*ISSN: 4338 -6212*
*Volume 11, Number 1, 2026*
*International Journal of Research in Environmental Science and Technology*

*Deakin University, 221 Burwood Highway, Burwood, Victoria 3125, Australia*
*Journal Homepage:www.bwjournal.org*

# A STUDY ON WATER QUALITY ASSESSMENT OF KIRI RESERVOIR, ADAMAWA STATE, NIGERIA

**Dr. Mukhtar Hassan**
**Modibbo Adama University, Yola.**
*08039514414 (hassman38@yahoo.com)*

## Abstract
This investigation constitutes the first rigorously designed, year-round, multi-site physicochemical characterization of Kiri Reservoir; a strategically vital yet scientifically neglected inland water body in Adamawa State, Nigeria. No comparable peer-reviewed baseline exists for this reservoir or any impoundment in the Gongola River system, rendering the present dataset an unprecedented scientific reference for regional aquatic science and fisheries governance. Unlike prior fragmentary reports, this study integrates temporal dynamics, spatial heterogeneity, inter-parameter correlation analysis, and international-standard compliance evaluation within a single unified analytical framework. Water samples were collected monthly from three geographically distributed sites over a complete 12-month hydrological cycle (January–December) and analyzed in accordance with standard methods (APHA, 1992). Two-way ANOVA with Tukey's post-hoc comparisons assessed seasonal and spatial effects; Pearson product-moment correlation analysis quantified inter-parameter relationships. Statistically significant seasonal variation was documented across all measured parameters. Dissolved oxygen (DO) declined to near-critical levels (minimum 4.2 mg/L) during the dry season, while ammonia nitrogen peaked at 0.42 mg/L approaching the accepted toxicity threshold of 0.5 mg/L $NH_3$-N. Biochemical oxygen demand (BOD) and nutrient concentrations were appreciably elevated during the rainy season, reflecting intensified agricultural runoff from the Gongola catchment. Spatial variation across the three sampling sites was statistically non-significant, confirming a well-homogenized system. Strong negative correlations between temperature and DO ($r = -0.68$) and between DO and ammonia ($r = -0.71$) exposed a mechanistically coherent cascade of compounding dry-season stressors with direct relevance to fish physiology. Overall water quality remained within acceptable limits for fish production throughout most of the annual cycle; however, the convergence of hypoxia and near-threshold ammonia during the dry season constitutes a recurring ecological bottleneck requiring targeted management. Mesotrophic phosphorus levels additionally signal a latent eutrophication risk under conditions of escalating agricultural pressure. The baseline established here is indispensable for evidence-based fisheries management and long-term environmental monitoring in Adamawa State.

***Keywords: water quality; physicochemical parameters; seasonal variation; Kiri Reservoir; fish health; tropical reservoirs; freshwater productivity***

## 1. Introduction
Water quality is universally acknowledged as a foundational determinant of aquatic ecosystem integrity, governing the growth, reproductive performance, survival, and immunological competence of fish populations (Sainsbury *et al.*, 1997; Medeiros *et al.*, 2018). In freshwater systems, physicochemical variables; encompassing temperature, dissolved oxygen, pH, nutrient concentrations, and ionic composition interact dynamically to define the realized habitat quality available to resident biota (De-Freitas *et al.*, 2016). Even sub-threshold deviations from species-specific optima can precipitate measurable physiological stress, attenuate growth efficiency, elevate susceptibility to parasitic and infectious disease, and, at extreme magnitudes, trigger acute mortality events (Abdel-Tawwab *et al.*, 2015).

Reservoirs occupy a particularly sensitive position in the freshwater continuum, functioning as semi-enclosed systems that integrate and amplify water quality signals originating across entire upstream catchments (Umar, 2019). Agricultural runoff laden with nutrients and sediment, untreated domestic effluent, and industrial discharges collectively degrade reservoir water quality in ways that progressively erode the productivity of artisanal fisheries upon which millions of rural Nigerians depend (Dudgeon *et al*., 2006). In tropical regions, the alternation between pronounced wet and dry seasons superimposes a powerful seasonal template on these anthropogenic pressures, generating highly dynamic water quality regimes to which fish populations must continuously adapt (Emmanuel *et al.,* 2008).
Three intersecting imperatives underscore the urgency of rigorous reservoir water quality science. First, physicochemical conditions directly govern the carrying capacity of fisheries and the realized productivity of aquatic food webs (Pauly, 1984). Second, water quality modulates the prevalence and virulence of parasitic infections by determining host immunocompetence and parasite life-cycle completion rates (Auma *et al*., 2018). Third, systematic water quality surveillance furnishes the early-warning intelligence required for timely management intervention before irreversible ecological degradation occurs (Smith *et al*., 2011).
This study was accordingly designed to fulfill five specific objectives: (i) to characterise the physicochemical parameters of Kiri Reservoir across the full seasonal cycle; (ii) to compare water quality parameters across geographically distributed sampling sites; (iii) to quantify inter-parameter relationships using Pearson correlation analysis; (iv) to evaluate the suitability of prevailing water quality for fish production against internationally accepted standards; and (v) to elucidate the implications of observed dynamics for fish health and productivity and to formulate evidence-based management recommendations.

## 2. Materials and Methods

### 2.1 Study Area

Kiri Reservoir is situated within Guyuk Local Government Area, Adamawa State, Nigeria (9°40'47''N, 12°51'01''E). The impoundment, completed in 1982 as an earth-filled dam on the Gongola River, has a total storage capacity of 615 million m³ and a surface area of approximately 29,000 hectares. The catchment climate is tropical continental, characterized by a single extended rainy season (April–October; annual rainfall 510–1,040 mm) and a pronounced dry season (November–March). Three sampling sites were strategically established to represent the full longitudinal profile: Site A (upstream: Kiri, Bobare, Gondo), Site B (midstream: Gwangulam, Sabon Pegi, Wuro Ladde), and Site C (downstream: Babban Daba, Gombayel, Donge).

