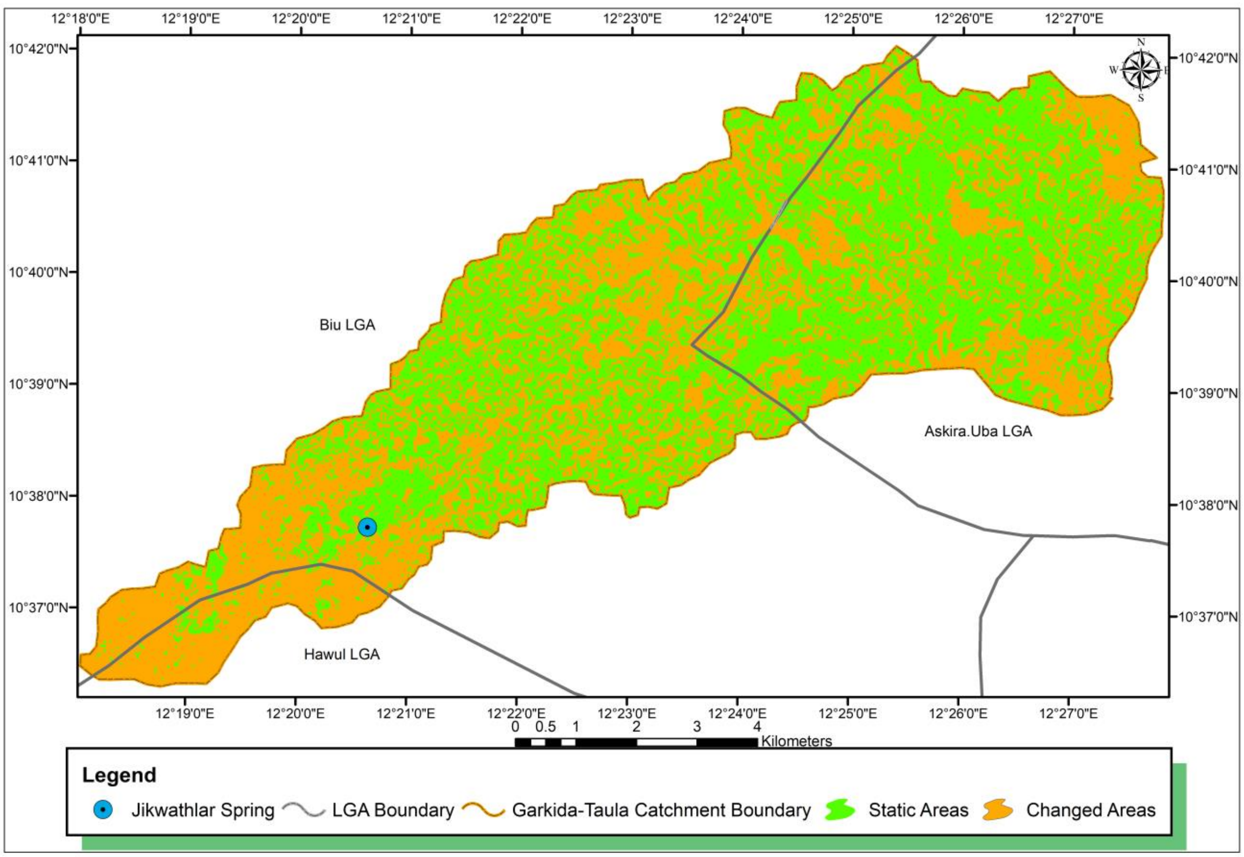

Figure 7: Static and changed areas of Garkida Taula catchment between 1982 to 2022

The analysis of the Garkida Taula catchment from 1982 to 2022 highlights the presence of Static or Persistent Zones, which are areas where land use/land cover (LULC) remained unchanged throughout the study period. These zones are evident along the diagonal of the LULC change matrices (Tables 7–10) and represent the resilient portions of the catchment. For instance, Bare Surface, Grasses/Farmland, Woodland, and Dense Vegetation showed consistent areas that did not convert to other LULC types, with the static areas increasing slightly from 42.59% in 1982–1992 to 55.26% in 2014–2022. Such static zones include ecologically significant features like the

Garkida Taula Groove and the Spring, which maintained their LULC throughout the 40 years, reflecting minimal anthropogenic or natural disturbances in these locations. These persistent areas indicate a degree of stability in land cover, which can be critical for conservation planning and ecosystem management.

