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ENVIRONMENTAL DRIVERS OF ANURAN DIVERSITY IN AN URBAN LAKE

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ABSTRACT

Urban freshwater ecosystems are increasingly threatened by anthropogenic activities that alter habitat quality and environmental conditions, with important implications for amphibian communities. This study assessed the influence of habitat characteristics and physicochemical variables on the diversity and distribution of anurans at Jabi Lake, Abuja, Nigeria. A total of 257 anurans were investigated, and findings revealed four anuran families: Bufonidae, Pipidae, Dicroglossidae, and Ranidae, comprising five species across four genera namely: Sclerophrys regularis, Xenopus fischbergi, Xenopus tropicalis, Hoplobatrachus occipitalis, and Amnirana galamensis. Anuran species richness and evenness were notably higher during the wet season, with biodiversity indices peaking in the rainy months. Simpson's index showed the least probability in August (0.2049) with an exponential increase of 0.5062 and 0.5556 in January and February. It was observed that Shannon-H of 0 in March and May (Dry season) indicate no evenness among the species during those months. However, this increased subsequently in the rainy season with the highest (1.597) observed in August. The CCA revealed that dissolved oxygen, water temperature, pH, and turbidity were the principal environmental variables influencing anuran distribution. Xenopus fischbergi and Amnirana galamensis were strongly associated with habitats characterized by elevated dissolved oxygen, lower pH, and cooler water, indicating relatively narrow ecological requirements. In contrast, Sclerophrys regularis exhibited greater tolerance to elevated temperature, higher pH, and moderate turbidity, reflecting considerable ecological plasticity and persistence under dry-season conditions. Hoplobatrachus occipitalis and Xenopus tropicalis showed comparatively weak associations with the measured physicochemical variables, suggesting broader ecological tolerances and responses to multiple interacting habitat factors.

Keywords: Amphibian ecology, Canonical Correspondence Analysis (CCA), Physicochemical parameters, Urban freshwater ecosystems, Wetland conservation

Introduction

Anurans (frogs and toads) represent the most species-rich order within the class *Amphibia* and are among the most evolutionarily successful groups of terrestrial vertebrates (Luedtke *et al.,* 2023; Morinaga *et al.,* 2023). They comprise approximately 5,200 formally described species, although recent taxonomic assessments recognize more than 7,800 extant species, making them the largest amphibian order (Campbell *et al.,* 2024). Their distribution spans all continents except Antarctica and extends to many oceanic islands, reflecting remarkable evolutionary diversification, ecological plasticity and adaptive radiation (Edo-Taiwo & Aisien, 2023). Consequently, anurans occupy an extensive range of habitats, including tropical rainforests, temperate wetlands, montane streams, savannas, floodplains, agricultural landscapes and urban ecosystems (Figueiredo *et al.,* 2019). Their broad ecological distribution and environmental sensitivity have established them as important model organisms for studying biodiversity, habitat selection, community ecology and ecosystem responses to environmental change (Luedtke *et al.,* 2023).

The ecological success of anurans is closely linked to specialized morphological, physiological, and behavioural adaptations. Their compact skeletal structure, characterized by a shortened vertebral column, lightweight skull and elongated hind limbs, enables diverse locomotor strategies including jumping, swimming, climbing, burrowing, walking, running and gliding, allowing species to exploit aquatic, terrestrial, arboreal and fossorial habitats (Campbell *et al.,* 2024; Vasallo *et al.,* 2022; Leavey *et al.,* 2023). This functional versatility has facilitated extensive adaptive radiation across diverse environmental conditions.

Physiologically, anurans are highly dependent on their surrounding environment because, as ectothermic vertebrates, they rely on external thermal conditions to regulate metabolism, locomotor performance, growth, reproduction and behavioural activity (Milsom *et al.,* 2022; Carilo Filho *et al.,* 2022). Temperature and humidity strongly influence breeding phenology, calling behaviour, feeding activity, larval development and survival, such that even subtle climatic fluctuations may alter reproductive success, population dynamics and community structure (Cook *et al.,* 2022).