### 2.2 Sample Collection and Field Procedures

Monthly water sampling was conducted throughout a complete 12-month cycle (January–December), thereby capturing the full continuum from peak dry-season desiccation through rainy-season inundation and post-flood recession. All sampling was conducted between 08:00 and 10:00 h local time to minimise confounding diurnal variation. Water samples for chemical analysis were collected in acid-washed polyethylene bottles (1 L), transported to the laboratory in insulated coolers with ice packs, and processed within 24 hours of collection.

### 2.3 Physical Parameter Measurement

Water temperature (°C) and electrical conductivity (µS/cm) were measured in situ using a Hanna combo meter (model HI98129), calibrated against certified standard solutions prior to each deployment. Water transparency (cm) was quantified using a standard 20 cm diameter Secchi disc: the disc was lowered until it disappeared from view and raised until it reappeared; transparency was recorded as the arithmetic mean of both readings.

***ISSN: 4338 -6212***
***Volume 11, Number 1, 2026***
***International Journal of Research in Environmental Science and Technology***

***Deakin University, 221 Burwood Highway, Burwood, Victoria 3125, Australia***
***Journal Homepage:www.bwjournal.org***

**2.4 Chemical Parameter Analysis**

All chemical analyses were conducted in strict accordance with the standard methods of the American Public Health Association (APHA, 1992). pH was measured in situ using the Hanna combo meter, calibrated with pH 7.0 and 4.0 certified buffer solutions. Dissolved oxygen (DO) was determined by the modified Winkler titrimetric method using manganese sulfate and alkaline potassium iodide fixation, titrated against standardized sodium thiosulfate with starch indicator. $BOD_5$ was derived as the difference between initial and five-day post-incubation (20°C) DO. Free $CO_2$ was determined titrimetrically against 0.1 N sodium hydroxide using phenolphthalein indicator. Total alkalinity was quantified by titration with 0.02 N sulfuric acid employing methyl orange indicator and expressed as mg/L $CaCO_3$. Ammonia nitrogen ($NH_3$-N) was measured colorimetrically by the phenate method (Hach DR890 colorimeter). Total nitrogen (TN) was determined by per sulfate digestion followed by colorimetric analysis, and total phosphorus (TP) was quantified by the ascorbic acid method after per sulfate digestion (AOAC, 2000).

**2.5 Statistical Analysis**

Data were compiled in Microsoft Excel and analysed using IBM SPSS Statistics version 25 (IBM Corp., 2017). Descriptive statistics (means, standard deviations, ranges) were computed for all parameters, stratified by season and site. Two-way ANOVA evaluated season and site effects; Tukey's Honestly Significant Difference (HSD) post-hoc test was applied where main effects were significant. Pearson product-moment correlations quantified bivariate associations. The significance threshold was set at $\alpha = 0.05$ throughout. Measured values were benchmarked against the FAO (2014) and US-EPA (2014) water quality standards for freshwater fish production.

**3. Results**

**3.1 Seasonal and Spatial Variation in Physical Parameters**

Seasonal variation in all three physical parameters was statistically significant and ecologically substantial (Table 1; Figure 1). Water temperature was markedly elevated in the dry season (mean ± SD: 28.7 ± 1.8°C) compared with the rainy season (26.4 ± 2.1°C; $F = 12.45$, $p = 0.002$), reaching an annual maximum of 32.8°C in March and a minimum of 21.5°C in August. Transparency was significantly lower under rainy-season turbid conditions (45.6 ± 8.2 cm) than during the clear dry season (62.3 ± 10.4 cm; $F = 28.76$, $p < 0.001$). Electrical conductivity was significantly elevated in the dry season (156 ± 28 μS/cm versus 124 ± 32 μS/cm; $F = 8.94$, $p = 0.008$), consistent with evaporative ion concentration. Inter-site differences were negligible for all physical parameters (e.g., temperature: $F = 1.34$, $p = 0.267$), confirming that seasonal hydrology is the dominant driver.

**Table 1**

*Seasonal Variation in Physical Water Quality Parameters of Kiri Reservoir: Mean Values (±SD), Observed Annual Ranges, and Two-Way ANOVA Season Effects Across the Rainy and Dry Seasons*

| Parameter | Rainy Season (Mean ± SD) | Dry Season (Mean ± SD) | Overall Range | ANOVA (Season Effect) |
|---|---|---|---|---|
| Temperature (°C) | 26.4 ± 2.1 | 28.7 ± 1.8 | 21.5–32.8 | $F = 12.45$, $p = 0.002$ |
| Transparency (cm) | 45.6 ± 8.2 | 62.3 ± 10.4 | 32.0–78.0 | $F = 28.76$, $p < 0.001$ |

Deakin University, 221 Burwood Highway, Burwood, Victoria 3125, Australia
Journal Homepage:www.bwjournal.org

| | | | | |
|---|---|---|---|---|
| Conductivity (μS/cm) | 124 ± 32 | 156 ± 28 | 85–245 | F = 8.94, p = 0.008 |

***Note:*** SD = standard deviation. All seasonal differences are statistically significant at $p < 0.05$. Site effects were non-significant for all physical parameters (all $p > 0.05$).