In contrast, the Active Transition Hotspots are regions experiencing frequent LULC conversions, reflecting dynamic landscape changes. For example, the transition of Grasses/Farmland to Woodland (notably 10.35 km² during 1992–2002) and Woodland to Dense Vegetation (5.25 km² during 2002–2014) illustrates areas of active transformation. These hotspots are primarily found in parts of the catchment where agricultural lands and open spaces gradually became more vegetated, indicating ecological succession or human-driven afforestation. The overall trend shows that 57.41% of the land changed in the earliest period (1982–1992), slightly decreasing to 44.74% by 2014–2022, suggesting that the catchment is stabilizing over time, yet key portions remain dynamic. Identifying these active transition zones is essential for targeting interventions such as sustainable land management or reforestation, as these areas are most susceptible to both degradation and improvement.

In the Garkida-Taula catchment, approximately 41.9% of the landscape remained unchanged over the study period, representing areas that have maintained a state of relative equilibrium despite ongoing anthropogenic and climatic pressures. These stable zones likely reflect localized ecological resilience, where factors such as favorable soil properties, gentle slope gradients, or protected status have mitigated the impacts of land use change and preserved vegetation cover. In contrast, 58% of the catchment experienced significant transformations, highlighting widespread landscape modification driven by human activity and environmental stressors. Among these, high-rate change areas are particularly notable, with net gains in bare surfaces (+8%) and grassland/farmland (+15%), indicating a strong conversion of natural vegetation to anthropogenic land uses. Such expansions exacerbate surface runoff, reduce soil infiltration, and disrupt groundwater recharge, thereby threatening the hydrological sustainability of the Jikwathlar Spring. This spatial variability underscores the need for targeted conservation measures in high-risk zones while reinforcing protection and sustainable management in the relatively stable areas to maintain eco-hydrological balance and mitigate further degradation of spring-dependent ecosystems.

Multiple Correlation of LULC classes

The Analysis of variance showing the multiple correlation of the landuse and landcover changes of Taula Garkida catchment between 1982 and 2022 is presented in Table 11.

Table 11: Multiple comparisons of LULC changes in Taula catchment (1982-2022)

Multiple Comparisons

Dependent Variable: Changes
LSD

(I) LULC	(J) LULC	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound

Bare Surface	Grassland/Farmland	-12.17400*	2.33990	.000	-17.1344	-7.2136
	Woodland	-7.49800*	2.33990	.006	-12.4584	-2.5376
	Dense Vegetation	3.88600	2.33990	.116	-1.0744	8.8464
Grassland/Farmland	Bare Surface	12.17400*	2.33990	.000	7.2136	17.1344
	Woodland	4.67600	2.33990	.063	-.2844	9.6364
	Dense Vegetation	16.06000*	2.33990	.000	11.0996	21.0204
Woodland	Bare Surface	7.49800*	2.33990	.006	2.5376	12.4584
	Grassland/Farmland	-4.67600	2.33990	.063	-9.6364	.2844
	Dense Vegetation	11.38400*	2.33990	.000	6.4236	16.3444
Dense Vegetation	Bare Surface	-3.88600	2.33990	.116	-8.8464	1.0744
	Grassland/Farmland	-16.06000*	2.33990	.000	-21.0204	-11.0996
	Woodland	-11.38400*	2.33990	.000	-16.3444	-6.4236

*. The mean difference is significant at the 0.05 level.

