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Evaluating the effects of land use changes on stream-flow patterns in the semi-arid region of Nigeria

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This study seeks to examine, model, and predict future changes in land use and land cover (LULC), as well as to observe their effects on streamflow patterns and behavior in a semi-arid area of northwestern Nigeria. Using remote sensing and GIS, LULC for the years 1990, 2000, and 2020 was mapped and classified, while the Cellular Automata (CA)–Markov model is used to forecast future LULC changes for 2040. The trend and pattern of streamflow in relation to LULC changes over the selected decades were evaluated via Mann-Kendall trend test and Inverse Distance Weighting (IDW). The LULC changes indicate a significant rise in construction land use, mainly at the expense of water and forest areas. The temporal connections between land use changes and streamflow variations suggest that the decade from 1990 to 2000 saw a rapid expansion of construction-related land use, coinciding with a period of high streamflow. This indicates an increase in surface runoff due to the concretization of surfaces, thereby raising the potential for flooding. The CA–Markov model projection suggests an increased flood risk, with construction and agriculture likely to dominate future land use.

Key words: Land use management, Stream flow pattern, semi-arid region, water resources.

INTRODUCTION

A major issue in relation to sustainable development and worldwide ecological changes are the alteration in land use and land cover (LULC). Rapid population growth and socioeconomic development are the primary human-induced factors behind this LULC change (Gu and Zeng, 2024; Sharma and Kumar, 2024). Through national, regional, and municipal policy, institutional variables can either heighten or mitigate the impacts of population growth as one of the primary factors in LULC changes.

Globalization processes further shape the economic opportunities available to people in developing continents, and their responses are diverse, intricate, and interconnected. This, in turn, has a variety of effects on land use and land cover patterns (Gu and Zeng, 2024; Sharma and Kumar, 2024). contributed to changes in the land and its uses. Climate, aside from anthropogenic factors, is the most dynamic

In addition to human influences, natural factors have also

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natural element affecting land cover, observable and measurable at annual and decadal levels (Gu and Zeng, 2024). The ongoing and chronic drought, along with its harsh impacts particularly in the semi-arid areas of West Africa, home to the Hadejia River Basin constitutes a climate-related concern that aggravates the problem of alterations in land use. The land cover was directly altered by the desiccation of soils and the shrinkage of water bodies, which stressed the floral composition of the region. This has ultimately jeopardized people's ability to use the land for agriculture and livestock farming, compelling them to seek alternative livelihoods, which usually results in changes to the area's land cover and land use (Dan'azumi and Ibrahim, 2023). Land use change can result in environmental and security problems, exacerbating issues attributable to both the local population and government.

For example, in Nigeria's Semi-Arid region, the agricultural threat posed by drought compelled farmers and pastoralists to relocate from arid zones to more humid areas or urban centers in search of employment. This migration exacerbated security problems and caused undesirable congestion. In northern Nigeria, the combined pressures of drought, population growth, and migration have prompted investments in soil and water conservation, as well as agricultural intensification (Sharma and Kumar, 2024). The conversion of forests to other land uses, such as agriculture and urbanization, has negatively impacted numerous environmental services, including streamflow (Dan'azumi and Ibrahim, 2023; Quamar et al., 2025), erosion control, local climate regulation (Rashedi et al., 2025), water availability, and soil fertility (Abbaszadeh et al., 2023).

Salman et al. (2017) assert that the consequences of these alterations have reduced the efficacy of ecosystem services, thereby preventing a full realization of the environment's maximum potential benefits. In light of these facts, it is crucial to determine and quantify land use dynamics and their effects on streamflow in order to aid in the management of land and water resources in the basin's vicinity (Doost et al., 2024). Thus, given the susceptibility of northern Nigeria's semi-arid region to severe climate fluctuations and land use modifications stemming from population growth and desertification, it is vital to conduct research of this nature (Zulkafli and Saadon, 2025). The research will help identify patterns, measure the extent and speed of LULC changes, and predict future changes. This will offer essential statistics for impending scheduling of policies aimed at managing excessive land use and its effects, especially on streamflow, which will aid in preserving the distinctive attributes of the environment being studied.