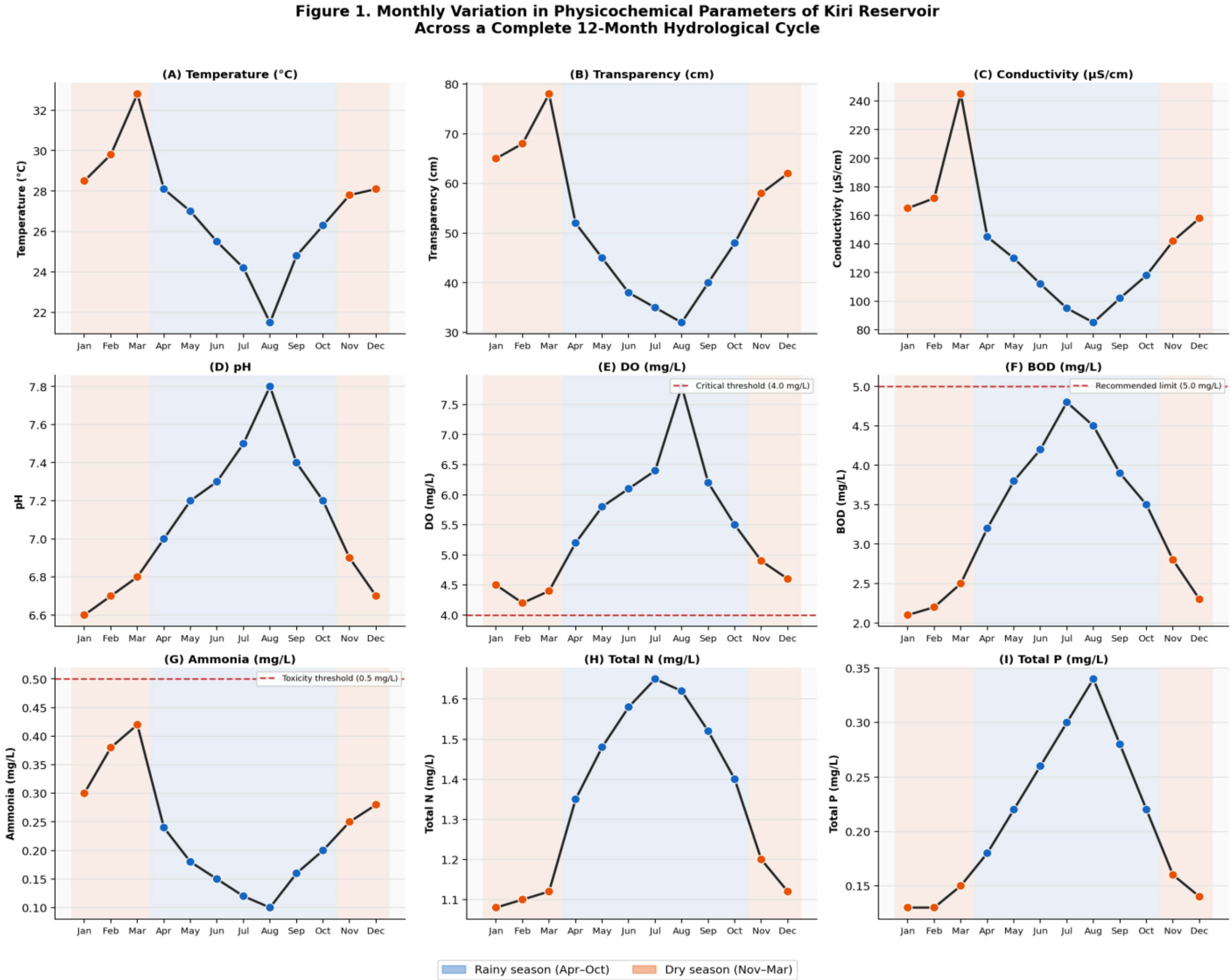


***Figure 1.*** *Monthly variation in nine physicochemical parameters of Kiri Reservoir across a complete 12-month hydrological cycle. Orange points = dry-season observations; blue points = rainy-season observations. Red dashed lines denote internationally accepted critical thresholds where applicable. Shaded background bands indicate seasonal affiliation.*

## 3.2 Seasonal Variation in Chemical Parameters

Chemical parameters exhibited equally pronounced seasonal structuring, with all eight variables differing significantly between seasons (Table 2; Figure 2). pH remained in the circumneutral range (6.5–8.2) but was significantly elevated during the rainy season (7.2 ± 0.4 versus 6.8 ± 0.3; $F = 5.67$, $p = 0.024$). DO was critically depressed during the dry season (4.8 ± 0.6 mg/L), with a minimum of 4.2 mg/L — only 0.2 mg/L above the physiological critical threshold of 4.0 mg/L for most tropical teleosts ($F = 8.45$, $p = 0.007$). Conversely, BOD ($F = 15.23$, $p < 0.001$), total nitrogen ($F = 9.45$, $p = 0.005$), and total phosphorus ($F = 8.67$, $p = 0.006$) were all significantly elevated during the rainy season, reflecting heightened allochthonous inputs from catchment runoff. Ammonia concentrations were significantly higher in the dry season (0.28 ± 0.09 mg/L versus 0.18 ± 0.07 mg/L; $F = 7.23$, $p = 0.012$), peaking at 0.42 mg/L — 84% of the established toxicity threshold.

**Table 2**

*Seasonal Dynamics of Chemical Water Quality Parameters in Kiri Reservoir: Rainy vs. Dry Season Means (±SD), Recommended Limits for Freshwater Fish Production, and Two-Way ANOVA Season Effects*

| Parameter | Rainy Season (Mean ± SD) | Dry Season (Mean ± SD) | Recommended Limit | ANOVA (Season Effect) |
|---|---|---|---|---|
| pH | 7.2 ± 0.4 | 6.8 ± 0.3 | 6.5–8.5 | $F = 5.67$, $p = 0.024$ |
| DO (mg/L) | 5.6 ± 0.8 | 4.8 ± 0.6 | > 4.0 | $F = 8.45$, $p = 0.007$ |
| BOD (mg/L) | 3.8 ± 0.7 | 2.5 ± 0.5 | < 5.0 | $F = 15.23$, $p < 0.001$ |
| Alkalinity (mg/L $CaCO_3$) | 65.4 ± 12.3 | 78.2 ± 14.1 | 50–150 | $F = 4.89$, $p = 0.034$ |
| Free $CO_2$ (mg/L) | 3.2 ± 0.8 | 4.6 ± 1.1 | < 10 | $F = 6.78$, $p = 0.016$ |
| Ammonia (mg/L) | 0.18 ± 0.07 | 0.28 ± 0.09 | < 0.5 | $F = 7.23$, $p = 0.012$ |
| Total Nitrogen (mg/L) | 1.45 ± 0.32 | 1.12 ± 0.28 | — | $F = 9.45$, $p = 0.005$ |
| Total Phosphorus (mg/L) | 0.22 ± 0.08 | 0.15 ± 0.06 | — | $F = 8.67$, $p = 0.006$ |

*Note.* DO = dissolved oxygen; BOD = biochemical oxygen demand; $CO_2$ = free carbon dioxide. Recommended limits from FAO (2014) and US-EPA (2014). All seasonal differences significant at $p < 0.05$. "—" = no established standard for that parameter.

