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Remote sensing of land use changes posing future threats to the avifauna in the Guinea Savanna zone, Nigeria

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Abstract The Guinea Savanna ecosystem in Nigeria is facing unprecedented threats from land use changes, which can have far-reaching consequences for the distribution of birds. This study employed remote sensing techniques to analyze land use changes retrospectively and predicted their future impacts on avifauna distribution in the Guinea Savanna region of Nigeria. Landsat imagery from 1982 to 2022 was used to assess land use changes, while the percentage average rate of change equation was employed to predict future changes. Point count method was used to record bird species in four stratified habitats: forest, woodland, grassland and riverside, which were identified as sites being mostly affected by anthropogenic activities. Sampling was done on four points within the four habitats of four selected sites of the region, making a total of 64 sampling points, for a period of two years (2023 and 2024). Canonical Correspondence Analyses (CCA) was used to relate land use types with avifauna distribution. Our results indicated significant changes in land use, with a 50% increase in agricultural land and a 60% decrease in forest, among others like built-up areas and woodland deforestation. The result of the CCA showed the 20 most abundant bird species with clear-cut preference to a particular land use type, which predicted that future land use changes will lead to significant declines in the distribution of several bird species. We identified areas of high conservation value and recommended proactive measures to mitigate the impacts of future land use changes on avifauna distribution in the region.

Keywords: avifauna distribution, land use change, Landsat imagery, remote sensing, Guinea Savanna, Nigeria

Összefoglalás A nigériai guineai szavanna ökoszisztémára a földhasználat megváltozása soha nem látott mértékű fenyegetést jelent, ami messzemenő következményekkel járhat a madarak elterjedésére nézve. A tanulmányban távérzékelési technikákat alkalmaztunk a földhasználati változások visszamenőleges elemzésére és a madárvilág elterjedésére gyakorolt jövőbeli hatásuk előrejelzésére a térségben. 1982 és 2022 közötti Landsat-felvételeket használtunk a földhasználati változások értékelésére, míg a jövőbeli változások előrejelzésére a változás százalékos átlagos mértékének egyenletét alkalmaztuk. A madarak felmérésére pontszámlálási módszert használtunk négy rétegzett élőhelyen: erdő, fás terület, gyep és folyópart, amelyeket az antropogén tevékenységek által leginkább érintett területként azonosítottunk. A mintavétel a régió négy kiválasztott helyszínének négy élőhelyén belül négy ponton, összesen 64 mintavételi helyen történt, két éven keresztül 2023-ban és 2024-ben. Kanonikus korrespondencia elemzést (CCA) alkalmaztunk a földhasználat változásai és a madárvilág eloszlása közötti összefüggések kimutatására. Eredményeink a földhasználatban bekövetkezett jelentős változásokat mutattak. A mezőgazdasági területek aránya 50%-kal nőtt, míg az erdőké 60%-kal csökkent, többek között a területek beépítése és az erdőirtás miatt. A CCA eredménye azt mutatta, hogy a 20 leggyakoribb madárfaj egyértelműen egy adott területhasználati típushoz kötődik, amelyek alapján várhatóan a jövőbeli földhasználati változások több madárfaj elterjedésében jelentős csökkenést fognak eredményezni. Azonosítottuk a magas természetvédelmi értékű területeket, és proaktív intézkedéseket javasolunk a jövőbeli földhasználati változásoknak a madárvilág elterjedésére gyakorolt hatásainak mérséklésére a régióban.

Kulcsszavak: madarak elterjedése, földhasználat változása, Landsat felvételek, távérzékelés, Guinea szavanna, Nigéria

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Introduction

The Guinea Savanna ecosystem, covering almost 600,000 km^2 across West Africa, is a key habitat for large number of avian species (Bennun & Fishpool 2000). Nigeria is home to approximately 975 bird species, making up almost 42% of Africa's estimated avian species (Avibase 2023, Clements *et al*. 2023). Avian species constitute the commonest fauna of all habitat types, and they are responsive to changes in our environment (Birdlife International 2018).

The conversion of natural habitats to agricultural land, urbanization, and other human-dominated landscapes has led to habitat fragmentation, degradation, and loss (Fahrig 2003). This, in turn, has resulted in population declines and local extinctions of many species (Donald *et al*. 2001).

The increasing urbanization of the world, with projections indicating that the majority of people will live in urban areas by 2050, poses significant threats to biodiversity (Liu *et al*. 2016). Land use change, including the conversion of native forests to pastures, croplands, and other human dominated habitats, is a primary driver of biodiversity loss in tropical regions (Sala *et al*. 2000, Liu *et al*. 2016). Like other ecological zones in Nigeira, the Guinea savannah eoregion is face high level of anthropogenic modification, resulting in varied land-use types that have significant inpact on biodiversity (Lambin *et al.*, 2001).

Remote sensing technology has emerged as a valuable tool for monitoring land use changes and their impacts on the environment (Turner *et al*. 2003). By analyzing satellite imagery, researchers can track changes in land cover, identify areas of high conservation value, and predict future trends (Macías-Duarte 2018).

Optical remote sensing is often suggested as a powerful tool to assist the mapping of protected habitats and vegetation. Moreover, space bore remote sensing offers the opportunity to map larger areas in a systematic, repeatable, and spatially exhaustive manner (Duro *et al*. 2007, Haest *et al*. 2017). For birds, remote sensing data have been widely used to map habitats, predict distribution, and estimate abundance (Hepinstall & Sader 1997, Dronova 2016, Macías-Duarte 2018, Coops *et al*. 2019).

