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Vegetation Change and Avian Community Responses to Infrastructure Expansion in a Semi-Arid University Landscape, Northeastern Nigeria

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ABSTRACT

Infrastructure expansion is a major driver of vegetation loss and habitat modification, particularly in rapidly developing semi-arid landscapes. This study assessed the effects of vegetation cover change associated with infrastructural development on avian diversity and abundance within Gombe State University, northeastern Nigeria. Specifically, the study aimed to (i) evaluate long-term vegetation and infrastructure changes using remote sensing and GIS techniques and (ii) investigate the relationship between vegetation features and bird diversity. Land-use and land-cover changes were analysed using Landsat satellite imagery for 2004, 2015, and 2025. Avian surveys were conducted across highly modified, natural, and semi-natural habitats using the point count method during both wet and dry seasons. Species diversity was assessed using the Shannon–Wiener Diversity Index, while Chi-square tests were used to examine associations between vegetation characteristics and avian community attributes. Results revealed a progressive increase in built-up areas and infrastructure, accompanied by a decline in vegetation cover across the university landscape. A total of 1,750 individuals representing 37 bird species, 30 genera, 25 families, and 12 orders were recorded. Species diversity was moderate ($H' = 1.20$), with semi-natural heterogeneous habitats supporting the highest species richness and abundance. Two species, the Eurasian Hoopoe and Rose-ringed Parakeet, were recorded for the first time within the study area. Significant associations were observed between vegetation type and bird abundance, behaviour, and activity patterns ($p < 0.001$). The findings demonstrate that infrastructure-driven vegetation loss alters avian community structure and highlight the importance of integrating vegetation conservation into institutional development planning.

Keywords: Avian diversity; bioindicators; infrastructure development; semi-arid ecosystems, vegetation cover change;

INTRODUCTION

Vegetation plays a fundamental role in maintaining ecosystem stability, particularly in semi-arid environments where biological communities depend heavily on limited habitat resources. Native vegetation provides critical ecosystem services including soil stabilization, microclimate regulation, water retention, and habitat for wildlife (Forey *et al.*, 2005; Millennium Ecosystem Assessment, 2005; Abdullah and Wilson, 2022). Within these ecosystems, vegetation structure is especially important for avian communities because it provides essential resources such as food, nesting sites, shelter from predators, and specialized microhabitats required for survival and reproduction (Manu and Cresswell, 2021; Isah *et al.*, 2022).

In recent decades, rapid infrastructure expansion has emerged as one of the major drivers of vegetation loss and habitat transformation in many developing regions. The construction of roads, buildings, and other infrastructure often leads to vegetation clearance and landscape fragmentation, which can substantially alter ecological processes and biodiversity patterns (Sato *et al.,* 2012; Haddad *et al.*, 2015; Rahman *et al.*, 2023). These changes frequently result in reduced habitat complexity and shifts in species composition, favouring disturbance-tolerant generalist species while reducing the abundance of habitat specialists (McKinney, 2008).

Birds are widely recognized as effective ecological indicators due to their sensitivity to environmental changes and their close association with vegetation structure (Whelan *et al.,* 2015; Şekercioğlu *et al.,* 2016; Callaghan *et al.*, 2020). Because they respond rapidly to habitat alteration across multiple spatial scales, bird communities provide valuable insights into ecosystem health and integrity (Whelan *et al.*, 2015; Ibáñez-Álamo *et al.,* 2020; Shanahan *et al.,* 2021). Changes in vegetation structure can significantly influence bird abundance, distribution, and community composition by altering the availability of food resources, nesting sites, and protective cover (Ibrahim *et al.*, 2020).

The ecological consequences of vegetation loss may be particularly pronounced in semi-arid environments such as northeastern Nigeria. In these regions, vegetation recovery is often slow due to climatic constraints, meaning that habitat disturbance can have long-lasting effects on biodiversity and ecosystem functioning (Abdullah and Wilson, 2022). Infrastructure development therefore poses a significant challenge to balancing urban growth with biodiversity conservation in such landscapes (Seto *et al.,* 2012; Güneralp *et al.*, 2017; Abdullah and Wilson, 2022) .

University campuses represent unique ecological landscapes within urban environments. Although they often experience rapid infrastructural expansion, they can also function as important refuges for biodiversity when natural vegetation is maintained (Aronson *et al.*, 2014; Akinyemi & Ogunjemite, 2016; Shanahan *et al.*, 2021). However, empirical research examining how institutional development influences vegetation structure and avian communities in northern Nigeria remains limited. This lack of region-specific data restricts the development of evidence-based strategies for integrating biodiversity conservation into campus planning and infrastructure development.

