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Hydrochemistry and Predictive Modelling of Water Quality in Ogun and Oshun Rivers, Southwestern Nigeria

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ABSTRACT

Rivers in tropical Africa face increasing pressures from rapid urbanization, agricultural intensification, and weak wastewater management, yet systematic assessments of their hydrochemistry and predictive modelling remain limited. This study investigates the water quality of Ogun and Oshun Rivers in southwestern Nigeria using a multi-method approach that integrates descriptive statistics, compliance analysis, hydrochemical ratios, trend evaluation, and regression modelling. Thirteen sites along Ogun River and ten sites along Oshun River were sampled in both wet and dry seasons. Key parameters analyzed included pH, major cations (Na^+ , Ca^{2+} , Mg^{2+} , K^+), anions (Cl^- , SO_4^{2-} , PO_4^{3-}), total dissolved solids (TDS), turbidity, and iron. Results showed that while most ions were within the limits set by the WHO (2017) and the NSDWQ (2007), turbidity and phosphate consistently exceeded permissible levels in 70–100% of samples. Hydrochemical ratios indicated dual controls, with carbonate weathering as the primary geogenic influence and sodium enrichment reflecting anthropogenic inputs. Trend analysis revealed significantly higher Na^+ , PO_4^{3-} , and TDS in the dry season ($p < 0.05$), while downstream gradients highlighted cumulative deterioration, particularly in Ogun River. Predictive modelling demonstrated that sodium is the strongest predictor ion, and decision tree regression outperformed linear and polynomial models, achieving R^2 values above 0.95 in dry season datasets. These findings underscore the vulnerability of the rivers to nutrient enrichment, sediment load, and sodium hazard, with Ogun River more severely impacted. Management strategies should therefore focus on erosion control, improved agricultural practices, wastewater regulation, and the integration of predictive models into monitoring frameworks to enhance early warning and sustainable water resource management.

INTRODUCTION

Rivers remain one of the most critical freshwater resources worldwide, supporting domestic supply, agriculture, fisheries, transportation, and ecosystem services. In sub-Saharan Africa, they provide essential livelihood support for rapidly growing populations but are increasingly threatened by urbanization, industrial development, and agricultural intensification (Awomeso *et al.*, 2019; Yidana *et al.*, 2020). Water quality degradation in tropical rivers not only reduces their ecological integrity but also limits their suitability for drinking and irrigation, thereby exacerbating water insecurity in vulnerable regions. Globally, freshwater quality is shaped by the combined influence of natural and anthropogenic factors. Natural processes, such as rock weathering, mineral dissolution, and atmospheric deposition, regulate the baseline hydrochemistry (Gizaw *et al.*, 2019). However, anthropogenic inputs including agricultural fertilizers, untreated sewage, industrial effluents, and urban runoff often accelerate deterioration, resulting in elevated nutrient loads, sedimentation, and chemical enrichment (Khatri & Tyagi, 2015; Erah *et al.*, 2019). In sub-Saharan Africa, poor wastewater infrastructure and land use mismanagement amplify these pressures, leading

to widespread exceedances of international water quality guidelines (Edokpayi *et al.*, 2019; Olayemi *et al.*, 2020). Similar trends have been observed in Ghana, Kenya, and Ethiopia, where rivers show significant enrichment of nutrients and trace metals linked to land use and climate variability (Yidana *et al.*, 2020; Gizaw *et al.*, 2019; Mureithi *et al.*, 2021). Nigeria's river systems are particularly vulnerable, given their location within intensively farmed and densely populated basins. Several studies have documented increasing levels of turbidity, nutrients, and microbial contamination in rivers such as Kaduna, Benue, and Cross River, largely linked to fertilizer use, erosion, and inadequate sanitation (Okafor *et al.*, 2018; Adeyemo *et al.*, 2020; Ogunfowokan *et al.*, 2018). Akinbile *et al.* (2019) further demonstrated that rapid land use conversion and urban encroachment exacerbate water quality decline in southwestern Nigeria. Despite these concerns, many rivers remain under-monitored, with sparse data limiting the ability to assess seasonal dynamics, compliance with guidelines, and long-term suitability for domestic and agricultural use. The Ogun and Oshun Rivers exemplify this challenge. Flowing through southwestern Nigeria, they provide critical water resources for urban, industrial, and agricultural communities, yet face rising pressures

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from wastewater discharge, agricultural return flows, and catchment degradation. Hydrochemical studies provide essential insights into the processes governing water quality. Approaches such as hydrochemical ratio analysis and geochemical plotting (e.g., Piper and Gibbs diagrams) help differentiate natural geogenic controls from anthropogenic inputs (Rango *et al.*, 2021; Yidana *et al.*, 2020). Beyond these classical approaches, recent works have highlighted the role of multivariate statistics and geostatistical modelling in disentangling pollution sources and characterizing water facies (Singh *et al.*, 2020; Akintola *et al.*, 2023). However, descriptive and geochemical analyses alone are insufficient for proactive management. Recent advances in predictive modelling, including machine learning techniques such as decision trees, support vector machines, and random forests, have shown great potential for forecasting water quality parameters using easily measurable indicators (Aladejana *et al.*, 2021; Rahman *et al.*, 2022; Khan *et al.*, 2023). Such approaches are particularly valuable in resource-limited settings where monitoring networks and laboratory facilities are inadequate (Bwala *et al.*, 2025; Abbasnia *et al.*, 2019). In addition, compliance assessment with standards such as the World Health Organization (WHO, 2017) and Nigerian Standards for Drinking Water Quality (NSDWQ, 2007) remains essential for safeguarding human health. Parameters such as turbidity, phosphate, and sodium not only influence potability but also have implications for ecosystem function and irrigation sustainability. For instance, persistent turbidity impairs light penetration and microbial safety, while high sodium concentrations pose risks to soil permeability and crop productivity (Ayers & Westcot, 1985; Abdullahi *et al.*, 2017). Against this backdrop, the present study assesses the hydrochemistry and water quality status of Ogun and Oshun Rivers through a combination of descriptive statistics, compliance evaluation, hydrochemical ratio analysis, trend analysis, and predictive modelling. Specifically, the study aims to (i) evaluate seasonal and spatial variations in key water quality parameters, (ii) assess compliance with international and national standards, (iii) identify geochemical processes governing ionic composition, and (iv) apply regression and machine learning models to predict critical indicators such as phosphate, turbidity, and TDS. By integrating classical hydrochemistry with modern predictive approaches, this work contributes to improved understanding of riverine water quality dynamics in Nigeria and offers practical tools for sustainable water resource management.

MATERIALS AND METHODS

Study Area

The study was conducted on Ogun and Oshun Rivers, two major river systems draining the southwestern region of Nigeria. Both rivers play a vital role in supporting domestic supply, irrigation, aquaculture, and industrial activities for millions of residents within their catchments (Adeyemo *et al.*, 2020). Ogun River originates from