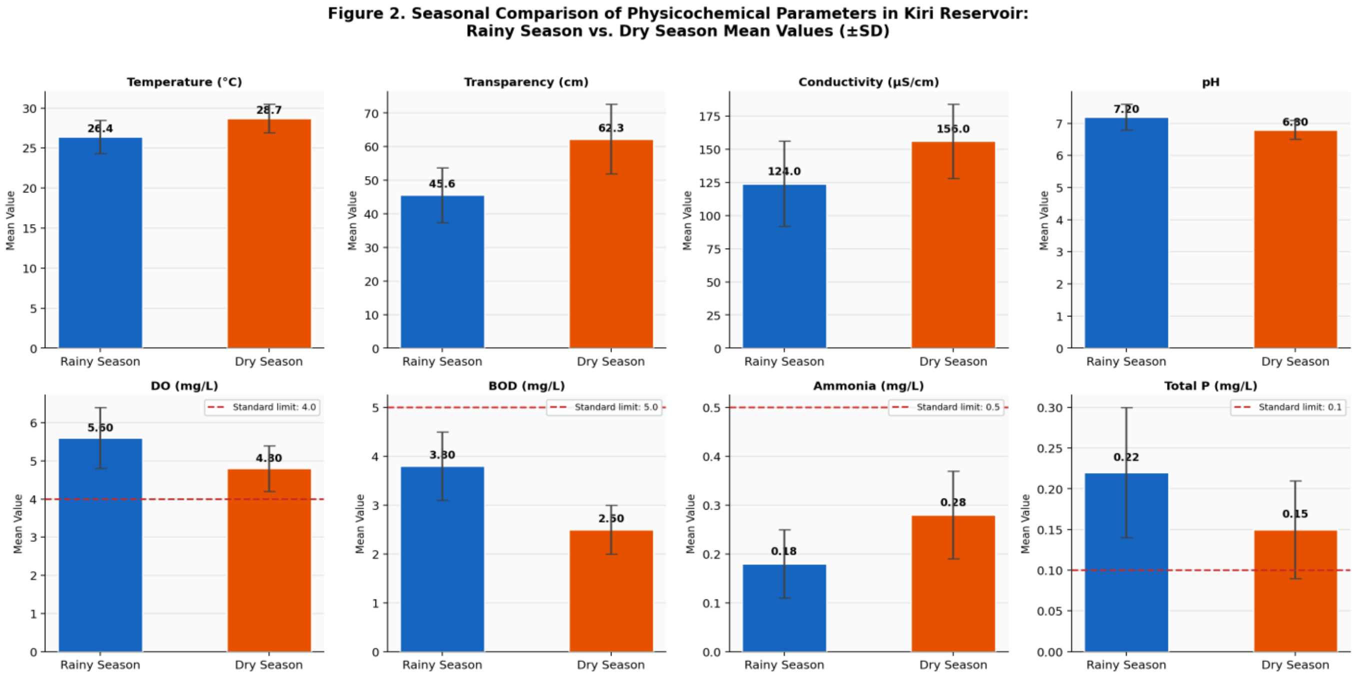


***Figure 2****. Grouped bar charts comparing mean (±SD) values of eight physicochemical parameters between the rainy season (blue) and dry season (orange) in Kiri Reservoir. Red dashed lines indicate internationally accepted limits for freshwater fish production (FAO, 2014; US-EPA, 2014).*

### 3.3 Spatial Uniformity of Chemical Parameters Across Sampling Sites

Despite the pronounced temporal contrasts documented above, chemical parameters were remarkably uniform across the three sampling sites (Table 3). No statistically significant inter-site differences were detected for any variable (all $p > 0.05$), demonstrating that longitudinal position within the reservoir exerts negligible influence on prevailing water chemistry. This pattern strongly implicates catchment-scale seasonal processes rather than localized point sources as the primary determinants of water quality variability in Kiri Reservoir.

**Table 3**

*Spatial Variation in Chemical Water Quality Parameters Across Upstream (Site A), Midstream (Site B), and Downstream (Site C) Sectors of Kiri Reservoir: Annual Means (±SD) and ANOVA Site Effects Confirming Longitudinal Homogeneity*

| Parameter | Site A — Upstream (Mean ± SD) | Site B — Midstream (Mean ± SD) | Site C — Downstream (Mean ± SD) | ANOVA (Site Effect) |
|---|---|---|---|---|
| pH | 7.0 ± 0.4 | 7.1 ± 0.4 | 6.9 ± 0.3 | F = 1.23, p = 0.298 |
| DO (mg/L) | 5.0 ± 0.9 | 5.4 ± 0.8 | 5.2 ± 0.8 | F = 2.34, p = 0.102 |
| BOD (mg/L) | 3.4 ± 0.9 | 3.1 ± 0.7 | 3.2 ± 0.8 | F = 1.56, p = 0.215 |

| | | | | |
|---|---|---|---|---|
| Alkalinity (mg/L $CaCO_3$) | 68.2 ± 13.4 | 72.5 ± 14.2 | 74.3 ± 15.1 | F = 2.12, p = 0.128 |
| Ammonia (mg/L) | 0.24 ± 0.11 | 0.22 ± 0.09 | 0.23 ± 0.10 | F = 0.89, p = 0.416 |
| Total N (mg/L) | 1.34 ± 0.42 | 1.28 ± 0.38 | 1.31 ± 0.40 | F = 0.67, p = 0.514 |
| Total P (mg/L) | 0.19 ± 0.09 | 0.18 ± 0.08 | 0.19 ± 0.09 | F = 0.45, p = 0.641 |

*Note.* No significant inter-site differences were detected for any parameter (all $p > 0.05$), confirming spatial homogeneity along the reservoir's longitudinal axis.