To address this knowledge gap, this study examined changes in vegetation cover associated with infrastructure expansion and evaluated their implications for avian diversity and abundance within Gombe State University main campus. Specifically, the study (i) evaluated long-term vegetation and infrastructure changes using remote sensing and GIS techniques and (ii) investigated the relationship between vegetation features and bird diversity.

MATERIALS AND METHODS

Study Area

Gombe State University is situated in the heart of Gombe City, which is located in the central part of Gombe State. The university campus is situated at coordinates 10°17'N 11°10'E, covering an area of approximately 500 hectares (Ajayi *et al.,* 2021). The region has a tropical savanna climate, characterized by a distinct wet and dry season. The annual rainfall ranges from 800 to 1,200 millimeters, with the rainy season typically lasting from May to October. The mean annual temperature is around 26°C, with the hottest months being April and May (Ede *et al.,* 2020). The topography of the study area is generally flat, with slight undulations and gentle slopes. The area is situated within the Benue Trough, a major geological feature in Nigeria, which has influenced the soil and vegetation characteristics of the region (Oladele *et al.,* 2022).

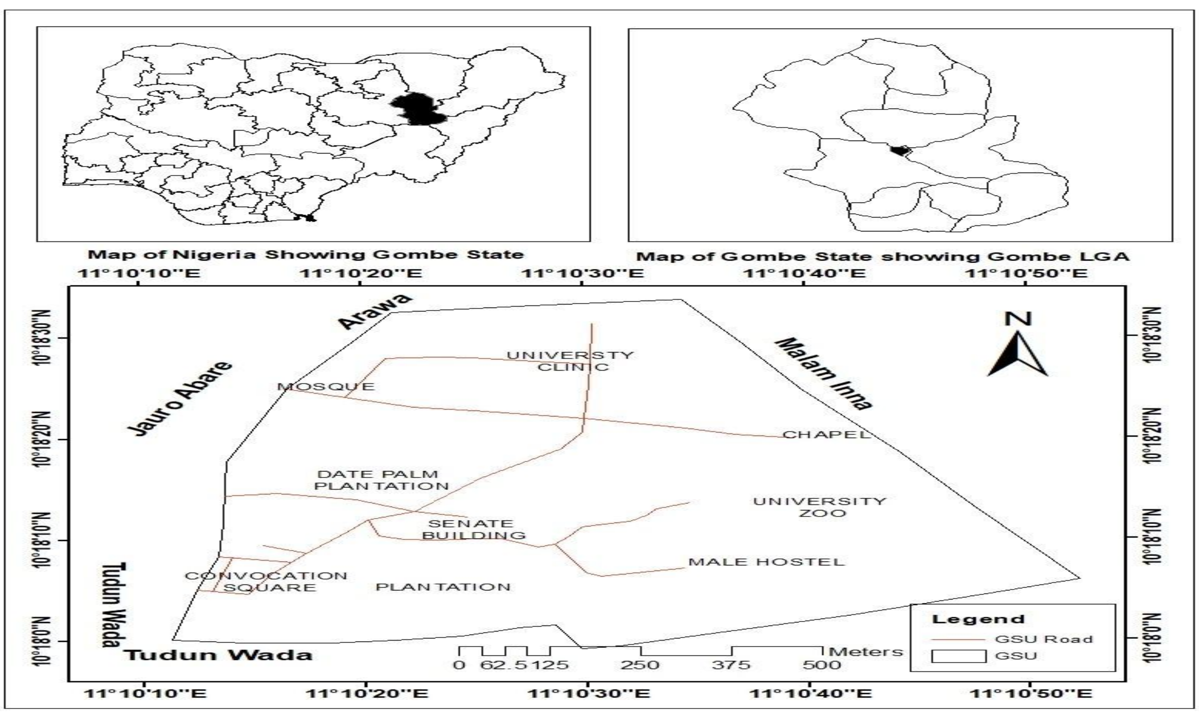

Figure 1: Map of the study area

Site Selection and Stratification

Sampling plots were established in both impacted (developed) and control (vegetated) areas, each measuring 50 × 50 meters and geo-referenced using GPS. Based on vegetation structure and degree of human modification, the study area was stratified into three habitat types: highly human modified, natural and semi-natural/mixed use habitats

This classification provided a framework for comparing avian community structure along gradients of habitat modification and vegetation complexity.

Land-Use and Land-Cover (LULC) Analysis

Landsat satellite images for the years 2004, 2015, and 2025 were used to assess land-use and land-cover (LULC) changes within the Gombe State University (GSU) landscape. The images were obtained from the United States Geological Survey (USGS) archive and selected based on minimal cloud cover, similar seasonal timing, and the standard 30-m spatial resolution of Landsat sensors. Pre-processing steps in ArcGIS included layer stacking, subsetting to the university boundary, and reprojection to the Universal Transverse Mercator Zone 32N (WGS 84).