MATERIAL AND METHODS

Study area

The study area is a sub-catchment of the Hadejia-Jama'are-

Komudugu-Yobe Basin (HJKYB). This sub-catchment covers an area of 24,680 km² (Doost et al., 2024; Sasanya et al., 2025). The climate of the basin is controlled by the north-east and south-west trade winds, which are two air masses. Precipitation levels in a specific region are dictated by the extent of coverage of south-west air masses, as the south-west trade wind transports rain from the Gulf of Guinea. These air masses typically lasted through the warm months from May to September. In the interim, from October to April, the northeast trade wind carries chilly and dry air from the Sahara Desert. The Inter-tropical Convergence Zone (ITCZ), as the boundary between these two air masses, controls the onset and cessation of rainfall across the basin with its north-south oscillation (Ofosu et al., 2025; Quamar et al., 2025). Precipitation exhibited both regional and temporal variations, with the latter being more pronounced. Mean annual precipitation in the region varies from under 400 mm in Hadejia and its vicinity in the basin's extreme northeast to 987 mm in the basin's southern area, near Tiga (Figure 1). In the months of April and May, prior to the onset of the rains, temperatures can soar to 35°C. According to Dan'azumi and Ibrahim (2023), the temperature can fall to 18°C in December or January. The average annual maximum temperature in the northeastern part of the basin (Hadejia station) is 33°C, while in the southern part (Tiga Station), it is 31°C. Correspondingly, the mean annual minimum temperature varies from 20°C at the Hadejia Station in the northeastern part of the basin to 19°C at the Tiga stations in the southern part. Although there is an increase in rainfall with elevation, temperatures show a gradient from north to south.

LULC Data Acquisition and Processing

This study employed Landsat TM (Thematic Mapper) imagery with a spatial resolution of 30m from the years 1990, 2000, and 2020 to identify alterations in land use and land cover (LULC). When choosing the collection, seasonal climate factors were considered, with a preference for images taken during the dry season when the sky is clearer. As a result, this will mitigate the impact of cloud cover and its related reflectivity. Additionally, the study made use of supplementary auxiliary data sources, including topography and land use/cover maps sourced from Nigeria's Federal Ministry of Land and Survey. Prior to the analysis and interpretation of the images, atmospheric correction via geometric rectification was carried out. The maps were first georeferenced in the UTM Zone 50 projection and then projected into UTM Zone 50 using the WGS84 datum to match the satellite image datum. Land use and land cover changes were identified through a supervised image classification technique that utilizes the maximum likelihood classification algorithm (Abbaszadeh et al., 2023).

This image classification method's successful creation of the final LULC classes is greatly dependent on prior knowledge of the area (Ogunbode et al., 2025). The classification of the LULC categories results in four slices: agriculture, forest, water body, and others, which includes all construction land uses, gullies, and rock outcrops. The classified photographs were vectorized with the ERDAS Imagine 9.1 image analysis program in the GIS environment of ArcMap 10.3. The temporal changes in LULC between the specified time periods were quantified to allow for a comparison of the changes that occur throughout the time series. Additionally, the transition probability matrices corresponding to each LULC type were employed to calculate and display the net changes of a specific LULC type, as well as the net changes in the persistence ratio. The LULC categories were created using the FAO's framework (FAO, 2020) as a basis, with adjustments made for the local context (Mekouar, 2020). Natural forests and plantations were grouped into the 'Forest' class, which encompasses areas greater than 0.5 hectares with a tree canopy cover exceeding 10% and trees taller than 5 meters. The 'Others' class includes built environments and construction zones, bare eroded land, gullies, and rock outcrops. These elements create impervious or non-vegetated