Remotely sensed spectral data can be directly employed in modelling approaches (Hepinstall & Sader 1997, Marcías-Duarte *et al*. 2018) or, more commonly, indirectly by an integration of remote sensing-derived products such as land cover data (Coops *et al*. 2019), vegetation indices (Butler *et al*. 2017), or image derived textural metrics (Bellis *et al*. 2008). In the context of avifauna conservation, remote sensing can help identify areas of high species richness, track changes in habitat quality, and predict how future land use changes may impact bird populations (Lawler *et al*. 2013). This study aimed to investigate the impact of land use changes on avifauna distribution in the Guinea Savanna region of Nigeria using remote sensing techniques.

Materials and Methods

Description of the study area

The study area covered selected parts of Guinea Savanna ecological zone of Nigeria at latitudes 7°42’55.29”N – 11°5’55.62”N and longitudes 4°0′44.05″E – 8°43′53.40″E. Almost half of the territory of Nigeria is occupied by Guinea Savanna. Annual precipitation here

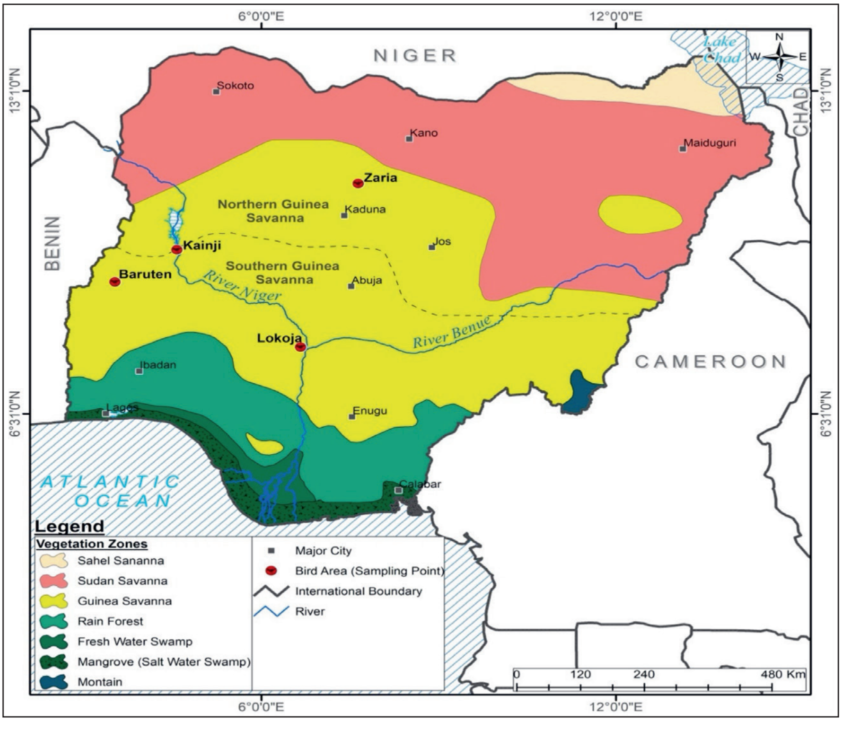

Figure 1a. Vegetation map of Nigeria showing sampling locations Source: Modified from Moberg and Esu (1991)

1a ábra Nigéria növényzeti térképe a mintavételi helyszínekkel Forrás: Moberg és Esu (1991) alapján módosítva

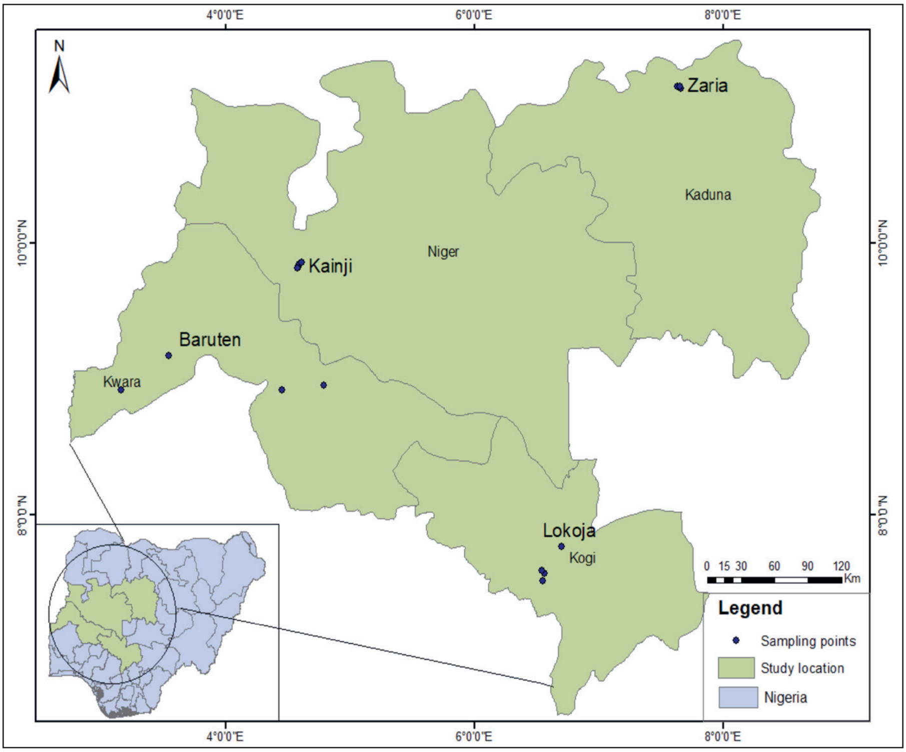

Figure 1b. Sampling sites and points in Guinea Savanna Zone of Nigeria. Source: ArcGIS 10.8 Version
1b ábra Mintavételi helyek és pontok Nigéria Guinea szavanna zónájában. Forrás: ArcGIS 10.8 verzió

amounts to 1,000–1,400 mm on the average. The plots of these savannas border the banks of the rivers with gallery forests where the grass reaches above 2 meters of height. Among the savanna vegetation in Nigeria, various types of so-called elephant grass predominate. The ecological zone is known to experience two seasons: dry (November – February) and wet season (March – October). The Guinea Savanna is composed of the northern Guinea Savanna and southern Guinea Savanna as shown in *Figure 1a*. The northern part is covered with grass, with scattered trees and shrubs dominate the vegetation. Trees are shorter and thorny and are fewer in numbers than in the southern Guinea Savanna (Kupika *et al*. 2017, Makinwa 2017).