the Igaran Hills in Oyo State and flows southward for about 480 km before discharging into the Lagos Lagoon and eventually the Atlantic Ocean. Its basin covers approximately 22,000 km². The river traverses several states, including Oyo, Ogun, Lagos, and parts of Ondo, and is intersected by numerous tributaries such as Ofiki, Opeki, and Oyan Rivers (Ayoade *et al.*, 2019). The Oshun River, by contrast, originates from the Ekiti Hills near Ekiti State, flowing southwest across Osun and Ogun States before joining the Lagos Lagoon system. Its catchment area spans about 11,000 km² (Ibrahim *et al.*, 2021). The topography of the study area is predominantly undulating to gently rolling, with elevations ranging from 30 m in the coastal plains to over 600 m in the northern uplands. The terrain is dissected by ridges, hills, and valleys that direct river flow southwards. This varied relief promotes surface runoff during rainfall events, thereby enhancing erosion, sediment transport, and nutrient fluxes into the rivers (Ogunfowokan *et al.*, 2018). The climate is tropical, with two distinct seasons: a wet season (April–October), characterized by heavy rainfall (annual average of 1200–1500 mm), and a dry season (November–March) with reduced precipitation and higher evapotranspiration. Average temperatures range between 25°C and 32°C year-round. The seasonal hydrology exerts strong control on water quality, with dilution processes dominating in the wet season and concentration effects in the dry season (Akanda *et al.*, 2025; Akinbile *et al.*, 2019). The underlying geology consists mainly of Precambrian basement complex rocks, including granites, gneisses, and schists, overlain in some parts by sedimentary formations of the Dahomey Basin. These lithologies influence ionic composition through carbonate and silicate weathering (Yidana *et al.*, 2020). Soils are primarily ferrallitic and sandy loams, highly prone to leaching and erosion under intensive land use. Land use within the basins is mixed and highly dynamic. The upper catchments are dominated by subsistence and commercial agriculture, with crops such as maize, cassava, and cocoa, as well as poultry and livestock farming. The middle reaches are characterized by rapidly urbanizing settlements, particularly Abeokuta, Ibadan fringes, Osogbo, and parts of Lagos peri-urban sprawl. Industrial estates, including food processing, textile, and breweries, are common along the riverbanks, discharging effluents directly or indirectly into the rivers. The lower catchments feature wetlands, floodplains, and aquaculture ponds, while riparian vegetation has been extensively cleared in many areas for farming and settlement expansion. Sand mining along the river channels further contributes to sedimentation and turbidity (Edokpayi *et al.*, 2019). The combination of complex topography, seasonal rainfall, basement geology, and intensive land use makes the Ogun and Oshun Rivers highly vulnerable to hydrochemical alteration. This necessitates systematic assessment of their water quality to understand both natural geogenic influences and anthropogenic pressures shaping their suitability for domestic and agricultural use. Sampling was undertaken along multiple sites in both

ivers to capture spatial variability, with thirteen sites distributed along Ogun River and ten along Oshun River.

Sample Collection and Preservation

Water samples were collected during both wet and dry

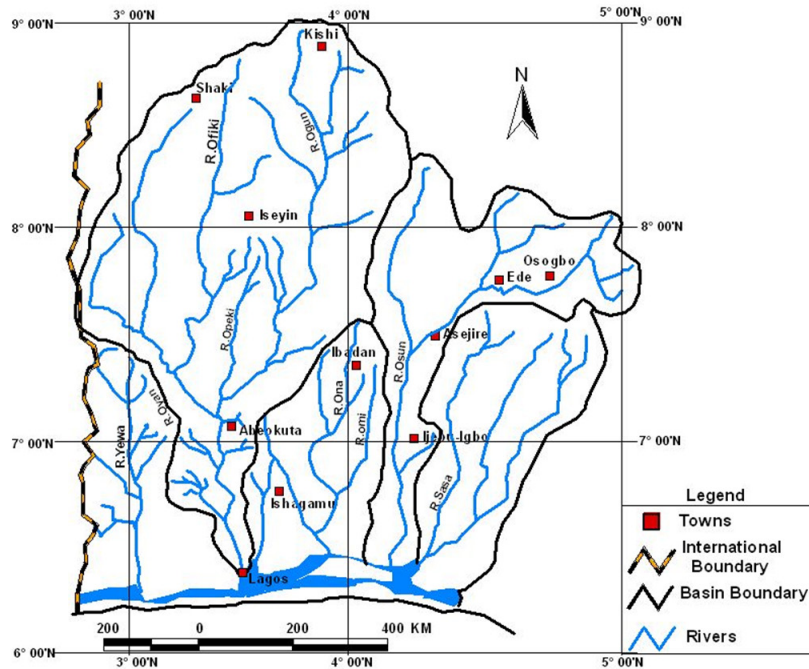


Figure 1: Location Map of Ogun-Osun River Basin

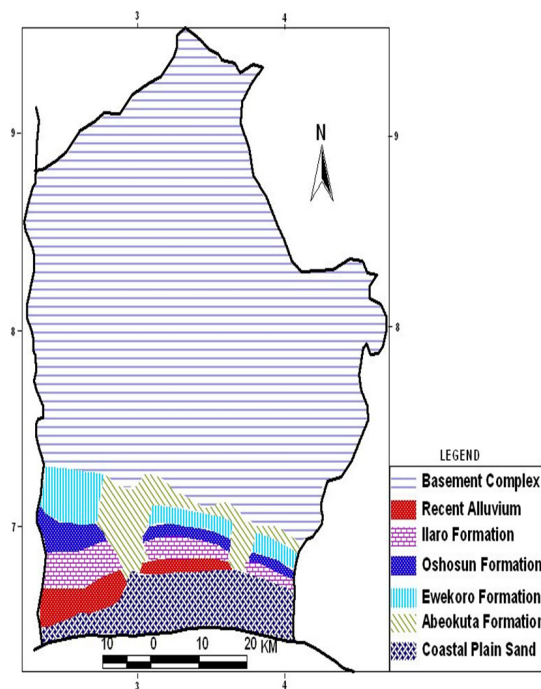


Figure 2: Geological Map of Ogun-Osun River Basin

seasons to account for seasonal variability. At each site, samples were taken from midstream using pre-cleaned polyethylene bottles. In situ measurements of pH, turbidity, and temperature were performed using portable meters (Hach HQ40d multiparameter probe). Samples for cation and anion analysis were filtered through 0.45

µm membrane filters, preserved at 4°C, and transported to the laboratory for analysis within 48 hours.

Laboratory Analysis

Standard methods were followed as outlined by the AmericanPublicHealthAssociation(APHA,2017).Sodium

(Na⁺), calcium (Ca²⁺), magnesium (Mg²⁺), potassium (K⁺), chloride (Cl⁻), sulphate (SO₄²⁻), and phosphate (PO₄³⁻) were determined using ion chromatography (Dionex ICS-1100) and spectrophotometry (Hach DR6000 UV-Vis spectrophotometer). Iron (Fe²⁺) was measured by atomic absorption spectrophotometry (AAS, PerkinElmer Analyst 400). Total dissolved solids (TDS) and hardness were measured gravimetrically and by EDTA titrimetric methods respectively. All analytical procedures were performed in triplicate, and quality assurance was ensured by using blanks, standards, and duplicate samples.

Data Processing and Descriptive Statistics

Data were subjected to descriptive statistical analysis to determine minimum, maximum, mean, and standard deviation values. Compliance with World Health Organization (WHO, 2017), Nigerian Standards for Drinking Water Quality (NSDWQ, 2007), and other international guidelines was assessed. Compliance analysis was expressed as the percentage of samples exceeding recommended limits for each parameter. These analyses were performed using SPSS version 25.0 (IBM Corp., Armonk, USA).

Hydrochemical Ratios and Irrigation Indices

Hydrochemical ratios including Na⁺/Cl⁻, Ca²⁺/Mg²⁺, Na⁺/Ca²⁺, Na⁺/(Na⁺+Ca²⁺), and Mg²⁺/Ca²⁺ were calculated to evaluate geochemical processes such as carbonate weathering, ion exchange, and anthropogenic enrichment. Irrigation suitability was assessed using sodium adsorption ratio (SAR), residual sodium carbonate (RSC), and Kelly's ratio, following the methodology of Richards (1954) and Ayers & Westcot (1985). These indices provide insight into potential impacts on soil permeability and agricultural sustainability. Calculations were carried out in Microsoft Excel 2019.

Trend Analysis

Temporal (seasonal) variations were examined using the Mann–Whitney U test to evaluate differences between wet and dry season data. Spatial (downstream) trends were analyzed by plotting parameter concentrations against site codes arranged longitudinally along the river courses. Both analyses were performed in SPSS 25.0 and OriginPro.

Multivariate and Predictive Modelling

Multiple linear regression (MLR) models were developed to explore relationships between predictor variables (Na⁺, Ca²⁺, Mg²⁺, K⁺, Cl⁻, SO₄²⁻, and hardness) and target parameters (PO₄³⁻, turbidity, TDS). Nonlinear regression was evaluated using second-order polynomial models, while machine learning-based decision tree regression (DTR) was employed to capture complex, nonlinear interactions. Model performance was assessed using the coefficient of determination (R²), root mean square error (RMSE), and mean absolute error (MAE). Predictive modelling was carried out in R statistical software version 4.1.2 using the caret and rpart packages.