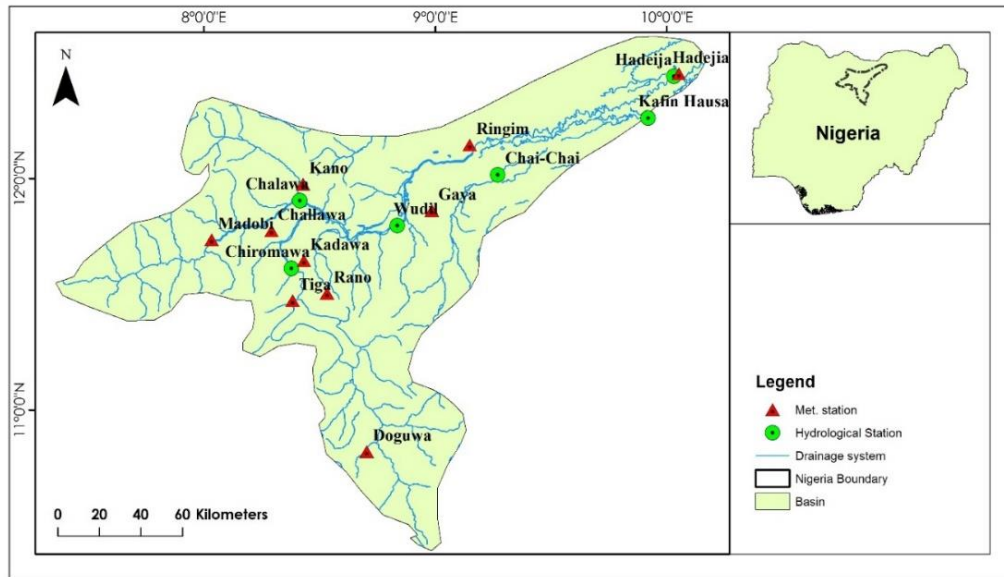


Figure 1. Map showing drainage, meteorological and hydrological stations.

Table 1. Descriptions of the land use/land cover (LULC) classes in use.

<i>LULC classes</i>	<i>General description</i>
<i>Agricultural</i>	Farming areas and other heterogeneous areas for agriculture
<i>Forested</i>	Natural vegetation and planted ones
<i>Waterbodies</i>	Permanent open water
<i>Others</i>	All types of erected structures, erosion places sites, gully and rocky areas.

surfaces that contribute to increased surface runoff (Table 1).

Classification accuracy assessment

The overall correctness of a specific map or categorized image can be assessed by calculating the total classification accuracy, producer and user accuracy, and Cohen's Kappa coefficient of agreement (Belay et al., 2024). This total accuracy indicates the proportion of sample points that were accurately categorized in relation to their corresponding reference data within each category. The

producer accuracy indicates omission errors, which are calculated by dividing the number of correctly identified samples within a specific category by the total number of samples in that category. The number of correctly classified samples is divided by the commission error, which is calculated by multiplying the user accuracy for that particular category by the total number of samples in that category. User accuracy shows the likelihood that a pixel on a map matches the correct class, whereas producer accuracy demonstrates how often the land cover of a specific area was accurately classified initially. User accuracy essentially reflects the viewpoint of a map user (how well

Table 1. Error matrices of the accuracy assessment.

<i>Land uses</i>	<i>Agriculture</i>	<i>Forest</i>	<i>Waterbodies</i>	<i>Others</i>	<i>Row Total</i>
<i>Agricultural</i>	90	0	3	0	93
<i>Forest ed</i>	6	27	0	0	33
<i>Waterbodies</i>	3	0	6	0	09
<i>Others</i>	0	0	0	15	15
<i>Column Total</i>	99	27	9	15	150
	<i>Agriculture</i>	<i>Forest</i>	<i>Waterbodies</i>	<i>Others</i>	
<i>User's accuracy</i>	0.62	0.22	0.06	0.006	
<i>Producer's accuracy</i>	0.90	0.00	0.03	0.0	
<i>Overall accuracy</i>	0.82				
<i>Overall Kappa</i>	0.85				

does this map meet my needs?), whereas producer accuracy reflects the viewpoint of a map producer (how effectively did my classification model perform across the whole study area?) (Umar et al., 2021). The Kappa index, despite facing various critiques, is the most widely used and reliable method for accuracy indexing, with a value that should not drop below 0.85. It serves to factor in the impact of change agreement on accuracy (Belay et al., 2024). The Kappa statistic (Table 2) indicates that the actual LULC maps for 1990, 2000, and 2020 are clearly comparable to the CA-Markov-simulated maps. The expected outcome and actual value of the LULC types are promising, as indicated by the Kappa statistic (0.85) and total accuracy exceeding 82% (Table 2). Consequently, the model is viewed as reliable for predicting future LULC changes, with the guarantee that a regular proportion of transformation will transpire.

