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Water Quality Variability and Its Implications for Mosquito Breeding: A Comparative Study from Northern Nigeria

Farida Jazuli Usman

fareedahjazuli902@gmail.com

Bayero University Kano

Abba Babandi

Bayero University Kano

Moses Momoh

Bayero University Kano

Salihu Ibrahim

Bayero University Kano

Kamaluddeen Babagana

Bayero University Kano

Hafeez Muhammad Yakasai

Bayero University Kano

Adamu Jibrin Alhassan

Bayero University Kano

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Abstract

Background

Mosquito breeding habitat characteristics critically influence the abundance, survival, and distribution of malaria vectors. Aquatic habitat physicochemical properties influence larval development and may contribute to ecological adaptation and insecticide resistance. This study evaluated the physicochemical characteristics of mosquito breeding habitats across selected locations in Kano, Bauchi, and Kogi States, Nigeria.

Methods

A comparative cross-sectional study was conducted using water samples collected from nine mosquito breeding habitats, with three sampling sites selected from each state. Water temperature was measured *in situ*, while pH, dissolved oxygen, conductivity, total dissolved solids (TDS), salinity, turbidity, total hardness, ammonia, nitrate, and phosphate concentrations were determined using standard analytical procedures. All measurements were performed in triplicate. Data were analysed using descriptive statistics and one-way analysis of variance (ANOVA), with statistical significance set at $P < 0.05$.

Results

Significant variation was observed in the physicochemical characteristics of mosquito breeding habitats across the study areas. Dissolved oxygen ranged from 2.0 to 4.7 mg/L, pH from 6.1 to 7.2, and water temperature from 28.7 to 30.8°C. Conductivity and total dissolved solids were highest in Kano and Azare, while Ibaji recorded the highest turbidity and nutrient concentrations. Salinity remained consistently low across all breeding habitats. One-way ANOVA indicated significant differences (**$P < 0.05$**) in several physicochemical parameters among the sampling locations, reflecting substantial heterogeneity in habitat quality.

Conclusions

The findings demonstrate that mosquito breeding habitats in northern Nigeria differ significantly in their physicochemical characteristics, reflecting varying environmental and anthropogenic influences. These variations may affect habitat suitability for mosquito development and have important implications for malaria vector ecology and integrated vector management. Vector surveillance programmes should include continuous monitoring of local water quality to strengthen evidence-based malaria control strategies.

Introduction

Water quality is a critical factor in determining the sustainability of freshwater resources for drinking, agricultural, and industrial applications. As water demand rises, ensuring access to clean, safe water remains a pressing global challenge. The chemical and physical characteristics of water influence its suitability for various uses, impacting both human health and ecological balance (Shailesh et al., 2024; World Health Organization, 2022). The presence of contaminants, whether from natural sources or anthropogenic activities, can significantly alter water quality parameters, posing risks to communities that rely on untreated or minimally treated water sources (Nishmitha et al., 2025).

Malaria remains one of the most significant vector-borne infectious diseases worldwide and continues to impose a substantial public health and socioeconomic burden, particularly in tropical and subtropical regions (World Health Organization, 2024b). Despite remarkable progress in malaria prevention and control over the past two decades, the disease remains endemic in many low- and middle-income countries, especially those in sub-Saharan Africa (World Health Organization, 2023, 2024a). According to the World Malaria Report 2024, an estimated 263 million malaria cases and 597,000 malaria-related deaths occurred globally in 2023, with the African Region accounting for approximately 94% of all malaria cases and 95% of malaria-related deaths (World Health Organization, 2024b). Nigeria continues to bear the greatest malaria burden worldwide, contributing more than one-quarter of global malaria cases and deaths (World Health Organization, 2024b). Although interventions such as long-lasting insecticidal nets (LLINs), indoor residual spraying (IRS), seasonal malaria chemoprevention, rapid diagnostic testing, and artemisinin-based combination therapies have substantially reduced malaria morbidity and mortality, progress has slowed because of increasing insecticide resistance, environmental changes, rapid urbanization, climate variability, and the persistence of productive mosquito breeding habitats (World Health Organization, 2024a).

Mosquitoes of the genus *Anopheles* are the primary vectors of human malaria, and their abundance, distribution, and vectorial capacity are strongly influenced by environmental conditions during their aquatic developmental stages (Ebhodaghe et al., 2024; Hoyochi et al., 2025). Female mosquitoes selectively lay eggs in habitats that maximize the survival and development of their offspring, while the physicochemical properties of breeding sites influence larval growth, pupal development, adult emergence, longevity, and ultimately malaria transmission potential (Djegbe et al., 2022; Marubini et al., 2025; Sabtiu et al., 2025). Because mosquito larvae are entirely aquatic, even subtle changes in water quality may alter breeding-site productivity and species composition (Ebhodaghe et al., 2024). Consequently, understanding the ecological characteristics of larval habitats has become an essential component of integrated vector management and malaria surveillance programmes (Yousefı et al., 2025).