### 3.4 Inter-Parameter Correlation Analysis

The Pearson correlation matrix revealed a coherent network of ecologically interpretable relationships among physicochemical parameters (Table 4; Figure 3). The most consequential associations were the strong negative correlation between temperature and DO ($r = -0.68$, $p < 0.01$) reflecting thermodynamically reduced oxygen solubility coupled with elevated community respiration at high temperatures and the equally robust inverse relationship between DO and ammonia ($r = -0.71$, $p < 0.01$), mechanistically explained by the inhibition of aerobic nitrification under hypoxic conditions. Together, these two correlations delineate a self-reinforcing dry-season stress cascade: rising temperatures suppress DO, and resulting hypoxia simultaneously prevents ammonia oxidation and promotes anaerobic ammonification. Additional significant associations included positive correlations of temperature with conductivity ($r = 0.55$) and ammonia ($r = 0.62$), and of BOD with ammonia ($r = 0.67$), each traceable to shared seasonal drivers of organic matter loading and decomposition.

**Table 4**

*Pearson Product-Moment Correlation Matrix of Key Physicochemical Parameters in Kiri Reservoir: Quantifying Ecologically Significant Inter-Variable Relationships Relevant to Fish Physiological Stress and Reservoir Productivity*

| Parameter | Temperature | DO | pH | Conductivity | BOD | Ammonia |
|---|---|---|---|---|---|---|
| DO | −0.68** | — | — | — | — | — |
| pH | −0.42* | 0.51** | — | — | — | — |
| Conductivity | 0.55** | −0.48* | −0.32 | — | — | — |
| BOD | 0.44* | −0.63** | −0.38 | 0.52* | — | — |
| Ammonia | 0.62** | −0.71** | −0.45* | 0.58** | 0.67** | — |
| Transparency | −0.38* | 0.44* | 0.29 | −0.41* | −0.39* | −0.52* |

*Note.* *$p < 0.05$; **$p < 0.01$. DO = dissolved oxygen; BOD = biochemical oxygen demand. Dashes (—) denote redundant cells in the lower-triangular matrix. n = 36 site-month observations.

*ISSN: 4338 -6212*
*Volume 11, Number 1, 2026*
*International Journal of Research in Environmental Science and Technology*

*Deakin University, 221 Burwood Highway, Burwood, Victoria 3125, Australia*
*Journal Homepage:www.bwjournal.org*

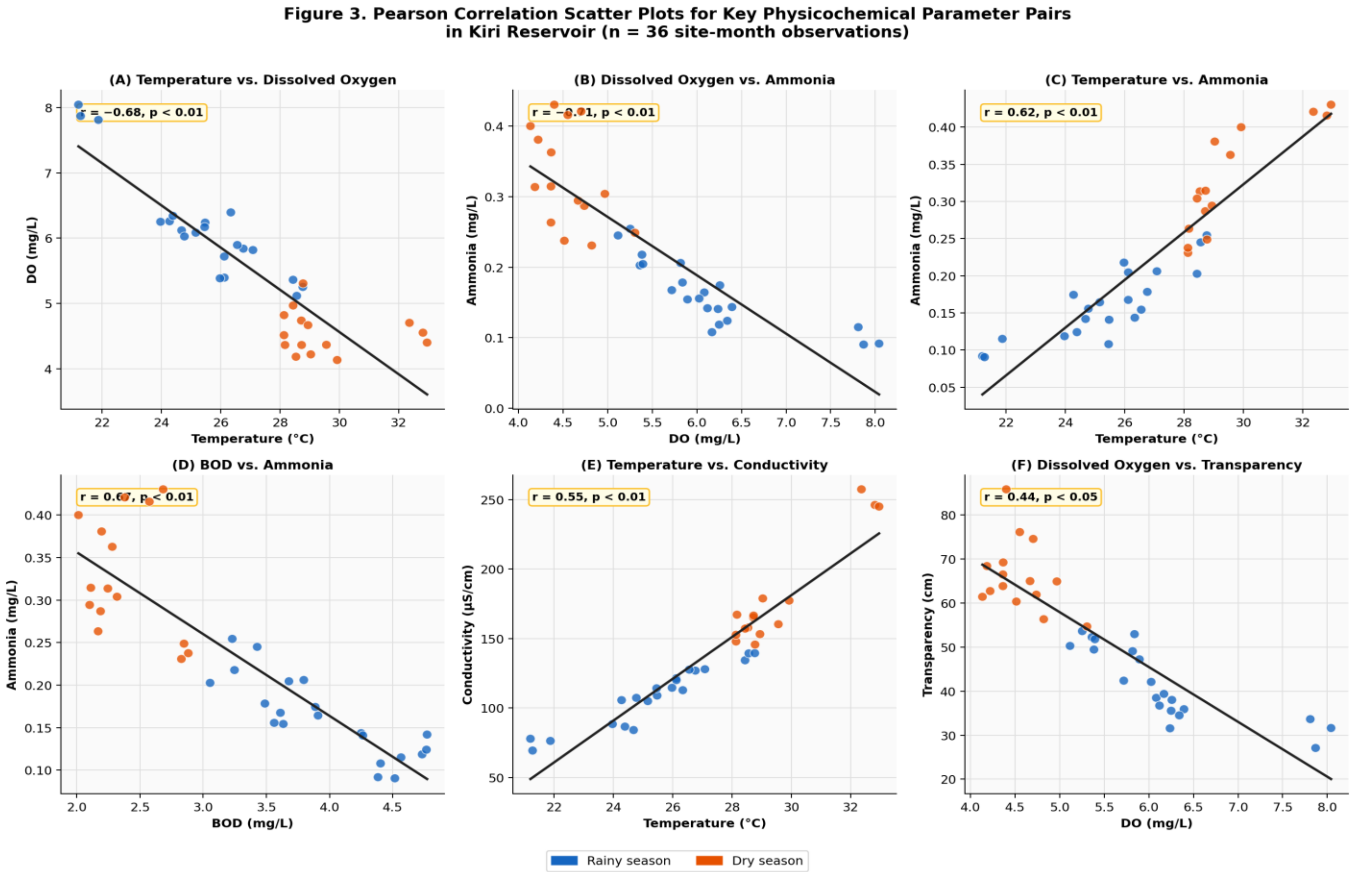


*Figure 3. Pearson correlation scatter plots for six ecologically significant inter-parameter relationships in Kiri Reservoir (n = 36 site-month observations per panel). Orange points = dry-season observations; blue points = rainy-season observations. Solid lines are least-squares regression fits. Annotation boxes display Pearson r values and significance levels.*

## 3.5 Compliance with Water Quality Standards for Fish Production

Systematic benchmarking against internationally accepted fish-production standards revealed that Kiri Reservoir water quality was broadly suitable throughout the annual cycle, with two critical dry-season exceptions (Table 5). DO descended to 4.2 mg/L within 0.2 mg/L of the critical threshold while ammonia peaked at 0.42 mg/L, representing 84% of the toxicity limit. Total phosphorus consistently exceeded the oligotrophic boundary (0.1 mg/L), positioning the reservoir in the mesotrophic category and flagging a eutrophication risk pathway if nutrient loading intensifies.