LULC change modelling

A coupled CA-Markov model was used to perform the LULC change modelling in this research. To enhance the simulation of LULC fluctuations for quantitative evaluation over time, the concept of integrating the CA-Markov model reflects advancements in spatiotemporal dynamics in modeling and forecasting (Biswas et al., 2019). The CA filter is combined with Markov functions and processes in the built-in algorithms of IDRISI Andes. These algorithms rely on the conversion tables and likelihood statistics derived from the conversion map employed in simulating and predicting LULC changes. Therefore, the stated algorithms were used to complete the entire process. The subsequent measures were the basis for the CA-Markov model simulation of future LULC changes in the current study: 1. The first-order Markov model was used to derive transition matrices for the LULC categories from 1990 to 2000 and from 2000 to 2020, based on the classified LULC maps of those years and conversion procedures (vector data to raster data) (Biswas et al., 2019); 2. The significant changes between LULC categories from 2000 to 2020 were the foundation for the transition suitability maps used to forecast and simulate the 2040 LULC (Mercado-Bettín et al., 2019). Using first-hand knowledge of the study area, the conversion rules, factors, and limitations were described. In addition, the neighbourhood definition for CA filters used was the standard 5 x 5 contiguity filter; 3. The modelling process of the CA-Markov model used a method in which the LULC for 2000 was modelled based on the change prospects

from 1990 to 2000, and the LULC base map for 2020 was modelled using the transition probabilities from 2000 to 2020. The extrapolation utilized a ten-year interval. The kappa statistic is used to assess how accurate and consistent the predicted and actual maps of LULC are; 4. Finally, the LULC was forecasted with the CA-Markov model in IDRISI, utilizing the 2020 LULC base map and conversion likelihoods from 2000 to 2020 (with a Kappa index exceeding 0.85), following a comparable procedure.

Streamflow Data Collection and Processing

This study utilized monthly river discharge data from six hydrological stations, provided by the Hadejia Jama'are River Basin Development Authority (HJRBD) and Jigawa State Ministry of Water Resources (JSMWR), over a 36-year period (1980-2015) to identify recurring trends.

Data analysis

Prior to applying the relevant statistics, a QA/QC analysis was performed on the data (Ningthoujam and Romeji, 2025). The information was scrutinized for anomalies, such as outliers and missing values. The QA/QC assessment indicated that the data were clean, with the exclusion of a few missing data points that constituted less than 10% of the entire dataset. To address these gaps in the missing data, the mean of the two recorded observations was used (Pereira et al., 2022). The river discharge trend was analyzed using Sen's slope estimator and the Mann-Kendall trend test (Mondal and Mukhopadhyay, 2012). A spatial interpolation technique known as inverse distance weighting (IDW) was utilized by Mallam et al. (2025).

RESULTS AND DISCUSSION

LULC change detection and prediction

Based on the characteristics of LULC change in the study area (Figure 2a, b, c, and d), four primary LULC types were

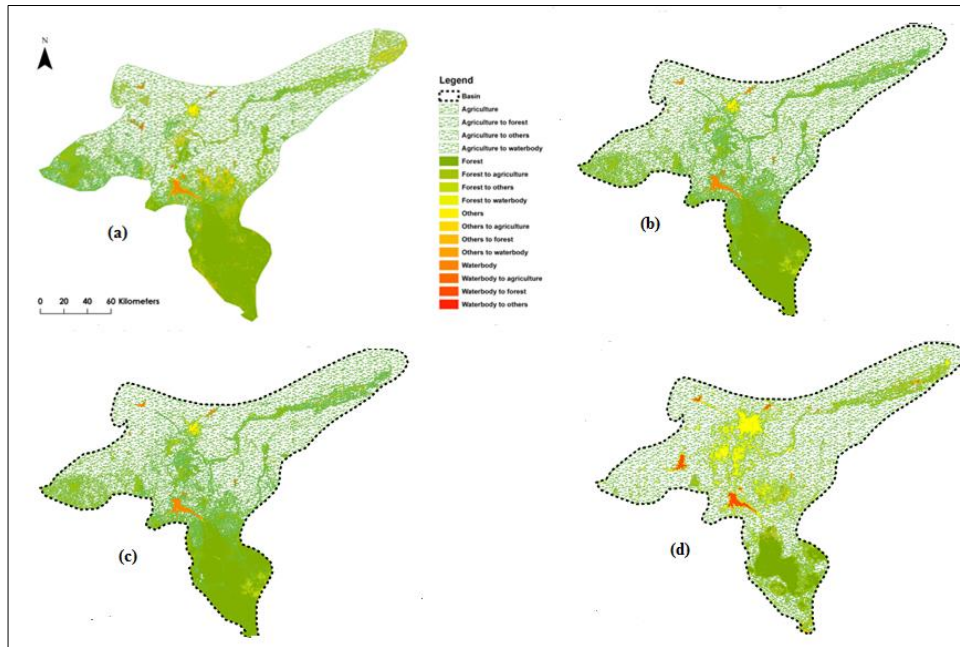


Figure 2. The classified LULC maps of the HRB for different years (a) 1990 (b) 2000 (c) 2020 and (d) the predicted 2040.

