African Journal of Environment and Natural Science Research
ISSN: 2689-9434
Volume 9, Issue 2, 2026 (pp. 124-140)
www.abjournals.org

STUDY OF THE WATER QUALITY IN THE URBAN NATURE RESERVE OF THE GRANDE NIAYE OF PIKINE AND DEPENDENCY (UNRGNPD), DAKAR/SENEGAL

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Cite this article:

Y. I. B., Sène, O., Diankha, O., Ndiaye, A., Ndiaye, E. M., Diouf, A. A. S., Ndiaye (2026), Study of the Water Quality in the Urban Nature Reserve of the Grande Niaye of Pikine and Dependency (UNRGNPD), Dakar/Senegal. African Journal of Environment and Natural Science Research 9(2), 124-140. DOI: 10.52589/AJENSR-EMVUSD3B

Manuscript History

Received: 5 Apr 2026

Accepted: 6 May 2026

Published: 4 Jun 2026

ABSTRACT: *This study assesses organic and nutrient pollution within the Urban Nature Reserve of the Grande Niaye of Pikine and Dependency (UNRGNPD), an urban wetland ecosystem located in Dakar, Senegal, and increasingly exposed to anthropogenic pressures associated with rapid urbanization. Between 2021 and 2025, a total of 70 water samples were collected from seven lakes of the reserve during both wet and dry seasons. Physicochemical parameters, including biochemical oxygen demand (BOD_5), dissolved oxygen, nitrates, nitrites, ammonium, sulphates, and phosphates, were analyzed using standard methods, while statistical analyses and the Organic Pollution Index (OPI) were applied to assess water quality and pollution dynamics. The findings reveal pronounced spatial heterogeneity, with the Dependency lakes exhibiting elevated concentrations of ammonium and phosphates, reflecting the influence of domestic and agricultural discharges, whereas sulphates dominate in the Technopole sector, associated with effluents from the wastewater treatment plant. Significant correlations between ammonium-phosphate and nitrate-sulphate concentrations confirm the presence of multiple anthropogenic pollution sources. The Organic Pollution Index revealed very high organic pollution across the seven studied lakes, with OPI values ranging from 1.00 to 1.75 and a mean BOD_5 concentration of 23.36 $mg \cdot L^{-1}$, indicating a substantial risk of eutrophication. Seasonal and interannual variations further highlight the influence of climatic conditions on pollution dynamics. These pressures may undermine fish biodiversity and threaten socio-economic activities such as fishing and market gardening. The study highlights the urgent need for integrated management strategies combining discharge regulation, ecological restoration, and environmental monitoring to preserve the ecosystem services of the UNRGNPD.*

KEYWORDS: Eutrophication; Nutrient pollution; Organic Pollution Index; Urban wetlands; Water quality; Dakar.

Article DOI: 10.52589/AJENSR-EMVUSD3B
DOI URL: https://doi.org/10.52589/AJENSR-EMVUSD3B

INTRODUCTION

Urban wetlands play a fundamental role in hydrological regulation by absorbing stormwater and reducing peak flows during periods of intense rainfall (Metcalfe et al., 2017). They also contribute to water purification by trapping various biological contaminants, thereby improving effluent quality (Xu et al., 2021). Owing to their remarkable biodiversity, these ecosystems support the reproduction of aquatic and riparian species while acting as key carbon sinks essential for climate change adaptation (Ribbe et al., 2021).

However, their location within densely populated areas exposes them to intense anthropogenic pressures, particularly organic and nutrient pollution resulting from domestic, agricultural, and industrial discharges (Marega et al., 2024). This contamination leads to a deterioration in water quality, characterised by increased biochemical oxygen demand (BOD_5), high concentrations of ammonium, nitrates, nitrites, and phosphates, and biogeochemical imbalances that promote eutrophication (Irie et al., 2023; Bouda et al., 2024). These dynamics threaten aquatic biodiversity and pose health risks to human populations through the proliferation of pathogens et algal toxins (Izdihar, 2022).

