Nigerian Journal of Science and Environment 2025 Volume 23 (3) 118 – 132 ISSN: 3043 – 4440
https://doi.org/10.61448/njse233259

ASSESSMENT OF WATER QUALITY PARAMETERS AND AQUATIC INSECTS' ASSEMBLAGES OF LAKE ALAU, BORNO STATE, NIGERIA

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ABSTRACT

In freshwater environments, aquatic insects have become one of the most trustworthy categories of bioindicators. They are useful tools for biomonitoring because of their ease of collection, comparatively sedentary nature, and variable sensitivity to environmental changes This study assessed the ecological condition of Lake Alau, Borno State, Nigeria, by integrating physicochemical parameters with aquatic insect assemblage data. Statistical monitoring across the three sampling stations revealed that the physicochemical parameters varied spatially, with pH ranging from slightly acidic to neutral (6.7–7.4), dissolved oxygen levels from 4.2 mg/L at the inflow to 6.1 mg/L at the mid-lake, and comparatively elevated nitrate (12–22 mg/L) and phosphate (15–18 mg/L) concentrations. Although the variations in pH and dissolved oxygen were not statistically significant ($p > 0.05$), the differences in nutrient concentrations (nitrate and phosphate) were significant ($p < 0.05$), indicating nutrient enrichment and a potential risk of eutrophication. Electrical conductivity (280–400 µS/cm), total dissolved solids (150–220 mg/L), and sulfate (22–35 mg/L) also showed spatial variation, with higher values at the inflow. A total of 1,246 aquatic insects from seven families were identified, dominated by Chironomidae (37.5%) and Culicidae (13.8%), while Odonata and Hemiptera contributed smaller proportions. Diversity peaked at the mid-lake station (Shannon 2.40; equitability 0.89), reflecting relatively stable conditions. The correlation analysis showed strong positive associations between dissolved oxygen and diversity indices, and strong negative correlations between nutrients and diversity, underscoring the influence of nutrient enrichment on community structure. Lake Alau is moderately impacted by anthropogenic pressures, with nutrient loading and low oxygen posing ecological stress. However, the presence of moderately sensitive taxa suggests resilience and recovery potential. Effective management should integrate routine physicochemical and biological monitoring, reduction of agricultural runoff, improved waste management, and sustainable fisheries regulation to safeguard the lake's ecological health and socio-economic functions.

KEYWORDS: Aquatic insects, water quality, Lake Alau, biodiversity, biomonitoring, Nigeria

INTRODUCTION

Freshwater ecosystems are among the most important natural resources globally, providing a wide range of ecological, economic, and social services (Dudgeon *et al*., 2006). They supply water for domestic, agricultural, and industrial purposes, support fisheries, regulate climate, and sustain biodiversity (Dudgeon *et al*., 2006). Lakes and reservoirs are essential for maintaining water security and supporting livelihoods in semi-arid parts of Africa where water scarcity is a recurring problem (Owusu *et al*., 2022).

Nigeria, in particular, relies significantly on lakes and man-made reservoirs to supply the growing demand for irrigation, aquaculture, and drinkable water (Ayoade, 2019). However, human activity, climatic variability, and natural processes are posing an increasing threat to these water bodies, making ongoing ecological health monitoring necessary (Ayoade, 2019).

Lake Alau located about 25 km southeast of Maiduguri in Borno State, northeastern Nigeria, is one such multipurpose reservoir (Ibrahim *et al*., 2020). The lake was created by damming the Ngadda River in the 1980s and supplies water for irrigation, household use, and fishing, all of which support the local population (Hummingbird Journals, 2024). In addition, it serves as a critical ecological habitat for diverse aquatic and semi-aquatic organisms (Hummingbird Journals, 2024). Despite its importance, Lake Alau has been exposed to anthropogenic stressors, including agricultural runoff, urban encroachment, overfishing, and siltation (Mohammed *et al*., 2017; Fabian *et al.,* 2023; Bwala *et al*., 2023). These activities, combined with the fragile ecological setting of the semi-arid Sahel, have raised concerns about the water quality and the ecological balance of the lake (Ibrahim *et al*., 2020). Assessing both physicochemical parameters and biological indicators is, therefore, crucial to safeguarding its ecological integrity.