Table 3. Summary of percentage changes of LULC.

Land Use Types	1990-2000				
	Agriculture	Forest	Others	Waterbodies	
Agricultural	70.55	3.53	0.34	0.01	
Forested	15.05	5.72	0.26	0.00	
Others	0.90	0.58	1.95	0.02	
Waterbodies	0.12	0.03	0.62	0.32	
Kappa Index = 0.91					
	2000-2020				
Agricultural	68.55	11.05	1.19	0.01	
Forested	8.24	5.32	0.60	0.01	
Others	1.75	1.64	5.31	0.17	
Waterbodies	0.01	0.01	0.91	0.00	
Kappa Index = 0.86					
	2020-2040 (projected)				
Agricultural	77.8	0.01	2.92	0.1	
Forested	4.0	0.55	0.06	0.8	
Others	0.5	0.5	7.8	0.0	
Waterbodies	0.1	0.8	0.0	0.0	

Others = construction land use, gullies, and eroded lands.

recognised: agriculture, forest, water bodies, and other. The latter encompasses all forms of built up areas, gully, and erosion affected places. The percentage changes between different time slices, shown in Tables 3 and 4, illustrate the rate of LULC change across the various periods. The

accuracy classification Kappa coefficients for all-time series (1980, 1990, 2000, and 2020) exceeded 0.80, demonstrating the reliability of the interpreted results for future projections.

Based on the nature of LULC transformation in the study

Table Error! No text of specified style in document.. LULC changes between 1990, 2000, 2020, and 2040 in the HRB.

<i>LULC Type</i>	<i>Total Percent Area Coverage (%)</i>				<i>Gain/Loss (%) Between Different Times</i>		
	<i>1990</i>	<i>2000</i>	<i>2020</i>	<i>2040</i>	<i>1990-2000</i>	<i>2000-2020</i>	<i>2020-2040</i>
<i>Agricultural</i>	69.15	70.55	68.55	77.8	1.4	-2.0	9.34
<i>Forested</i>	16.33	5.72	5.32	0.55	-10.69	-0.4	-4.77
<i>Others</i>	0.50	1.95	5.31	7.8	1.45	3.36	2.53
<i>Waterbodies</i>	0.48	0.32	0.00	0.00	0.16	-0.32	0.00

Others = construction land use, gullies, and eroded lands; positive sign = gain and negative sign = loss.

area (Figure 2a, b, c, and d), four primary LULC types were acknowledged: agriculture, forest, water bodies, and other. The latter encompasses all forms of built up areas, gully and areas affected by erosion.

The Kappa statistical values (0.85) and an overall accuracy exceeding 91% (Table 3) indicate a strong promise between the expected result and the actual value of the LULC types (Sedano et al., 2019). Consequently, the model is viewed as reliable for predicting future LULC changes, with the assurance that a constant rate of change will occur. Cultivated and forested areas comprised of 80% of the total area, making them the most prevalent land use types in the Hadejia River Basin (Table 3).

Over the four decades (1990–2000, and 2000–2020), as well as the projected period (2020–2040), two major trends in land use changes emerged: a decrease in forested areas and an increase in agricultural and construction land uses. In comparison to 1990, the figures for 2000 showed a rise of 1.4% for agricultural land and a rise of 1.5% for building land, while forests and water bodies experienced reductions of 10.61 and 0.16%, respectively. Between 2000 and 2020, there was a trend of decline in the areas of water bodies, forests, and agricultural land, with respective decreases of -0.32, -0.4, and -2.0%. Consequently, construction is the only land use category that has seen a 3.36% increase due to heightened urban expansion, indicating that other categories have benefited from losses in forest, agricultural, and waterbody areas. Conversely, for the projected period of 2020–2040, agricultural and construction land uses experienced percentage increases of 9.34 and 2.53%, respectively, while forests saw a percentage decrease of 4.77% and water bodies remained unchanged at 0.00% (Table 4). Current surface waterbodies are expected to disappear starting in the 2030s when compared to their baseline levels in 1990; climate change may exacerbate this process.