In Senegal, the Urban Nature Reserve of the Grande Niaye of Pikine and Dependency (UNRGNPD), located in the heart of Dakar, the nation's capital, exemplifies these challenges. As a genuine refuge for wildlife migratory birds, reptiles, and both freshwater and brackish fish it faces major pressures linked to wastewater discharges, agricultural inputs rich in fertilisers and pesticides, and the inflow of domestic and stormwater drainage channels (Guèye et al., 2022). These factors threaten not only the physicochemical quality of water bodies but also biodiversity, groundwater, and local agricultural activities. Yet few studies have assessed the water quality of the UNRGNPD or applied the Organic Pollution Index (OPI) as an indicator of ecological degradation.

The present study aims to characterise the physicochemical quality of the UNRGNPD's waters and to better understand the anthropogenic pressures that affect them. Specifically, it seeks to:

i. characterise the physicochemical quality of the UNRGNPD's water bodies through key parameters (nutrients, dissolved oxygen, BOD_5, etc.);

ii. analyse the spatial variability of pollution between the Technopole and Maristes lakes to highlight potential differences in exposure to anthropogenic pressures;

iii. evaluate the relationships between nutrients and other indicators to identify potential pollution sources; and

iv. apply the Organic Pollution Index (OPI) to assess the degree of ecological degradation and the overall condition of these aquatic ecosystems.

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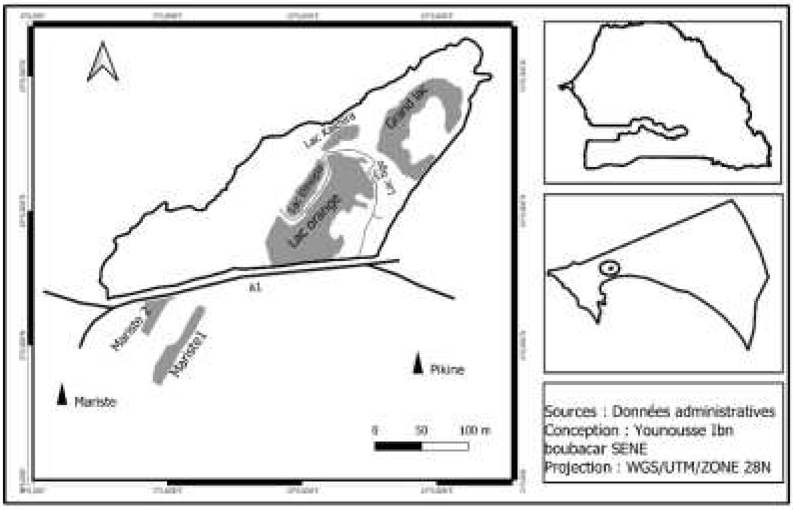
www.abjournals.org

MATERIALS AND METHODS

The Urban Nature Reserve of the Grande Niaye of Pikine and its Dependency (UNRGNPD), located in the heart of the Dakar metropolitan area, covers approximately 313 hectares and comprises two main sectors: Technopôle and Maristes, encompassing a total of seven water bodies (Figure 1). Owing to its basin-like topography, the UNRGNPD functions as a natural retention area that collects runoff from the surrounding neighborhoods during the rainy season. It is also fed by drainage channels carrying domestic, agricultural, and stormwater effluents, making it particularly sensitive to anthropogenic inputs.

This hydrological dynamic gives the reserve a strategic role in regulating urban waters but also heightens its vulnerability to organic and nutrient pollution. The UNRGNPD's water bodies thus lie at the intersection of hydrological and anthropogenic pressures, making the site highly relevant for assessing the physicochemical quality of urban aquatic environments.

Figure 1. Map of the Urban Nature Reserve of the Grande Niaye of Pikine and Dependency



a. Data Collection

Between 2021 and 2025, sampling campaigns were conducted across the seven lakes of the reserve, including five located within the Technopôle area and two in the Maristes sector, a densely populated zone. Sampling was carried out during both the rainy and dry seasons (Figure 1) to account for seasonal variability.