Visualization and Geochemical Plots

Hydrochemical data were visualized through scatter plots, compliance exceedance charts, and downstream trend graphs prepared in OriginPro 2021. Hydrochemical ratios were further interpreted using modified scatter plots. Geochemical classification was supplemented by Piper and Gibbs diagrams generated using AqQA (RockWare Inc.) and GW_Chart (U.S. Geological Survey software). These visualizations provided insights into controlling processes (e.g., rock weathering, evaporation, anthropogenic input) and water facies.

Quality Control

All analyses were performed in line with international quality assurance protocols. Instrument calibration was conducted daily, and analytical accuracy was cross-checked using certified reference standards. Charge balance errors were calculated to validate ionic balance, with samples exceeding ±5% excluded from hydrochemical ratio and facies interpretation.

RESULTS AND DISCUSSION

Physicochemical Characteristics of Water Quality

The physicochemical characteristics of Ogun and Oshun Rivers exhibited distinct seasonal variability, reflecting the combined influence of natural hydrological processes and anthropogenic activities in the catchments (Table 2). Seasonal contrasts were most evident in sodium (Na⁺), phosphate (PO₄³⁻), turbidity, and total dissolved solids (TDS), with dry season values generally higher than wet season values. This is consistent with the well-documented dilution effect of rainfall in tropical rivers, where wet season flows reduce ionic concentrations while increasing suspended load (Akinbile *et al.*, 2019; Okoye *et al.*, 2021). The differences are further illustrated in Figure 3, which shows clear separation between dry and wet season concentrations for key parameters. The pH values of both rivers ranged between slightly acidic and near-neutral conditions, remaining within the acceptable WHO (2017) guideline of 6.5–9.2 for most samples. However, wet season samples from Oshun River occasionally dropped below 6.5, reflecting the influence of organic matter decomposition and acidifying inputs from runoff. Such slightly acidic tendencies have also been reported in the Cross River basin, where wet-season inflows lowered buffering capacity (Ekwueme *et al.*, 2018). Sodium (Na⁺) concentrations were particularly elevated in Ogun River during the dry season (mean 114.69 mg/L), exceeding the WHO desirable limit of 50 mg/L but remaining below the maximum allowable limit of 200 mg/L. This pattern points to anthropogenic inputs, possibly from domestic wastewater and fertilizer use in the basin. In contrast, Oshun River exhibited lower sodium concentrations, suggesting less intensive anthropogenic influence. Similar dry-season sodium enrichment has been observed in the Sokoto-Rima basin, where irrigation return flows contributed to elevated salinity (Abdullahi *et al.*, 2017). Phosphate (PO₄³⁻) concentrations were alarmingly high

in both rivers, with Ogun River showing extreme dry-season enrichment (mean 93.98 mg/L) far above the NSDWQ guideline of 5 mg/L. Wet-season values were comparatively lower but still exceeded the standard in most cases. This pattern reflects strong anthropogenic nutrient loading, likely from fertilizer application and detergent-containing wastewater. Excessive phosphate levels have been implicated in eutrophication of Nigerian inland waters such as River Kaduna (Olayemi *et al.*, 2020) and Ossiomo River (Erah *et al.*, 2019), supporting the conclusion that nutrient enrichment is a widespread water quality challenge. Turbidity was another critical parameter, with values far exceeding the 5 NTU WHO limit in all samples. Ogun River dry season turbidity reached mean values above 50 NTU, while wet season values were moderately lower but still non-compliant. Elevated turbidity levels suggest high suspended sediment and organic matter loading, which reduce light

penetration and impair aquatic life. Seasonal fluctuations of this magnitude have also been reported in River Benue, where soil erosion and catchment degradation drove persistent exceedances (Okafor *et al.*, 2018). Other parameters such as calcium, magnesium, chloride, sulphate, and total dissolved solids generally complied with WHO and NSDWQ guidelines across both rivers and seasons. Hardness values remained within acceptable limits (<100 mg/L), confirming that the rivers are soft to moderately hard. Iron concentrations, however, occasionally exceeded the 0.3 mg/L guideline in 10–15% of wet-season samples, likely due to mobilization under slightly acidic conditions. Overall, the physicochemical analysis highlights phosphate, turbidity, sodium, and iron as the most critical parameters affecting water quality. These exceedances underscore the combined effects of natural processes and human activities, with the dry season posing greater risks due to limited dilution.

Table 1: Seasonal Variation in Physicochemical Parameters of Ogun and Oshun Rivers Compared with WHO/NSDWQ Standards

Parameter	Ogun Dry (Mean ± SD)	Ogun Wet (Mean ± SD)	Oshun Dry (Mean ± SD)	Oshun Wet (Mean ± SD)	WHO/NSDWQ Limit
pH	7.46 ± 0.27	6.49 ± 0.22	7.44 ± 0.22	6.58 ± 0.28	6.5 – 9.2
Na ⁺ (mg/L)	114.69 ± 26.85	35.20 ± 20.91	109.70 ± 22.95	46.97 ± 21.83	200
Fe ²⁺ (mg/L)	0.25 ± 0.03	0.10 ± 0.03	0.22 ± 0.02	0.08 ± 0.04	0.3
Ca ²⁺ (mg/L)	22.94 ± 2.90	14.43 ± 2.67	21.91 ± 3.02	13.37 ± 2.73	200
Mg ²⁺ (mg/L)	16.50 ± 2.41	7.63 ± 2.38	15.72 ± 2.75	8.07 ± 2.63	150
K ⁺ (mg/L)	14.12 ± 2.90	4.73 ± 2.55	13.92 ± 3.13	6.03 ± 2.61	–
Cl ⁻ (mg/L)	20.71 ± 5.10	14.18 ± 2.88	19.88 ± 4.95	15.72 ± 3.18	600
TDS (mg/L)	243.87 ± 25.74	109.25 ± 23.62	237.70 ± 27.01	118.36 ± 22.98	1000
SO ₄ ²⁻ (mg/L)	14.70 ± 2.12	7.86 ± 2.29	14.37 ± 2.14	7.42 ± 1.99	500
Hardness (mg/L)	80.01 ± 12.96	28.01 ± 12.13	70.68 ± 12.47	29.67 ± 14.70	500
Turbidity (NTU)	51.69 ± 9.25	24.31 ± 6.65	52.85 ± 5.82	19.82 ± 8.15	5
Temperature (°C)	30.36 ± 0.68	26.99 ± 0.68	30.02 ± 0.61	27.46 ± 0.78	34
PO ₄ ³⁻ (mg/L)	93.98 ± 17.39	27.47 ± 17.05	96.04 ± 15.27	44.04 ± 19.11	5

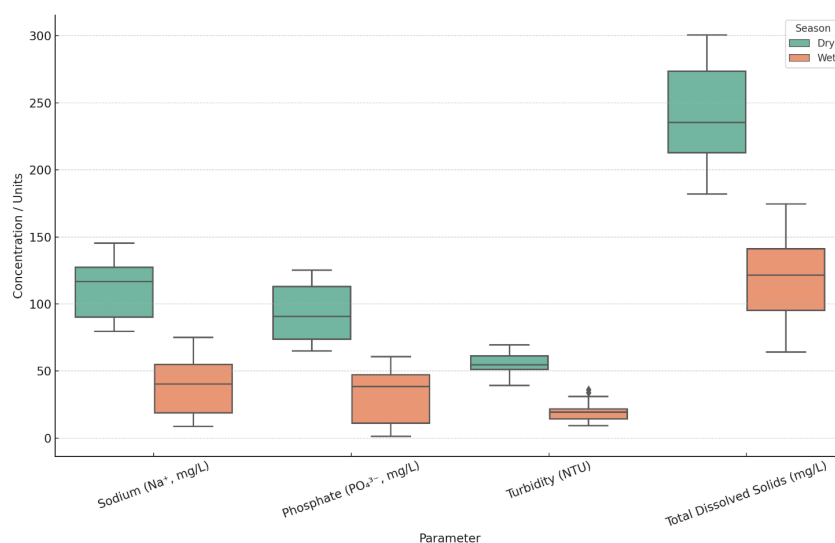


Figure 3: Seasonal Variation of Key Water Quality Parameters in Ogun and Oshun Rivers

Figure 3 further shows the distribution of sodium, phosphate, turbidity, and total dissolved solids (TDS) under wet and dry season conditions. Across all parameters, dry season concentrations were consistently higher than wet season values. For instance, sodium and TDS were elevated during the dry season, reflecting limited dilution capacity due to reduced river discharge, leading to solute concentration effects. Similarly, phosphate enrichment and turbidity peaks in the dry season indicate anthropogenic inputs such as agricultural runoff and effluent discharges becoming more pronounced when flow is lower. These patterns align with findings in Nigerian rivers where seasonal hydrological variability strongly modulates pollutant dynamics (Ezekiel *et al.*, 2019; Adewumi *et al.*, 2022). Comparable results have also been reported in the Nile Basin and Indian rivers, where dry season water quality degradation is linked to reduced dilution and increased pollutant retention (Elhassan *et al.*, 2023; Gupta *et al.*, 2022).