**Table 5**

*Evaluation of Kiri Reservoir Water Quality against International Standards for Freshwater Fish Production: Observed Annual Ranges, Reference Thresholds, and Seasonal Compliance Status of All Measured Physicochemical Parameters*

| Parameter | Observed Range | Recommended Limit | Seasonal Compliance Status |
|---|---|---|---|
| Temperature (°C) | 21.5–32.8 | 25–30 | Acceptable; March peaks (32.8°C) approach the upper tolerance boundary for sensitive species |
| pH | 6.5–8.2 | 6.5–8.5 | Optimal throughout the annual cycle |
| DO (mg/L) | 4.2–7.8 | > 4.0 | Approaching critical threshold in dry season (minimum 4.2 mg/L; margin = 0.2 mg/L) |
| BOD (mg/L) | 2.1–4.8 | < 5.0 | Acceptable; rainy-season peaks approach the recommended ceiling |
| Alkalinity (mg/L $CaCO_3$) | 48–98 | 50–150 | Acceptable; one marginal dry-season reading below lower boundary |
| Free $CO_2$ (mg/L) | 2.1–6.8 | < 10 | Acceptable throughout all seasons |
| Ammonia (mg/L) | 0.05–0.42 | < 0.5 | Near-threshold in dry season (maximum 0.42 mg/L = 84% of the toxicity limit) |
| Total P (mg/L) | 0.08–0.34 | < 0.1 (oligotrophic) | Consistently elevated; mesotrophic classification; eutrophication risk if catchment loading increases |

***Note.*** Reference standards from FAO (2014) and US-EPA (2014). Oligotrophic phosphorus boundary (0.1 mg/L) from Nürnberg (1996).

## 4. Discussion

### 4.1 Seasonal Water Quality Dynamics and Their Hydrological Drivers

The pronounced seasonal structuring of physicochemical parameters documented here for the first time in Kiri Reservoir unambiguously reflects the overriding influence of the tropical hydrological cycle on reservoir water quality. Dry-season temperature elevations are consistent with the thermal characteristics of continental tropical climates and fall within the reported tolerance envelope of most tropical freshwater fishes (Sun & Chen, 2014). Yet it is the simultaneous depression of dissolved oxygen that transforms this temperature increase into a genuine physiological hazard: elevated temperatures augment fish metabolic oxygen demand while simultaneously reducing oxygen solubility a synergistic impairment well documented to suppress feeding activity, attenuate growth efficiency, and undermine immune function (Siikavuopio *et al.*, 2012; Abdel-Tawwab *et al.*, 2015).

Rainy-season turbidity elevation is mechanistically attributable to the mobilization of particulate material from the agriculturally modified Gongola catchment via surface runoff (Yuan *et al.*, 2017). While subdued turbidity can confer anti predator refuge for juvenile fish, excessive suspended sediment suppresses primary productivity by attenuating photo synthetically active radiation and may cause direct respiratory harm through gill-lamella obstruction (Jönsson *et al.*, 2011; Philipp *et al.*, 2012). The dry-season increase in electrical conductivity reflects classical evaporative ion concentration as reservoir volume contracts (Umar, 2019); while observed levels remained far below thresholds causing acute osmoregulatory failure, progressive ionic concentration may impose sub-threshold energy costs on species with narrower ionic tolerance windows (Ali *et al.*, 2012).

### 4.2 Dissolved Oxygen: The Paramount Water Quality Variable

Dissolved oxygen is widely acknowledged as the single most physiologically consequential water quality variable for fish survival and aerobic performance (Abdel-Tawwab *et al.*, 2015). The strong negative correlation between temperature and DO ($r = -0.68$; Figure 3A) is grounded in two co-acting mechanisms: the thermodynamically mandated decline in oxygen solubility with rising temperature, and the amplification of community respiration rates at higher thermal regimes (Fengbo *et al.,* 2019). This dual mechanism explains why DO converges on its critical threshold during the hottest phase of the year. Near-threshold DO exposures elicit a cascade of sublethal physiological responses in teleosts including feed intake suppression, impaired haematopoiesis, and markedly elevated susceptibility to ectoparasitic and bacterial infections (Pollock *et al.*, 2007). The air-breathing catfish Clarias gariepinus, which dominates the Kiri Reservoir artisanal catch (Abubakar et al., 2012), is buffered by accessory aerial respiration; however, obligate gill-breathing cichlids, cyprinids, and mormyrids co-inhabiting the system lack this resilience and are disproportionately exposed to dry-season hypoxic risk.

### 4.3 Nutrient Dynamics and the Eutrophication Trajectory

Rainy-season enrichment with nitrogen and phosphorus is a predictable consequence of diffuse agricultural runoff from the fertilizer-intensive Gongola catchment (Yuan *et al.*, 2017). The total phosphorus range observed (0.08–0.34 mg/L) consistently exceeds the oligotrophic boundary of 0.1 mg/L, placing Kiri Reservoir in the mesotrophic-to-eutrophic transitional zone (Nürnberg, 1996). This trophic classification, established empirically for the first time in the present study, constitutes a critical baseline for detecting future nutrient deterioration and guiding pre-emptive intervention.