Emerging evidence demonstrates that the physicochemical characteristics of aquatic habitats play a central role in determining mosquito larval abundance and habitat suitability (Hoyochi et al., 2025; Sabtiu et al., 2025). Parameters such as dissolved oxygen (DO), temperature, pH, electrical conductivity, salinity, turbidity, total dissolved solids (TDS), total hardness, nitrate, phosphate, and ammonia influence microbial productivity, nutrient availability, predator communities, and larval metabolism, thereby

affecting mosquito development and survival (Busari et al., 2025; Jaafar et al., 2020). Water temperature regulates metabolic activity and developmental rate, whereas dissolved oxygen influences respiration and physiological adaptation during immature stages. Similarly, pH affects nutrient availability and microbial composition, while turbidity, conductivity, and dissolved solids often reflect organic pollution and anthropogenic disturbances that can modify breeding-site suitability (Ebhodaghe et al., 2024; Sabtiu et al., 2025).

Environmental modification resulting from agricultural intensification, irrigation development, urbanization, industrial activities, and indiscriminate waste disposal has substantially altered the quality of mosquito breeding habitats throughout Africa (Babandi et al., 2026; Kalisa G., 2026; Sabtiu et al., 2025; Tolani et al., 2025). Agricultural fertilizers and pesticides, domestic wastewater, livestock waste, and urban runoff enrich aquatic habitats with organic matter and nutrients, leading to changes in dissolved oxygen, nutrient concentrations, conductivity, turbidity, and microbial communities (Izah & Ogwu, 2026). Furthermore, increasing evidence suggests that polluted larval habitats contribute to the selection of insecticide-resistant mosquito populations by exposing immature mosquitoes to sublethal concentrations of pesticides and other environmental contaminants, thereby inducing detoxification pathways involving cytochrome P450 monooxygenases, glutathione S-transferases, and carboxylesterases (Lakhwani et al., 2026).

Nigeria encompasses diverse ecological zones that support a wide range of mosquito breeding habitats. However, comparative assessments of breeding-site water quality across multiple ecological zones in Northern Nigeria remain limited, particularly regarding the implications of physicochemical variation for mosquito breeding and insecticide resistance (Babandi et al., 2026; Ebhodaghe et al., 2024).

Therefore, this study investigated the physicochemical characteristics of mosquito breeding habitats across selected communities in Kano, Bauchi, and Kogi States, Northern Nigeria. Specifically, the study evaluated dissolved oxygen, pH, conductivity, total dissolved solids, salinity, temperature, turbidity, total hardness, phosphate, ammonia, and nitrate concentrations to determine spatial variations in water quality and assess their potential implications for mosquito breeding, insecticide resistance, and malaria transmission. By providing comparative data across three ecologically distinct northern Nigerian states, this study contributes to a better understanding of the environmental determinants of malaria vector ecology and provides evidence to support environmentally informed integrated vector management and malaria control programmes.

MATERIALS AND METHODS

Study area

This cross-sectional study was conducted in nine naturally occurring mosquito breeding habitats distributed across three northern Nigerian states: Kano, Bauchi, and Kogi. Three representative breeding sites were selected from each state to capture geographical variation in water quality. The sampling

locations comprised Bayero University Kano (11.9756° N, 8.4783° E), Gaya Local Government Area (LGA) (11.7816° N, 9.0285° E), and Wudil LGA (11.8080° N, 8.8442° E) in Kano State; Azare LGA (11.6767° N, 10.1919° E), Dalli (11.4157° N, 10.1029° E), and Jama'are LGA (11.7486° N, 9.9281° E) in Bauchi State; and Lokoja (7.8023° N, 6.7333° E), Idah LGA (7.1137° N, 6.7387° E), and Ibaji LGA (6.5280° N, 6.1680° E) in Kogi State. These locations represent distinct ecological settings characterized by varying degrees of urbanization, agricultural activity, and human settlement, all of which are known to influence the physicochemical characteristics of mosquito breeding habitats and malaria vector ecology.