Traditionally, water quality assessment has focused primarily on physicochemical parameters such as pH, temperature, dissolved oxygen (DO), total dissolved solids (TDS), nutrients, and heavy metals. These parameters provide direct information on the suitability of water for domestic, agricultural, and fisheries purposes (SON, 2015; WHO, 2022). For instance, dissolved oxygen levels are critical in sustaining fish and macroinvertebrate populations, while nutrient concentrations (nitrates and phosphates) are indicators of eutrophication risk. However, physicochemical measurements often capture only instantaneous conditions and may not fully reflect the cumulative and long-term impacts of pollution (Wetzel, 2001). As such, there has been a growing interest in complementing these measures with biological indicators to obtain a more holistic understanding of ecosystem health.

In freshwater environments, aquatic insects have become one of the most trustworthy categories of bioindicators (Komolafe and Imoobe, 2020; Frontiers, 2023). They are useful tools for biomonitoring because of their ease of collection, comparatively sedentary nature, and variable sensitivity to environmental changes (Adu and Oyeniyi, 2019). Although Ephemeroptera, Plecoptera, and Trichoptera (EPT taxa) are frequently found in environments with high ecological integrity and pristine conditions, families like Chironomidae are known to withstand high organic loads and frequently dominate polluted habitats (Adu and Oyeniyi, 2019). Therefore, in addition to physicochemical analyses, aquatic insects offer integrative data that represents the historical and present state of water quality (Rosenberg and Resh, 1993; Arimoro and Keke, 2017).

Numerous studies conducted in Nigeria have shown how beneficial aquatic insects are for evaluating the ecological conditions of rivers and reservoirs, for example, Arimoro and Muller (2010) reported that mayfly community structures could effectively indicate the ecological status of Niger Delta streams, while Edegbene *et al*. (2024) developed multimetric indices using aquatic macroinvertebrates to monitor water quality in Nigerian rivers. These findings align with global practices, such as the South African Scoring System (SASS) and the Biological Monitoring Working Party (BMWP) index, which rely heavily on aquatic insects to determine ecological quality (Dallas and Day, 2004). Despite these developments, there are still few thorough studies on the aquatic insect assemblages in Lake Alau; the majority of earlier studies concentrated on fish diversity, physicochemical parameters, and hydrological features.

Considering the socioeconomic importance and pollution susceptibility of Lake Alau, it is imperative that aquatic insect assemblages and water quality parameters be integrated. The lake's water chemistry may be changed by ongoing nutrient input from upstream catchment farming operations and urban runoff from Maiduguri city, which could result in eutrophication, hypoxia, and a decline in biodiversity. Early warning signs of this kind of ecological stress can be provided by aquatic insects, enabling stakeholders to take prompt action. Furthermore, preserving Lake Alau's ecological health is essential to regional food security and poverty reduction because it sustains artisanal fisheries that give thousands of people access to protein and employment opportunities (Shettima *et al.*, 2014). Thus, this study aims to evaluate Lake Alau's ecological status by combining physicochemical parameters with aquatic insect assemblages from a combined approach. The study intends to describe the water quality of Lake Alau, record the variety and constitution of aquatic insect assemblages, and investigate the connections between water quality parameters and insect community structure using verified Nigerian and international biomonitoring techniques. The results added to the expanding body of knowledge on freshwater bioassessment in Nigeria and sub-Saharan Africa and offered a scientific foundation for Lake Alau's sustainable management.