Bird Survey Methods

Birds Sample Technique

Avain surveys were connducted using direct visual observation and opportunistic auditory identification. The study focused on diurnal bird species, as surveys were conducted during daylight hours (6:30am-9am in the mornings and 4:30pm 6:00pm in the evenings) when bird activity is highest. Bird populations were monitored through point counts. During point counts, all birds seen or heard within a 50-meter radius over 10-minute sessions were recorded. These observations were repeated three times at each point during both the wet and dry seasons to account for seasonal variations (Matthew *et al.*, 2024, Sutherland *et al.,* 2021).

Species Identification and Classification

The Field guide "Birds of Western Africa" by Borrow and Demey (2014) was used for species identification where direct identification proves difficult. Binoculars and digital recorders were used to capture call signatures. For each bird encountered, the species identity, number of individuals observed, habitat type, behaviour, activity and resource or habitat feature utilised were all recorded. Birds were subsequently classified into feeding guilds in order to assess functional diversity and habitat suitability. These classifications help assess their usefulness as indicators of ecosystem health (Danmallam *et al.*, 2024).

Species Abundance and Diversity

Species Abundance

Species abundance was determined as the total number of individuals of each species recorded throughout the survey period. Relative abundance was calculated as the proportion of individuals of a given species relative to the total number of birds observed.

Species Diversity

Species diversity was determined using the Shannon Weiner Diversity index (H). To determine Shannon Weiner species diversity, the proportion of species (i) relative to the total number of species (pi) is calculated, and then multiplied by the natural logarithm of this proportion (lnpi), see equation below.

$$\text{Shannon Weiner index H}' = -\sum_{i=1}^{S} p_i log_e p_i$$

$$\text{H}'(\text{Shannon Weiner index}) = -p_i log_e p_i$$

Where pi = the proportion of individuals of species "i" in relation to the total population of all species. H' = Shannon Wiener Diversity Index. loge = natural logarithm of base e

is a measure of uncertainty in predicting the species identity of an individual that is taken at random from the data set,is not a measure of true diversity. (Magurran & McGill, 2011; Chao *et al.,* 2014).

Data Analysis

Collected data was analyzed using a combination of statistical and ecological techniques. Descriptive statistics was used to summarize species composition, abundance, habitat use and behavioural patterns. Chi-square test was employed to examine associations between bird species, behaviour, activity patterns, resource or habitat use and time of the day. All statistical tests were conducted at a 95% confidence level, and significance was determined at $p < 0.05$.

RESULTS

Land-Use and Land-Cover Changes Associated With Infrastructural Development

Land use and land cover changes within Gombe state university campus between 2004, 2015 and 2025 are presented in Table 1 and Figure 2, 3 and 4. The LULC maps (Figure 2, 3 and 4) reveal a progressive increase in built-up areas and road networks over time, accompanied by a decline in vegetation and grass land cover.

Table 1: Land Use Land Cover Areas and Percentages for 2004, 2015 and 2025

Class/Year	2004 (%)	2015 (%)	2025 (%)
Vegetation	160,099.40 (19.72)	330,480.80 (40.70)	242,713.00 (29.89)
Built-up	47,184.91 (5.81)	80,011.49 (9.85)	124,469.00 (15.33)
Grassland	326,040.90 (40.16)	272,575.00 (33.57)	90,869.67 (11.19)

Bare surface	278,607.90 (34.31)	267,088.10 (32.89)	125,992.00 (15.52)
Roads	-	43,482.87 (5.35)	46,184.00 (5.69)

Source: GSU GIS Lab Analysis (2025).