Study design

The study was conducted in selected areas within the Guinea Savanna ecological zone of Nigeria in purpose, considering especially forests, woodlands and rivers/lakes located near Important Bird Areas (IBAs), and protected sites *(Figure 1a, b)*. These sites included ABU Phase II forests, ABU dam (Zaria, Kaduna State); Federal University, Lokoja forests, River Lokoja (Lokoja, Kogi State); Western Borgu forests, River Moshi (Baruten, Kwara State), Kainji Lake National Park and Kainji dam (Kainji, Niger State). These sampling

Table 1. Sampling locations within Guinea Savanna Zone with their coordinates in the study area
1. táblázat A mintavételi helyek a vizsgálati területen azok koordinátáival

S/N	Sampling locations	Central coordinates	Habitat type
1	Ahmadu Bello University Phase II	11°11′60″N – 7°41′59.9″E	Forest
2	Ahmadu Bello University Dam	11°7′60″N – 7°39′59.8″E	Riverine
3	Area BZ, ABU-Zaria	11°09′28″N – 07°37′56″E	Woodland/Grassland
4	Kainji Lake National Park	10°21′59″N – 4°32′59.9″E	Forest/Woodland/ Grassland
5	Kainji Dam	9°8′25″N – 4°59′33″E	Riverine
6	Borgu game reserve, Baruten	10°02′27″N – 4°03′36″E	Forest/Woodland/Grassland
7	River Moshi, Baruten	9°9′22″N – 4°25′36″E	Riverine
8	Federal University, Lokoja	6°31′0″N – 3°23′10″E	Forest/Woodland/ Grassland
9	River Niger, Lokoja	7°45′51″N – 6°41′45″E	Riverine

sites are indicated in *Table 1.* The habitats were stratified into four (forest, grassland, riverine and woodland) and random sampling was used to establish four permanent counting points in each habitat type (Jankowski *et al*. 2009), in the four sites, making a total of 64 sampling points.

Determination of bird species distribution and abundance

Birds were counted at each sampling point using a point count method (Bryan *et al*. 1984) for a period of two years (2023 and 2024), spanning the wet and dry seasons. Ten minutes was used to count and record all birds observed or heard within 30 m radius (Terborgh *et al*. 1990, Robinson *et al*. 2000), and double counting was avoided because the points were 100 m apart.

The recording of birds was conducted from 6:30–10:30 in the morning of the same day, as this is the period when most birds are active (Bryan *et al*. 1984). Observation of birds was done using digital camera binoculars 12 × 32 m (Model: 1080P) and date, bird species, number, habitat type, were recorded and coordinates were taken using a hand-held GPS (Model N9 GARMIN eTrexLegend) personal navigator. Birds were identified to the species level (Borrow & Demey 2013). Each sampling point was visited twice in a year for replication.

Determination of remote sensing data

Land use patterns were assessed by obtaining data from satellite imagery using ArcGIS 10.8 version to record the rate of changes that have taken place over 40 years at 20 years intervals. Landsat images were downloaded from the United States Geological Survey (USGS) website, Earth Explorer (https://earthexplorer.usgs.gov/). Landsat images of 1982, 2002 and 2022 were used to produce land use maps. Landsat 1–5: Multispectral Scanner (MSS) images acquired in 1982, Landsat 7: Enhanced Thematic Mapper (ETM) images acquired in 2002 and Landsat 8: Operational Land Imager (OLI) and Thermal Infrared Sensor

(TIRS) images acquired in 2022 were used to analyze the changes that have occurred. The interval of years was authoritatively selected to be able to observe major changes in land use. Medium resolution (15–30 m) was used.

Land Use/Land Cover (LULC) classification was performed using the Support Vector Machine (SVM) algorithm in ENVI 5.3 software. Land use maps were created from these images, classifying land cover into built-up areas, agricultural areas, woodland, forests, water bodies and bare surfaces. The validation of land cover classes was done by field observations (ground truthing), comparison with other data, expert evaluation and cross-validation. The area of each land use class was calculated for each of the three years.

Data analysis

Bird species diversity, richness and evenness were calculated using Shannon–Wiener diversity Index. Generalized Linear Model (GLM) was used to compare mean abundance of bird species, across different habitats and study locations, and Kernel Density Estimation method was used to produce violin plots for distribution of birds across habitats.

Canonical Correspondence Analysis (CCA) was conducted to examine the relationships between species richness and abundance with habitat types and land use patterns. The extent of land use change was determined by computing the percentage average rate of change equation, and it is indicated in bold numbers in *Table 2–5*. The annual rate of change was calculated by dividing the extent of change over 20, being the interval for each group of land use change.

A p value ≤ 0.05 was considered as statistically significant. All analyses were performed in R v4.1.2 (R Core Team 2022).

Results

A total of 136 bird species were recorded in this study. Species richness ranged from 54 on grassland to 86 in forest. There was a significant variation of of species richness across habitats (then the GLM: $Chi^2 = 10.182$, $df = 3$, $p = 0.017$). However, the difference was only through a pairwise comparison, that is, a likelihood ratio test between forest and grassland ($p = 0.03$); and grassland and woodland ($p = 0.04$) *(Figure 2)*.

There was a larger number of bird species within a narrow land area with close canopy of trees in the forest compared with that of the woodland that had more land area with open canopy of trees. The grassland habitat had more sparsely distributed bird species as shown in *Figure 3*.