Study design and sample collection

A comparative cross-sectional study design was employed to evaluate the physicochemical characteristics of mosquito breeding habitats across the three study states. Water samples were collected from identified mosquito larval habitats during the sampling period using sterile 500-mL polyethylene sampling bottles. Prior to sample collection, the water temperature of each breeding habitat was measured *in situ*. All sampling bottles were labelled immediately after collection and transported in insulated containers to the Biochemistry Laboratory, Bayero University Kano, where physicochemical analyses were performed immediately or within the recommended holding period to minimize changes in water quality.

Determination of physicochemical parameters

The physicochemical characteristics of each water sample were determined using standard analytical procedures recommended by the American Public Health Association (APHA, 2023) for water and wastewater analysis.

Water temperature (°C), pH, dissolved oxygen (DO), electrical conductivity ((μS/cm), salinity (%), and total dissolved solids (TDS; mg/L) were measured directly using a calibrated multiparameter water quality meter according to the manufacturer's operating instructions.

Turbidity (NTU) was determined using a calibrated digital turbidimeter after gently homogenizing each water sample before measurement.

Total hardness was determined by ethylenediaminetetraacetic acid (EDTA) titrimetric analysis and expressed as milligrams of calcium carbonate equivalent per litre (mg/L $CaCO_3$).

Ammonia, nitrate, and phosphate concentrations were quantified colorimetrically using standard analytical reagents and a digital colorimeter following APHA standard methods. All measurements were performed in triplicate, and the average values were used for subsequent analyses.

Data analysis

All physicochemical measurements were performed in triplicate for each water sample, and the results are presented as mean ± standard deviation (SD). Data were entered into Microsoft Excel 2021 and analysed using IBM SPSS Statistics version 29.0 (IBM Corp., Armonk, NY, USA). Descriptive statistics were used to summarize the physicochemical characteristics of mosquito breeding habitats. Differences in the mean values of physicochemical parameters among the sampling sites were evaluated using one-way analysis of variance (ANOVA). Where significant differences were detected, Tukey's honestly significant difference (HSD) post hoc test was performed for pairwise comparisons. Statistical significance was established at $P < 0.05$.

RESULTS AND DISCUSSION

Results

The physicochemical characteristics of mosquito breeding habitats varied across the nine sampling locations in Kano, Bauchi, and Kogi States (Tables 1–3). Water temperature remained relatively stable among the study sites, while pH values ranged from slightly acidic to neutral. Variations were observed in dissolved oxygen, electrical conductivity, total dissolved solids, turbidity, total hardness, and nutrient concentrations, indicating differences in water quality among the breeding habitats. Elevated conductivity and total dissolved solids were recorded in some locations, whereas turbidity and nutrient concentrations (ammonia, nitrate, and phosphate) were markedly higher in others, reflecting varying degrees of environmental influence. One-way analysis of variance (ANOVA) revealed significant differences ($P < 0.05$) in several physicochemical parameters among the sampling locations, demonstrating spatial heterogeneity in the environmental characteristics of mosquito breeding habitats.

Table 1
Physicochemical Characteristics of Mosquito Breeding Sites in Kano State

Dissolved Oxygen (mg/L)	**Kano** **4.3 ± 0.1**	**Wudil** **4.7 ± 0.1**	**Gaya** **3.7 ± 0.1**
pH	7.1 ± 0.2	7.0 ± 0.0	7.2 ± 0.1
Conductivity ((µS/cm)	580 ± 0.0	210.3 ± 1	540 ± 0.0
Total dissolved solid (TDS) (mg/L)	321.3 ± 1	122.6 ± 0.3	30.7 ± 0.1
Temperature (°C)	30.2 ± 0.4	30.0 ± 0.6	28.7 ± 0.2
Salinity(%)	0.02 ± 0.0	0.00 ± 0.0	0.02 ± 0.0
Turbidity(NTU)	45.3 ± 0.1	19.5 ± 0.0	5.71 ± 0.1
Total Hardness (mg/L)	120 ± 0.1	80.0 ± 0.2	60.0 ± 0.0
Phosphate (mg/L)	0.00 ± 0.0	0.00 ± 0.0	0.10 ± 0.1
Ammonia (mg/L)	18.0 ± 0.1	9.00 ± 0.2	8.00 ± 0.0
Nitrate (mg/L)	9.70 ± 0.1	3.40 ± 0.1	1.40 ± 0.2

Table 2
Physicochemical Characteristics of Mosquito Breeding Sites in Bauchi State

