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Assessment of Limnological Variables Following the Shrinkage of Natu Lake, Bakura, Zamfara State, Nigeria

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ABSTRACT
Natu Lake, a shallow freshwater body in Bakura Local Government Area, Zamfara State, Nigeria, supports fishing, irrigation and farming in the surrounding communities of Bakura, Yarkofoji, Balgare and Gamji, yet no physicochemical baseline exists. This study established a preliminary physicochemical baseline for the lake water and adjoining soils. One composite water sample was analysed for pH, electrical conductivity (EC), temperature, nitrate, total dissolved solids (TDS), dissolved oxygen (DO), turbidity and total phosphorus (TP), and four soil samples were analysed for pH, EC, organic carbon, total nitrogen, available phosphorus, exchangeable bases, cation exchange capacity (CEC) and particle-size distribution. Water pH (6.77), TDS (230 mg/L) and nitrate (5.6 mg/L) were within WHO (2022) and Nigerian Standard for Drinking Water Quality (NSDWQ, 2015) limits. However, turbidity (285.3 NTU) exceeded the 5 NTU guideline more than fifty-fold, DO (4.1 mg/L) was below the 5 mg/L level adequate for fish, and TP (0.03 mg/L) placed the lake in the upper mesotrophic range. The soils were slightly acidic (pH 6.53 ± 0.19), clay loam in texture, low in total nitrogen (0.78 ± 0.06 g/kg) and CEC (4.13 ± 0.11 cmol(+)/kg), and very low in available phosphorus (0.24 ± 0.01 mg/kg). Sand content was moderately, but not significantly, negatively correlated with CEC ($r = -0.70$, $n = 4$). The high turbidity and low DO are consistent with catchment erosion linked to vegetation loss and desertification, and with irrigation, farming and fishing pressures. Seasonal multi-station monitoring, protection of catchment vegetation and soil-test-guided fertilizer use are recommended.

Keywords: Natu Lake; Water Quality; Soil Physicochemical Properties; Climate Change; Anthropogenic Activities; Bakura; Zamfara State; Sokoto-Rima Basin

INTRODUCTION

Freshwater lakes and seasonal water bodies in the Sudano-Sahelian belt of northwestern Nigeria are vital to local communities. They support fishing, dry- and wet-season irrigation, and livestock and domestic water needs, especially as rainy seasons become increasingly unreliable (Ekpoh & Nsa, 2011; Ezemonye & Emeribe, 2015). Zamfara State, created from the former Sokoto State in 1996, lies within the semi-arid Sokoto-Rima River Basin and is recognised as one of the regions of Nigeria most vulnerable to desertification, with an estimated 50–75% of its land area affected by degradation caused by wind erosion, deforestation and overgrazing (Azare *et al.*, 2020). A long-term hydro-climatic study of the basin (1980–2020) showed a clear warming trend and increased runoff variability, despite no consistent change in seasonal rainfall totals (Akudo & Otaru, 2023). More recent satellite-based analyses across Nigeria corroborate this picture of change without a simple decline, reporting a modest but statistically significant increase in rainfall over northern Nigeria alongside greater within-season variability (Salami, 2025). Satellite land-cover data for Nigeria's northern border states, including Zamfara, also show substantial vegetation loss between 1984 and 2016, a key driver of desertification and downstream siltation (Nwilo *et al.*, 2020).

Bakura LGA, where Natu Lake is located, lies within the wider Sokoto-Rima floodplain, which also hosts the Bakolori Dam and its irrigation scheme on the Sokoto River. Since the late 1970s, this scheme has reorganised floodplain hydrology and farming practices across Bakura, Maradun and Talata Mafara LGAs, and survey-based evidence indicates that dry-season rice production under the scheme remains a major source of livelihood and income for farming households in the area (Lawal, 2019). In the communities of Bakura, Yarkofoji, Balgare and Gamji, which surround Natu Lake, fishing, irrigation and rain-fed farming are the principal economic activities. These activities are sensitive to changes in water quantity and quality. They can, in turn, alter the physicochemical condition of a water body through agrochemical runoff, sediment disturbance and organic loading (Ngene *et al.*, 2021).