Land use pattern could affect bird species abundance and diversity

The Land Use/Land Cover (LULC) changes in the study area showed remarkable differences within the 40-year retrospective study. Forests and woodlands dominated the landscape of Baruten occupying 74.31% and 15.32% respectively, in 1982. Agriculture took up 9.19%

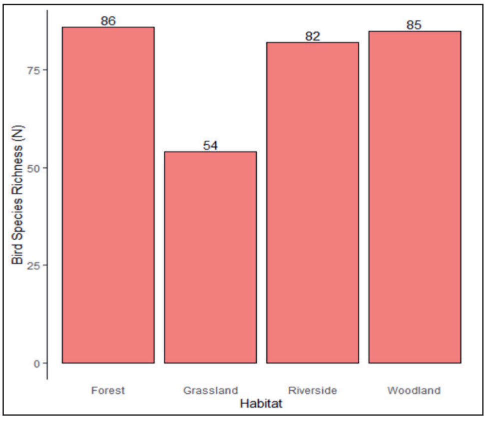

Figure 2. Species richness of birds across habitats in the study area (GLM: $Chi^2 = 10.182$, $df = 3$, $p = 0.017$)

2. ábra A madarak fajgazdagsága a vizsgált terület különböző élőhelyein (GLM: $Chi^2 = 10{,}182$, $df = 3$, $p = 0{,}017$)

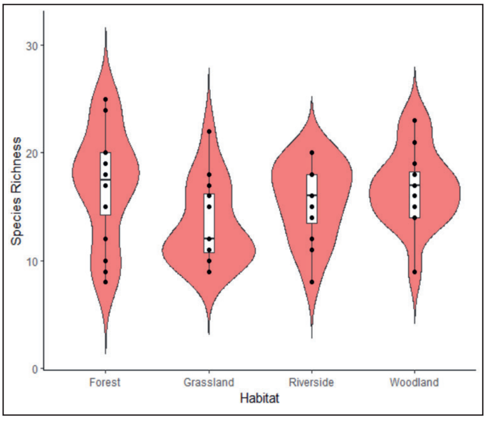

Figure 3. Distribution of bird species richness across the habitats in the study area

3. ábra A madarak fajgazdagsága élőhelyek között a vizsgálati területen

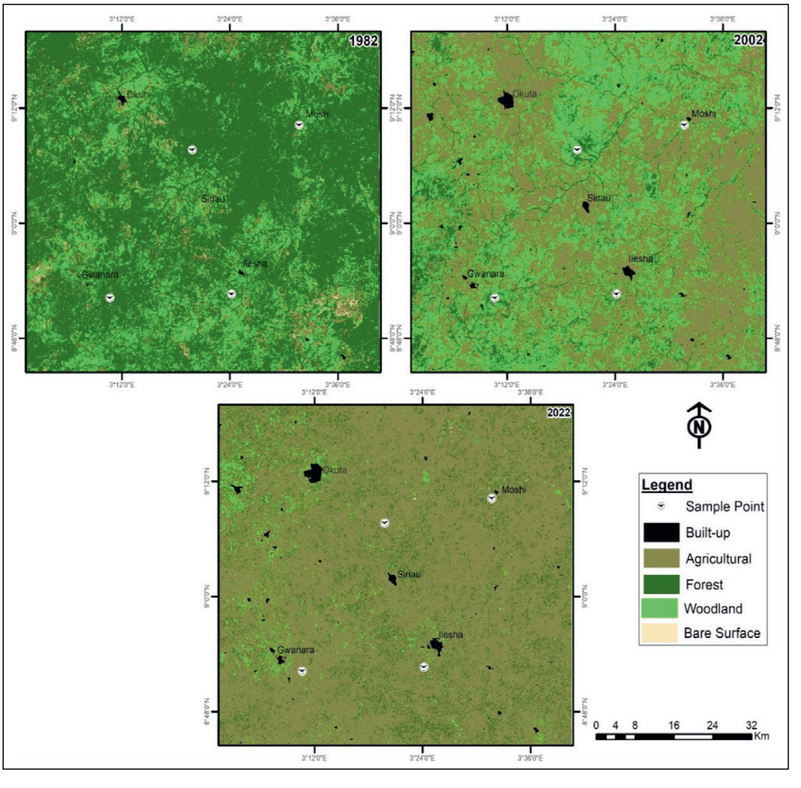

Figure 4. Landsat images of Land Use/Land Cover changes in parts of Baruten: 1982, 2002 and 2022

4. ábra Baruten földhasználati módjainak és borításának változása műholdfelvételeken 1982-ben, 2002-ben és 2022-ben

Table 2. Extent of Land Use/Land Cover changes in parts of Baruten between 1982 and 2022
2. táblázat A földhasználat és a növényborítás változásainak mértéke Baruten egyes részein 1982 és 2022 között

	Land Area						Extent of Change					
	1982		2002		2022		1982–2002		2002–2022		1982–2022	
Land use	(km^2)	(%)	(km^2)	(%)	(km^2)	(%)	(km^2)	(%)	(km^2)	(%)	(km^2)	(%)
Built-up	6.08	0.13	25.57	0.54	29.56	0.63	**19.49**	**320.42**	**3.99**	**15.59**	**23.48**	**385.95**
Agricultural	434.61	9.19	2789.76	59.00	4077.85	86.24	**2355.16**	**541.91**	**1288.08**	**46.17**	**3643.24**	**838.29**
Forest	3513.45	74.31	668.27	14.13	474.60	10.04	**2845.19**	**-80.98**	**-193.66**	**-28.98**	**-3038.85**	**-86.49**
Bare Surface	49.90	1.06	3.91	0.08	3.01	0.06	**-45.99**	**-92.16**	**-0.90**	**-22.99**	**-46.89**	**-93.96**
Woodland	724.36	15.32	1240.89	26.24	143.38	3.03	**516.53**	**71.31**	**-1097.51**	**-88.45**	**-580.98**	**-80.21**
Total	4728.41	100.00	4728.41	100.00	4728.41	100.00						

of the land area in the same year *(Figure 4, Table 2)*. Within the study period (1982–2022) the environment witnessed a dramatic change where forests decreased by 86.49% at an annual rate of -4.32% giving way to agricultural and built-up areas, which increased by 838.29% and 385.95%, respectively.