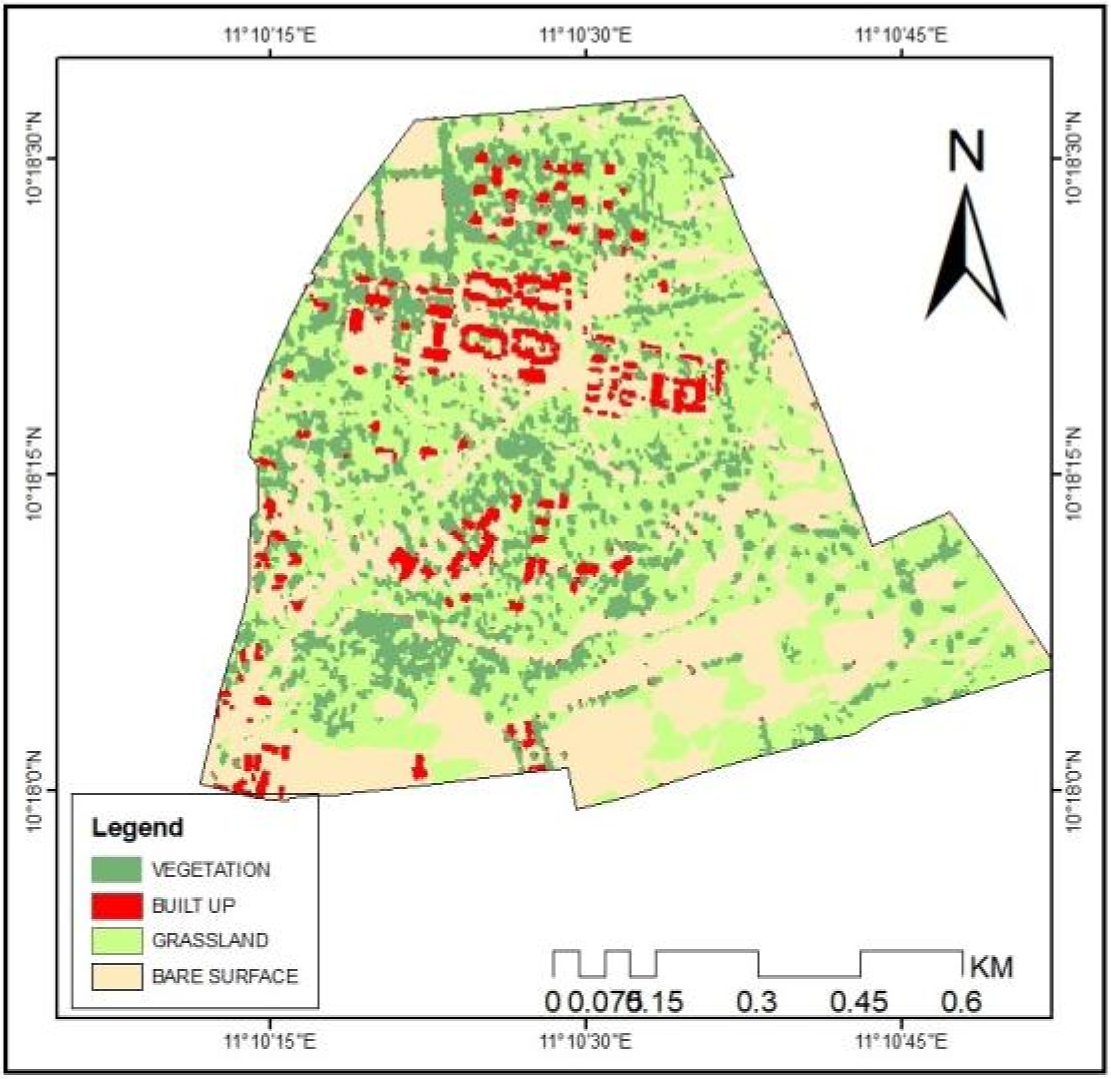

Figure 2: Land Use Land Cover Map of the Study Area for 2004
Source: GSU GIS Analysis Lab (2025)