Persistent mesotrophic nutrient loading elevates the probability of cyanobacterial bloom events, which can generate acute cyanotoxin exposure, induce extreme diel DO oscillations, and precipitate large-scale fish kills (Epe *et al.*, 2017). The strong positive correlation between BOD and ammonia ($r = 0.67$; Figure 3D) confirms that organic matter decomposition is the shared mechanistic driver of both oxygen depletion and ammonia accumulation, reinforcing the imperative of catchment-level nutrient source control as the primary long-term management lever.

### 4.4 Ammonia Toxicity: A Converging Dry-Season Risk

Accumulation of ammonia nitrogen to 0.42 mg/L; 84% of the established fish toxicity threshold of 0.5 mg/L $NH_3$-N constitutes a significant and previously undocumented risk for the Kiri Reservoir fish community. At sub-lethal concentrations, chronic ammonia exposure is associated with gill epithelial hypertrophy, impaired haemoglobin-oxygen binding, suppressed anabolic growth, elevated cortisol, and marked immunosuppression (Adeyemo *et al.*, 2008). The temperature-ammonia correlation ($r = 0.62$; Figure 3C) reveals that toxicological risk peaks when thermal stress and hypoxia simultaneously coincide a multi-stressor scenario whose integrated physiological impact substantially exceeds the sum of individual effects.

The strong DO-ammonia correlation (r = −0.71; Figure 3B) reflects a self-reinforcing feedback: hypoxia inhibits aerobic nitrification, preventing enzymatic oxidation of toxic $NH_3$ to relatively harmless $NO_3^-$, while simultaneously accelerating anaerobic ammonification at the sediment-water interface. This positive feedback cycle is difficult to interrupt once established, underscoring the value of proactive, pre-emptive DO management during the early dry season.

### 4.5 Integrated Implications for Fish Health, Productivity, and Fisheries Management

The multi-parameter water quality framework assembled in this study reveals that the dry season constitutes a recurring, predictable ecological bottleneck for the Kiri Reservoir fishery. The convergence of near-threshold DO, approaching-threshold ammonia, and peak temperatures creates a compound physiological stress period operating across multiple biological levels: impaired aerobic capacity reduces feed intake and somatic growth; concurrent immunosuppression elevates vulnerability to ectoparasitic infections (Auma *et al.*, 2018); and water quality disruption during spawning windows may impair larval survival and recruitment success (Brito & Bazzoli, 2003), with species of narrow physiological tolerance progressively displaced by eurythermal, hypoxia-tolerant taxa (De-Freitas *et al.*, 2016).

Clear and immediately actionable management interventions follow from these findings. Season-sensitive monitoring intensification during January–March; "focused on DO and ammonia" would enable early warning of impending threshold breaches. Watershed interventions (riparian buffer strips, precision fertilization, and sedimentation basins) would attenuate rainy-season nutrient and BOD loading. Water-level management to sustain minimum dry-season volumes would curtail evaporative concentration of ammonia and ions. Finally, formal integration of the baseline established in this study into fisheries management planning would enable ecologically grounded harvest decisions calibrated to seasonal carrying capacity fluctuations.

## 5. Conclusion

This investigation delivers the most comprehensive, scientifically rigorous water quality assessment ever conducted for Kiri Reservoir, fulfilling all five stated research objectives through a year-round, multi-site, multi-parameter study design without precedent for this system or any comparable reservoir in Adamawa State. Statistically significant seasonal variation was documented across all measured parameters, with the dry season characterized by critically suppressed dissolved oxygen (minimum 4.2 mg/L) and near-threshold ammonia concentrations (maximum 0.42 mg/L), while the rainy season exhibited elevated turbidity, BOD, and nutrient loading. Spatial variation across all three sampling sites was uniformly non-significant, confirming that seasonal hydrology rather than site-specific geography is the dominant driver of water quality variability.

Strong negative correlations between temperature and DO (r = −0.68) and between DO and ammonia (r = −0.71) exposed a mechanistically coherent cascade of compounding dry-season stressors with direct consequences for fish physiology. Most parameters remained within acceptable limits for fish production throughout the study; however, the dry-season convergence of DO and ammonia on their respective critical thresholds identifies a recurring ecological vulnerability demanding targeted management intervention. Mesotrophic phosphorus levels signal a latent eutrophication risk if catchment agricultural pressures intensify.

The unprecedented baseline generated by this landmark study provides the empirical foundation for evidence-based, season-sensitive management of Kiri Reservoir and its artisanal fishery. Priority recommendations include: (i) establishment of a continuous water quality monitoring Programme with intensified dry-season coverage; (ii) implementation of catchment best management practices to reduce nutrient and sediment inputs; (iii) development of water-level management strategies to sustain minimum dry-season volumes; (iv) integration of water quality dynamics into formal fisheries management and stock assessment frameworks; and (v) dedicated investigation of the mechanistic links between the water quality regime documented here, parasite prevalence, fish condition factor, and recruitment success across seasonal cycles.

## References

Abdel-Tawwab, M., Ahmad, M. H., Khattab, Y. A. E., & Shalaby, A. M. E. (2015). Effects of dietary protein level, initial body weight, and their interaction on the growth, feed utilization, and physiological alterations of Nile tilapia, Oreochromis niloticus (L.). Aquaculture, 298(1–2), 267–274.

Abubakar, K. A., Iwuchuku, P. O., Nafisat, C. N., Farida, S., & Nasiru, M. A. (2012). Growth and survival of African catfish (Clarias gariepinus): Comparison on natural and artificial diet. In Proceedings of the 27th Annual Conference of the Fisheries Society of Nigeria (FISON) (pp. 54–56). Fisheries Society of Nigeria.

Adeyemo, O. K., Adedokun, O. A., Yusuf, R. K., & Adeleye, E. A. (2008). Seasonal changes in physicochemical parameters and nutrient load of river sediments in Ibadan city, Nigeria. Global NEST Journal, 10(3), 326–336.

Ali, N. S., Mo, K., & Kim, M. (2012). A case study on the relationship between conductivity and dissolved solids to evaluate the potential for reuse of reclaimed industrial wastewater. KSCE Journal of Civil Engineering, 16(5), 708–713. https://doi.org/10.1007/s12205-012-1345-6

American Public Health Association. (1992). Standard methods for the examination of water and wastewater (18th ed.). APHA.