Kainji area was equally dominated by forests (45.28%) and woodland (31.80%). However, throughout the study period, forests decreased by -71.30%, while woodland decreased by -6.44% *(Figure 5, Table 3)*.

Similarly, forest and woodland occupied most of the land in Lokoja accounting to 43.85% and 31.38% of the landscape in Lokoja in 1982 *(Figure 6, Table 4)*. As a result of population growth and rural-urban migration as well as the demand for agricultural food production, agricultural and built-up areas have respectively increased by 396.63% and 98.24% between 1982 and 2022 *(Table 4)*.

Meanwhile, in 1982, the dominant LULC types in ABU and environs were forests (30.91 km^2) and woodland (25.90 km^2) *(Figure 7, Tables 5, 6)*. Further, the LULC in the landscape changed substantially between 1982 and 2022 with forests and woodlands annually decreasing by 75.10% and 62.28%, respectively. This could be attributed to the increasing population which might have caused agricultural and built-up areas to increase by 174.33% and 112.94%, respectively. However, it should be noted that between 2002 and 2022, forests increased by 139.99%, which could be accounted for the various afforestation and gully recovery programs by ABU within its extensive land. The prediction model for the next 20 years, from 2022 to 2042, is presented in *Table 7*, showing that the percentage of land cover for forest will be increased by 100% since the annual rate of change was known.

The result of Canonical Correspondence Analysis (CCA) shows the 20 most abundant bird species in this study *(Figure 8)*. The species

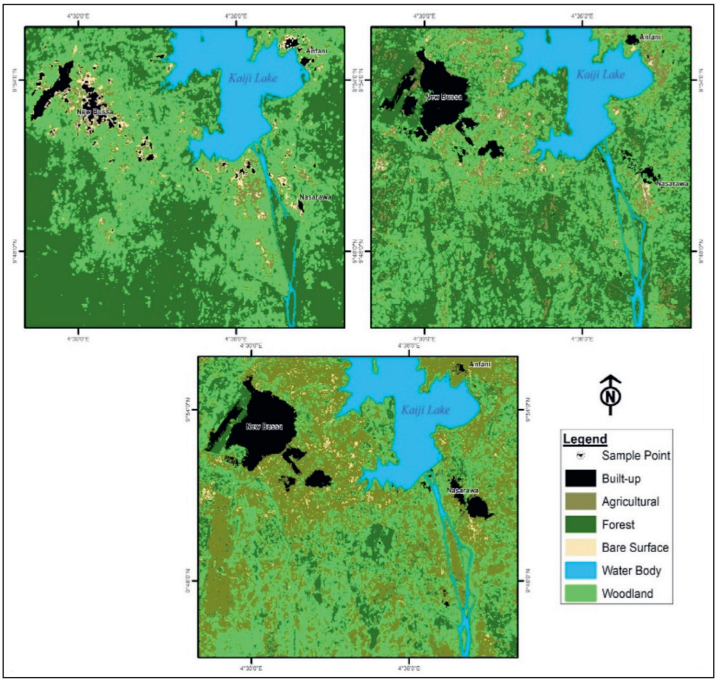

Figure 5. Landsat images of Land Use/Land Cover changes in parts of Kainji: 1982, 2002 and 2022

5. ábra Kainji földhasználati módjainak és borításának változása műholdfelvételeken 1982-ben, 2002-ben és 2022-ben

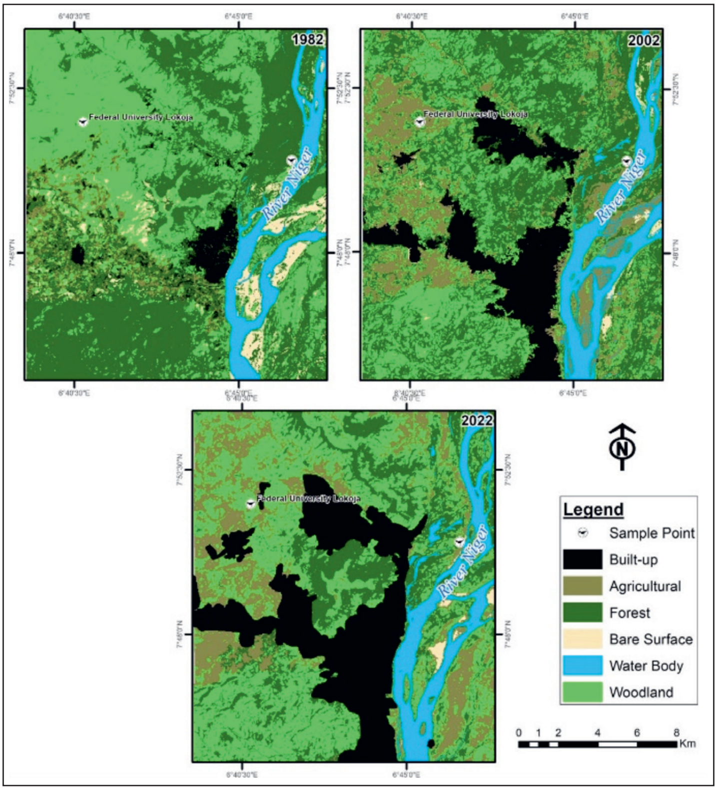

Figure 6. Landsat images of Land Use/Land Cover changes in parts of Lokoja: 1982, 2002 and 2022