In the HRB, the percentage change in land use was less pronounced from 1990 to 2000 than from 2000 to 2020, during which three of the four primary land uses agriculture, forests, and water bodies—experienced losses of different magnitudes. Conversely, the reduction of forest cover was more significant from 1990 to 2000 (10.99%), and this is similarly applicable to the rise in surface runoff during these

years (Figure 3a) as a result of swift removal of vegetation during that time.

Over the projected period from 2020 to 2040, the agricultural gain was the largest at 9.3%, which supports the expected population growth that will necessitate making more land available for farming to feed the growing population.

Thus, forecasting the impending trend of rising land use for development and agricultural purposes at the cost of forests and water bodies is crucial (see Table 4). Changes were categorized into two groups: the conversion of farmland to other land uses, particularly construction, and the reciprocal conversion of forest to agricultural land. Future population growth and immigration from nearby areas (like Yobe and Borno states, as shown in Figure 4), where the local population continues to be affected by insurgency, will likely lead to a greater percentage increase in agricultural land use compared to previous years, when construction land use saw a higher percentage increase.

Individuals from neighboring states, particularly Yobe and Borno states, seek refuge in any calm surrounding state for safety and their livelihoods. These states are mainly agricultural and generally peaceful. The generation and flow of runoff are somewhat influenced by the percentage dominance of a specific land use type in an area. Consequently, when forest areas are converted to agricultural land use, the amount and proportion of runoff generation are affected (Doost et al., 2024). Likewise, urbanization the transformation of forested areas into land designated for physical development, such as the various types of construction we undertook can often lead to a significant increase in runoff due to the removal of trees and surface concretization that diminishes the rate of infiltration (Doost et al., 2024).

Boko Haram's insurgent activities, which resulted in the displacement of numerous individuals particularly young people who formed the agricultural workforce either joining the group or seeking safety elsewhere, are primarily responsible for the reduction in agricultural land use from 2000 to 2020 (Etor and Asekhauno, 2024). Moreover, the yearly population growth of 4.3% has implications that are directly associated with the observed rise in construction land use during the study period. This growth creates new demands for additional farmland to feed the increased



Figure 3 a-m. Annual and monthly river discharge trends in HRB.

population and for urban expansion, as more housing will inevitably be required (Pushpalatha et al., 2025). According to a similar finding, urbanization has caused LULC instability in the Su Xi-Chang region of China (Gu & Zeng, 2024; Pushpalatha et al., 2025). On an individual basis, the percentage changes from one land use to another show that

from 1990-2000, the transformation from forested to cultivated land use were the highest (6.27% and 15.5%, respectively), and from forested to water bodies were the lowest (0.00% for both time slices). In contrast, from 2000-2020, the conversion from agricultural to forested were the highest (11.05%) and from agriculture to water bodies were

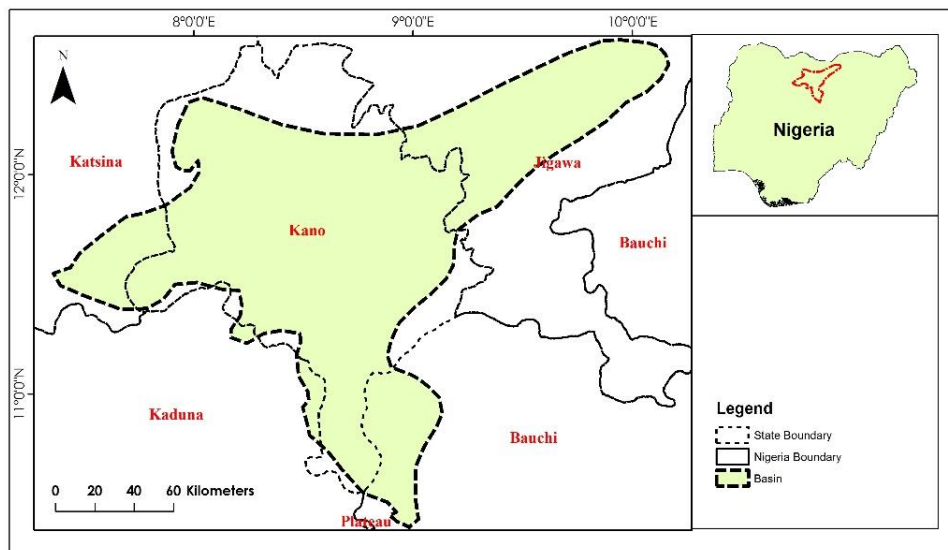


Figure 4. Map of Hadejia River Basin with neighboring states.