Despite the evident coupling between climate variability, land use and water resources in the Sokoto-Rima Basin, Natu Lake has, to the best of the authors' knowledge, no published physicochemical baseline. Without such a baseline, future change cannot be detected or linked to climatic or human drivers, and surrounding communities cannot be advised on sustainable lake use. This gap persists even as a growing body of recent physicochemical surveys has documented comparable small reservoirs and streams elsewhere in northern Nigeria, including Sabke, Zobe and Mairuwa Reservoirs in Katsina State (Nasir *et al.*, 2024; Bashir *et al.*, 2025), Wasai Reservoir in Kano State (Shehu *et al.*, 2025), Lake Alau in Borno State (Abasiryu *et al.*, 2025) and the Kandola Shella stream at Usmanu Danfodiyo University, Sokoto (Samrawi *et al.*, 2024); none of these, however, extends to Natu Lake.

This study presents the first preliminary physicochemical characterisation of Natu Lake water and its adjoining soils, interpreted with reference to World Health Organization (WHO, 2022) and Nigerian Standard for Drinking Water Quality (NSDWQ; Standards Organisation of Nigeria, 2015) guidelines, regional soil-fertility literature, recent comparative reservoir studies, and the broader climate-change and land-use context of the Sokoto-Rima Basin. The specific objectives were to: (i) characterise selected physicochemical parameters of Natu Lake water in relation to WHO (2022) and NSDWQ (2015) guideline values; (ii) characterise the physicochemical and textural properties of soils adjoining the lake at two depths and at two additional points; and (iii) discuss the results in the context of climate change and the fishing, irrigation and farming activities of the surrounding communities.

MATERIALS AND METHODS

Study Area

Natu Lake lies in Bakura LGA, Zamfara State, northwestern Nigeria, close to Bakura town, the LGA headquarters (approximately 12°43′N, 5°52′E), and near Gamji, one of the four communities considered in this study. Bakura LGA covers about 1,366 km² and lies within the Sudano-Sahelian climatic zone, characterised by a short, intense rainy season and a long dry season, a mean annual temperature of around 33 °C, and a marked seasonal contrast in humidity (Zamfara State Civil Service Commission, n.d.). The economy of Zamfara State is predominantly agrarian, as reflected in the state slogan "Farming is our Pride", with millet, guinea corn, maize, rice, groundnut and cotton as the major crops (Nigerian Investment Promotion Commission, 2019). The four communities considered in this study (Bakura, Yarkofoji, Balgare and Gamji) depend principally on fishing, irrigation and rain-fed farming, activities that place them in direct, daily contact with, and reliance on, the water and soil resources evaluated here.

The area falls within the Sokoto-Rima River Basin, downstream and west of the Bakolori Dam on the Sokoto River, a scheme that has shaped irrigation and floodplain farming in Bakura, Maradun and Talata Mafara LGAs since the late 1970s (Lawal, 2019). Soils of the Sokoto-Rima floodplain near Bakura and neighbouring Talata Mafara have been described as slightly to moderately acidic, sandy to sandy loam in texture, and generally low in organic matter and nitrogen (Esu *et al.*, 1991). A more recent survey of soil salinity in Gusau LGA, also in Zamfara State, similarly reported low electrical conductivity and predominantly non-saline conditions in cultivated savanna soils (Musa *et al.*, 2022). Together, these studies provide context for the soils sampled around Natu Lake.

Sample Collection and Laboratory Analysis

One composite water sample was collected from Natu Lake and analysed for pH, electrical conductivity (EC), temperature, nitrate (NO_3^-), total dissolved solids (TDS), dissolved oxygen (DO), turbidity and total phosphorus (TP), following standard methods for the examination of water and wastewater (APHA, AWWA & WEF, 2017).

Four soil samples were collected from land adjacent to the lake: a two-depth profile at 0–15 cm (A) and 15–30 cm (B), representing the topsoil and the immediate sub-surface horizon, and two surface composite samples (Sample 1 and Sample 2) from nearby farming and irrigation sites. The soil samples were air-dried, sieved and analysed for pH, EC, organic carbon (OC), total nitrogen (N), available phosphorus (P), exchangeable calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^+), sodium (Na^+), cation exchange capacity (CEC) and particle-size distribution (sand, silt and clay), using standard soil analysis protocols consistent with regional practice for Sokoto-Rima Basin soils (Esu *et al.*, 1991).

The water and soil determinands listed above are referred to throughout this paper as the "selected physicochemical parameters" assessed in this baseline. Biochemical and chemical oxygen demand, ammonium, phosphate fractions, sulphate, chloride, hardness, alkalinity, microbiological indicators (coliforms/*Escherichia coli*), heavy metals and pesticide residues were outside the scope of this phase of the project and were not measured. Because the study draws on a single water sample and four soil records collected on one occasion, it characterises the lake and adjoining soils at the time of sampling rather than a temporal or spatial trend. These limitations, and their implications for interpreting climate-change and human-activity signals, are addressed in the Discussion.