6. ábra Lokoja földhasználati módjainak és borításának változása műholdfelvételeken 1982-ben, 2002-ben és 2022-ben

Table 3. Extent of land use/land cover changes in parts of Kainji between 1982 and 2022
3. táblázat A földhasználat és a növényborítás változásainak mértéke Kainji egyes részein 1982 és 2022 között

	Land Area						Extent of Change					
	1982		2002		2022		1982–2002		2002–2022		1982–2022	
Land use	(km^2)	(%)	(km^2)	(%)	(km^2)	(%)	**km^2**	**(%)**	**km^2**	**(%)**	**km^2**	**(%)**
Built-up	11.33	2.57	19.33	4.39	26.51	6.02	**8.00**	**70.61**	**7.18**	**37.14**	**15.18**	**133.98**
Agricultural	27.72	6.30	64.98	14.76	187.12	42.51	**37.26**	**134.38**	**122.14**	**187.96**	**159.39**	**574.94**
Forest	199.31	45.28	165.21	37.53	57.20	12.99	**-34.10**	**-17.11**	**-108.01**	**-65.38**	**-142.11**	**-71.30**
Bare Surface	11.71	2.66	7.43	1.69	5.81	1.32	**-4.28**	**-36.55**	**-1.62**	**-21.84**	**-5.90**	**-50.41**
Water	50.14	11.39	47.80	10.86	46.91	10.66	**-2.33**	**-4.66**	**-0.89**	**-1.87**	**-3.23**	**-6.44**
Woodland	139.98	31.80	135.42	30.76	116.65	26.50	**-4.55**	**-3.25**	**-18.78**	**-13.87**	**-23.33**	**-16.67**
Total	440.18	100.00	440.18	100.00	440.18	100.00						

Table 4. Extent of land use/land cover changes in parts of Lokoja between 1982 and 2022
4. táblázat A földhasználat és a növényborítás változásainak mértéke Lokoja egyes részein 1982 és 2022 között

	Land area						Extent of change					
	1982		2002		2022		1982–2002		2002–2022		1982–2022	
Land use	(km^2)	(%)	(km^2)	(%)	(km^2)	(%)	**(km^2)**	**(%)**	**(km^2)**	**(%)**	**(m^2)**	**(%)**
Built-up	27.40	9.55	34.16	11.91	54.31	18.94	**6.76**	**24.68**	**20.15**	**58.99**	**26.91**	**98.24**
Agricultural	13.26	4.62	48.17	16.80	65.87	22.97	**34.91**	**263.18**	**17.70**	**36.74**	**52.61**	**396.63**
Forest	125.74	43.85	98.89	34.48	53.83	18.77	**-26.85**	**-21.36**	**-45.06**	**-45.57**	**-71.91**	**-57.19**
Bare Surface	12.11	4.22	1.99	0.70	1.34	0.47	**-10.12**	**-83.54**	**-0.65**	**-32.78**	**-10.77**	**-88.94**
Water	18.28	6.38	26.61	9.28	23.87	8.32	**8.33**	**45.53**	**-2.74**	**-10.30**	**5.59**	**30.55**
Woodland	89.99	31.38	76.97	26.84	87.57	30.53	**-13.02**	**-14.47**	**10.60**	**13.77**	**-2.42**	**-2.69**
Total	286.79	100.00	286.79	100.00	286.79	100.00						

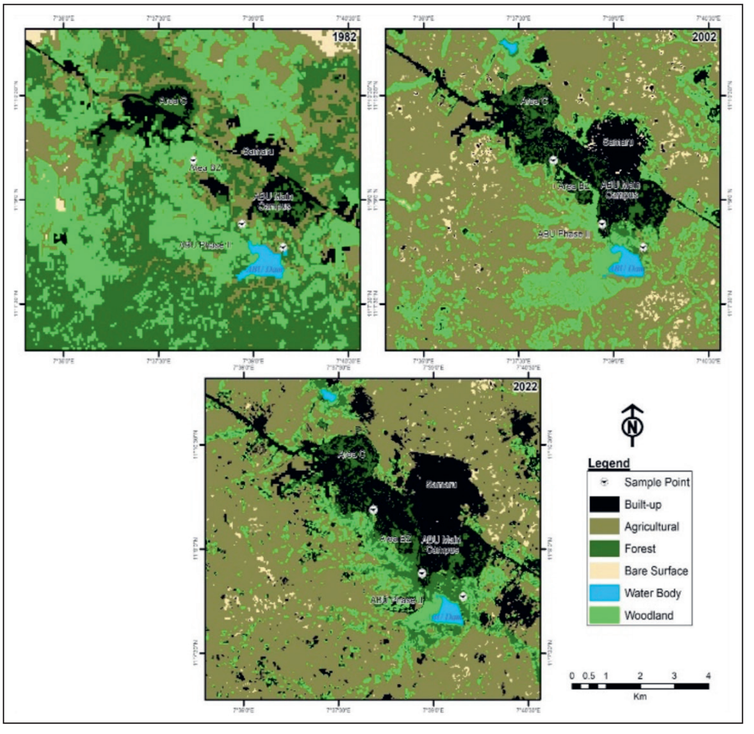

Figure 7. Landsat images of Land Use/Land Cover changes in parts of Zaria: 1982, 2002 and 2022
7. ábra Zaria földhasználati módjainak és borításának változása műholdfelvételeken 1982-ben, 2002-ben és 2022-ben