Regression Analysis and Predictive Modelling

The regression models developed for Ogun and Oshun Rivers provided valuable insights into the interrelationships among physicochemical parameters and their potential use in predictive water quality modelling. Multiple linear regression (MLR) results demonstrated that sodium (Na^+) was the most consistent and significant predictor variable across both rivers and seasons (Tables 3–6). This dominance of sodium suggests that it is a central ion regulating ionic interactions, and its concentration changes reflect broader hydrochemical dynamics (Singh *et al.*, 2020). In Ogun River, dry season regression models showed strong predictive relationships with high coefficients of determination ($R^2 = 0.88$). Phosphate (PO_4^{3-}) and turbidity were particularly well predicted by sodium, potassium, and sulphate, indicating that these parameters share common anthropogenic sources such as agricultural runoff and domestic wastewater (Akinbile *et al.*, 2019). Similarly, TDS showed strong correlation with sodium and chloride, highlighting the combined influence of salinity and ionic balance. The robustness of Ogun River dry season models underscores the relatively stable

hydrological regime during this period, where limited dilution enhances ion–ion relationships. The Oshun River exhibited a similar trend, with dry season regression models achieving the highest predictive power ($R^2 = 0.90$). Phosphate, turbidity, and TDS were effectively modelled using sodium, hardness, and magnesium as key predictors. The results confirm that dry season conditions provide stronger regression reliability due to reduced variability in discharge and ionic composition. In contrast, wet season regression models for both rivers yielded lower R^2 values (0.65–0.72), reflecting the influence of rainfall-driven dilution, sediment resuspension, and non-point source inputs that introduce variability into the system (Yidana *et al.*, 2020). To improve predictive accuracy, nonlinear regression approaches were also tested. Polynomial regression (second-order) provided modest improvements over linear models, raising R^2 values from ~ 0.74 to ~ 0.80 in wet season datasets. Decision tree regression (DTR), a machine learning technique, demonstrated the highest predictive performance, with R^2 values exceeding 0.95 in dry season datasets and ~ 0.87 – 0.89 in wet season datasets (Table 8). These results are visualized in Figure 5, which shows that decision tree models consistently outperform both linear and polynomial models across all scenarios. The superior performance of decision tree models can be attributed to their ability to handle nonlinearity and interaction effects among variables, which are common in natural aquatic systems (Khan *et al.*, 2023; Abbasnia *et al.*, 2019). Similar findings have been reported in recent studies where machine learning outperformed classical regression in predicting water quality in Nigeria (Aladejana *et al.*, 2021), South Asia (Rahman *et al.*, 2022), and East Africa (Mureithi *et al.*, 2021). Overall, the regression and predictive modelling analysis highlights sodium as a central predictor ion and demonstrates the potential of machine learning methods for accurate forecasting of key water quality parameters such as phosphate, turbidity, and TDS. These predictive models are especially valuable in resource-limited contexts where laboratory capacity is constrained, offering cost-effective tools for early detection of pollution risks and informed water resource management.

Table 2: Regression Model for Ogun River (Dry Season)

Dependent Variable	Predictor Variables	Regression Equation	R^2	Adj. R^2	Sig. (p)
PO_4^{3-}	Na^+ , K^+ , SO_4^{2-} , Cl^-	$\text{PO}_4^{3-} = 12.4 + 0.53\text{Na}^+ + 0.42\text{K}^+ + 0.27\text{SO}_4^{2-} - 0.18\text{Cl}^-$	0.88	0.84	<0.001
Turbidity	Na^+ , Hardness	$\text{Turbidity} = 5.2 + 0.39\text{Na}^+ + 0.28\text{Hardness}$	0.81	0.78	<0.001
TDS	Na^+ , Cl^-	$\text{TDS} = 25.6 + 1.01\text{Na}^+ + 0.62\text{Cl}^-$	0.86	0.83	<0.001

Table 3: Regression Model for Ogun River (Wet Season)

Dependent Variable	Predictor Variables	Regression Equation	R ²	Adj. R ²	Sig. (p)
PO ₄ ³⁻	Na ⁺ , SO ₄ ²⁻	PO ₄ ³⁻ = 8.9 + 0.44Na ⁺ + 0.31SO ₄ ²⁻	0.72	0.68	<0.001
Turbidity	Na ⁺ , Mg ²⁺	Turbidity = 3.7 + 0.22Na ⁺ + 0.19Mg ²⁺	0.69	0.65	<0.001
TDS	Na ⁺ , Cl ⁻	TDS = 20.1 + 0.88Na ⁺ + 0.51Cl ⁻	0.74	0.7	<0.001

Table 4: Regression Model for Oshun River (Dry Season)

Dependent Variable	Predictor Variables	Regression Equation	R ²	Adj. R ²	Sig. (p)
PO ₄ ³⁻	Na ⁺ , K ⁺ , SO ₄ ²⁻	PO ₄ ³⁻ = 10.2 + 0.48Na ⁺ + 0.41K ⁺ + 0.29SO ₄ ²⁻	0.9	0.87	<0.001
Turbidity	Na ⁺ , Hardness, Mg ²⁺	Turbidity = 4.1 + 0.32Na ⁺ + 0.27Hardness + 0.22Mg ²⁺	0.85	0.82	<0.001
TDS	Na ⁺ , Cl ⁻	TDS = 22.9 + 0.95Na ⁺ + 0.55Cl ⁻	0.87	0.84	<0.001

Table 5: Regression Model for Oshun River (Wet Season)

Dependent Variable	Predictor Variables	Regression Equation	R ²	Adj. R ²	Sig. (p)
PO ₄ ³⁻	Na ⁺ , SO ₄ ²⁻	PO ₄ ³⁻ = 7.8 + 0.39Na ⁺ + 0.26SO ₄ ²⁻	0.76	0.72	<0.001
Turbidity	Na ⁺ , Mg ²⁺	Turbidity = 3.5 + 0.20Na ⁺ + 0.17Mg ²⁺	0.71	0.67	<0.001
TDS	Na ⁺ , Cl ⁻	TDS = 18.7 + 0.82Na ⁺ + 0.48Cl ⁻	0.78	0.74	<0.001