Understanding how habitat characteristics and environmental variables influence anuran diversity and distribution at Jabi Lake is therefore important for biodiversity conservation, urban wetland management and sustainable land-use planning. Identifying the environmental factors that most strongly influence species occurrence will support habitat restoration, conservation of breeding sites, maintenance of ecological connectivity and improved environmental monitoring. Moreover, the study provides baseline ecological information for long-term amphibian conservation in Nigeria and contributes to the limited body of knowledge on amphibian ecology within West African urban wetlands.

Accordingly, this study investigates the influence of habitat characteristics and environmental drivers on the diversity and distribution of anurans in Jabi Lake, Abuja, Nigeria. Specifically, it evaluates the relationships between habitat conditions and anuran community structure to generate scientific evidence that supports effective wetland conservation, biodiversity management, and environmentally sustainable urban development.

Materials and Methods

Study Area

The study was conducted at Jabi Lake, Abuja, Federal Capital Territory (FCT), Nigeria (9°04′N, 7°29′E). Jabi Lake is an artificial freshwater reservoir located within the Jabi District of Abuja (Fig. 1) between and represents one of the most important urban freshwater ecosystems in the FCT (Osodi *et al.,* 2024). The lake supports multiple ecosystem services, including recreation, fisheries, biodiversity conservation, and water storage, while simultaneously experiencing increasing anthropogenic pressures associated with rapid urbanization and commercial development. The area experiences a tropical wet-and-dry (Aw) climate characterized by two distinct seasons: a warm, humid rainy season extending from April to October and a dry season from November to March (Ezeamaka *et al.,* 2019). During the rainy season, daytime temperatures generally range between 28–30°C, while nighttime temperatures vary from 22–23°C (Atiribom *et al.,* 2012). In contrast, dry-season daytime temperatures may exceed 40°C, with nighttime temperatures occasionally falling to approximately 12°C (Ezeamaka *et al.,* 2019). The relatively high altitude and gently undulating terrain of the FCT moderate local climatic conditions, creating diverse microhabitats that influence vegetation structure, hydrology, and amphibian distribution (Goma & Kuku, 2024).

The shoreline of Jabi Lake comprises a heterogeneous landscape of riparian vegetation, marshy habitats, recreational parks, commercial infrastructure, and fishing areas. This environmental heterogeneity provides a wide range of aquatic and terrestrial habitats suitable for anuran breeding, foraging, refuge, and dispersal, making the lake an ideal location for investigating the influence of habitat characteristics and environmental variables on anuran diversity and distribution.