Dissolved Oxygen	**Azare**	**Dalli**	**Jama'are**
(mg/L)	**2.0 ± 0.1**	**4.0 ± 0.1**	**3.9 ± 0.1**
pH	6.1 ± 0.1	6.8 ± 0.1	6.6 ± 0.1
Conductivity ((µS/cm)	303.3 ± 10	39.7 ± 0.1	60 ± 0.0
Total dissolve solid (TDS) (mg/L)	177.3 ± 0.2	31.1 ± 0.1	48.7 ± 0.1
Temperature (°C)	30.5 ± 0.1	30.3 ± 0.2	30.0 ± 0.1
Salinity(%)	0.01 ± 0.0	0.00 ± 0.0	0.00 ± 0.0
Turbidity(NTU)	362 ± 0.1	76.0 ± 0.0	20.2 ± 0.0
Total Hardness (mg/L)	152 ± 0.1	22.0 ± 0.0	40.0 ± 0.0
Phosphate (mg/L)	1.05 ± 0.0	0.00 ± 0.0	0.00 ± 0.0
Ammonia (mg/L)	50.0 ± 0.1	19.0 ± 0.0	15.0 ± 0.1
Nitrate (mg/L)	13.0 ± 0.1	4.01 ± 0.1	0.6 ± 0.1

Table 3
Physicochemical Characteristics of Mosquito Breeding Sites in Kogi State

Dissolved Oxygen	**Lokoja**	**Idah**	**Ibaji**
(mg/L)	**4.3 ± 0.1**	**3.6 ± 0.1**	**2.8 ± 0.1**
pH	6.8 ± 0.1	6.9 ± 0.1	6.4 ± 0.0
Conductivity ((µS/cm)	164.3 ± 0.0	160 ± 0.0	110 ± 0.0
Total dissolve solid (TDS) (mg/L)	164.2 ± 0.1	95.7 ± 0.1	72.5 ± 0.3
Temperature (°C)	30.4 ± 0.1	30.1 ± 0.2	30.8 ± 0.3
Salinity(%)	0.01 ± 0.1	0.00 ± 0.0	0.00 ± 0.0
Turbidity(NTU)	121 ± 0.0	36.0 ± 0.2	619 ± 0.1
Total Hardness (mg/L)	94.0 ± 0.0	52.0 ± 0.0	50.0 ± 0.0
Phosphate (mg/L)	0.21 ± 0.1	0.50 ± 0.2	5.00 ± 0.1
Ammonia (mg/L)	23.0 ± 0.1	2.00 ± 0.0	40.0 ± 0.0
Nitrate (mg/L)	4.20 ± 0.1	0.40 ± 0.1	70.0 ± 0.1

Discussion

This study showed considerable spatial variation in the physicochemical characteristics of mosquito breeding habitats across Kano, Bauchi, and Kogi States, indicating that natural environmental conditions and anthropogenic activities shape mosquito larval habitats in northern Nigeria. Differences in dissolved oxygen, pH, electrical conductivity, total dissolved solids (TDS), turbidity, hardness, and nutrient concentrations suggest that breeding habitats differ in their ecological suitability for mosquito development. These findings agree with recent studies showing that physicochemical characteristics are key determinants of mosquito larval distribution, habitat productivity, and vector abundance (Avramov et al., 2024; Babandi et al., 2026; Busari et al., 2025).

Water temperature remained within the optimum range for mosquito development throughout the study. This confirms studies reporting that temperatures between 28 and 32°C are associated with accelerated larval development, shorter developmental periods, and increased adult emergence (Krol et al., 2019;

Marubini et al., 2025). The slightly acidic to neutral pH recorded across the breeding habitats agrees with previous reports describing these conditions as favourable for Anopheles larval development (Busari et al., 2025; Hoyochi et al., 2025). The relatively high conductivity and total dissolved solids observed in Kano and Azare suggest greater anthropogenic influence arising from agricultural runoff, domestic wastewater, and other human activities (Nishmitha et al., 2025). Increasing evidence suggests that malaria vectors are becoming adapted to moderately polluted aquatic habitats (Busari et al., 2025; Ebhodaghe et al., 2024; Izah & Ogwu, 2026).

High turbidity and elevated nutrient concentrations observed particularly in Ibaji and Azare indicate nutrient enrichment resulting from organic matter decomposition, agricultural activities, and runoff (Nishmitha et al., 2025; Shailesh KD et al., 2024). These nutrients stimulate microbial growth, providing food resources for mosquito larvae (Avramov et al., 2024). The observed differences among the three states emphasize the importance of incorporating routine water quality monitoring into integrated vector management programmes. Environmental sanitation and improved waste management can reduce the availability of productive mosquito breeding habitats (Busari et al., 2025; Izah & Ogwu, 2026; Jaafar et al., 2020). Limitations of this study include that mosquito species identification, larval abundance, seasonal sampling, and molecular insecticide resistance markers were not investigated. Future studies integrating physicochemical characteristics with vector population dynamics and molecular surveillance would provide a more comprehensive understanding of malaria vector ecology (Avramov et al., 2024).