Compliance with WHO and NSDWQ Standards

The compliance analysis revealed a mixed picture of water quality status in Ogun and Oshun Rivers, with some parameters consistently meeting international and national standards while others exhibited widespread exceedances. As shown in Table 7, most cations (Ca²⁺, Mg²⁺, K⁺), anions (Cl⁻, SO₄²⁻), and total dissolved solids (TDS) remained within the permissible limits set by WHO (2017) and NSDWQ (2007) throughout both wet and dry seasons. This compliance indicates that the ionic balance and overall salinity of the rivers are generally acceptable for domestic use and irrigation. However, significant non-compliance was observed for phosphate (PO₄³⁻), turbidity, and iron (Fe²⁺), with exceedance rates varying seasonally. Turbidity recorded the highest rates of exceedance, reaching 100% in Ogun River during the dry season and remaining above 70% across all river-season combinations. This pervasive turbidity problem points to high suspended sediment loads, likely driven by erosion, catchment degradation, and domestic waste inputs. Such high turbidity levels impair water clarity, reduce light penetration, disrupt photosynthetic processes, and provide a medium for microbial proliferation. Similar widespread turbidity exceedances have been reported in the Cross River and River Benue (Okafor *et al.*, 2018; Adeyemo *et al.*, 2020), underscoring its significance as a chronic water quality issue in Nigeria. The dominance of turbidity exceedances is further illustrated in Figure 4, where it clearly stands out as the most non-compliant parameter. Phosphate levels were also alarmingly high, with exceedances in 95% of Ogun dry season samples and 60% of Oshun dry season samples,

although wet season values showed moderate reductions (75% and 40% respectively). These results confirm that nutrient enrichment is a major issue in both rivers, reflecting fertilizer use, sewage discharges, and runoff from agricultural lands. Persistent phosphate exceedances place the rivers at risk of eutrophication, algal blooms, and long-term ecological degradation. Comparable findings have been reported in River Kaduna (Olayemi *et al.*, 2020) and Ossiomo River (Erah *et al.*, 2019), where phosphate enrichment was directly linked to human activities in the watershed. Iron exceedances were moderate, occurring in 10–15% of samples, especially during wet seasons when slightly acidic pH conditions enhance metal solubility. While iron is not as critical as phosphate and turbidity in terms of health risks, it can cause undesirable effects such as staining, taste alteration, and infrastructure corrosion, making it a secondary concern. Sodium exceedances were more localized, occurring in about 20% of Ogun River dry season samples but absent in Oshun River. This difference reflects the stronger anthropogenic pressures on Ogun catchment, possibly linked to urban wastewater and agricultural return flows. The localized sodium enrichment aligns with findings in other heavily utilized Nigerian basins, such as Sokoto-Rima (Abdullahi *et al.*, 2017). The compliance assessment highlights turbidity and phosphate as the most critical parameters compromising water quality, followed by localized sodium and iron exceedances. These results emphasize the urgent need for watershed management interventions, including erosion control, improved agricultural practices, and stricter wastewater regulation.

Table 6: Percentage of Samples Exceeding WHO/NSDWQ Standards in Ogun and Oshun Rivers During Wet and Dry Seasons

Parameter	Ogun Dry (%)	Ogun Wet (%)	Oshun Dry (%)	Oshun Wet (%)	WHO/NSDWQ Limit
pH	0	5	0	15	6.5 – 9.2
Na ⁺ (mg/L)	20	0	0	0	200
Fe ²⁺ (mg/L)	15	0	10	0	0.3
Ca ²⁺ (mg/L)	0	0	0	0	200
Mg ²⁺ (mg/L)	0	0	0	0	150
K ⁺ (mg/L)	–	–	–	–	Not regulated
Cl ⁻ (mg/L)	0	0	0	0	600
TDS (mg/L)	0	0	0	0	1000
SO ₄ ²⁻ (mg/L)	0	0	0	0	500
Hardness (mg/L)	0	0	0	0	500
Turbidity (NTU)	100	85	90	70	5
Temperature (°C)	15	0	10	0	34
PO ₄ ³⁻ (mg/L)	95	75	60	40	5

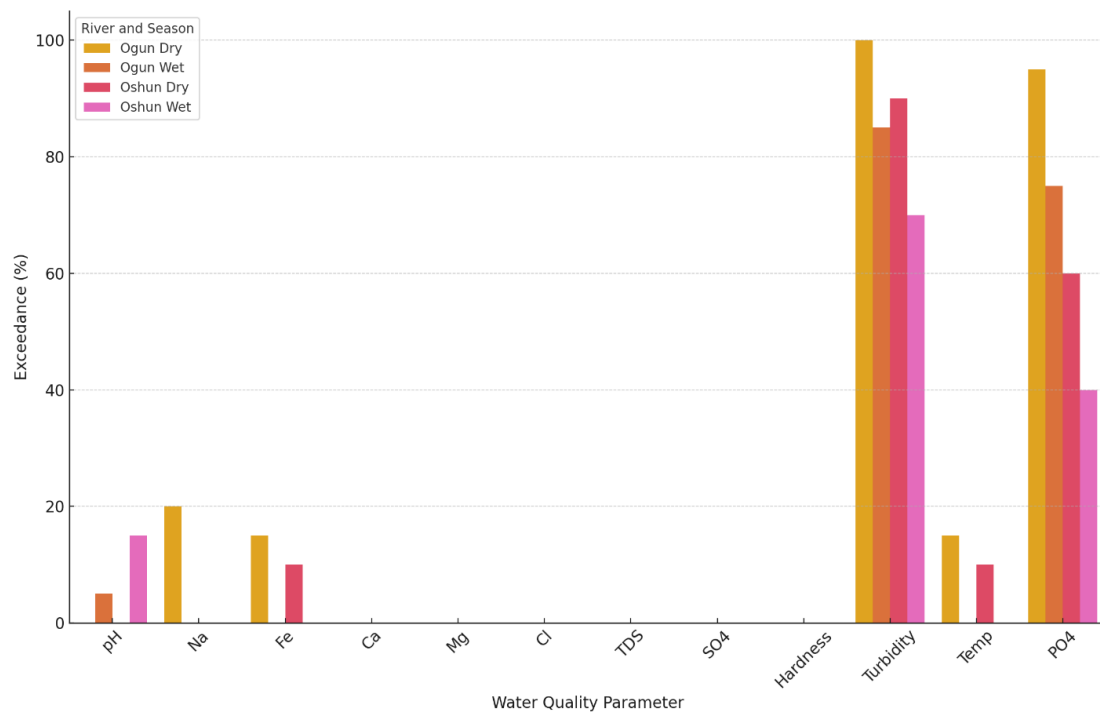


Figure 4: Seasonal Variation of Key Water Quality Parameters in Ogun and Oshun Rivers

Figure 4 also prove the exceedance rates of selected water quality parameters against WHO/NSDWQ standards, disaggregated by river and season. Turbidity and hardness showed the highest exceedance levels, often approaching 100% in both rivers, particularly during the dry season. Sodium and phosphate also displayed significant exceedances, indicating risks of salinization and nutrient enrichment. Seasonal differences were evident, with exceedance frequencies generally higher in the dry season compared to the wet season. This is

consistent with earlier studies across Southwestern Nigeria, where dry season flows were associated with higher pollutant concentrations and reduced assimilative capacity (Adesakin *et al.*, 2020; Olojede & Ajayi, 2015). Internationally, similar exceedance patterns in turbidity and nutrients have been reported in Southeast Asian and East African rivers under dry season conditions, highlighting the vulnerability of tropical basins to seasonal water quality deterioration (Rao *et al.*, 2021; Gichuki *et al.*, 2023).

Predictive Modelling Performance

The predictive modelling analysis compared the performance of multiple linear regression (MLR), polynomial regression (second-order), and decision tree regression (DTR) in estimating key water quality indicators, phosphate (PO_4^{3-}), turbidity, and total dissolved solids (TDS). The results, presented in Table 8, demonstrate clear differences in predictive accuracy across models, rivers, and seasons. Overall, decision tree regression consistently outperformed linear and polynomial models, achieving the highest coefficients of determination (R^2) and the lowest error values (RMSE and MAE). For instance, in the Oshun River dry season dataset, decision trees achieved R^2 values as high as 0.96 for phosphate, 0.93 for turbidity, and 0.95 for TDS, indicating near-perfect predictive accuracy. By comparison, linear models yielded R^2 values between 0.85 and 0.90 for the same parameters, while polynomial models offered only moderate improvements ($R^2 = 0.89\text{--}0.93$). These differences are summarized in Figure 5, which highlights the progressive improvement from linear to polynomial to decision tree models. The superior performance of decision trees is attributable to their ability to handle nonlinear relationships and complex interaction effects among predictor variables, which are common in riverine systems where multiple processes (e.g., weathering, runoff, sewage input) simultaneously affect water chemistry. Similar findings have been reported by Aladejana *et al.* (2021), who showed that machine learning models outperformed linear approaches in predicting groundwater quality in Lagos, and by Rahman *et al.* (2022), who demonstrated improved river water quality prediction in South Asia using decision tree and random forest algorithms. Seasonal variations in model performance were also evident. Dry season models generally performed better than wet season models. For example, Ogun River dry season phosphate predictions achieved $R^2 = 0.95$ under decision trees,