MATERIALS AND METHODS

Study Area

Lake Alau (Figure1) is an impoundment of the Ngadda River, located about 25 km southeast of Maiduguri, Borno State (11°38′N; 13°15′E). It supports domestic water supply, irrigation, and artisanal fisheries. Three sampling stations were established: Station 1 (Inflow): upstream entry point receiving agricultural runoff, Station 2 (Mid-Lake): central pelagic zone and Station 3 (Outflow): near the dam spillway.

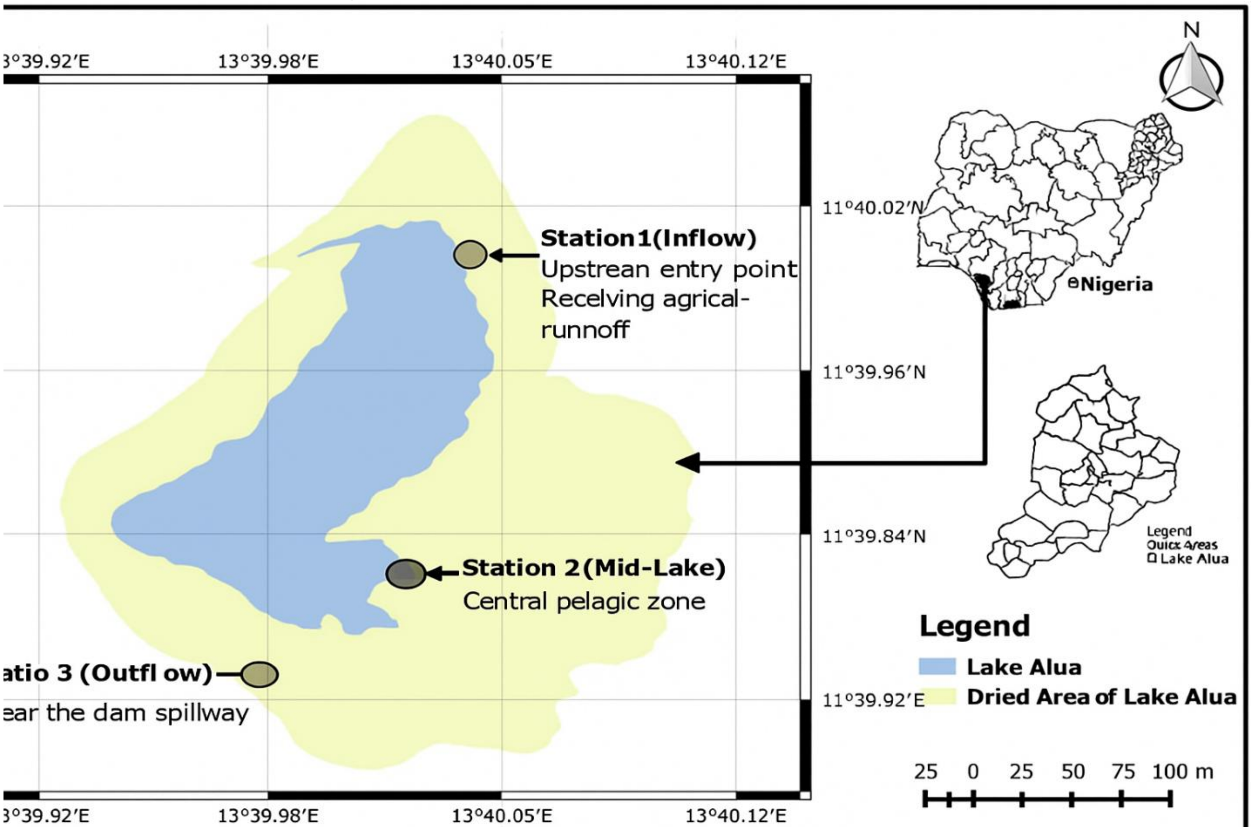

Fig. 1: Map of Nigeria showing Maiduguri State, and the various stations sampled in Lake Alau