Data Analysis

Because the water dataset consists of a single composite sample, results are presented descriptively; no measure of dispersion. They were compared with the WHO (2022) and NSDWQ (2015) drinking-water guidelines, the OECD trophic-state boundaries for total phosphorus (Vollenweider & Kerekes, 1980), the FAO guidelines for irrigation water quality (Ayers & Westcot, 1985), and published values for comparable water bodies in northern Nigeria.

For the four soil records, descriptive statistics were calculated for each parameter: minimum, maximum, mean, sample standard deviation (SD, $n - 1$) and coefficient of variation (CV = SD/mean × 100). The sum of exchangeable bases ($Ca^{2+} + Mg^{2+} + K^+ + Na^+$) and percentage base saturation (sum of exchangeable bases/CEC × 100) were derived from the measured values. Pearson correlation coefficients (r) and their associated probabilities (P) were computed between CEC and three potential controlling variables (sand, clay and organic carbon). Because of the very small sample size (n = 4; two degrees of freedom), these coefficients are treated as provisional indicators of internal consistency with established pedological relationships rather than as tests of hypotheses (see Discussion). Soil textural class was determined using the USDA soil-texture triangle (Soil Survey Staff, 2014).

RESULTS AND DISCUSSION

Selected Physicochemical Parameters of Natu Lake Water

Table 1 presents the selected physicochemical parameters of the Natu Lake water sample alongside the WHO (2022) and NSDWQ (2015) guideline values. The water was near-neutral (pH 6.77), and its temperature at the time of sampling (29.0 °C) was typical of Sudano-Sahelian surface waters. Electrical conductivity (366 µS/cm), nitrate (5.6 mg/L) and total dissolved solids (230 mg/L) were all within guideline limits. In contrast, turbidity (285.3 NTU) exceeded the 5 NTU guideline by more than fifty-fold, and dissolved oxygen (4.1 mg/L) was below the 5 mg/L generally recommended for healthy fish populations. Total phosphorus (0.03 mg/L, i.e. 30 µg/L) placed the lake in the upper mesotrophic range, close to the mesotrophic–eutrophic boundary of 35 µg/L in the OECD trophic-state classification (Vollenweider & Kerekes, 1980). Thus, of the eight parameters measured, five were within acceptable limits, while turbidity, dissolved oxygen and total phosphorus indicated a degraded or nutrient-enriched condition.

Table 1: Selected Physicochemical Parameters of Natu Lake Water Compared with WHO (2022) and NSDWQ (2015) Guideline Values

Parameter	Unit	Value	Guideline value	Remark
pH	–	6.77	6.5–8.5	Within limit
Electrical conductivity	µS/cm	366	1,000[a]	Within limit
Temperature	°C	29.0	Ambient	–
Nitrate (NO_3^-)	mg/L	5.6	≤ 50	Within limit
Total dissolved solids	mg/L	230	≤ 500	Within limit
Dissolved oxygen	mg/L	4.1	≥ 5[b]	Below recommended level
Turbidity	NTU	285.3	≤ 5	Exceeds limit (> 50-fold)
Total phosphorus	mg/L	0.03	0.010–0.035[c]	Upper mesotrophic

Guideline values are WHO (2022)/NSDWQ (2015) drinking-water values unless otherwise indicated. [a]NSDWQ (2015) maximum permitted level. [b]Minimum dissolved oxygen generally recommended for healthy fish populations. [c]OECD mesotrophic range for total phosphorus (Vollenweider & Kerekes, 1980).

Physicochemical Properties of Soils Adjoining Natu Lake

Table 2 presents the physicochemical and textural properties of the four soil samples. Soil pH was slightly acidic at all points, ranging from 6.33 in the 0–15 cm layer (A) to 6.70 in Sample 1, consistent with the slightly to moderately acidic soils reported for the neighbouring Talata Mafara area of the Sokoto-Rima Basin (Esu *et al.*, 1991). Electrical conductivity was low and uniform (176.32–185.60 µS/cm). Organic carbon ranged from 11.97 g/kg in layer A to 14.00 g/kg in Sample 2 and was slightly higher in the two surface composite samples than in the profile, whereas total nitrogen was low throughout (0.70–0.84 g/kg), giving C:N ratios of 15.6–17.7. Available phosphorus was very low and almost invariant (0.23–0.24 mg/kg). CEC was uniformly low (3.98–4.22 cmol(+)/kg), while the sum of exchangeable bases (3.15–3.37 cmol(+)/kg) corresponded to a base saturation of 75.5–84.7%, the highest value being recorded in Sample 1. Exchangeable Na^+ was highest in layer A (0.35 cmol(+)/kg) and lowest in Sample 1 (0.17 cmol(+)/kg).