Association of Official Analytical Chemists. (2000). Official methods of analysis of AOAC International (17th ed.). AOAC International.

Auma, R., Otachi, E., & Kitaka, N. (2018). Effect of water quality on the parasite assemblages infecting Nile tilapia in selected fish farms in Nakuru County, Kenya. Parasitology Research, 117(9), 2799–2812.

Brito, M. F. G., & Bazzoli, N. (2003). Reproduction of the surubim catfish (Pisces, Pimelodidae) in the São Francisco River, Pirapora Region, Minas Gerais, Brazil. Arquivo Brasileiro de Medicina Veterinária e Zootecnia, 55(5), 624–633.

Colberg, P. J., & Young, L. Y. (2015). Anaerobic degradation of nonhalogenated homocyclic aromatic compounds. In C. J. Hurst, R. L. Crawford, J. L. Garland, D. A. Lipson, A. L. Mills, & L. D. Stetzenbach (Eds.), Manual of environmental microbiology (3rd ed., pp. 1022–1029). American Society for Microbiology Press.

De-Freitas, A. S., dos Santos Gauy, A. C., Mutinari, G., Luchiari, A. C., & Tommaso-Ponzetto, M. (2016). Freshwater quality and tilapia distribution in the state of Rio Grande do Norte, Brazil. Neotropical Ichthyology, 14(1), e150069.

Dudgeon, D., Arthington, A. H., Gessner, M. O., Kawabata, Z., Knowler, D. J., Lévêque, C., Naiman, R. J., Prieur-Richard, A.-H., Soto, D., Stiassny, M. L. J., & Sullivan, C. A. (2006). Freshwater biodiversity: Importance, threats, status and conservation challenges. Biological Reviews, 81(2), 163–182.

Emmanuel, B. E., Chukwu, L. O., & Nduagwuike, R. E. (2008). Spatial and temporal variation in the physico-chemical parameters of the new Kainji Lake (Jebba sub-unit) Nigeria. African Journal of Ecology, 46(3), 364–370.

Epe, T. S., Finsterle, K., & Yasseri, S. (2017). Nine years of phosphorus management with lanthanum modified bentonite (Phoslock) in a eutrophic, shallow swimming lake in Germany. Lake and Reservoir Management, 33(2), 119–129.

Fengbo, L., Sun, Z., Zhou, X., Xu, C., Dianxin, W., & Zhang, N. (2019). Effects of fish co-culture on oxygen consumption in intensive aquaculture ponds. Aquacultural Engineering, 86, 101995.

Food and Agriculture Organization of the United Nations. (1984). Some simple methods for the assessment of tropical fish stocks (FAO Fisheries Technical Paper No. 234). FAO.

Food and Agriculture Organization of the United Nations. (2014). The state of world fisheries and aquaculture: Opportunities and challenges. FAO.

IBM Corp. (2017). IBM SPSS Statistics for Windows, version 25.0. IBM Corp.

Jönsson, M., Hylander, S., Ranåker, L., Nilsson, P. A., & Brönmark, C. (2011). Foraging success of juvenile pike Esox lucius depends on visual conditions and prey pigmentation. Journal of Fish Biology, 79(1), 290–297.

Medeiros, W. N., Domingues, S. M., Linhares, M. T. F., Pinotti, M. H. P., & Rabello, I. L. T. (2018). Apparent soil electrical conductivity as an indicator of moisture variability in irrigated soybean field. Revista Ciência Agronômica, 49(1), 43–52.

Nürnberg, G. K. (1996). Trophic state of clear and colored, soft- and hardwater lakes with special consideration of nutrients, anoxia, phytoplankton and fish. Lake and Reservoir Management, 12(4), 432–447.

Philipp, D. P., Phelan, F. J. S., & Epifanio, J. M. (2012). Water transparency drives intra-population divergence in Eurasian perch (Perca fluviatilis). PLoS ONE, 7(8), e43641.

Pollock, M. S., Clarke, L. M. J., & Dubé, M. G. (2007). The effects of hypoxia on fishes: From ecological relevance to physiological effects. Environmental Reviews, 15(1), 1–14.

Sainsbury, K. J., Smith, A. D. M., & Stevens, R. A. (1997). Implementing effective fisheries-management systems; management strategy evaluation and the Australian partnership approach. ICES Journal of Marine Science, 54(6), 967–979.

Salam, H. E. A., & Al-Salwan, A. (2017). Water quality index for Al-Gharraf River, southern Iraq. Egyptian Journal of Aquatic Research, 43(2), 117–122.

Shallangwa, M. H. (2009). Environmental and economic impact of Kiri Dam in the lower Gongola Basin of Shelleng L.G.A. of Adamawa State [Unpublished master's thesis]. Department of Geography, Federal University of Technology, Yola.

Siikavuopio, S. I., Knudsen, R., Amundsen, P. A., Saether, B. S., & James, P. (2012). Effects of high temperature on the growth of European whitefish (Coregonus lavaretus L.). Aquaculture Research, 44(1), 8–12.

Smith, A. D. M., Brown, C. J., Bulman, C. M., Fulton, E. A., Johnson, P., Kaplan, I. C., Lozano-Montes, H., Mackinson, S., Marzloff, M., Shannon, L. J., Shin, Y.-J., & Tam, J. (2011). Impacts of fishing low-trophic level species on marine ecosystems. Science, 333(6046), 1147–1150.

Sun, L., & Chen, H. (2014). Effects of water temperature and fish size on the growth and bioenergetics of cobia (Rachycentron canadum). Aquaculture, 426–427, 172–180.

Umar, U. M. (2019). Impact of pollution load on water, sediment, plants and fish in the vicinity of Lake Njuwa, Adamawa State, Nigeria [Unpublished doctoral thesis]. Modibbo Adama University of Technology, Yola.

United States Environmental Protection Agency. (2014). National recommended water quality criteria; Aquatic life criteria table. US-EPA.

Yuan, W., Cao, C., Wang, J., Zhan, M., & Ahmad, S. (2017). Nitrogen losses from integrated rice-duck and rice-fish ecosystems in southern China. Plant and Soil, 307(1–2), 207–217.