Conclusion

This study demonstrated significant spatial variation in the physicochemical characteristics of mosquito breeding habitats across Kano, Bauchi, and Kogi States, highlighting the influence of environmental conditions on habitat suitability for mosquito development. The differences in dissolved oxygen, conductivity, total dissolved solids, turbidity, hardness, and nutrient concentrations suggest varying degrees of environmental disturbance among the study locations.

The elevated conductivity, turbidity, and nutrient concentrations observed in several breeding habitats indicate the influence of agricultural activities, domestic waste disposal, and other anthropogenic factors that may enhance habitat productivity and potentially contribute to the persistence of malaria vectors. These findings emphasize the importance of routine monitoring of water quality as part of integrated vector management programmes. Overall, this study provides baseline information on the physicochemical characteristics of mosquito breeding habitats in northern Nigeria and contributes to understanding the ecological factors that influence malaria vector distribution.

Declarations

Ethics Approval

This study did not involve human subjects or animal experiments; therefore, formal ethical approval was not required. All data handling and analyses were conducted responsibly and in compliance with

standard academic and institutional guidelines.

Consent for publication

Not applicable

Competing interests

The authors declare no competing interests.

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Author Contribution

Study concept, design, and experiment: FJU and AB. Data analysis and curation: AB, KB, FJU, and SI. Drafting of the manuscript: AB and FJU. Critical revision of the manuscript for important intellectual content and supervision: HMY and AJA. All authors read and approved the final manuscript.

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Availability of data and materials

Data will be made available on request.