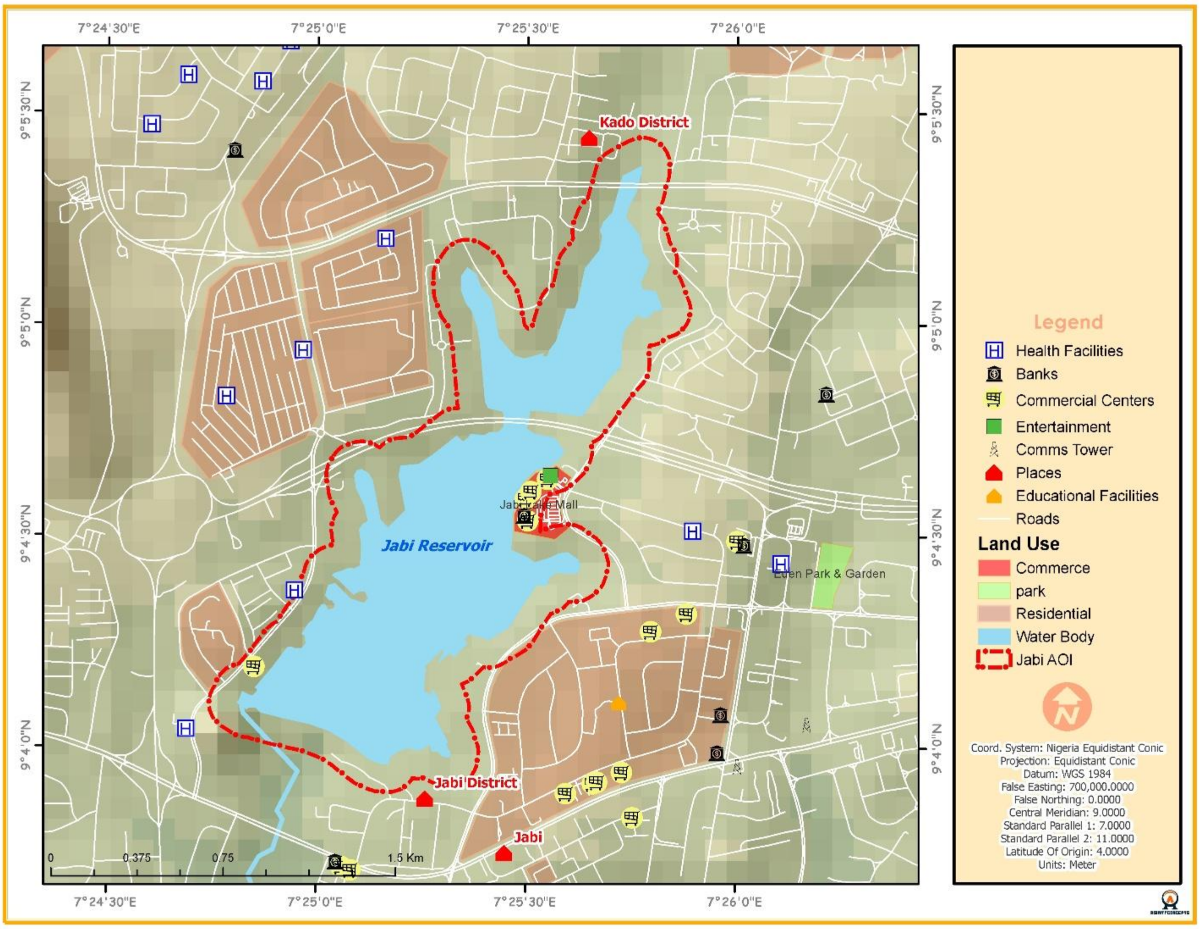

Figure 1: Map of Jabi Lake, Abuja (Osodi *et al.*, 2024).

Field Sampling and Anuran Survey

The Anurans (toads and frogs) were collected overnight between 20:00 and 05:00hrs once a month (January-December 2023) in vegetation close and away from the lake, underneath leaf litter and on the trees so as to include all species present in the lake. Auditory surveys and opportunistic samplings were used both in breeding and non-breeding periods so as to include most of the species in the study area (Osodi *et al.,* 2024). This nocturnal sampling required a five man-effort assisted with a handheld torchlight to increase anuran detection during sampling. Purposive sampling methods were employed to construct permanent quadrats and transects with a total of five permanent quadrats measuring 25 m × 25 m were set up at areas close to the lake. Besides, 100 m nocturnal transects were used to survey anurans in the vegetation away from the lake and vegetation trails with human disturbance. The GPS locations of all four angles of the quadrats and transects were obtained with a hand-held GPS in relation to the Universal Transvers Mercator (UTM) were taken for onward transmission to the GIS laboratory where the Google Earth Pro Software was used to produce pictures of the location (Yahaya *et al.,* 2025). Each ecological data, such as time and date of capture, microhabitat, and microclimate, were documented in a survey form. Safety precautions were put in place particularly as it concerned snakes by wearing thick boots, usage of hand gloves and bandaging exposed areas of the hand, other measures include usage of whistles on site, usage of back packs instead of handbags, and the usage of ankle length sticks to remove leaf litters coupled with well sharpened cutlasses and the usage of torch for proper illumination. The photographs of each anuran including dorsal, ventral, and side views were taken using iPhone xr for identification. In-situ water quality parameters were assessed at the lake each month to characterize the aquatic environment. Water temperature was recorded using a standard mercury-in-glass thermometer. The pH of the water samples was measured using a portable Corning pH meter (Model 315). Dissolved oxygen (DO) concentrations were measured in situ using a Jenway DO meter (Model 9071). To ensure analytical accuracy, all DO measurements were validated using the modified Winkler method as described by the American Public Health Association ("Standard Methods for the Examination of Water and Wastewater: 20th Ed," 2000).