In total, 70 water samples were collected. During each campaign, water was stored in 1.5 L plastic bottles, kept at 4 °C in an insulated cooler, and subsequently transported to the laboratory for analysis.

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b. Sample Analysis

b.1. Biochemical Oxygen Demand (BOD_5)

The five-day biochemical oxygen demand (BOD_5) was determined in accordance with the procedures described in the *Standard Methods for the Examination of Water and Wastewater* (APHA, 2017). When necessary, samples were diluted with oxygen-saturated distilled water and seeded with a microbial inoculum to ensure adequate bacterial activity.

The initial dissolved oxygen concentration (DO_0) was measured immediately after sample preparation. The bottles were then incubated for five days at 20 ± 1 °C in complete darkness to prevent photosynthetic oxygen production. After incubation, the final dissolved oxygen concentration (DO_5) was measured, and the BOD_5 was calculated as follows:

$$\mathrm{BOD_5} = \mathrm{DO_0} - \mathrm{DO_5}$$

b.2. Oxygen Saturation Rate

The dissolved oxygen saturation rate was determined by comparing the measured dissolved oxygen concentration with the theoretical maximum concentration of oxygen that water can hold under local conditions of temperature, salinity, and atmospheric pressure, according to the following equation:

$$\%\mathrm{Saturation} = \frac{[\mathrm{O_2}]_{\mathrm{measured}}}{[\mathrm{O_2}]_{\mathrm{maximum}}} \times 100$$

where $[\mathrm{O_2}]_{\mathrm{measured}}$corresponds to the dissolved oxygen concentration ($mg \cdot L^{-1}$) determined using the Winkler method (Winkler, 1888), and $[\mathrm{O_2}]_{\mathrm{maximum}}$represents the theoretical oxygen solubility calculated as a function of temperature, salinity, and barometric pressure (Weiss, 1970; Garcia and Gordon, 1992).

Two critical thresholds at which adverse effects on aquatic fauna may occur were identified (Aminot and Kérouel, 2004).

b.3. Mineral elements (NO_3^-, NO_2^-, NH_4^+, SO_4^{2-} and PO_4^{3-})

The concentrations of dissolved nutrients (nitrate, nitrite, ammonium, sulphate, and phosphate) were determined by UV-Visible spectrophotometry, following the procedures described in the *Standard Methods for the Examination of Water and Wastewater* (APHA, 2017) and the corresponding ISO standards. Measurements were carried out using a spectrophotometer.

➢ **Nitrate (NO_3^-)**

Nitrate determination was performed using the cadmium reduction method. Nitrates present in the sample were reduced to nitrites by passage through a copper-activated cadmium column, then reacted with sulphanilamide in an acidic medium and N-(1-naphthyl)-ethylenediamine (NED) to form a red-pink azo dye. The absorbance was measured at 543 nm (APHA, 2017; ISO, 2004).

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➢ **Nitrite (NO_2^-)**

Nitrites were determined directly by the sulphanilamide colorimetric method. In an acidic medium, nitrites react with sulphanilamide and NED to produce an azo complex, the absorbance of which was measured at 543 nm (APHA, 2017; ISO, 2004).

➢ **Ammonium (NH_4^+)**

Ammonium concentrations were measured using the phenate (Berthelot) method. In the presence of hypochlorite and phenol under alkaline conditions, ammonium reacts to form indophenol blue, a reaction catalysed by sodium nitroprusside. Absorbance was measured at 630 nm (APHA, 2017; ISO, 2004).

➢ **Sulphate (SO_4^{2-})**

Sulphates were determined using the barium chloride turbidimetric method. In an acidic medium, sulphate ions react with barium to form a finely dispersed barium sulphate precipitate. The resulting turbidity is proportional to the sulphate concentration and was measured spectrophotometrically at 420 nm (APHA, 2017; ISO, 2004).