Geology, Hydrology, and Vegetation

Lake Alau lies within the Chad Basin, underlain by Quaternary alluvial deposits and sedimentary formations that promote high siltation and nutrient accumulation. The reservoir was formed in the mid-1980s through the impoundment of the Ngadda River to provide water for domestic and agricultural uses. It exhibits marked seasonal hydrological variations, with inflows peaking during the rainy season and declining drastically in the dry season. Surrounding vegetation belongs to the Sahel–Sudan savanna zone, dominated by drought-resistant species such as *Acacia*, *Faidherbia*, and *Prosopis*, along with riparian macrophytes that stabilize shorelines and provide habitats for aquatic life. However, human pressures, deforestation, and overgrazing have reduced vegetative cover, leading to increased erosion and sediment inflow into the lake (Mohammed *et al*., 2017; Bwala *et al.*, 2023; Sahel Journal of Applied Biology, 2024; AFDB, 2024).

Climate Spread and Human Activities

The Area experiences a semi-arid Sahelian climate with a long dry season (November–May) and a short-wet season (June–September), characterized by annual rainfall of about 400–500 mm and mean temperatures exceeding 28°C. Rainfall patterns largely influence the lake's water level and nutrient input. Lake Alau supports diverse socio-economic activities, including irrigation, fisheries, and municipal water supply to Maiduguri. However, anthropogenic impacts such as agricultural runoff, domestic waste discharge, and overfishing have degraded the lake's ecological balance and reduced water quality. Preserving the lake's health is crucial for maintaining food security and employment among surrounding communities (Shettima *et al.,* 2014; Mohammed *et al*., 2017; Bwala *et al*., 2023).

Aquatic Insect Sampling Period and Technique

Aquatic insects were collected biweekly from March to August, 2024 using a standard D-frame dip net (500 µm mesh). Sampling was carried out in littoral zones with submerged vegetation between 09:00 and 16:00 hours. Each sampling event consisted of five minutes of active sweeping per site, replicated four times. Specimens were preserved in 70% ethanol and transported to the laboratory. Identification to family level was done using African freshwater insect keys (Subramanian and Sivaramakrishnan, 2005; Umar *et al*., 2013)

Benthic Insect Sorting and Identification Procedures

In the laboratory, preserved samples were rinsed through a 500 µm sieve to remove debris and fine sediments. Specimens were then sorted manually under a dissecting microscope (×10–40 magnification) using forceps and white sorting trays. Sorting was done under adequate light to distinguish organisms based on size, color, and body segmentation. Non-biological materials such as plant debris, detritus, and sediment particles were discarded. Larger insects were separated using forceps, while smaller taxa were isolated with pipettes (Subramanian and Sivaramakrishnan, 2005; Merritt *et al.,* 2008).

Identification was carried out to the family level using standard African freshwater insect identification keys, including those developed by Day *et al*. (2003); Subramanian and Sivaramakrishnan (2005). Diagnostic features such as head capsule morphology, wing pad development, gill structure, and caudal filament arrangement were used for classification. Taxonomic grouping followed standard references such as Day *et al*. (2003); Merritt *et al*. (2008) for Ephemeroptera, Trichoptera, Odonata, Coleoptera, and Diptera families commonly found in African inland waters.

Physicochemical Parameters

Water quality parameters were determined following standard limnological procedures. Temperature of the water at each sampling station was measured *in situ* using a mercury-in-glass thermometer immersed to a depth of approximately 10 cm and left until a stable reading was obtained. The pH, dissolved oxygen (DO), electrical conductivity (EC), and total dissolved solids (TDS) were recorded using a portable multiparameter probe (HANNA Instruments, USA) that was calibrated prior to each field trip according to the manufacturer's instructions (Boyd and Tucker, 2012; APHA, 2017).

The pH was measured electrometrically, DO via the membrane electrode method, EC using a conductometric sensor, and TDS was computed from EC using a standard conversion factor (0.64).