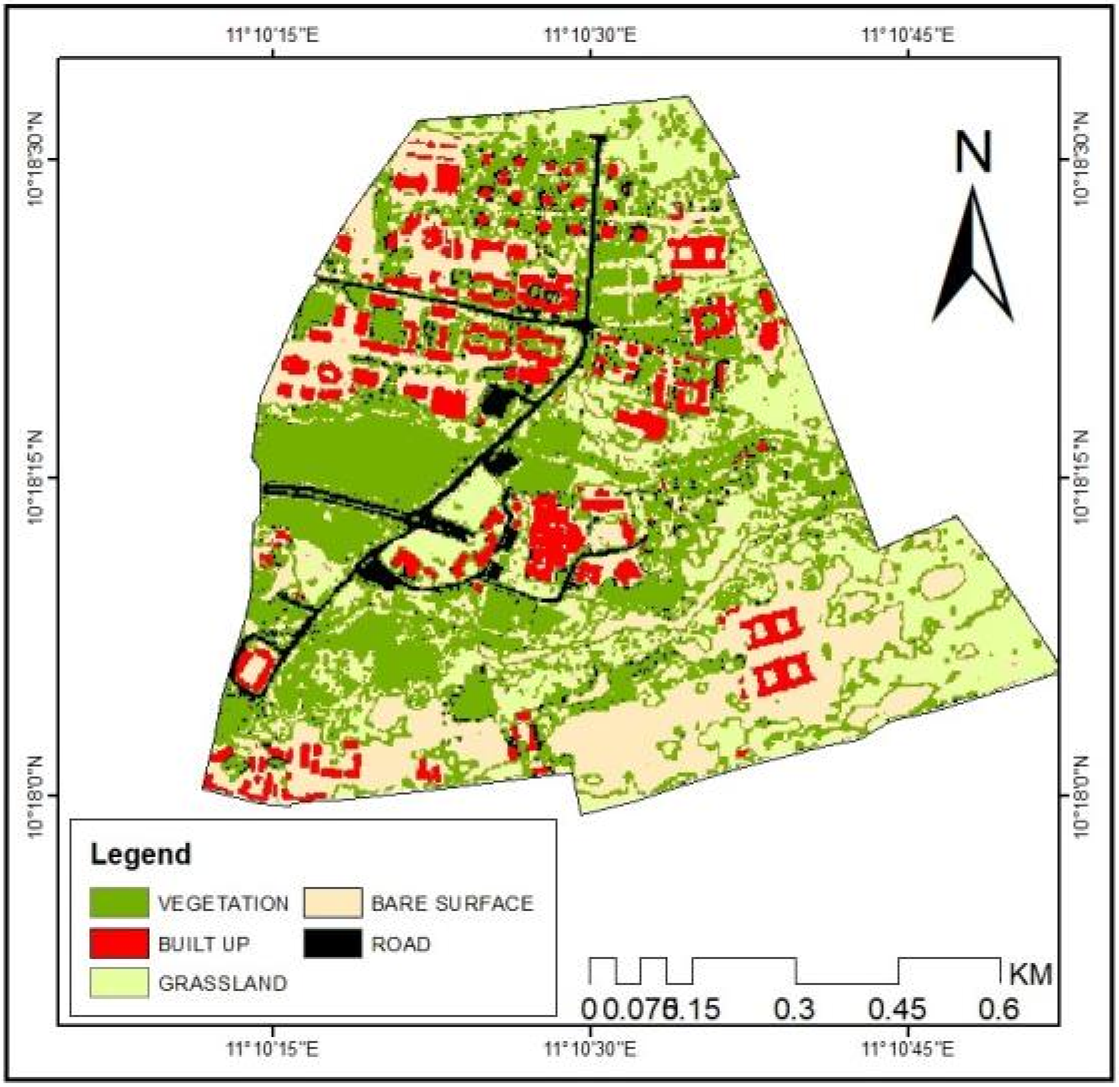

Figure 3: Land Use Land Cover Map of the Study Area for 2015
Source: GSU GIS Analysis Lab (2025)