➢ **Phosphate (PO_4^{3-})**

Orthophosphates were determined using the ascorbic acid-reduced molybdenum blue method. In an acidic medium, phosphates react with ammonium molybdate and antimony to form a phosphomolybdic complex, which is subsequently reduced by ascorbic acid to produce a blue compound measured at 880 nm (APHA, 2017; ISO, 2004).

c. Quality Assurance and Quality Control (QA/QC)

A rigorous quality assurance and quality control protocol was applied in accordance with Standard Methods (APHA, 2017) and ISO 17025 principles.

Field phase: Field and equipment blanks, as well as field duplicates (10% of samples), were collected during each campaign. Samples were preserved at 4 ± 2 °C and analyzed within recommended holding times. A chain-of-custody procedure was followed.

Laboratory phase: Calibration curves were prepared daily with certified standards ($r^2 \geq 0.995$). Each analytical batch included reagent blanks, laboratory duplicates (10–15% of samples), and matrix spikes. Relative percent difference (RPD) between duplicates was maintained below 10% for nutrients and below 20% for BOD_5. Spike recoveries ranged from 85% to 115%. Certified reference materials (CRM) were analyzed regularly and fell within acceptable limits.

Parameter-specific controls:

- BOD_5: Glucose-glutamic acid (GGA) checks were performed with each series (acceptable range: 198 ± 30.5 $mg \cdot L^{-1}$). Seed and dilution water blanks were systematically controlled.
- Nutrients: Cadmium column reduction efficiency for nitrate was verified weekly (> 95%). All colorimetric and turbidimetric methods included independent secondary standards.

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- Dissolved oxygen: Winkler method was validated with potassium iodate standards.

Data were only accepted when all QC criteria were satisfied. Measurement uncertainties were estimated for each parameter.

This QA/QC framework ensured the accuracy, precision, and reliability of the results.

d. Organic Pollution Index (OPI)

The Organic Pollution Index (OPI) is an indicator developed by *Leclercq (2001)* to provide a synthetic assessment of the quality of surface waters with respect to organic pollution. This index is based on the analysis of four physicochemical parameters closely associated with this type of pollution: biochemical oxygen demand (BOD_5), ammonium ions (NH_4^+), nitrites (NO_2^-), and phosphates (PO_4^{3-}).

The calculation of the OPI allows water bodies to be classified into different quality categories, each associated with a standardised colour code. Thus, blue indicates unpolluted water (no organic contamination), green corresponds to slight pollution, yellow to moderate pollution, while orange and red represent high and very high levels of pollution, respectively.

The final Organic Pollution Index value is obtained as the mean of the pollution classes for all four parameters (Table 1).

Table 1: Classification grid of the Organic Pollution Index (Leclercq, 2001)

Classes	$NH4^+$ ($mg \cdot L^{-1}$)	DBO_5 ($mgO_2 \cdot L^{-1}$)	$PO4^{3-}$ ($\mu g \cdot L^{-1}$)	$NO2^-$ ($\mu g \cdot L^{-1}$)	IPO	organic pollution
5	<0,1	<2	<15	<5	4,6-5,0	None
4	0,1-0,9	2,1-5	16-75	6-10	4,0-4,5	Low
3	1-2,4	5,1-10	76-250	11-50	3,0-3,9	Moderate
2	2,5-6	10,1-15	251-900	51-150	2,0-2,9	High
1	>6	>15	>900	>150	1,0-1,9	Very High

e. Statistical Data Analysis

The measured parameters were explored using Principal Component Analysis (PCA) and correlation circles to identify relationships and groupings among variables. To test differences between categories, non-parametric statistical analyses were performed. The Kruskal-Wallis test was used to detect significant differences between groups (Kruskal & Wallis, 1952). (Kruskal &Wallis, 1952). When this test indicated a significant difference, a Dunn post-hoc test with a Bonferroni-adjusted significance threshold was applied to determine which groups were responsible for these differences (Dunn, 1952). The statistical significance level was set at $p \leq 0.05$. The statistical analysis using the Kruskal-Wallis test revealed no significant differences among the seven lakes of the UNRGNPD. In this context, the study area was reclassified into two distinct groups, the Technopole and the Maristes (Dependency), in order to better capture spatial contrasts.