the lowest (0.01%), the largest change was from forest to agriculture (4.02%), while the smallest change was from built up areas to water bodies (0.00%) (Table 3.). As a result, in both historical analyses and projections, the land use categories that expanded most rapidly were construction and agriculture. However, agriculture will be the land use type that grows most rapidly in the future. The rise in the use of land for construction will mainly be due to urban expansion and the development of other infrastructures, with its direction maintaining the historical pattern, which generally follows the linear profile of the Hadejia River and revolves around the Kano-Wudil axis (Figure 2). As a result, it was discovered that urbanization resulted in a greater average runoff in regions undergoing rapid urban expansion (Figure 4). Furthermore, due to the greater urbanization of the upstream area compared to the downstream, spatial differences in runoff generation and stream flow between the two locations are said to be affected by land use transformation.

As a result, the elevated mean discharge observed at Wudil station can be linked to its location at the convergence of two rivers as well as to the augmented runoff resulting from urban development upstream.

Streamflow trends and variations

Previous studies have reported flood incidents (Aliyu et al., 2024; Aliyu et al., 2024; Muhammad and Babaji, 2024).

Should the anticipated trend of land use change persist into the future, it will be necessary to expect an increase in flooding difficulties particularly recurrent and flash floods as well as their related ramifications.

Nevertheless, the results of the monthly trend analysis revealed a mix of positive and negative developments. With the exception of May, monthly trends in the basin's upstream regions have generally shown growth; however, the Hadejia and Kafin Hausa stations in the downstream part of the basin exhibited a significant downward trend (Figure 5; Tables 6).

Overall, only the Kafin Hausa and Hadejia stations demonstrate a significant declining trend in their annual data (Table 6). Nonetheless, a significant decline in the monthly trend was observed in September at Chai-Chai, in November at Kafin Hausa, and in May, June, and August at Hadejia station (Table 6). Time series plots of river discharge showing yearly and decadal averages indicated that the 1990s represented the decades with the lowest and highest river discharge, respectively, while 1990 and 2001 were identified as the low and high flow years (Figure 5).

The space-based and time-based scrutiny of the interaction between LULC changes and streamflow oscillations suggests that LULC changes have an impact on the spatial and temporal behavior of river discharge. This was confirmed by the evident difference in runoff generation between the basin's upstream and downstream regions, which have a clear distinction in LULC composition (Figure 3a). In a similar vein, the decadal synthesis demonstrated

Table 5. Annual river discharge trend in Hadejia River Basin (1980-2015).

Stations	Slope	MK (z)	Trend
<i>Chiromawa</i>	0.13	0.60	Increasing
<i>Challawa</i>	0.04	0.38	Increasing
<i>Wudil</i>	0.02	0.90	Increasing
<i>Chai-Chai</i>	-0.20	-0.12	Decreasing
<i>Kafin-Hausa</i>	-0.34	-0.02	Decreasing
<i>Hadejia</i>	-0.58	-0.02	Decreasing
<i>Basin</i>	-0.94	-2.06	Decreasing

Table 6. MK trend test statistics for river discharge in Hadejia River Basin.