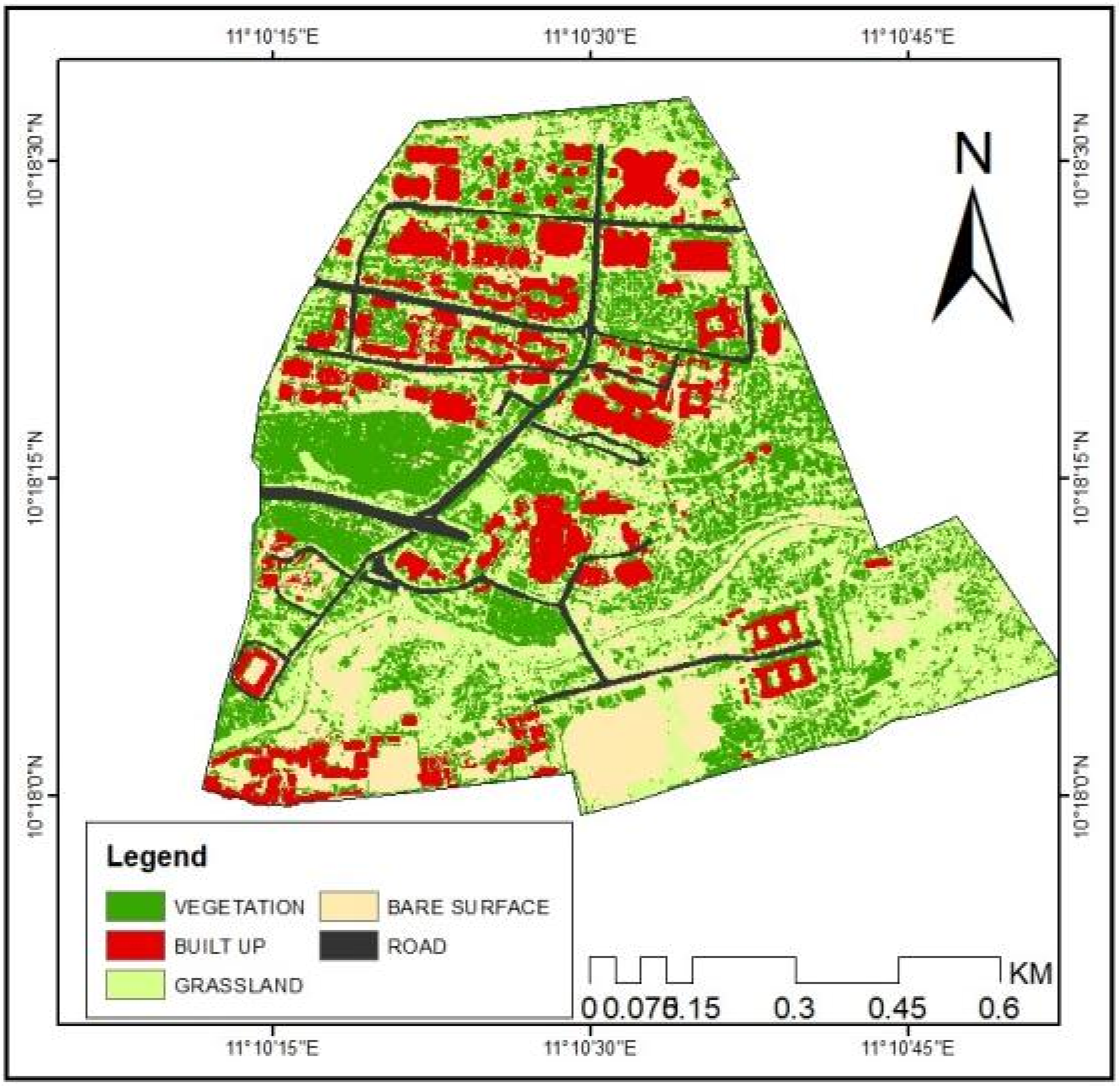

Figure 4: Land Use Land Cover Map of the Study Area for 2025
Source: GSU GIS Analysis Lab (2025)

Association Between Vegetation Features and Avian Abundance and Diversity

A total of 1750 individuals from 37 species, 30 genera, 25 family and 12 order were recorded at the end of the study . Two species recorded in this study have never been recorded previously in the study area, these are; The Eurasian Hoopoe and Rose ringed Parakeet. Variation in bird abundance and diversity across habitat types with differing vegetation characteristics is shown in table 2 and figure 3. Areas characterized by heterogenous vegetation structure supported higher numbers of individuals and species compared to sparsely vegetated or highly modified areas.

A Chi-square test of independence showed a statistically significant association between vegetation/ habitat type and bird abundance, $x^2(80, N=781) = 146.51$, $p<0.001$. Similarly,vegetation/habitat type was significantly associated with bird activity, $x^2(48, N=781) = 1701.64$, $p<0.001$, and bird behaviour $x^2(24, N=781) = 176.10$, $p<0.001$.

Species diversity analysis using the Shannon-Wiener Index yielded a value of H' = 1.20, indicating moderate species diversity within the study area. This suggests that although species richness was relatively high, community structure was influenced by the dominance of a few generalist species such as laughing dove and cattle egret.

Table 2: Association between Vegetation Features and Avian Abundance and Diversity in the Study Area

SPECIES	HHM (22)	NAT/ HOMO (24)	SN/ HET (36)	SN/ HOMO (20)
Abyssinian Roller	5	4	9	0
African Silverbill	0	1	7	1
African Thrush	4	5	21	5
Beautiful Sunbird	3	3	19	1
Black-headed Lapwing	12	103	28	39
Black-shouldered kite	1	1	3	0
Brown Babbler	6	9	10	4
Cattle egret	27	62	92	29
Chest-nut bellied Starling	4	0	21	0
Common Bulbul	14	3	26	2
Common Swift	0	2	0	1
Double-toothed Barbet	0	0	2	0
Eurasian Hoopoe	0	0	3	0
Grey-headed Kingfisher	0	6	12	0
Lanner falcon	16	6	16	5
Laughing Dove	177	38	140	54
Little Swift	0	0	2	3
Little Weaver	0	0	5	0
Long-tailed Glossy Starling	74	14	75	19
Northern Red-billed Hornbill	1	2	14	2
Piapiac	24	12	35	11
Pied Crow	0	0	2	0
Purple Starling	28	9	71	7
Red-billed Firefinch	0	0	15	3
Red-cheeked Cordon Bleu	12	16	33	0
Rose Ringed Parakeet	0	0	6	0
Scarlet-chested Sunbird	0	4	10	0
Senegal Coucal	9	1	19	0