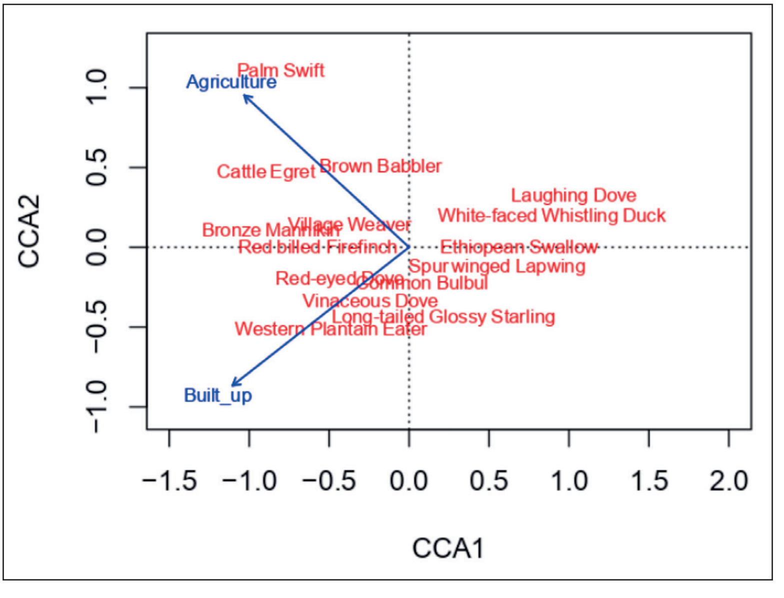

Figure 8. Relationship among bird species richness, abundance, and land use in all habitats and locations
8. ábra Az összes élőhely és terület fajgazdagsága, abundanciája és területhasználata közötti kapcsolat

Table 5. Extent of land use/land cover changes in parts of Zaria between 1982 and 2022
5. táblázat A földhasználat és a növényborítás változásainak mértéke Zaria egyes részein 1982 és 2022 között

	Land area						Extent of change					
	1982		2002		2022		1982–2002		2002–2022		1982–2022	
Land use	(km^2)	(%)	(km^2)	(%)	(km^2)	(%)	**(km^{22})**	**(%)**	**(km^{22})**	**(%)**	**(km^{22})**	**(%)**
Built-up	4.02	4.88	8.15	9.89	8.56	10.39	**4.13**	**103.0**	**0.41**	**5.03**	**4.54**	**112.94**
Agricultural	19.87	24.11	53.80	65.27	54.51	66.15	**33.93**	**171.0**	**0.71**	**1.33**	**34.64**	**174.33**
Forest	30.91	37.50	3.21	3.89	7.70	9.34	**-27.70**	**-90.0**	**4.49**	**139.99**	**-23.21**	**-75.10**
Bare Surface	0.90	1.10	2.63	3.19	1.34	1.63	**1.72**	**191.0**	**-1.29**	**-49.01**	**0.44**	**48.31**
Water	0.82	0.99	0.70	0.85	0.54	0.66	**-0.12**	**-15.0**	**-0.16**	**-22.48**	**-0.28**	**-33.92**
Woodland	25.90	31.42	13.94	16.92	9.77	11.85	**-11.96**	**-46.0**	**-4.17**	**-29.93**	**-16.13**	**-62.28**
Total	82.42	100.00	82.42	100.00	82.42	100.00						

Table 6. Annual Rate of land use/land cover changes in Zaria between 1982 and 2022
6. táblázat A földhasználat és a növényborítás változásainak éves mértéke Zaria területén 1982 és 2022 között

	(1982–2002)		(2002–2022)		(1982–2022)	
Land use	km^2	%	km^2	%	**km^2**	**%**
Built-up	0.21	5.14%	0.02	0.25%	**0.11**	**2.82**
Agricultural	1.70	8.54%	0.04	0.07%	**0.87**	**4.36**
Forest	-1.39	-4.48%	0.22	7.00%	**-0.58**	**-1.88**
Bare surface	0.09	9.54%	-0.06	-2.45%	**0.01**	**1.21**
Water body	-0.01	-0.74%	-0.01	-1.12%	**-0.01**	**-0.85**
Woodland	-0.60	-2.31%	-0.21	-1.50%	**-0.40**	**-1.56**

Table 7. Prediction model of land use/land cover changes in parts of Zaria from 1982 and 2042
7. táblázat Előrejelzési modell a földhasználat és a talajborítás változásairól Zaria egyes részein 1982 és 2042 között

	Extent of Change				Prediction	
	1982-2002		2002-2022		2022-2042	
Land use	(km²)	(%)	(km²)	(%)	**(km²)**	**(%)**
Built-up	4.13	103.0	0.41	5.03	**0.82**	**10.06**
Agricultural	33.93	171.0	0.71	1.33	**1.41**	**2.66**
Forest	-27.70	-90.0	4.49	139.99	**8.98**	**279.98**
Bare Surface	1.72	191.0	-1.29	-49.01	**-2.58**	**-98.02**
Water	-0.12	-15.0	-0.16	-22.48	**-0.32**	**-44.96**
Woodland	-11.96	-46.0	-4.17	-29.93	**-8.34**	**-59.86**

Table 8. Bird species composition based on their relative abundance in the study area
8. táblázat A madárfajok összetétele a vizsgálati területen mért relatív gyakoriságuk alapján