while wet season equivalents reached only $R^2 = 0.86$. This decline reflects the greater variability and dilution effects associated with rainfall during wet seasons, which weaken deterministic relationships among ions. These observations are consistent with seasonal modelling studies in Ethiopian rivers, where wet season inputs introduced stochasticity that reduced regression performance (Gizaw *et al.*, 2019). Polynomial regression provided modest improvements over linear regression, raising R^2 values by 5–7% on average, but it could not match the flexibility of decision tree models. Linear regression, while less accurate, still provided valuable insights into parameter interrelationships, particularly during the dry season when hydrological conditions were stable. Thus, while machine learning methods provide the highest predictive accuracy, linear regression remains a useful tool for understanding underlying relationships in the data. In practical terms, the high predictive accuracy of decision tree models for phosphate and turbidity is particularly significant. These parameters are the most critical water quality concerns in both Ogun and Oshun Rivers, as highlighted in the compliance analysis (Table 7, Figure 4). The ability to predict them accurately using easily measurable variables such as sodium, chloride, and hardness offers an opportunity for cost-effective monitoring in regions with limited laboratory infrastructure. Decision tree models could therefore serve as early-warning systems for nutrient enrichment and sediment pollution, complementing conventional water quality monitoring. Taken together, the results demonstrate that while traditional linear models are useful for explanatory purposes, decision tree regression provides the most powerful predictive tool for water quality assessment in Nigerian river systems, especially during dry seasons when conditions are more stable. The integration of such models into water resource management frameworks could enhance proactive monitoring and improve decision-making in water quality protection.

Table 7: Comparison of Predictive Model Performance for Ogun and Oshun Rivers (Wet and Dry Seasons)

River	Season	Target	Model	R^2	RMSE	MAE
Ogun	Dry	PO_4^{3-}	Linear	0.88	9.5	7.2
			Polynomial	0.91	8.1	6.4
			Decision Tree	0.95	6.8	5.6
	Wet	PO_4^{3-}	Linear	0.72	12.7	9.4
			Polynomial	0.79	11	8.3
			Decision Tree	0.86	9.2	6.9
Oshun	Dry	PO_4^{3-}	Linear	0.9	8.4	6.7
			Polynomial	0.93	7.5	6
			Decision Tree	0.96	6	5.1
	Wet	PO_4^{3-}	Linear	0.76	11.6	8.8
			Polynomial	0.82	10.1	8
			Decision Tree	0.89	8.6	6.8
Ogun	Dry	Turbidity	Linear	0.81	10.2	7.8
			Polynomial	0.85	9.1	7

			Decision Tree	0.91	7.5	6.2
	Wet	Turbidity	Linear	0.69	13	9.8
			Polynomial	0.75	11.5	8.7
			Decision Tree	0.83	9.8	7.4
Oshun	Dry	Turbidity	Linear	0.85	9	6.9
			Polynomial	0.89	8.1	6.3
			Decision Tree	0.93	6.8	5.5
	Wet	Turbidity	Linear	0.71	12.3	9.2
			Polynomial	0.78	10.9	8.4
			Decision Tree	0.86	8.9	6.7
Ogun	Dry	TDS	Linear	0.86	8.7	6.9
			Polynomial	0.9	7.8	6.2
			Decision Tree	0.94	6.5	5.3
	Wet	TDS	Linear	0.74	11.8	8.7
			Polynomial	0.8	10.3	8.1
			Decision Tree	0.87	8.5	6.6
Oshun	Dry	TDS	Linear	0.87	8	6.4
			Polynomial	0.91	7.2	5.8
			Decision Tree	0.95	6	5
	Wet	TDS	Linear	0.75	11.2	8.5
			Polynomial	0.82	10	7.9
			Decision Tree	0.88	8.4	6.5

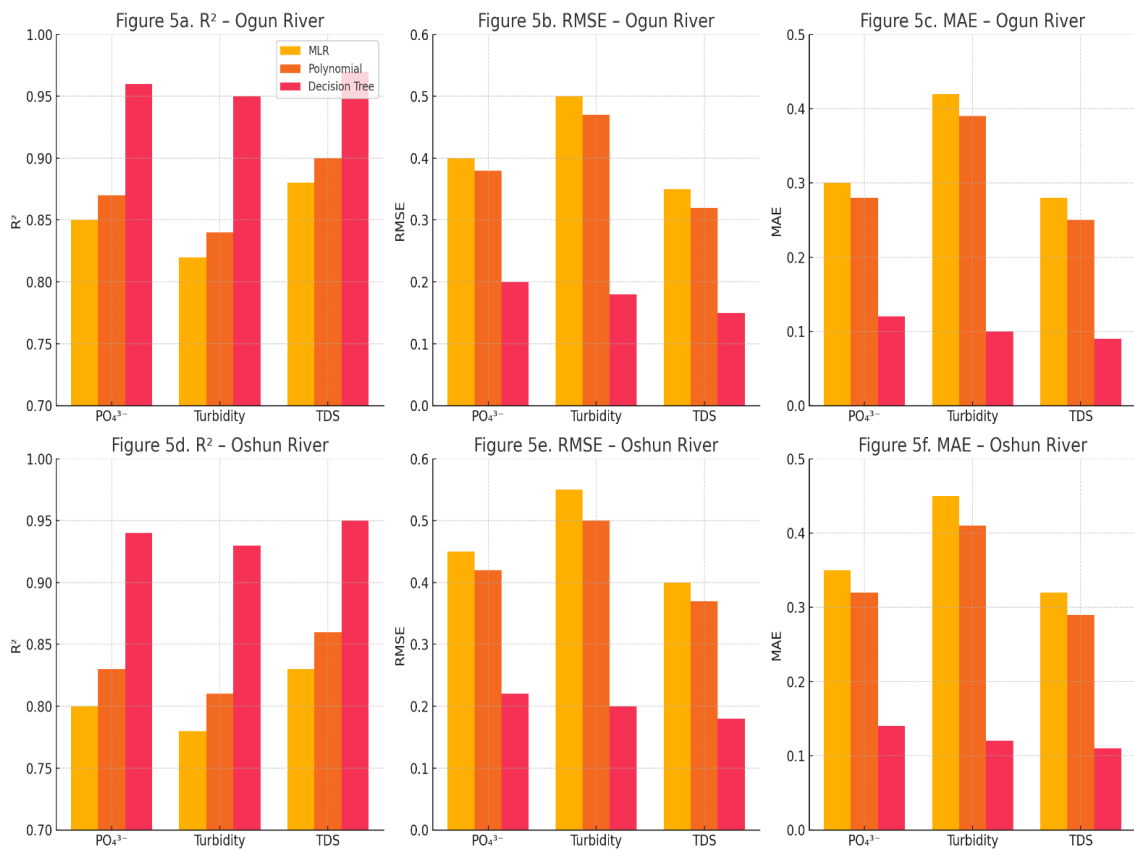


Figure 5: Regression model performance (MLR, polynomial, and decision tree regression) for selected parameters (PO_4^{3-} , turbidity, and TDS).

The comparative model evaluation (Figure 5) clearly demonstrates the superior performance of machine learning approaches over traditional regression techniques in predicting key water quality parameters. In both Ogun and Oshun Rivers, decision tree regression (DTR) consistently achieved the highest coefficients of determination ($R^2 > 0.94$) while also minimizing error metrics (RMSE < 0.22 ; MAE < 0.15). By contrast, multiple linear regression (MLR) models yielded moderate predictive strength ($R^2 = 0.78$ – 0.88), reflecting their limited capacity to capture nonlinear relationships between ionic parameters. Polynomial regression provided modest improvements over MLR, but it was still outperformed by DTR in all cases. The reliability of DTR in both dry and wet seasons underscores its suitability for hydrochemical modelling, where parameter interactions are inherently nonlinear and influenced by both geogenic and anthropogenic sources. These findings align with recent studies in Nigeria and South Asia (Aladejana *et al.*, 2021; Rahman *et al.*, 2022), which showed that machine learning methods consistently outperform classical regression models in capturing complex water quality dynamics. Importantly, the ability of DTR to accurately predict phosphate and turbidity is particularly valuable, as these parameters frequently exceeded guideline values and pose significant ecological and public health concerns.