Speckled Pigeon	23	7	13	6
Variable Sunbird	1	5	21	0
Village Ingido Bird	3	0	6	5
Village Weaver	1	3	16	0
Vinaceous Dove	0	0	3	0
Western-grey Plantain eater	0	0	11	1
Yellow-billed Shrike	0	0	3	6
Yellow-crowned Gonolek	0	0	3	0
Yellow-fronted Tinker bird	0	2	11	0
	445	318	783	204

Note: Values within brackets represent total number of species. Highlighted species are habitat specialist (those dependent on only one of the four available habitat types). HHM = Highly human modified, NAT/HOMO = Natural homogeneous, SN/HET = Semi natural Heterogeneous, SN/HOMO = Semi natural Homogeneous.

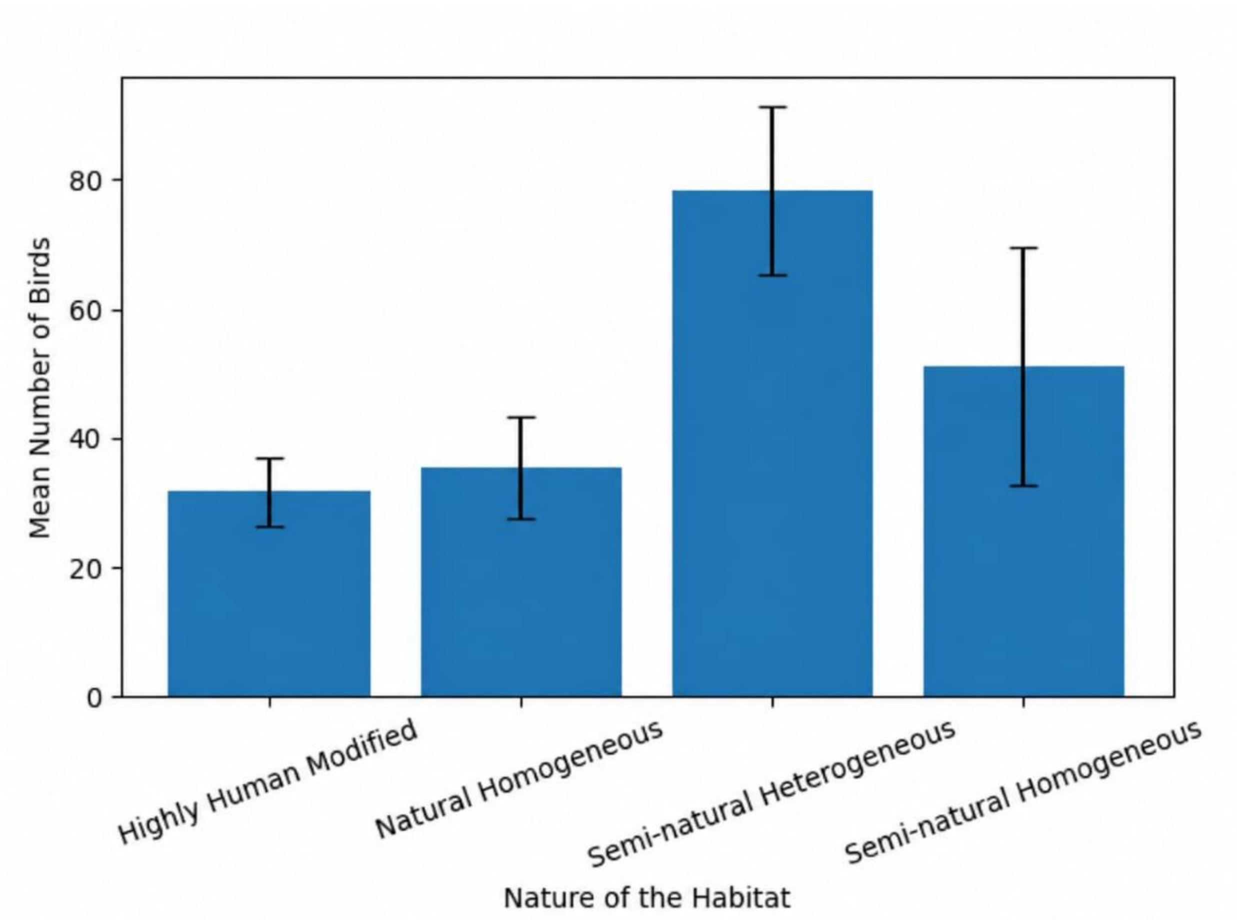

Figure 5: Mean Habitat Use and Abundance of birds in the study area (Mean ± SE**)**