To estimate the number of species expected to be present in a random sample of individuals taken from any given collection (Colwell et al., 2012), a rarefaction curve was generated using a sample-based rarefaction method in **Estimate Version 9.1.0** (Colwell & Elsensohn, 2014). All diversity indices were analyzed using MVSP Version 3.22 to calculate the Shannon-Wiener Diversity Index (H'). The Shannon-Wiener analysis was used to measure the species diversity in a community, while species evenness (E) was calculated using Simpson's Index to determine whether individuals in a community were dominated by one species or evenly distributed. Additionally, the Simpson Index was used to measure the probability that two randomly selected individuals will belong to the same species. This index assists in measuring the richness and evenness of the community in a given period of time or area under study. The evenness index was used to estimate the distribution of occurrences of different anuran species. The Chao-1 index was used to measure the abundance of species assuming that the number of organisms identified for a taxon has a Poisson distribution.

Canonical Correspondence Analysis (CCA) was conducted using Paleontological Statistics (PAST) Version 3.22 to determine the relationship between anuran species and environmental variables.

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Figure 2: Quadrat 1

Figure 3: Quadrat 2

Figure 4: Quadrat 3

Figure 5: Quadrat 4

Figure 6: Quadrat 5

Results

Table 1: Monthly distribution of Anuran species.

Species	January	February	March	April	May	June	July	August	September	October	November	December
S. regularis	0	1	2	6	3	6	9	10	10	5	7	1
X. fischbergi	6	0	0	0	0	1	6	10	10	10	10	7
X. tropicalis	1	0	0	0	0	6	6	10	9	8	10	9
H. occipitalis	0	0	0	0	0	0	0	8	4	6	4	1
A. galamensis	2	2	0	0	0	4	10	8	6	6	7	8
Total	9	3	2	6	3	17	31	48	39	35	38	26

Source: Field work 2023

From the result (Table 1), there is a pattern of distribution of Anuran species throughout the season with an increased number occurring during the rainy season (July, August, September, October and November).

Regarding species richness, which is denoted by the number of species present, an increase in the number of species was observed from the dry to rainy season. Specifically, all the species are present from August to December while there is reduced species abundance in January to May (Table 2).

The Simpson's index measures the probability that two random selections will be the same species. The lowest probability was observed in August (0.2049), which is the peak of the rainy season. However, an exponential increase in the probability in January and February which are 0.5062 and 0.5556 respectively and Simpson's index of 1 from March to May was observed (Table 2). This is because only one species (*S. regularis*) was observed because most anurans aestivate during this period.

With regards to the Shannon-H index which measures richness and evenness of a species, the results indicated a Shannon-H of 0 in March and May (Dry season) which indicates zero evenness of the species for the month. However, this increased subsequently in the rainy season with the highest (1.597) observed in August (Table 2).

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Table 2: Biodiversity index of Anuran species at Jabi Lake, Abuja

Month/	Chao-1	Equitabilit	Shannon_	Simpson’	Individual	Taxa_S
January	3	0.7725	0.8487	0.5062	9	3
February	2	0.9183	0.6365	0.5556	3	2
March	1	0	0	1	2	1
April	1	0	0	1	6	1
May	1	0	0	1	3	1
June	4	0.8961	1.242	0.308	17	4
July	4	0.9808	1.36	0.2633	31	4
August	5	0.9925	1.597	0.2049	48	5
September	5	0.968	1.558	0.2189	39	5
October	5	0.9804	1.578	0.2131	35	5
November	5	0.9711	1.563	0.2175	38	5
December	6	0.8287	1.334	0.2899	26	5

The evenness index estimates how close the number of occurrences of different species of anuran is. From the study, the Evenness Index (J) was high almost throughout the year indicating that anuran species are closely or evenly distributed in the community. However, the index was 0 in March, April, and May due to the presence of one anuran species (*S. regularis*) during those months. Finally, the Chao-1 index from the study revealed a higher abundance in December (6) with relatively high abundance (4-5) from June to November. However, there was low abundance (1) from March to May.