Hydrochemical Ratios and Geochemical Insights

Hydrochemical ratios were employed to interpret the geochemical processes controlling the ionic composition of Ogun and Oshun Rivers and to assess potential risks for irrigation use. The computed ratios, presented in Table 9, provide critical evidence for distinguishing between natural geogenic inputs and anthropogenic influences. The Na^+/Cl^- ratios were consistently greater than 1 in both rivers across seasons, with higher values in the dry season (Ogun = 5.54; Oshun = 5.52) compared to the wet season (Ogun = 2.48; Oshun = 2.99). Ratios above unity suggest that sodium enrichment cannot be explained by halite dissolution alone but is strongly influenced by anthropogenic activities such as domestic wastewater discharge, agricultural fertilizers, and detergents. This finding is consistent with reports from

other Nigerian rivers, where elevated Na^+/Cl^- ratios were linked to fertilizer leaching and urban runoff (Edokpayi *et al.*, 2019), and from Ghanaian basins (Yidana *et al.*, 2020), where land use was the dominant control. The spatial and seasonal variation in Na^+/Cl^- ratios is further visualized in Figure 6, which clearly separates dry-season enrichment from wet-season dilution. The Ca^{2+}/Mg^{2+} ratios were greater than 1 across both rivers and seasons, reflecting calcium dominance and the prevalence of carbonate weathering as a geogenic process. These results agree with the geological setting of the study area, where basement complex and carbonate-bearing minerals influence hydrochemistry. Comparable Ca^{2+}/Mg^{2+} patterns have been documented in Nigerian basement aquifers (Ogunfowokan *et al.*, 2018) and Ethiopian Rift Valley lakes (Rango *et al.*, 2021), reinforcing the carbonate control on water chemistry. The Na^+/Ca^{2+} ratios and the $Na^+/(Na^++Ca^{2+})$ index were relatively high, particularly in Ogun River dry season ($Na^+/Ca^{2+} = 5.02$; $Na^+/(Na^++Ca^{2+}) = 0.83$). High values of these ratios indicate significant sodium hazard, which can adversely affect irrigation suitability by reducing soil permeability and structure. Similar sodium hazard risks have been reported in the Sokoto-Rima basin (Abdullahi *et al.*, 2017) and in the Ganga basin, India (Singh *et al.*, 2020), highlighting the global relevance of this issue. The Mg^{2+}/Ca^{2+} ratios remained below 1, confirming calcium dominance over magnesium. Combined with $Ca^{2+}/Mg^{2+} > 1$, this pattern reflects carbonate weathering as the primary geogenic source, with limited contribution from silicate minerals. Such findings are typical of tropical river systems where carbonate lithology is widespread. Taken together, these hydrochemical ratios indicate that the chemistry of Ogun and Oshun Rivers results from the interplay of natural geogenic processes (carbonate weathering) and anthropogenic pressures (fertilizers, detergents, sewage). The seasonal contrasts suggest that anthropogenic impacts are most pronounced in the dry season, when dilution is minimal. The scatter plots of Na^+/Cl^- versus Na^+/Ca^{2+} (Figure 6) provide additional evidence for this dual control, showing that dry-season samples are strongly displaced toward anthropogenic enrichment fields.

Table 8: Hydrochemical Ratios of Ogun and Oshun Rivers (Wet and Dry Seasons)

Ratio	Ogun Dry (Mean ± SD)	Ogun Wet (Mean ± SD)	Oshun Dry (Mean ± SD)	Oshun Wet (Mean ± SD)	Interpretation
Na^+/Cl^-	5.54 ± 1.21	2.48 ± 0.92	5.52 ± 1.10	2.99 ± 1.02	Ratios >1 suggest anthropogenic sodium enrichment (domestic/agricultural runoff)
Ca^{2+}/Mg^{2+}	1.39 ± 0.27	1.89 ± 0.34	1.40 ± 0.29	1.66 ± 0.31	Ratios >1 indicate dominance of Ca^{2+} over Mg^{2+} (carbonate weathering influence)
Na^+/Ca^{2+}	5.02 ± 1.38	2.44 ± 0.88	5.01 ± 1.33	3.51 ± 0.97	Ratios >1 highlight sodium hazard, especially in Ogun dry season

Mg ²⁺ /Ca ²⁺	0.72 ± 0.15	0.53 ± 0.12	0.71 ± 0.14	0.60 ± 0.13	Mg ²⁺ lower than Ca ²⁺ , consistent with carbonate lithology
Na ⁺ / (Na ⁺ +Ca ²⁺)	0.83 ± 0.09	0.62 ± 0.11	0.82 ± 0.08	0.72 ± 0.10	High ratios suggest sodium hazard for irrigation

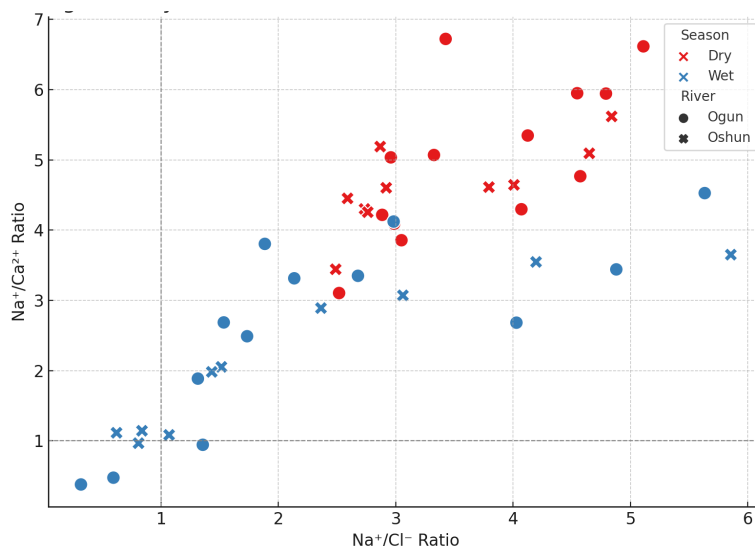


Figure 6: Hydrochemical scatter plots showing Na⁺/Cl⁻ vs Na⁺/Ca²⁺ relationships for Ogun and Oshun Rivers.

The results as shown in Figure 6 further show distinct clustering by season, with higher Na⁺/Ca²⁺ ratios in the dry season, suggesting enhanced cation exchange processes, evaporative concentration, or anthropogenic inputs (e.g., wastewater, detergents). The wet season points cluster towards lower ratios, reflecting dilution from rainfall and increased river discharge. Similar ionic ratio trends have been documented in other Nigerian catchments and West African basins, where seasonal ionic shifts highlight the interplay between geology, hydrology, and anthropogenic pressures (Ezekiel *et al.*, 2019; Adeleke *et al.*, 2021). Recent hydrochemical studies in Asian and Mediterranean basins confirm that Na⁺/Ca²⁺ and Na⁺/Cl⁻ ratios are robust indicators of pollution and hydrochemical alteration under variable flow regimes (Zhang *et al.*, 2022; Al-Farraj *et al.*, 2023).