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Figures

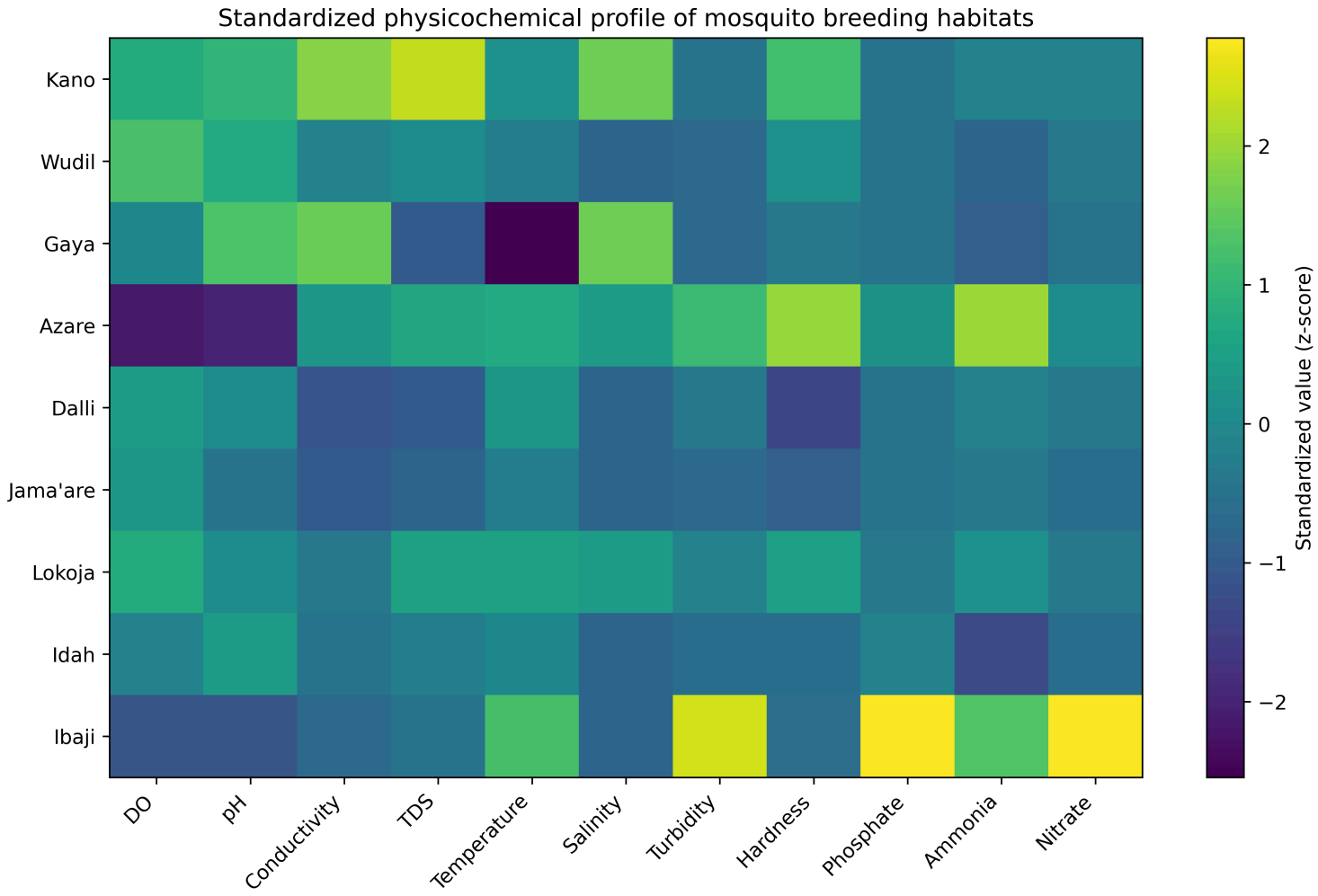


Figure 1

Standardized physicochemical characteristics of mosquito breeding habitats across nine sampling locations in Kano, Bauchi and Kogi States, Nigeria. Values are expressed as standardized z-scores to facilitate comparison among parameters measured on different scales.