Table 2: Physicochemical Properties of Soils Adjoining Natu Lake, Bakura LGA

Parameter	Unit	A (0–15 cm)	B (15–30 cm)	Sample 1	Sample 2
pH	–	6.33	6.41	6.70	6.68
EC	µS/cm[d]	181.82	185.60	176.32	180.22
Organic carbon	g/kg	11.97	12.37	13.37	14.00
Total nitrogen	g/kg	0.77	0.70	0.84	0.81
C:N ratio	–	15.6	17.7	15.9	17.3
Available P	mg/kg	0.24	0.23	0.24	0.24
Ca^{2+}	cmol(+)/kg	1.10	1.20	1.30	1.25
Mg^{2+}	cmol(+)/kg	0.90	0.80	0.95	0.85
K^+	cmol(+)/kg	0.83	0.89	0.95	1.00
Na^+	cmol(+)/kg	0.35	0.26	0.17	0.22
Sum of exchangeable bases	cmol(+)/kg	3.18	3.15	3.37	3.32
CEC	cmol(+)/kg	4.21	4.10	3.98	4.22
Base saturation	%	75.5	76.8	84.7	78.7
Sand	%	24.1	28.0	41.8	33.9
Silt	%	38.6	38.0	28.8	34.7
Clay	%	37.3	34.0	29.4	31.4
USDA textural class	–	Clay loam	Clay loam	Clay loam	Clay loam

A and B, 0–15 cm and 15–30 cm depths of a single profile; Samples 1 and 2, surface composite samples from nearby farming and irrigation sites. EC, electrical conductivity; CEC, cation exchange capacity. C:N ratio, sum of exchangeable bases and base saturation were derived from the measured values. [d]1 dS/m = 1,000 µS/cm.

The descriptive statistics in Table 3 show that, on average, the soils were slightly acidic (pH 6.53 ± 0.19), moderate in organic carbon (12.93 ± 0.93 g/kg), low in total nitrogen (0.78 ± 0.06 g/kg) and CEC (4.13 ± 0.11 cmol(+)/kg), and very low in available phosphorus (0.24 ± 0.01 mg/kg), with a mean base saturation of 78.9 ± 4.0%. Variability among the four samples was low for most parameters (CV < 10%), indicating broadly uniform soil chemical conditions around the lake. The exceptions were sand content (CV = 24.1%) and exchangeable Na^+ (CV = 30.5%), while silt (CV = 12.8%) and clay (CV = 10.3%) showed moderate variability.

Table 3: Descriptive Statistics of Physicochemical Properties of Soils Adjoining Natu Lake (n = 4)

Parameter	Unit	Minimum	Maximum	Mean	SD	CV (%)
pH	–	6.33	6.70	6.53	0.19	2.9
EC	µS/cm	176.32	185.60	180.99	3.85	2.1
Organic carbon	g/kg	11.97	14.00	12.93	0.93	7.2
Total nitrogen	g/kg	0.70	0.84	0.78	0.06	7.8
C:N ratio	–	15.6	17.7	16.6	1.0	6.2

Parameter	Unit	Minimum	Maximum	Mean	SD	CV (%)
Available P	mg/kg	0.23	0.24	0.24	0.01	2.1
Ca^{2+}	cmol(+)/kg	1.10	1.30	1.21	0.09	7.0
Mg^{2+}	cmol(+)/kg	0.80	0.95	0.88	0.06	7.4
K^{+}	cmol(+)/kg	0.83	1.00	0.92	0.07	8.0
Na^{+}	cmol(+)/kg	0.17	0.35	0.25	0.08	30.5
Sum of exchangeable bases	cmol(+)/kg	3.15	3.37	3.26	0.11	3.3
CEC	cmol(+)/kg	3.98	4.22	4.13	0.11	2.7
Base saturation	%	75.5	84.7	78.9	4.0	5.1
Sand	%	24.1	41.8	32.0	7.7	24.1
Silt	%	28.8	38.6	35.0	4.5	12.8
Clay	%	29.4	37.3	33.0	3.4	10.3

SD, sample standard deviation (n − 1); CV, coefficient of variation. Means and SDs are reported as mean ± SD in the text.