Nutrient concentrations, including nitrate, phosphate, and sulfate, were analyzed in the laboratory using a UV-Visible spectrophotometer (Jenway, UK). Water samples were first collected in pre-rinsed 1 L high-density polyethylene plastic containers at each station, stored in ice-filled coolers, and transported to the laboratory within 6 hours of collection for analysis. Nitrate was determined by the cadmium reduction method, phosphate by the ascorbic acid method, and sulfate by the turbidimetric method, as described by the American Public Health Association (APHA, 2017).

Hydrological parameters were also recorded at each station. Water depth was measured using a calibrated graduated rod placed vertically at the sampling point, while flow velocity was estimated using the float displacement method, which involved timing the travel of a floating object (orange peel) over a measured distance and applying corrections for surface velocity. Three readings were taken at each station and averaged to minimize error.

All instruments were rinsed with distilled water after each measurement to prevent cross-contamination. Sampling was carried out in triplicates across the designated stations to ensure reliability, and the mean values were used for data analysis.

Data Analysis

Physicochemical data were analyzed with one-way ANOVA (SPSS v22) to test for spatial differences ($p < 0.05$). Aquatic insect diversity indices (Shannon-Wiener H′, Simpson 1-D, Margalef, and Equitability J) were calculated using PAST software version 4.03. Pearson correlation was applied to examine relationships between insect diversity and physicochemical variables.

RESULTS

Water Quality Parameters

Table 1 presents the mean values of physicochemical parameters of Lake Alau across sampling stations revealed significant spatial variations ($p < 0.05$) in dissolved oxygen (DO), nitrate, phosphate, and electrical conductivity (EC) among stations, while pH and total dissolved solids (TDS) showed no significant differences ($p > 0.05$). The inflow station recorded the lowest dissolved oxygen (DO, 4.2 mg/L), while the mid-lake had the highest (6.1 mg/L). pH values were slightly acidic to neutral (6.7–7.4). Electrical conductivity (EC) and total dissolved solids (TDS) ranged between 280–400 µS/cm and 150–220 mg/L, respectively. Nutrient enrichment was evident, with nitrate ranging from 12–22 mg/L and phosphate from 15–18 mg/L, both of which were significantly higher at the inflow compared to the mid-lake and outflow stations ($p < 0.05$).

Table 1. Physicochemical parameters of Lake Alau across stations

Station	Temp (°C)	pH	DO (mg/L)	EC (µS/cm)	TDS (mg/L)	Nitrate (mg/L)	Phosphate (mg/L)	Sulfate (mg/L)
Inflow	27.5^{a}	6.7^{a}	4.2^{a}	400^{c}	220^{c}	22^{c}	18^{b}	35^{c}
Mid-lake	28.3^{b}	7.1^{b}	6.1^{c}	320^{b}	180^{b}	12^{a}	15^{a}	28^{b}
Outflow	29.0^{c}	7.4^{c}	5.0^{b}	280^{a}	150^{a}	18^{b}	16^{ab}	22^{a}
FAO/EIFAC Recommended Range	20-30	6.5-8.5	≥ 5.0	<500	<500	<20	<0.5	<250

Values with different superscripts in the same column are significantly different at $p < 0.05$.

Aquatic Insect Assemblages

A total of 1,246 aquatic insects belonging to seven families were identified (Table 2). Dipterans (Chironomidae and Culicidae) dominated the community, constituting over half of all specimens. The most abundant group was Chironomidae (37.5%), followed by Libellulidae (21.3%) and Culicidae (13.8%). Hemipteran families such as Gerridae, Nepidae, and Naucoridae occurred in lower proportions. The taxonomic resolution was limited to the family level only but not species. Within the six months of this work, 1, 246 insects from 7 families were sorted, counted and identified but no pictures were snapped

Nigerian Journal of Science and Environment 2025 Volume 23 (3) 118 – 132 ISSN: 3043 – 4440
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Table 2. Composition and abundance of aquatic insects in Lake Alau

Family	Abundance	Percentage (%)
Chironomidae	466	37.5
Culicidae	156	13.8
Libellulidae	265	21.3
Coenagrionidae	160	12.8
Gerridae	85	6.8
Nepidae	65	5.2
Naucoridae	49	2.6

Diversity Indices

Diversity indices are presented in Table 3. Shannon-Wiener index (H′) was highest at the mid-lake station (2.40), indicating greater diversity compared to the inflow (1.20) and outflow (1.85). Similarly, Simpson's diversity index and Margalef's richness index showed the same trend, with equitability values highest at the mid-lake station (0.89).