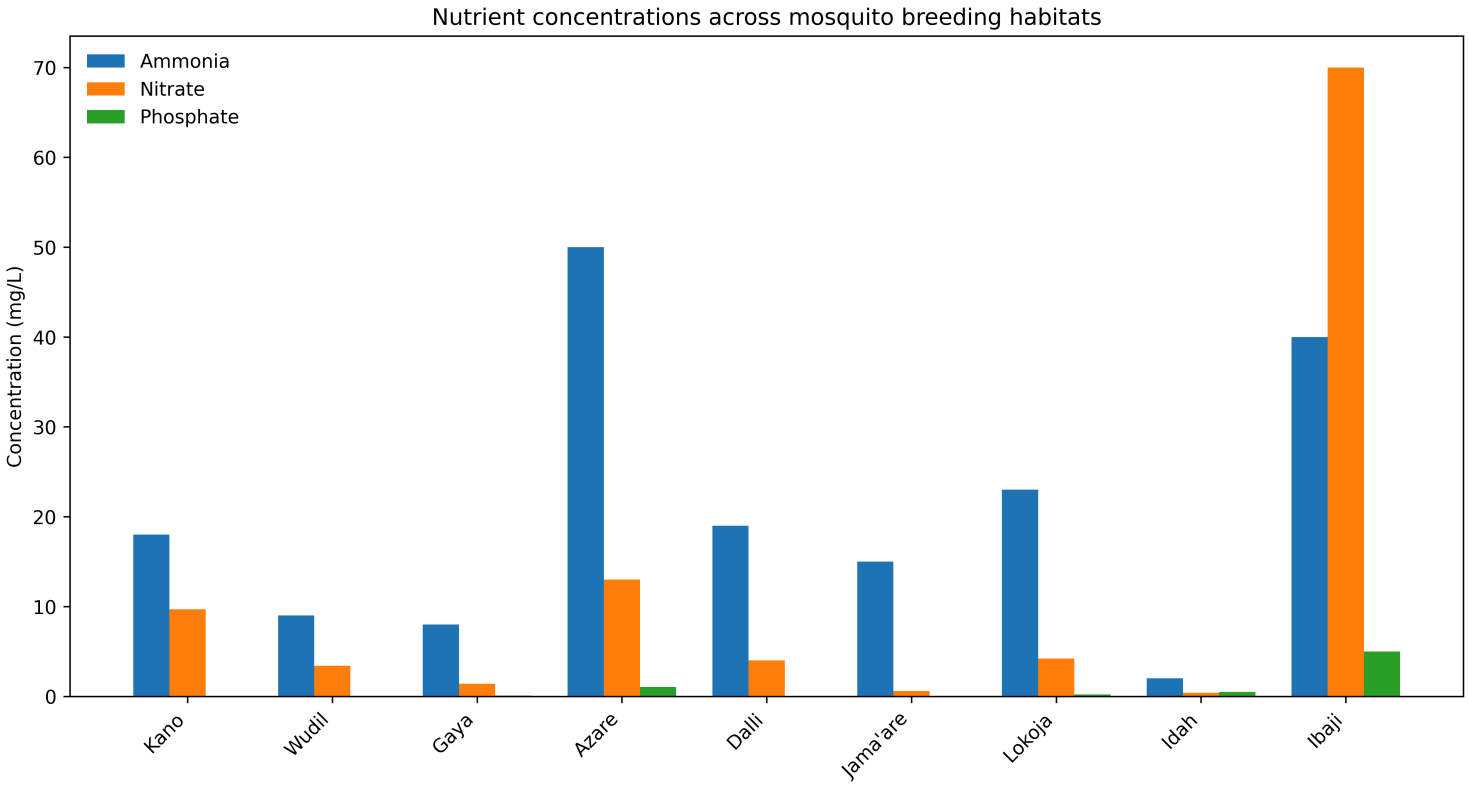


Figure 2

Concentrations of ammonia, nitrate, and phosphate in mosquito breeding habitats across the nine study locations. Values are expressed in mg/L.

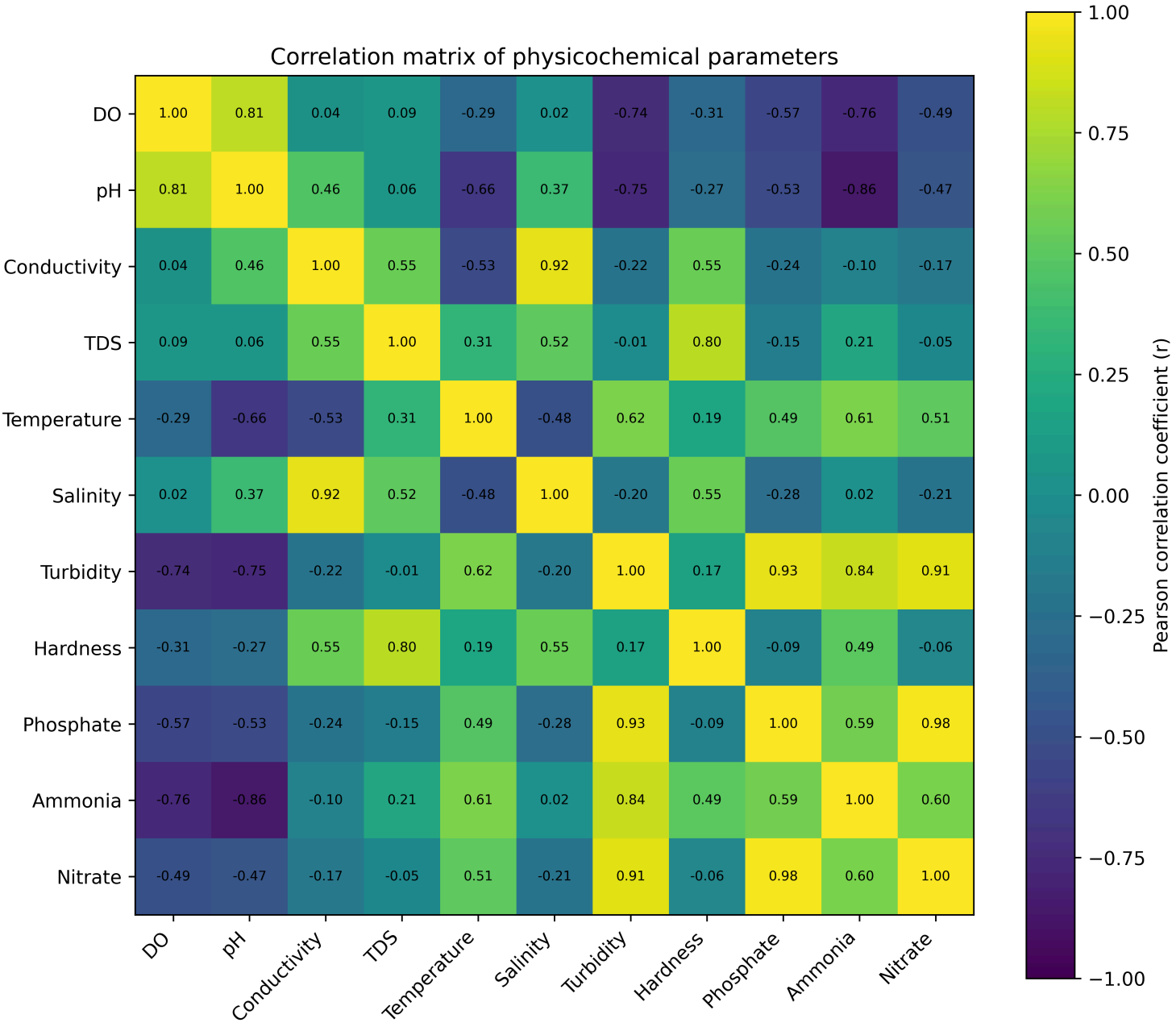


Figure 3

Pearson correlation matrix showing relationships among physicochemical parameters measured in mosquito breeding habitats across Kano, Bauchi, and Kogi States. Positive and negative coefficients indicate the direction and strength of associations among variables.