DISCUSSION

The results of this study clearly indicate that infrastructure expansion within Gombe State University has significantly altered vegetation cover over time. Although an increase in vegetation was observed during the early phase of campus development, this trend declined as construction activities intensified. Similar patterns have been widely reported in developing urban and institutional landscapes, where initial greening efforts are often overshadowed by rapid infrastructural growth (Seto *et al.*, 2012; Güneralp *et al.*, 2017; Ibáñez-Álamo *et a*l., 2020). Vegetation loss associated with expanding built-up areas has been identified as a major driver of habitat fragmentation and ecological simplification, particularly in savanna-derived landscapes (Fahrig, 2017; Haddad *et a*l., 2015). In African contexts, studies by Adepoju *et a*l. (2020) similarly report that increasing impervious surfaces reduce vegetation continuity and ecosystem resilience.

Similarly, Rahman *et al.* (2023) found that infrastructure development significantly altered vegetation structure and reduced habitat availability for wildlife in developing urban environments. In a study conducted within northern Nigeria, Ibrahim *et al.* (2020) observed that campus development activities contributed to vegetation loss and changes in habitat quality, with potential implications for biodiversity conservation. The decline in vegetation cover recorded in 2025 in the present study therefore reflects a broader trend associated with infrastructure expansion across many developing regions. However, the temporary increase in vegetation cover observed between 2004 and 2015 suggests that landscape management practices and natural regeneration may partially offset vegetation loss during the early stages of development. Similar observations were reported by Ede *et al.* (2020), who noted that green spaces within institutional environments can provide important ecological functions despite ongoing urbanisation pressures. The decline in vegetation cover observed in this study suggests increasing pressure on natural habitats, which may have implications for biodiversity conservation if not properly managed.

The strong association observed between vegetation features and bird diversity and abundance highlights the importance of habitat structure in shaping avian communities. Areas with higher vegetation heterogeneity supported significantly greater bird abundance and species richness compared to sparsely vegetated or human modified habitats. Recent recent studies reinforce this relationship, showing that vegetation complexity is a critical predictor of bird diversity in both urban and semi-natural landscapes (Aronson *et al.*, 2014; Beninde *et al.*, 2015; Ikin *et al.*, 2019). In tropical and subtropical regions, Ibáñez-Álamo *et al.* (2020) and Shanahan *et al.* (2021) demonstrated that green spaces with multi-layered vegetation support richer and more stable bird assemblages. Studies by Akinyemi and Ogunjemite (2016) and Lawal *et al.* (2021) further corroborate these patterns at the local scale. These findings confirm that vegetation features play a crucial role in determining avian diversity and abundance.

The findings of the present study are consistent with earlier avifaunal surveys conducted within Gombe State University campus. Adang *et al.* (2015) recorded 37 bird species across various habitat types within the campus, despite extensive habitat modification associated with infrastructure development. This similarity suggests that university campuses, even when heavily altered, can support considerable avian diversity if patches of natural vegetation are retained.

Differences in species richness and community composition between studies may be attributed to variations in sampling period, seasonal effects, habitat coverage, and methodological intensity. The presence of migratory species reported by Adang *et al.* (2015) further indicates the importance of campus environments as temporary refugia within the broader Sudan Savanna landscape. Although relatively high bird species richness was recorded within the campus, the community was dominated by disturbance-tolerant species, particularly habitat generalist and synanthropic species. This pattern is consistent with findings from urban ecology studies worldwide, which show that generalist species often persist in modified environments due to their ecological flexibility (McKinney, 2008; Sol *et al.*, 2014). The moderate Shannon-Wiener diversity index value suggests that although species richness is relatively high, species evenness is influenced by the dominance of a few generalist species such as laughing dove and Cattle Egret. While species richness may remain stable, community composition frequently shifts toward a subset of adaptable species, masking underlying biodiversity loss.

CONCLUSION

This study assessed long-term changes in vegetation cover, infrastructure expansion and their effects on avian species composition, diversity and abundance within Gombe State University main campus. Using remote sensing and GIS techniques, the results unequivocally demonstrated that vegetation cover decreased while built-up areas increased over the past two decades.
Bird surveys showed a relatively high richness of avian species, with structural complexity of vegetation strongly influencing bird abundance and diversity. Generalist species adapted to human-modified environments were more abundant, while specialist species were largely confined to semi-natural habitats. Statistical tests confirmed significant associations between vegetation features and bird abundance, activity, and behavioural patterns. Overall, the findings highlight the critical role of vegetation heterogeneity in sustaining bird communities, even in landscapes experiencing rapid infrastructure expansion. The results provide a scientific basis for environmentally informed planning and habitat conservation with academic settings.

CONFLICTS OF INTEREST

The Authors declare no conflicts of interest

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