S/N	Habitat	Common name	Scientific name	Family	Abundance	Rel. Abund.
1	Riverside	White-faced Whistling Duck	*Dendrocygna viduata*	Anatidae	172	19.725
2	Riverside	Spurr-wing Lapwing	*Vanellus spinosus*	Charadriidae	62	7.110
3	Forest	Common Bulbul	*Pycnonotus barbatus*	Pycnonotidae	51	7.634
4	Riverside	Ethiopean Swallow	*Hirundo aethiopica*	Hirudinidae	49	5.619
5	Riverside	Common Bulbul	*Pycnonotus barbatus*	Pycnonotidae	48	5.505
6	Grassland	Bronze Mannikin	*Spermestes cucullatus*	Estrildidae	46	10.222
7	Forest	Piapiac	*Ptilostomus afer*	Corvidae	43	6.437
8	Forest	Bronze Mannikin	*Spermestes cucullatus*	Estrildidae	42	6.287
9	Forest	Long-tailed Starling	*Lamprotormis caudatus*	Sturnidae	39	5.838
10	Grassland	Common Bulbul	*Pycnonotus barbatus*	Pycnonotidae	38	8.444
11	Woodland	Common Bulbul	*Pycnonotus barbatus*	Pycnonotidae	37	6.666
12	Riverside	Cattle Egret	*Bubulcus ibis*	Ardeidae	31	3.555
13	Riverside	Brown Babbler	*Turdoides plebejus*	Timaliidae	29	3.325
14	Woodland	Piapiac	*Ptilostomus afer*	Corvidae	29	5.225
15	Woodland	Long-tailed Glossy Starling	*Lamprotormis caudatus*	Sturnidae	28	5.045
16	Forest	Village Weaver	*Ploceus cucullatus*	Ploceidae	27	4.041
17	Riverside	Long-tailed Glossy Starling	*Lamprotormis caudatus*	Sturnidae	26	2.981
18	Woodland	Vinacious Dove	*Turtur abyssinicus*	Columbidae	26	4.684
19	Forest	Brown Babbler	*Turdoides plebejus*	Timaliidae	25	3.742
20	Riverside	Yellow-crowned Gonolek	*Laniarius barbarous*	Malaconotidae	25	2.866

composition of the 20 most abundant species is presented in *Table 8*. Only built-up and agricultural areas were highlighted by the analysis, therefore, the other variables – forest, woodland, bare surface and water body were removed from the figure due to their redundancy. In addition, the analysis was not significant (p = 0.08; permutation test for CCA). Therefore, the CCA model does not significantly explain the variation in species composition. Most of the species had clear preferences for particular land use types. For instance, Cattle Egret *(Bulbucus ibis)*, Palm Swift *(Cypsiurus parvus)*, Brown Babbler *(Turdoides plebejus)*, Bronze Mannikin *(Lonchura cucullata)*, and Village Weaver *(Ploceus cucullatus)* were highly associated with agricultural areas, while Vinaceous Dove *(Streptopelia vinacea)*, Red-eyed Dove *(S. semitorquata)* and Western Plaintain-eater *(Crinifer piscator)* were associated with built-up areas. Common Bulbul *(Pycnonotus barbatus)* and Long-tailed Glossy Starling *(Lamprotornis caudatus)* to an extent were also associated with built-up areas. Red-billed Firefinch *(Lagonosticta senegala)* preferred both built-up areas and agricultural lands. Although White-faced Whistling Duck *(Dendrocygna viduata)*, Spur-winged Lapwing *(Vanellus spinosus)* and Ethiopian Swallow *(Hirundo aethiopica)* are known to be birds associated with water bodies, the variables were redundant to show the association as observed in the *Figure 8*.

Discussion

The high species richness of birds in this study could be attributed to its geographical significance, land characteristics and number of tree diversity, grasses and water bodies which make the habitats structurally complex. However, anthropogenic activities have resulted in significant land use changes over the years. This was largely due to human population growth and rural-urban migration as well as the demand for agricultural food production. The extent of changes in Baruten and Kainji due to agricultural practices as well as Lokoja due to urbanization over the studied forty years period was due to lack of conservation efforts of replenishing the forests and woodland by afforestation programmes.

The study identified 136 bird species across various habitats, highlighting the importance of these areas for avifauna conservation, as habitat specificity and generalization were observed in the distribution of bird species. The results of this study agree with the observation of Askins *et al*. (2012) and that of Buckley and Freckleton (2010) who both noted that bird species distribution is responsible for the spatial structure of their environments and habitat requirements.

The changes in Land Use/Land Cover (LULC) across the study area revealed the extent of anthropogenic activities, particularly deforestation resulting from agricultural practices and built-up areas leading to urbanization, although national policies do not allow it, but it was abused. This follows a marked reduction of tree diversity leading to environmental changes, unlike how conservation efforts by afforestation and drastic reduction of hunting would have influenced some indicator bird species to be stabilized in the IBA, which could have also attracted a number of new species in the area. This might have provided favourable habitats for both generalist and specialist bird species and would have boosted the ornithological significance of the IBA. This is consistent with the work of Ezealor (2001) who reported that several countries have developed bird monitoring schemes because they are the indicators of the state of the environment.

The results of this study highlight the potential threat of land use changes to avifauna distribution in the Guinea Savanna region of Nigeria. The remote sensing analysis revealed significant changes in land use/land cover (LULC) between 1982 and 2022, with a notable increase in agricultural land and a decrease in natural vegetation. These changes in LULC can have far-reaching consequences for avifauna populations, including habitat loss, fragmentation, and degradation (Donald *et al*. 2001, Fahrig 2003). The loss of natural habitats can lead to population declines and local extinctions of bird species (Balmford *et al*. 2001). This is consistent with the results of Vickery *et al*. (2014) who reported that high rate of deforestation of any habitat strongly influences the composition and abundance of its flora and fauna, just as urbanization negatively affects landscapes by changing resources such as food, water and nesting sites for birds to survive.

The results of the prediction model also suggest that land use changes can alter the habitat suitability of bird species in the study area. The models predicted that the distribution of several bird species would be affected by changes in land use, particularly the conversion of natural habitats to agricultural land.

These findings are consistent with previous studies that have highlighted the impacts of land use changes on avifauna populations in Africa (for instance, Weideman *et al*. 2020, Mugatha *et al*. 2023).

Concluding and conservation remarks

The results showed that land use changes, particularly the conversion of natural habitats to agricultural land and urbanization, pose a significant threat to avifauna populations in the study area. The study highlights the need for sustainable land use practices that balance human needs with environmental conservation. We recommend that sustainable land use planning practices that involve both humans and wildlife should be encouraged, as well as establishing a monitoring and evaluation system to track changes in land use and avifauna populations over time.

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