The particle-size distribution of the soils is shown in Figure 1. In the profile, clay content was higher in the 0–15 cm layer (37.3%) than in the 15–30 cm layer (34.0%), while sand increased correspondingly from 24.1% to 28.0%. The surface composite samples were coarser, with Sample 1 having the highest sand content (41.8%) and the lowest silt (28.8%) and clay (29.4%) contents. Despite this range, all four samples fell within the clay loam class of the USDA texture triangle.

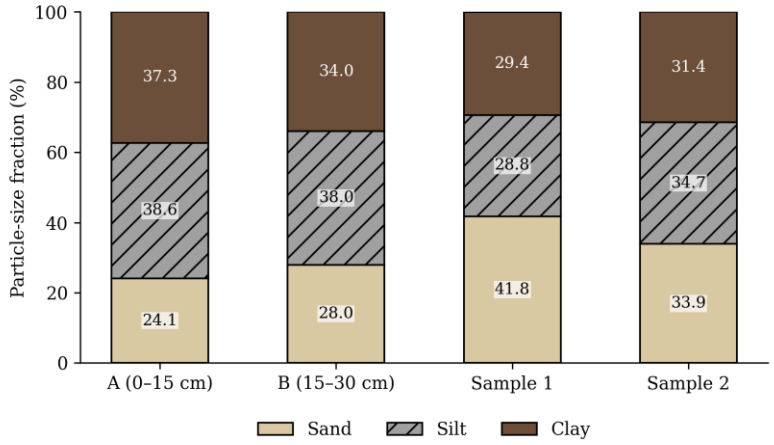

Figure 1: Particle-size Distribution (Sand, Silt and Clay, %) of Soils Adjoining Natu Lake. All Samples Fall within the USDA Clay Loam Class

Figure 2 shows the distribution of exchangeable basic cations. Ca^{2+} was the dominant basic cation at all sampling points (1.10–1.30 cmol(+)/kg), and Na^{+} was the least abundant (0.17–0.35 cmol(+)/kg). On average, the cations followed the order Ca^{2+} (1.21) > K^{+} (0.92) > Mg^{2+} (0.88) > Na^{+} (0.25 cmol(+)/kg), although Mg^{2+} slightly exceeded K^{+} in layer A and the two were equal in Sample 1.

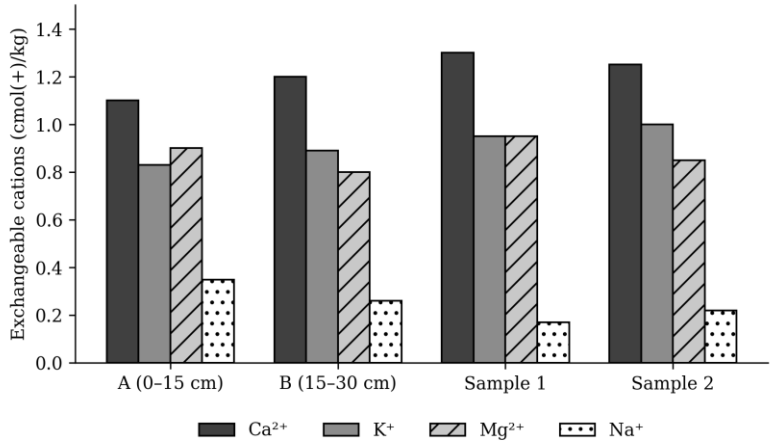

Figure 2: Exchangeable Basic Cations (cmol(+)/kg) in Soils Adjoining Natu Lake

Relationships Among Soil Variables

Given the very small sample size (n = 4), the correlation coefficients in Table 4 are indicative rather than confirmatory. With only two degrees of freedom, none of the coefficients between CEC and its potential controlling variables reached statistical significance (critical $|r| = 0.950$ at $P = 0.05$); they are retained solely to flag patterns for testing in the expanded follow-up study proposed in the Discussion. Sand content showed a moderate negative association with CEC ($r = -0.70$, $P = 0.30$) and clay content a moderate positive association ($r = 0.62$, $P = 0.38$), both in the direction expected from the established pedological principle that finer-textured soils retain more exchangeable cations than coarser-textured soils. No relationship was apparent between organic carbon and CEC ($r = -0.10$, $P = 0.91$), which is unsurprising given the narrow range of organic carbon values observed and the limited statistical power of a four-point dataset.