Source: SPSS output on ANOVA of LULC changes (1982-2022)

The LULC that were not significant as shown in Table 11 include:

i. Changes from Bare Surface to Woodland (0.006)
ii. Changes from Bare Surface to Dense Vegetation (0.116)
iii. Changes from Grassland/Farmlands to Woodland (0.063)
iv. Changes from Grassland/Farmlands to Bare Surface (0.006)
v. Changes from Woodland to Grassland/Farmlands (0.063)
vi. Changes from Woodland to Bare Surface (0.116)

The LULC that showed no significant differences, are those LULC that changes into other LULC are very slow or rarely occur. For instance, changes from bare surface to woodland or dense vegetation takes several years to occur. Likewise, changes in woodland to bare surface. The slow changes among the LULC results into the insignificant differences among the LULCs.

Implications of LULC changes of Garkida-Taula catchment on Jikwathlar Spring

The spatio-temporal dynamics of land use and land cover (LULC) change in the Garkida–Taula catchment as revealed in this study between 1982 and 2022 have shown significant transformations across the landscape, yet the Jikwathlar Spring and its immediate environs have remarkably remained within a dense vegetation zone throughout the forty-year period. While the broader catchment experienced continuous increases in bare surfaces and farmlands alongside substantial reductions in woodland and dense vegetation cover, the persistence of forested land around the spring signifies its ecological resilience and hydrological importance. The dense vegetation in the Jikwathlar Spring area continues to serve as a vital natural buffer that regulates infiltration, minimizes surface runoff, and maintains steady groundwater recharge, ensuring the spring's perennial flow and ecological integrity despite widespread land degradation elsewhere in the catchment (Adewuyi & Badamasi, 2020).

However, the broader LULC changes across the catchment still pose indirect risks to the spring's sustainability. The progressive depletion of woodland and vegetation in the surrounding lowlands has increased runoff, erosion, and sediment transport, potentially threatening the recharge zones that sustain the spring. Similar studies in semi-arid regions of northern Nigeria have shown that loss of vegetation cover reduces infiltration rates and alters local hydrogeological connectivity, leading to declining groundwater yields (Ibrahim et al., 2021). The long-term persistence of the dense vegetation around Jikwathlar Spring therefore offers a strong case for targeted conservation and protection measures. Designating the spring and its forested environs as a protected hydrological reserve would help preserve its dense vegetation and prevent agricultural encroachment, logging, and settlement expansion. Maintaining this ecological stability is essential not only for safeguarding the hydrological balance of the spring but also for sustaining the water supply, biodiversity, and environmental resilience of the Biu Plateau region. Thus, the enduring dense vegetation cover around Jikwathlar Spring represents both an indicator of natural resilience and a critical focal point for sustainable watershed management.

CONCLUSION

The analysis of LULC changes in the Garkida-Taula catchment reveals significant landscape transformation over the 1982–2022 period, characterized by increases in bare surfaces and grassland/farmland and declines in dense vegetation and woodland. These changes have altered the hydrological regime of the Jikwathlar Spring by reducing infiltration, limiting groundwater recharge, and increasing surface runoff. Approximately 41.9% of the catchment remained stable, indicating areas of ecological resilience capable of sustaining spring flow. However, 58% experienced high-rate changes, with net gains in bare surfaces (+8%) and farmland (+15%), highlighting zones most vulnerable to degradation. Climatic variability, including periods of drought, compounded by population pressures, has accelerated vegetation loss. The sharp decline in dense vegetation, particularly between 1982–1992 and 2002–2014, signals reduced eco-hydrological stability. Spatial heterogeneity in land cover suggests that slope, soil, and geomorphic factors influence local recharge and spring flow. Sustainable land management, including afforestation, soil conservation, and protection of remnant vegetation, is critical to mitigate further degradation. The findings emphasize the need for integrated watershed management to safeguard spring ecosystems. Overall, LULC dynamics pose a clear threat to the long-term hydrological sustainability of Jikwathlar Spring.