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Table 3: Mean Value of Physio-chemical Parameters at Jabi Lake Abuja

Month/2023	Water Temp.	Dissolved Oxygen	pH	Turbidity
January	18.47	5.86	6.7	21.5
February	20.9	5.62	6.7	21.6
March	26.2	6.05	7.0	21.6
April	29.04	5.37	7.4	21.4
May	28.49	5.45	7.6	21.4
June	26.29	5.26	7.5	22.2
July	23.11	5.09	6.2	23.6
August	19.93	4.72	6.4	24.2
September	21.79	5.43	6.9	23.7
October	22.45	6.10	7.3	23.6
November	23.56	7.04	7.8	21.8
December	23.03	6.6	7.6	21.6

Source: Field Work 2023

The monthly variation in the physio-chemical characteristics of Jabi Lake demonstrates the strong influence of seasonal climatic conditions on the aquatic environment and provides important insight into the environmental factors governing anuran diversity and distribution. Although fluctuations were observed in water temperature, dissolved oxygen (DO), pH, and turbidity throughout the study period, all measured parameters remained within ranges generally considered suitable for freshwater amphibians. Seasonal changes in these variables are characteristic of tropical urban lakes, where rainfall, evaporation, runoff, and biological productivity collectively regulate water quality and habitat suitability (Mann et al., 2022; Wang et al., 2023).

The result of the Canonical Correspondence analysis (CCA) map below (Figure 7) shows the association between the physicochemical parameters (dissolved oxygen, turbidity, pH and water temperature) and the five anuran species observed. The analysis indicated that dissolved oxygen and water pH are negatively correlated, as is water temperature. The water turbidity has a positive correlation with the water temperature but negative correlation with the pH.

Concerning the association of the Anuran species to the physicochemical parameters, it was observed that *X. fischbergi* and *A. galamensis* are more sensitive to increased dissolved oxygen in the water and are mostly observed when water oxygen levels are high. Conversely, they are more adapted to lower pH and water temperature conditions. *S. regularis* is sensitive to high pH, and the study revealed that they are likely to be observed when both pH and water temperature are high, in contrast to what was exhibited by *X. fischbergi* and *A. galamensis*. This is important because *S. regularis* is the only anuran species we observed to be present during the dry season (March to May). This explains their ability to survive these conditions. During the dry season, water temperature rises, which also raises the water pH due to increased algal activity. However, *S. regularis* populations increase with turbidity, and they prefer clear and clean water bodies. H. occipitalis was observed to be randomly occurring and not necessarily influenced by the physicochemical parameters, meaning they are readily available without strong preference for any specific physicochemical conditions.

Finally, the *X. tropicalis* displays a similar characteristic as *H. occipitalis* but are still seldom affected by physicochemical parameters, as indicated by their presence or closeness to the center of the Canonical Correspondence Analysis map.