Table 4: Indicative Pearson Correlation Coefficients between CEC and Selected Soil Variables (n = 4)

Variable pair	*r*	*P*	Strength and direction	Significance
Sand (%) vs CEC	−0.70	0.30	Moderate, negative	ns
Clay (%) vs CEC	0.62	0.38	Moderate, positive	ns
Organic carbon vs CEC	−0.10	0.91	Negligible	ns

r, Pearson correlation coefficient; *P*, probability; ns, not significant at $P = 0.05$. Critical value of $|r|$ at $P = 0.05$ with 2 degrees of freedom = 0.950.

Discussion

The most notable water-quality finding is the very high turbidity of Natu Lake water (285.3 NTU), which exceeds the WHO/NSDWQ drinking-water guideline of 5 NTU by more than fifty-fold. Seasonal studies of the River Sokoto, which drains the same basin, have similarly reported elevated organic loading and turbidity-related exceedances, especially during the rainy season, associated with agricultural runoff and sediment inputs from the catchment (Raji *et al.*, 2015). In a shallow Sudano-Sahelian lake such as Natu Lake, high turbidity may reflect soil erosion in the catchment linked to the vegetation loss and land degradation documented across Zamfara and neighbouring northern states (Azare *et al.*, 2020; Nwilo *et al.*, 2020). Local activities such as fishing, livestock watering and irrigation along the lake margins may also resuspend bottom sediments.

In contrast, pH (6.77), EC (366 µS/cm) and TDS (230 mg/L) were normal and well within guideline values, suggesting no measurable industrial, saline or strongly mineralised influence at the time of sampling. From an irrigation perspective, the EC (0.37 dS/m) and TDS values fall below the thresholds of 0.7 dS/m and 450 mg/L under which the FAO guidelines indicate no restriction on the use of water for irrigation based on salinity (Ayers & Westcot, 1985; Rizani *et al.*, 2016; Minhas & Qadir, 2024). The water is therefore currently suitable for the irrigation activities of the surrounding communities with respect to salinity, although its high suspended-sediment load may affect irrigation infrastructure (Lawal & Shehu, 2024; Setyadin *et al.*, 2026).

With respect to nutrient status, the total phosphorus concentration (0.03 mg/L) places Natu Lake in the upper mesotrophic range, close to the eutrophic boundary of the OECD classification (Vollenweider & Kerekes, 1980), where algal productivity typically begins to increase. Nitrate (5.6 mg/L), by contrast, was well within guideline values, suggesting no acute inorganic-nitrogen contamination at the time of sampling. Because the communities of Bakura, Yarkofoji, Balgare and Gamji rely heavily on irrigation and farming, activities that can introduce fertilizer-derived phosphorus and nitrogen into nearby water bodies through runoff, continued or increased agrochemical use in the catchment could plausibly contribute to further eutrophication over time (Lawal & Shehu, 2024; Subedi *et al.*, 2025). A single sampling event cannot confirm this, and repeated seasonal sampling would be required to identify a trend. Phosphate fractions (e.g. orthophosphate) and chlorophyll-*a*, which would sharpen this trophic-state assessment, were not measured and are recommended for the follow-up study.

The dissolved oxygen concentration (4.1 mg/L), which reflects the condition of the aquatic ecosystem, was below the 5 mg/L level generally considered necessary to support healthy fish populations. At the measured water temperature of 29 °C, air-saturated fresh water holds approximately 7.7 mg/L of oxygen, so the observed value corresponds to only about 53% saturation. This deficit is consistent with the sediment and organic loading implied by the elevated turbidity, since suspended and settled organic matter increases biochemical oxygen demand and thereby depresses dissolved oxygen; high water temperatures, which reduce oxygen solubility, compound this effect in a warming basin (Akudo & Otaru, 2023). Because local communities rely on the lake for fishing, the combination of high turbidity and low dissolved oxygen directly affects livelihoods and warrants season-specific monitoring. Biochemical oxygen demand (BOD) and chemical oxygen demand (COD), which would allow a fuller, oxygen-budget-based assessment, were not measured in this baseline and are recommended for future work.