RECOMMENDATIONS

The following recommendations are proposed to promote sustainable land use, ecological stability, and the conservation of hydrological resources within the Garkida–Taula catchment:

i. Key strategies such as enactment and implementation of 50–100meter riparian buffer, devoid of anthropogenic activities in order to stabilize the landcover of the catchment

ii. There is also an urgent need to embark on large-scale afforestation and reforestation programmes in areas where woodlands and dense vegetation have been depleted Jikwathlar Spring catchment.

iii Establishment of policy for long-term vegetation preservation such as anti-grazing, afforestation, and restriction of anthropogenic activities such as farming, hunting and bush burning

REFERENCES

Abdullahi, J. (2014). Evolution of volcanic craters on the Biu Plateau, Borno State, Nigeria. (Unpublished Ph. D Thesis). Department of Geography, University of Maiduguri, Borno State, Nigeria.

Abu, R. D., Yakubu, E., Songu, G. A., Thlakma, R. S., Abu, G. O. & Gajere, E. N, 2020. Impact of landuse/landcover dynamics on vegetation cover in part of Biu Plateau, Borno**,** Nigeria.*Ilorin Journal of Business and Social Sciences, Faculty of Social Sciences. University of Ilorin, Vol. 22(1), pages 155-166.*

Adane, M., Kebede, S., & Gebremichael, M. (2023). Hydrogeological controls on groundwater recharge in volcanic terrains: Insights from East African basaltic aquifers. *Journal of Hydrology: Regional Studies*, 47, 101402. https://doi.org/10.1016/j.ejrh.2023.101402

Adewuyi, T. O., & Badamasi, M. M. (2020). Assessment of land use and land cover change on hydrological processes in semi-arid Northern Nigeria using remote sensing and GIS techniques. *Journal of Environmental Geography, 13(1–2), 11–22. https://doi.org/10.2478/jengeo-2020-0002*

Baba, M., Attahiru, I.M., Musa, W.A., Zitta, N. & Waziri A.M. (2024). Vulnerability assessment of drought over Borno State. ETSJ 15(2) Dec 2024. 74-86

Babaremu, K. O., Taiwo, O., & Ajayi, D. (2024). Impacts of land use and land cover changes on hydrological response: A review of current understanding and implications for watershed and water resources management. *TWIST Journal*, 19(1), 256–267. https://doi.org/10.5281/zenodo.10049652

Berihun, M. L., Tsunekawa, A., Haregeweyn, N., & Meshesha, D. T. (2023). Exploring the impacts of land use and land cover changes on hydrology and sediment yield in watershed systems. *Sustainability*, 15(3), 2456. https://doi.org/10.3390/su15032456

Bwala, A. A. (2011). Domestic water resources availability and utilization in the Biu Plateau region of Borno State. (Unpublished Ph. D Thesis) Department of Geography, Federal University of Technology, Yola

Bwala, J. M. (2022). Effect of land tenure dynamic on agricultural sector in Biu Plateau, Borno State, Nigeria (Unpublished Ph. D Thesis) Department of Geography Modibbo Adama University, Yola.

Dibaba, W. T., Demissie, T. A., & Miegel, K. (2021). Drivers and implications of land use/land cover dynamics on hydrological processes in dryland regions. *Environmental Systems Research*, 10(1), 22. https://doi.org/10.1186/s40068-021-00226-3

Dibal, I. J., Danladi, H. & Hena, M. K. (2020). Analysis of agricultural land use around Lake Tilla, Hawul LGA of Borno State, Nigeria. *Journal of Agricultural Economics, Environment and Social Sciences* 6(1):159 – 170 June, 2020.