Table 3. Diversity indices of aquatic insects at Lake Alau

Stations	Shannon (H′)	Simpson (1-D)	Margalef	Equitability (J)
Inflow	1.20	0.55	2.5	0.65
Mid-lake	2.40	0.82	4.8	0.89
Outflow	1.85	0.71	3.6	0.77

Correlation Analysis

The correlation matrix (Fig.2) shows that dissolved oxygen (DO) is strongly and positively correlated with Shannon diversity (H′), Simpson's index, Margalef's richness, and equitability, indicating that higher oxygen levels support greater insect diversity. Nitrate and phosphate concentrations display strong negative correlations with all diversity indices, suggesting that nutrient enrichment is associated with lower diversity. Electrical conductivity (EC), total dissolved solids (TDS), and sulfate also show negative relationships with diversity

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measures. In contrast, temperature and pH exhibit positive correlations with diversity indices, indicating that within the observed ranges, these parameters favor insect community stability.

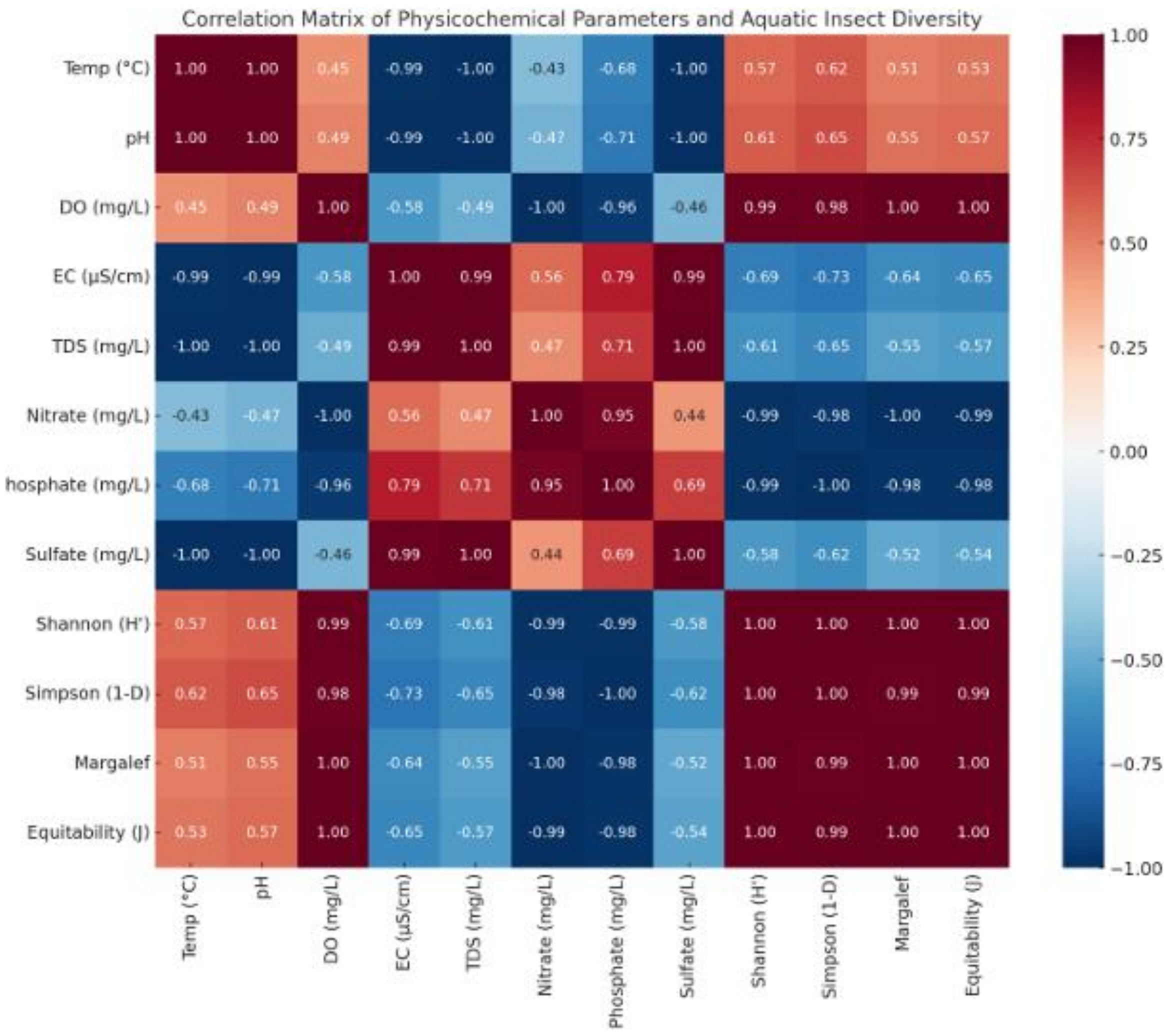

Figure 2 Correlation heatmap of physicochemical parameters and aquatic insects

The Correlation Heatmap's Color Key:

Dark Red (values close to +1.00): Very strong positive correlation

Light Red to Pink (values around +0.50): Moderate positive correlation

White (value around 0.00): No correlation / neutral relationship

Light Blue (values around –0.50): Moderate negative correlation

Dark Blue (values close to –1.00): Very strong negative correlation

DISCUSSION

The results of this study showed that Lake Alau exhibits moderate ecological stress, with physicochemical parameters mostly within permissible limits but with occasional deviations that have significant ecological implications. Dissolved oxygen (DO) at the inflow (4.2 mg/L) fell below the FAO/EIFAC (1996) recommended threshold of 5 mg/L for aquatic life (Alabaster and Lloyd, 1980), suggesting