Recent physicochemical surveys of comparable Sahel- and Sudan-savanna reservoirs in northern Nigeria support this interpretation and place the Natu Lake data in a broader regional context. Seasonal sampling between October 2023 and July 2024 at Zobe, Sabke and Mairuwa Reservoirs in Katsina State showed that Sabke Reservoir, the most comparable to Natu Lake, had a turbidity of 300.44 NTU, very close to the 285.3 NTU recorded here, but a dissolved oxygen concentration of about 8 mg/L, nearly twice that of Natu Lake (Bashir *et al.*, 2025). An earlier assessment of Sabke reported a moderate positive correlation between turbidity and total dissolved solids, indicating runoff-driven sediment loading as a primary pressure on this reservoir type (Nasir *et al.*, 2024). A twelve-month spatio-temporal study of Wasai Reservoir likewise recorded seasonal exceedances of EC, TDS and BOD above WHO and FEPA limits, reinforcing that sediment and organic-loading pressures on small reservoirs in the region are widespread rather than unique to Natu Lake (Shehu *et al.*, 2025).

Further east, Lake Alau in Borno State, which also supports irrigation, fishing and domestic use, had phosphate concentrations exceeding the 0.1 mg/L drinking-water limit, attributed to farm waste and agrochemical runoff (Abasiryu *et al.*, 2025). Closer to the study area, a 2023–2024 biomonitoring study of the Kandola Shella stream at Usmanu Danfodiyo University, Sokoto, used benthic

macroinvertebrate and aquatic-insect indices to classify the stream as only slightly polluted, with sediment and organic loading, rather than chemical contamination, as the main issues (Samrawi *et al.*, 2024). Taken together, these 2024–2025 studies indicate that high turbidity and low dissolved oxygen at Natu Lake are part of a broader pattern of sediment and nutrient pressure on small reservoirs, dams and streams across northern Nigeria. Despite these pressures, pH, nitrate and dissolved solids generally remain within guideline limits, and these water bodies continue to support fishing and irrigation.

The soils adjoining Natu Lake are slightly acidic and low in nitrogen, available phosphorus and CEC, reflecting the broader pattern reported for cultivated soils of the Sokoto-Rima Basin, including the nearby Talata Mafara area (Esu *et al.*, 1991). Their low EC is also consistent with the predominantly non-saline cultivated savanna soils reported for Gusau LGA, elsewhere in Zamfara State (Musa *et al.*, 2022). In such areas, continuous cultivation, residue burning and limited return of organic matter progressively reduce soil fertility. The low CEC values (3.98–4.22 cmol(+)/kg) indicate a limited capacity to retain nutrients, implying that a substantial part of the fertilizer applied during irrigated and rain-fed farming around the lake may be lost through leaching or runoff rather than taken up by crops (Mahmood *et al.*, 2021). Such losses may plausibly be associated with the nutrient-related water-quality patterns described above.

Although clay loam soils would ordinarily be expected to have a moderate CEC, the low values recorded here, despite clay contents of 29–37%, most likely reflect the dominance of kaolinite, a low-activity clay mineral that is the principal clay mineral of well-drained Nigerian savanna soils (Ojanuga, 1979), combined with only moderate organic carbon. The moderate negative correlation between sand content and CEC and the moderate positive correlation between clay content and CEC (Table 4) are consistent with these textural controls; however, because they are based on only four data points, they remain indicative rather than confirmatory. The high base saturation (75.5–84.7%) shows that the limited exchange sites present are largely occupied by basic cations, particularly Ca^{2+}, consistent with the soil's only slightly acidic reaction.

Available phosphorus (0.23–0.24 mg/kg) was very low, far below the 10 mg/kg threshold below which available phosphorus is rated low in Nigerian savanna soils (Esu, 1991), and represents a major fertility constraint for farming around the lake. The contrast between this very low soil phosphorus and the near-eutrophic phosphorus concentration in the lake water suggests that phosphorus reaching the lake may be transported mainly in particulate form with eroded sediment, or may derive directly from applied fertilizer, rather than from the native soil phosphorus pool (Ebrahimi & Ojani, 2024). This hypothesis could be tested in the follow-up study by measuring phosphorus fractions in both the water and the soils.

CEC and EC are distinct soil properties reported in different units. CEC, a measure of nutrient-holding capacity, is expressed in cmol(+)/kg, whereas EC, a measure of dissolved ion concentration in the soil extract, is reported in µS/cm. The recorded soil EC values (176–186 µS/cm, equivalent to 0.18–0.19 dS/m) indicate non-saline conditions typical of these low-salinity savanna soils and do not reflect an unusual reading or a unit error.