Stations	Chiromawa		Challawa		Wudil		Chai-Chai		Kafin Hausa		Hadejia	
Months	Slope	MK	Slope	MK	Slope	MK	Slope	MK	Slope	MK	Slope	MK
<i>Jan.</i>	-0.04	0.54	0.00	1.00	0.14	0.10	0.00	1.00	0.00	1.00	-0.12	0.24
<i>Feb.</i>	0.00	0.90	0.00	1.00	0.00	0.86	0.00	1.00	0.00	1.00	-0.11	0.27
<i>Mar.</i>	-0.01	0.70	0.00	1.00	0.07	0.23	0.00	1.00	0.00	1.00	-0.05	0.45
<i>April</i>	-0.03	0.77	0.02	0.14	-0.05	0.77	0.00	1.00	0.00	1.00	-0.14	0.22
<i>May</i>	-0.03	0.74	-0.23	0.22	-0.69	0.06	0.00	1.00	0.00	1.00	-0.33	0.01
<i>Jun.</i>	0.05	0.48	0.00	0.88	1.23	0.12	0.02	0.26	0.00	1.00	-0.48	0.02
<i>Jul.</i>	-0.14	0.56	0.70	0.01	-0.42	0.74	-0.07	0.06	0.01	0.43	-0.61	0.10
<i>Aug.</i>	0.28	0.70	-0.47	0.16	-0.05	0.91	-0.08	0.12	-0.10	0.11	-1.36	0.04
<i>Sept.</i>	0.65	0.68	0.64	0.13	-1.46	0.38	-0.15	0.04	-0.11	0.18	-1.27	0.10
<i>Oct.</i>	0.52	0.28	-0.01	0.65	0.61	0.53	0.03	0.15	-0.03	0.33	-0.52	0.31
<i>Nov.</i>	0.08	0.38	0.00	0.19	0.00	1.00	0.00	1.00	-0.35	0.02	-0.24	0.26
<i>Dec.</i>	-0.02	0.73	0.00	1.00	0.08	0.53	0.00	1.00	0.00	1.00	-0.16	0.25
<i>Annual</i>	0.13	0.59	0.04	0.39	0.02	0.91	-0.20	0.12	-0.35	0.02	-0.59	0.02

Bold font is significant at 95%.

that the decade marked by elevated river discharge was also the one subjected to significant forest removal, and vice versa.

Conclusion

This research identified a trend of land use and land cover (LULC) change in the Hadejia River Basin, located in north-western Nigeria and classified as semi-arid by climate. Markov and CA–Markov models were employed to simulate and project future LULC changes. The results were subsequently integrated into a GIS environment to further evaluate the time-based and space-based relationship between transformation in LULC and streamflow fluctuations in the basin. The model's validation with actual data from the base year produced an overall satisfactory outcome, indicating that CA–Markov is a suitable and reliable model for forecasting future LULC changes. The expected LULC results suggest that with the growth of construction and agricultural land use, forest areas and

water bodies diminish. The expected LULC results suggest that with the growth of construction and agricultural land use, forest areas and water bodies diminish. Looking at the time trends of the changes, agricultural land use underwent the most rapid changes, with the period from 2000 to 2020 experiencing the greatest magnitude of changes. In summary, it was demonstrated that the land use of the HRB changed less noticeably from 1990 to 2000, but more noticeably from 2000 to 2020. Between 1990 and 2000, the forest's decline became more pronounced (10.99%), corresponding to the uptake of new states created during that time. Nevertheless, looking at the projected timeframe (2020–2040), agriculture is anticipated to gain the most (9.3%). The expected upsurge in number of people, which would compel the provision of more farming space to nourish the increasing inhabitants, backs this up. Moreover, the historical trend of prioritizing construction and agriculture over forests and waterbodies is likely to persist in the similar mode going forward. The sequential valuation of stream flow specifies that the 1990s had the highest stream flow of any considered decade, coinciding with significant forest

clearance from 1990 to 2000. Likewise, the space-based analysis of LULC modification demonstrated that areas undergoing rapid urbanization, such as the newly expanded settlements around Wudil and Kano suburbs, generate significant surface runoff due to surface concretization that diminishes infiltration.

Other factors that affect the relationship between streamflow and changes in LULC include the intensity and duration of precipitation, soil characteristics and geological features, temperature fluctuations, evapotranspiration rates, and river management practices.

Given the essentials and complications of the primary factors influencing the basin's hydrology and water resources changes in land use and land cover (LULC) being just one of them—a comprehensive study of land and water resources in the basin is highly recommended. Such a study should include various other components, especially those related to climate and hydrological modeling. Ultimately, this study will aid in the management of land and urban zones and in assessing the impacts of land use alterations on the hydrology and water resources of the basin. The significant reduction in forest land use, combined with the expansion of agricultural and construction land uses, could suggest both a high surface runoff and a growing demand for water.

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