Ibrahim, U., Musa, I. J., & Abdulkarim, L. (2021). Impacts of land use and land cover changes on groundwater recharge in parts of northeastern Nigeria. *Environmental Earth Sciences, 80(19), 1–14.* https://doi.org/10.1007/s12665-021-09924-8

Ikusemoran, M., Odihi, J.O. & Manu, H. Y. (2017). Geographical synthesis of Biu Plateau. *Academic Research International Vol. 8(2) June 2017. 18-34.*

Kumari, Y. S. (2023). Land cover change and Its impact on groundwater resources: Findings and recommendations. In Groundwater; New advances and challenges. IntechOpen. https://doi.org/10.5772/intechopen.110311

Mbaya, R.P. (2025). Assessment of indigenous knowledge and landuse practices in the Jikwathlar spring catchment in Garkida-Taula, Biu LGA, Borno State, Nigeria. Unpublished Ph. D Thesis, Department of Geography University of Maiduguri, Nigeria

Muhammad, A, B., Bukar, W. M., Kyari, B. & Mbaya, R. P. (2020). Monitoring vegetation change using NDVI analysis and image differencing from lands at imagery in North-Eastern Nigeria, 1975 – 2016. *IOSR Journal of Environmental Science, Toxicology and Food Technology* (IOSR-JESTFT), 14(10), pp 26-34. DOI: 10.9790/2402-1410032634

Musa, M, (2023). Assessment of fadama ecological services in Biu Plateau region, Borno State. An unpublished Ph. D thesis submitted to Post Graduate School, Modibbo Adama University, Yola. Adamawa State.

Obiefuna, G. I., & Orazulike, D. M. (2023). Hydrogeological characteristics of basaltic terrains and their influence on groundwater occurrence in northeastern Nigeria. *Journal of African Earth Sciences*, 198, 104789. https://doi.org/10.1016/j.jafrearsci.2023.104789

Odoh, B. I., Nwokeabia, C. N., & Odinye, A. C. (2024). Impact of land use and land cover changes on hydrological characteristics and drainage density in urban and semi-urban areas of Abia State, Southeastern Nigeria. *Research Journal of Pure Science and Technology*, 7(3), 147–163.

Padma, K. K & Srinivas, K. (2015). Change detection matrix of landuse and landcover mapping of eleven Mandals using RS and GIS in coastal part of east Godavari district, Andhra Pradesh, India. International conference on science, technology and management. University of Delhi conference center, 27th Sept., 2015.

Singh, V. K., Sinha, R., & Tiwari, K. N. (2022). Influence of geological and geomorphological factors on groundwater recharge and spring dynamics in mountainous and plateau regions. *Journal of Hydrology*, 610, 127866. https://doi.org/10.1016/j.jhydrol.2022.127866

Soleimani, M, M., Kamawa, B., Christopher, S. & Imasiku, N. (2025). Integrating environmental and LULC drivers of groundwater droughts in groundwater-dependent ecosystems. *Ecological Processes*, 14, Article 633. https://doi.org/10.1186/s13717-025-00633-w

Tufa, F. G., Gemeda, D. O., & Wakjira, M. T. (2024). Effects of land use/land cover and climate variability on hydrological processes in semi-arid regions. *Environmental Monitoring and Assessment*, 196, 112. https://doi.org/10.1007/s10661-023-12045-7

Usman H. M., Ikusemoran M., Elijah E., and Joel M.B. (2016). Implications of landuse and landcover changes on the socio-economic activities in the Nigerian portion of the Lake Chad. *European journal of economic and financial research 1(1) 2016. Pp 84-95.*

Woldeyohannes, T., Abbaspour, K. C., & Schulin, R. (2022). Hydrological response to land use and land cover changes in a tropical catchment. *Journal of Hydrology*, 610, 127834. https://doi.org/10.1016/j.jhydrol.2022.127834

Yakubu, D. (2009). Analysis of the determinant of land use dynamics in Hawul Local Government Area of Borno State. (Unpublished M. Sc. Thesis). Department of Geography, University of Maiduguri, Borno State, Nigeria.

Yigez, B., Guo, R. and Mengesha, T. (2018). Assessment of landuse and landcover change in Finote Birihan Kebele, Amhara region, Ethiopia. *International journal of scientific research publications, Vol. 8, Issue 6, June 2018.pp 1-8*