Classifying all four samples as clay loam, despite the range in sand content (24.1–41.8%), indicates moderately heterogeneous but broadly similar parent material across the sampled points. This texture is generally favourable for water retention under irrigation, consistent with the area's long-standing role, alongside the neighbouring Maradun and Talata Mafara LGAs, in the Bakolori Dam-fed irrigation landscape that supports substantial dry-season rice production and household income (Lawal, 2019).

These water and soil conditions should also be viewed against the climatic context of the basin. A long-term hydro-climatic study of the Sokoto-Rima Basin revealed a significant warming trend and increased runoff variability between 1980 and 2020, despite no clear trend in seasonal rainfall totals (Akudo & Otaru, 2023), and more recent satellite-based analyses report a modest increase in rainfall over northern Nigeria accompanied by greater within-season variability (Salami, 2025). Satellite data also indicate extensive vegetation loss and desertification in Zamfara and neighbouring states over recent decades (Azare *et al.*, 2020; Nwilo *et al.*, 2020). The high turbidity observed at Natu Lake is consistent with, but does not prove, such erosion processes. Human activities, particularly irrigation, fishing and farming around Natu Lake, may further contribute to sediment disturbance, organic loading and nutrient enrichment, with implications for livelihoods in Bakura, Yarkofoji, Balgare and Gamji. These climatic and human factors are likely to be intertwined: climate-associated land degradation can increase soil erodibility, while farming and irrigation influence when and how eroded material and agrochemical residues enter the lake. Similar combinations of climatic and anthropogenic pressure have been reported at larger scales, most notably in the Lake Chad Basin, where desertification and land-cover change interact with increasing human water demand (Nwilo *et al.*, 2020).

The findings of this study should be interpreted in light of its limitations. The baseline is based on a single composite water sample from one location on Natu Lake and four soil records from land adjoining the lake, all collected during a single sampling event. Several limitations arise from this design and are explicitly acknowledged here, in line with the study's aim of establishing a preliminary rather than a definitive baseline. First, a single water sample and four soil records cannot capture spatial heterogeneity across the lake and its catchment. The Pearson correlations reported in Table 4 (n = 4) are therefore indicative only: they illustrate consistency with known pedological relationships, but they are not statistically significant. Second, the determinants were deliberately restricted to a selected set of physicochemical parameters (see Materials and Methods). Biochemical and chemical oxygen demand, ammonium, phosphate fractions, sulphate, chloride, hardness, alkalinity, microbiological indicators (coliforms/*E. coli*), heavy metals and pesticide residues were outside the scope of this phase and were not assessed. Because several of these, particularly BOD, COD and microbial indicators, directly determine the safety of the water for the fishing, irrigation and domestic uses documented in Bakura, Yarkofoji, Balgare and Gamji, their inclusion is a priority for the next monitoring phase rather than an optional extension.

Third, as a single sampling event, this study characterises the lake and its adjoining soils at the time of sampling. It cannot, by itself, distinguish a stable baseline from an emerging seasonal or long-term trend, nor can it attribute the observed patterns to climate variability, human activity or their interaction beyond the associative discussion presented above. Repeat sampling in the wet and dry seasons at an expanded set of stations is required to test whether the elevated turbidity, low dissolved oxygen and near-eutrophic phosphorus concentration reported here represent a stable condition or a developing trend.

CONCLUSION

This study establishes a preliminary physicochemical baseline for Natu Lake, Bakura LGA, Zamfara State, and its adjoining soils. Among the selected water-quality parameters, pH, nitrate and total dissolved solids were within WHO (2022) and NSDWQ (2015) guideline values, and the salinity of the water does not restrict its use for irrigation. In contrast, turbidity was very high, dissolved oxygen was below the level generally required for healthy fish populations, and total phosphorus placed the lake near the mesotrophic–eutrophic boundary. The adjoining soils are slightly acidic, clay loam in texture, and low in nitrogen, available phosphorus and cation exchange capacity. Considering the evidence of climate-associated desertification and hydro-climatic change in the Sokoto-Rima Basin, together with active fishing, irrigation and farming around the lake, these findings are consistent with ongoing erosion and nutrient loading driven by both climatic and anthropogenic factors. However, because this baseline rests on a single sampling event and a small number of samples, the observed patterns cannot yet be attributed with confidence to either driver. It is therefore recommended that catchment vegetation around the lake be protected or restored and soil-test-guided fertilizer application be promoted among the surrounding communities, while a seasonal, multi-station follow-up survey incorporating BOD, COD, nutrient fractions, microbiological indicators and heavy metals is undertaken to fully assess the suitability of the lake for fishing, irrigation and domestic use.

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