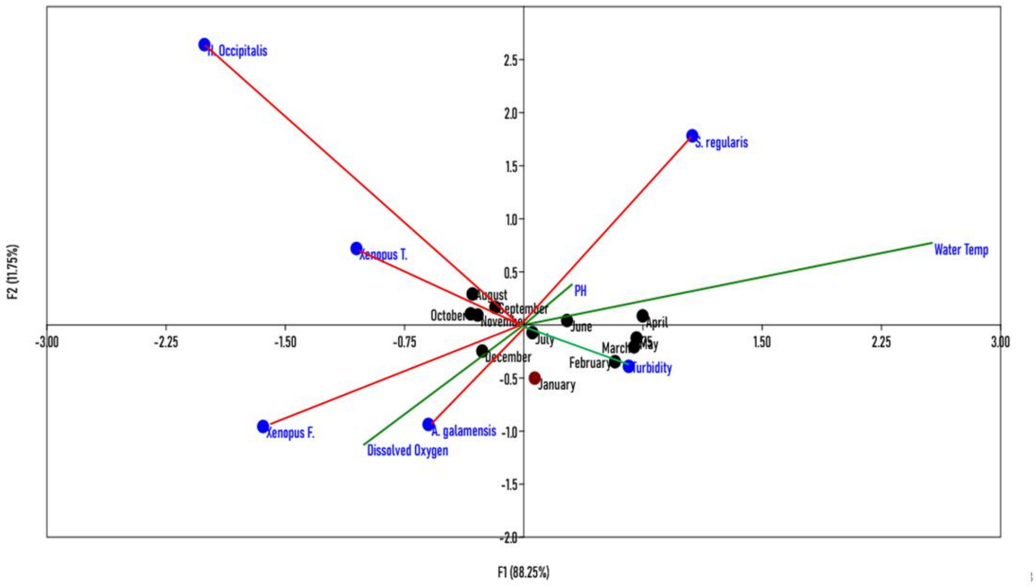

Figure 7: CCA graph showing the relationship between Anurans distribution and Environmental parameters

Discussion

There is ample evidence to suggest that the rainy season increases the diversity of anuran species, and this is because the rainy season provides the ideal breeding conditions for anurans and there is an increase in food supply such as insects, earthworms, and other invertebrates. Forti *et al.* (2022) discovered that anuran diversity in tropical forests peaks during the rainy season, which was observed in this study as well. Campbell *et al.* (2024) also noted that the presence and activity of anuran species are boosted when temporary pools or ponds are available when it rains, resulting in higher humidity and perfect conditions for larval development and breeding. From this study, an increase during the rainy season was observed; this might be due to the fact that there is an abundance of water bodies and food for the anurans.

In terms of abundance, because there are more breeding grounds and resources available during the wet season, species richness and diversity are higher (Ceron *et al.,* 2020) according to a study on anuran metacommunities in Western Brazil and another in Southeastern Nigeria (Nneji et *al.*, 2021). This study shows an increase in species richness from the dry to the rainy season, which is consistent with studies carried out in other tropical locations including in Nigeria. In a study conducted in Benin, Nigeria, Gansa *et al.* (2023) found that anuran richness was higher during the wet months. They attributed this to the seasonal availability of mating grounds. Similarly, Edo-Taiwo and Aisien (2023) found that seasonal variations have a substantial impact on anuran populations, with a discernible rise in species diversity during wet seasons. Ecological studies typically use biodiversity indices, such as Shannon's and Simpson's, to measure species evenness and diversity. The significance of these indices in comprehending the dynamics and structure of communities was highlighted by Kunakh *et al.* (2023). The observation of increased indices during the wet season highlights the seasonal implications for biodiversity, which is consistent with trends observed in other research (Jolaosho *et al.,* 2023). These indices aid in comprehending a community's species distribution and abundance (Kabanze, 2024).

Furthermore, in terms of the checklist of anurans recorded in the lake, Anele *et al.* (2020) recorded a similar number of anuran species in their study in Zaria, Nigeria with the exception of *Amnirana galamensis* which was recorded in this research. Also, in the Guinea savanna at New Bussa, Niger state Nigeria, Aisien *et al.* (2004) only recorded 4 anuran species (*A.galamensis, H. occipitalis, S. maculata* and *S. regularis*) in their study. Although this was to be expected since the study took a short period of time in contrast to the present investigation which span two seasons and thus provided a higher possibility for more anuran species to be inclusive or encountered.

The Canonical Correspondence Analysis (CCA) (Fig. 7) demonstrated that variation in anuran distribution at Jabi Lake was strongly associated with key physicochemical variables, particularly dissolved oxygen (DO), pH, water temperature, and turbidity. These findings indicate that water quality constitutes a primary environmental filter influencing species occurrence and habitat use. The observed inverse relationship between DO and both pH and temperature are consistent with established limnological principles: increasing water temperature generally reduces oxygen solubility, while elevated pH often reflects intensified photosynthetic activity and shifts in carbonate chemistry. Such interactions are critical to amphibian ecology, as oxygen availability directly affects embryonic survival, larval metabolism, and physiological fitness (Ferreira et al., 2025; Mausberg et al., 2023)

Species-specific responses to these environmental gradients were evident. *Xenopus fischbergi* and *Amnirana galamensis* showed a strong positive association with elevated DO and lower pH, suggesting a dependence on stable, well-oxygenated aquatic habitats. These conditions likely facilitate successful larval development and metamorphosis while minimizing the physiological stress associated with hypoxic environments (Zhao & Wang, 2021). Conversely, *Sclerophrys regularis* exhibited a positive association with higher pH, elevated water temperature, and turbidity. The consistent presence of *S. regularis* during the dry season (March–May) highlights its ecological plasticity and resilience to the environmental stressors of disturbed urban landscapes, such as shoreline modification, sediment resuspension, and temperature fluctuations (Edo-Taiwo & Aisien, 2023).