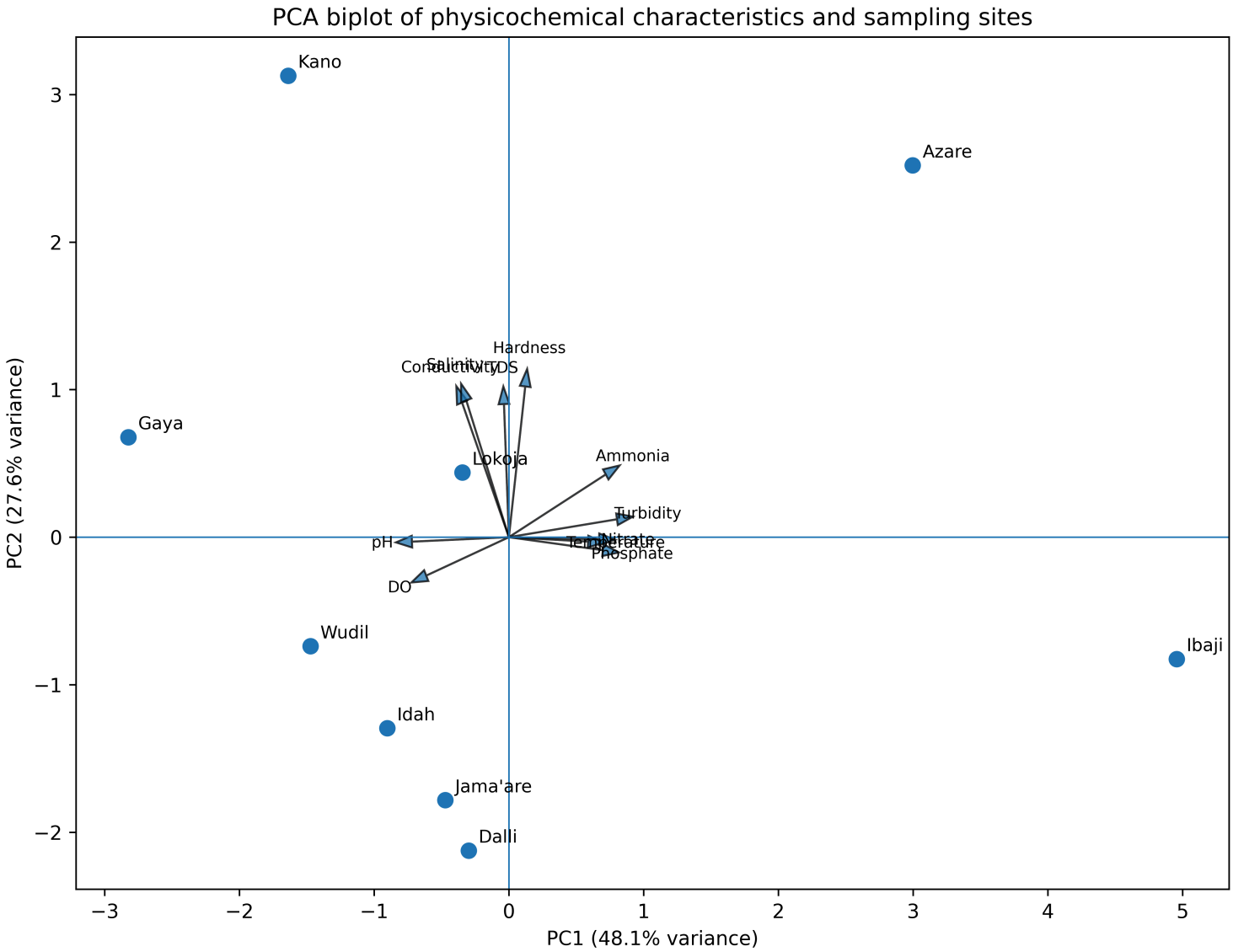


Figure 4

Principal component analysis biplot showing the distribution of mosquito breeding sites and physicochemical variables. The first two principal components summarize the major environmental gradients responsible for variation among sampling locations.