localized organic loading, likely from agricultural runoff and domestic effluents. Similar oxygen deficits have been reported in other Nigerian freshwater systems, such as Aahoo Stream (Adu and Oyeniyi, 2019), and Ala Stream (Owaseye *et al.,* 2025) where human activities along the catchment directly influenced oxygen regimes. Concentrations of nutrients, particularly phosphates (15–18 mg/L) and nitrates (12–22 mg/L), further suggest the risk of eutrophication. According to Arimoro and Muller (2010), these values are higher than those found in uncontaminated reference streams in southwest Nigeria and are close to levels that can cause DO depletion and algal blooms (WHO, 2022). The study's strong negative correlation between nitrate and diversity is in line with research by Edegbene *et al*. (2024), which showed that nutrient enrichment in Nigerian rivers dramatically decreased the number of Ephemeroptera, Plecoptera, and Trichoptera (EPT) taxa. Although sensitive taxa were scarce in Lake Alau, the dominance of tolerant groups such as Chironomidae corroborates the eutrophication hypothesis and signals progressive ecological imbalance (Adu and Oyeniyi, 2019).

The assemblages of aquatic insects offer additional information about Lake Alau's ecological well-being. The dominance of Culicidae (13.8%) and Chironomidae (37.5%) indicates adaptation to low-oxygen or polluted environments; this pattern has also been documented in other African reservoirs (Dallas and Day, 2004) and the Niger Delta (Arimoro and Muller, 2010). Conversely, the occurrence of Libellulidae and Coenagrionidae indicates some level of resilience and habitat heterogeneity, as odonate nymphs thrive in relatively well-oxygenated littoral zones (Subramanian and Sivaramakrishnan, 2005). However, the near absence of Trichoptera and Ephemeroptera, which are highly sensitive to pollution, underscores the anthropogenic pressure on the lake.