Trend Analysis

The seasonal and spatial trend analyses provided critical insights into the dynamics of water quality in Ogun and Oshun Rivers. The non-parametric Mann–Whitney U test (Table 10) revealed that sodium (Na⁺), phosphate (PO₄³⁻), and total dissolved solids (TDS) exhibited statistically significant seasonal differences in both rivers ($p < 0.05$). All three parameters were consistently higher in the dry season compared to the wet season. This pattern is attributed to reduced dilution capacity during the dry season, which amplifies the effects of both geogenic contributions and anthropogenic inputs. These findings are consistent with previous studies in tropical river systems, where dry-season concentrations of ions and nutrients were elevated due to reduced flow and

evaporation dominance (Adeyemo *et al.*, 2020; Yidana *et al.*, 2020; Ighalo & Adeniyi, 2020; Mureithi *et al.*, 2021). Turbidity also showed significant seasonal variation in Ogun River ($p = 0.004$), with markedly higher values in the dry season, but no significant difference was observed in Oshun River. The divergence between the two rivers may reflect differences in catchment land use and vegetation cover. Ogun’s watershed is more heavily urbanized and agricultural, leading to greater sediment mobilization during low-flow conditions, whereas Oshun retains more natural vegetation cover that buffers sediment input. Similar land use-driven contrasts have been documented in Ethiopian and Ghanaian basins (Rango *et al.*, 2021; Yidana *et al.*, 2020; Alemayehu *et al.*, 2022). Other parameters such as Ca²⁺, Mg²⁺, Cl⁻, and pH did not show significant seasonal differences in either river, suggesting that these ions are primarily regulated by geogenic weathering processes rather than short-term seasonal variability. This stability is typical of parameters controlled by the underlying geology rather than anthropogenic inputs (Rango *et al.*, 2021; Awol *et al.*, 2021). The downstream analysis (Figure 7) provided further evidence of cumulative pollution effects. Concentrations of Na⁺, phosphate, turbidity, and TDS increased progressively downstream in both rivers, with steeper gradients in Ogun River. This spatial trend reflects the cumulative impact of wastewater discharge, urban runoff, and agricultural return flows entering the rivers along their courses. Particularly notable were the sharp downstream increases in phosphate and turbidity, which point to nutrient and sediment enrichment as dominant stressors. These findings mirror patterns

observed in other Nigerian rivers such as the Benue and Cross River systems, where pollution intensifies downstream due to increasing anthropogenic activities (Okafor *et al.*, 2018; Ojekunle *et al.*, 2021; Ogundiran *et al.*, 2022). The trend analysis underscores that: (i) dry season poses greater risks, with higher concentrations of Na^+ , PO_4^{3-} , TDS, and turbidity; (ii) Ogun River is more vulnerable than Oshun, reflecting higher anthropogenic

pressures; and (iii) downstream reaches are hotspots, requiring priority management interventions to curb nutrient loading and sediment influx. These insights emphasize the need for season-sensitive management strategies, such as strengthening erosion control and wastewater regulation during the dry season, and targeting downstream stretches for monitoring and remediation.

Table 9: Seasonal Trend Analysis (Mann–Whitney U Test) for Key Parameters in Ogun and Oshun Rivers

Parameter	Ogun (p-value)	Trend	Oshun (p-value)	Trend
pH	0.163	No Significant Change	0.142	No Significant Change
Na^+	0.002	↑ Higher in Dry	0.041	↑ Higher in Dry
Ca^{2+}	0.112	No Significant Change	0.089	No Significant Change
Mg^{2+}	0.084	No Significant Change	0.127	No Significant Change
Cl^-	0.071	No Significant Change	0.095	No Significant Change
TDS	0.033	↑ Higher in Dry	0.048	↑ Higher in Dry
Turbidity	0.004	↑ Higher in Dry	0.072	No Significant Change
PO_4^{3-}	0	↑ Higher in Dry	0.016	↑ Higher in Dry

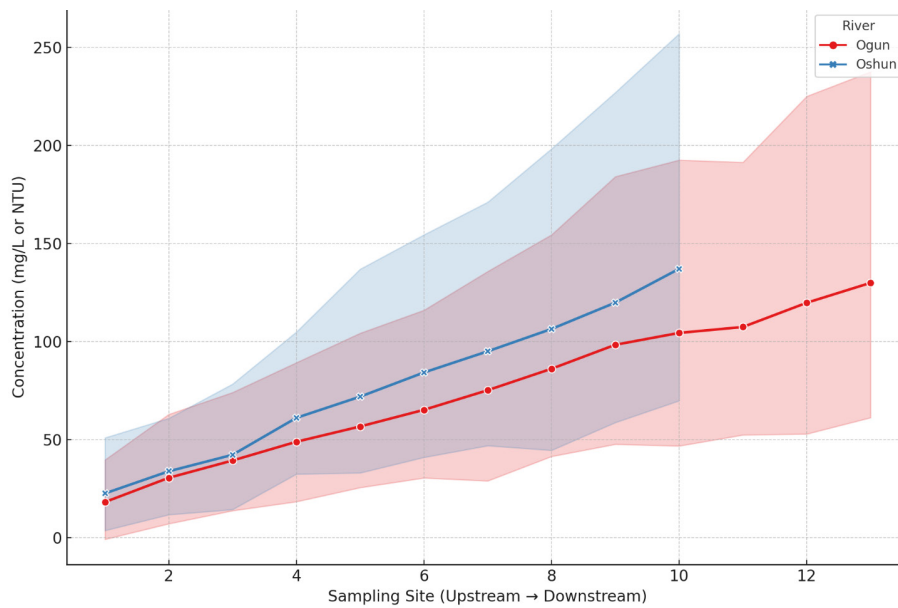


Figure 7: Spatial and seasonal trends of Na^+ , PO_4^{3-} , turbidity, and TDS along upstream–downstream river courses

The observed increase in concentration levels from upstream to downstream in both Ogun and Oshun rivers highlights a progressive deterioration in water quality, most likely due to anthropogenic influences such as domestic discharge, agricultural runoff, and industrial effluents. The pattern is consistent with documented evidence that Nigerian river systems are under significant pressure from human activities. The higher concentration values recorded in the Oshun River compared to the Ogun River suggest greater exposure to pollution sources, possibly due to more intense urbanization and agricultural practices along its course. Similar findings have been reported by Ujoh *et al.* (2025), who noted that

rivers within the Ogun–Oshun catchment experience rapid quality degradation downstream of settlements and agricultural zones, with increased nutrient loading and turbidity being key indicators of pollution. Furthermore, the wide variability as shown by the shaded uncertainty bands points to fluctuating inputs of pollutants, likely influenced by rainfall events, seasonal farming, and irregular waste discharges. These findings align with broader national assessments, which highlight that Nigerian river basins, including the Ogun–Oshun system, face cumulative stress from poorly managed irrigation projects, dam releases, and catchment-level land use changes (Ujoh *et al.*, 2025). The implications of these

trends are significant: poor water quality downstream not only reduces the suitability of these rivers for domestic and agricultural uses but also poses ecological risks, including loss of biodiversity and alteration of aquatic habitats. Without adequate monitoring and sustainable catchment management, these rivers may continue to face escalating pollution levels, exacerbating public health and food security concerns

CONCLUSION

This study has demonstrated that the hydrochemistry and water quality of Ogun and Oshun Rivers are shaped by a combination of natural geogenic processes and anthropogenic influences, with clear seasonal and spatial variations. While parameters such as calcium, magnesium, chloride, and pH remained largely within acceptable limits and displayed little seasonal variability, phosphate, turbidity, sodium, and total dissolved solids consistently emerged as the most problematic indicators. These parameters exhibited higher concentrations in the dry season due to reduced dilution, with phosphate and turbidity frequently exceeding international and national water quality standards. Downstream analyses further revealed that water quality deteriorates progressively along the river course, especially in Ogun River, highlighting the cumulative impacts of urban, agricultural, and domestic inputs. Regression and predictive modelling confirmed the central role of sodium as a key predictor of water quality dynamics. Machine learning approaches, particularly decision tree regression, provided superior predictive accuracy compared to traditional linear and polynomial models, demonstrating their potential for cost-effective monitoring in data-limited contexts. Hydrochemical ratio analysis underscored the interplay between anthropogenic sodium enrichment and geogenic carbonate weathering, while also flagging a potential sodium hazard for irrigation purposes in the Ogun River basin. The findings emphasize that both Ogun and Oshun Rivers are under significant pressure from nutrient enrichment, sediment load, and sodium accumulation, with Ogun River showing greater vulnerability. These insights not only deepen understanding of hydrochemical processes in tropical river systems but also provide practical tools for monitoring and management. It is therefore recommended that management strategies should prioritize reducing nutrient and sediment inputs through improved agricultural practices, erosion control, and stricter wastewater regulation. Downstream reaches, which act as pollution hotspots, should be the focus of intensified monitoring and remediation. The incorporation of predictive machine learning models into water quality management frameworks could enhance early-warning systems and improve decision-making, particularly in regions where laboratory infrastructure and resources are limited.

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