In contrast to the specialists, *Hoplobatrachus occipitalis* and *Xenopus tropicalis* occurred near the center of the CCA ordination, indicating weak responses to the measured physicochemical variables. This suggests that these species possess broader ecological tolerances and are likely influenced by a more complex array of factors—such as habitat structure, vegetation complexity, prey availability, and hydroperiod—rather than water chemistry alone (Mausberg et al., 2023). This ecological generalism is a well-documented trait among amphibians capable of persisting in highly modified, semi-urban environments where environmental conditions are frequently in flux (Lehtinen et al., 2023; Marsh et al., 2023)

Overall, these findings demonstrate that anuran communities at Jabi Lake do not respond uniformly to environmental change; rather, they exhibit species-specific preferences that dictate community composition. As urbanization and climatic variability continue to alter the water quality of the lake, sensitive taxa are likely to experience population declines, while generalist species will remain dominant. From a conservation perspective, these results highlight the urgency of maintaining water quality and protecting heterogeneous riparian habitats. Regular monitoring of physicochemical parameters, combined with the mitigation of shoreline pollution, should form an integral component of biodiversity management strategies for urban freshwater ecosystems.

Conclusion

This study demonstrates that habitat characteristics and physicochemical conditions are major determinants of anuran diversity and distribution at Jabi Lake, Abuja, Nigeria. The Canonical Correspondence Analysis (CCA) showed that dissolved oxygen, water temperature, pH and turbidity significantly influenced species occurrence and community composition, confirming that water quality functions as an important ecological filter within this urban freshwater ecosystem. The observed variation in species responses highlights the importance of habitat heterogeneity in maintaining amphibian diversity, as different species exhibited distinct ecological preferences and tolerances.

Species-specific responses revealed clear differences in ecological adaptability. *Xenopus fischbergi* and *Amnirana galamensis* were closely associated with well-oxygenated habitats characterized by relatively low pH and cooler water temperatures, indicating greater dependence on stable aquatic conditions and increased sensitivity to environmental disturbance. Conversely, *Sclerophrys regularis* demonstrated broader ecological tolerance by persisting under warmer, more alkaline, and moderately turbid conditions during the dry season, reflecting greater ecological plasticity and resilience. In contrast, *Hoplobatrachus occipitalis* and *Xenopus tropicalis* exhibited relatively weak associations with the measured physicochemical variables, suggesting that their distribution is influenced by a broader combination of habitat attributes beyond water chemistry alone.

The findings further indicate that environmental degradation associated with urbanization, shoreline modification, recreational activities, and declining water quality could progressively alter amphibian community structure by favoring disturbance-tolerant species while reducing populations of environmentally sensitive taxa. Maintaining suitable physicochemical conditions, conserving riparian vegetation, protecting breeding habitats, and preserving habitat connectivity are therefore essential for sustaining amphibian populations and the ecological integrity of Jabi Lake. Routine monitoring of key water-quality parameters should be integrated into urban wetland management programs to enable early detection of environmental change and support evidence-based conservation interventions.

This study contributes valuable baseline information on the relationships between habitat characteristics, environmental variables, and anuran communities within an urban freshwater ecosystem in Nigeria. It also addresses an important knowledge gap in West African amphibian ecology by demonstrating the usefulness of Canonical Correspondence Analysis in identifying the environmental drivers of species distribution. The findings provide a scientific foundation for biodiversity conservation, long-term ecological monitoring, and sustainable management of urban wetlands. Future studies should incorporate additional environmental variables, including vegetation structure, hydroperiod, landscape connectivity, and land-use dynamics, together with long-term seasonal monitoring, to improve understanding of the ecological processes influencing amphibian communities under increasing anthropogenic and climate-related pressures.

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