Diversity indices indicate that Lake Alau is under moderate ecological stress. The Shannon–Wiener diversity index was highest at the mid-lake station, reflecting relatively stable ecological conditions compared to the more disturbed inflow and outflow zones. This spatial trend aligns with findings from Aahoo Stream, where less impacted sections supported greater insect diversity (Adu and Oyeniyi, 2019). Similarly, equitability values revealed uneven species distribution, largely influenced by the dominance of pollution-tolerant *Diptera*. This observation concurs with global bioassessment reports that moderate pollution often favors tolerant taxa over sensitive groups (Eriksen *et al*., 2021).

According to the correlation analysis, there are significant relationships between Lake Alau's aquatic insect diversity indices and physicochemical parameters. A more varied and stable aquatic insect community was supported by higher oxygen levels, as evidenced by the strong positive correlations observed between dissolved oxygen (DO) and Shannon diversity ($r = 0.99$), Simpson index ($r = 0.98$), and Margalef's richness ($r = 1.00$). Since oxygen depletion frequently favors tolerant taxa like Chironomidae while decreasing sensitive Ephemeroptera, Plecoptera, and Trichoptera (EPT) taxa, this supports earlier findings that dissolved oxygen is a key determinant of macroinvertebrate distribution and survival (Arimoro and Muller, 2010; Adu and Oyeniyi, 2019).

In contrast, nitrate and phosphate concentrations showed strong negative correlations with insect diversity indices ($r \approx -0.99$), suggesting that nutrient enrichment contributed to community simplification. Overnutrition can cause eutrophication, which lowers insect biodiversity by causing algal blooms and hypoxic conditions (Wetzel, 2001; Owaseye *et al*., 2025). Similarly, high nutrient levels in Nigerian streams decreased the diversity of macroinvertebrates, causing tolerant dipterans to take over assemblages (Edegbene *et al*., 2024). In Lake Alau, this explains the dominance of Chironomidae and reduced representation of sensitive taxa.

Electrical conductivity (EC) and total dissolved solids (TDS) were moderately negatively correlated with diversity indices ($r = -0.61$ to -0.73). Elevated EC and TDS typically reflect increased ionic load from agricultural runoff and urban discharges (Ibrahim *et al*., 2020). Such ionic stress can alter insect osmoregulation and reduce species richness, as reported in other African reservoirs (Dallas and Day, 2004). Sulfate and diversity also had a moderately negative correlation ($r \approx -0.58$), suggesting that higher sulfate loads might be a factor in decreased insect diversity and abundance.

Relatively stable tropical conditions that support insect development and reproduction were reflected in the positive correlations between temperature and pH and diversity indices ($r = 0.55–0.62$). Within the narrow ranges observed (27.5–29.0 °C and pH 6.7–7.4), both variables remained suitable for insect colonization and survival (WHO, 2022). Beyond these thresholds, however, persistent temperature increases may worsen oxygen depletion and consequently lower biodiversity.

CONCLUSION

This study finds that anthropogenic activities have a moderate impact on Lake Alau, with ecological stress highlighted by nutrient enrichment, low dissolved oxygen at the inflow, and the dominance of tolerant aquatic insect taxa. Nevertheless, the presence of moderately sensitive groups suggests resilience and potential for recovery if effective management is implemented.

An integrated approach is advised for the management of Lake Alau, combining sustainable fisheries regulation, catchment management to minimize nutrient inputs, optimal water treatment for potable supply, and routine physicochemical monitoring with aquatic insect biomonitoring. Long-term, multidisciplinary monitoring programs should be instituted, incorporating both local stakeholders and policy frameworks to safeguard the ecological integrity and socio-economic value of the reservoir.

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