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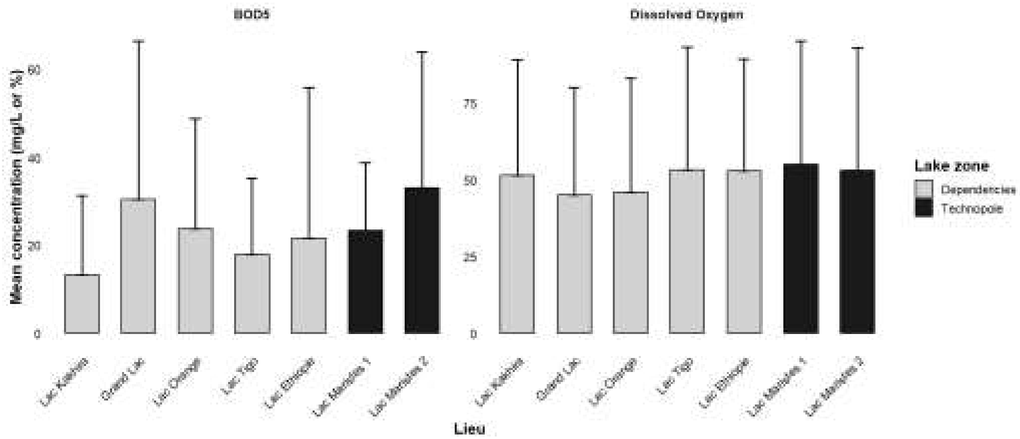
RESULTS

a. Spatial variations of environmental parameters

Figure 2 shows the concentrations of BOD_5 and dissolved oxygen (DO) in the UNRGNPD. BOD_5 ranged from 0.37 to 123 mg·L⁻¹, with a mean of 23.36 ± 26.09 mg·L⁻¹. Values were similar between the Technopole Lake (21.43 ± 26.76 mg·L⁻¹; 0.37–123 mg·L⁻¹) and the dependency lakes (28.17 ± 24.31 mg·L⁻¹; 0,39–77,45 mg·L⁻¹). These levels frequently exceed the 20 mg·L⁻¹ threshold set for surface waters. DO concentrations ranged from 0.8 to 132.3%, with a mean of 50.95 ± 36.59%. In the Technopole Lake, they ranged from 0.8 to 116.6% (54.10 ± 39%), while in the dependency lakes, they fluctuated between 2.8 and 132.3% (54.10 ± 39%).

Figure 2: Spatial variations of BOD_5 and dissolved oxygen levels in the UNRGNPD.



Nutrient concentrations in the Urban Nature Reserve of the Grande Niaye of Pikine and Dependency (UNRGNPD) showed variations between the Technopole lakes and the dependency lakes (Figure 3). Ammonium concentrations reached up to 115.2 mg·L⁻¹, exceeding the recommended standard (0.3 mg·L⁻¹), with significantly higher levels in the dependency (15.58 ± 25.60 mg·L⁻¹) than in the Technopole (3.75 ± 8.51 mg·L⁻¹; $p = 0.00004$). Phosphate concentrations were higher in the dependency, with a mean of 11.36 ± 11.83 mg·L⁻¹ compared to 2.67 ± 3.44 mg·L⁻¹ in the Technopole ($p < 0.05$). Sulfate levels ranged from 0.11 to 508 mg·L⁻¹, with higher concentrations recorded in the Technopole (99.62 ± 107.86 mg·L⁻¹) than in the dependency (25.29 ± 17.51 mg·L⁻¹; $p < 0.05$), although the overall mean concentration (78.39 ± 97.41 mg·L⁻¹) remained below the recommended threshold (500 mg·L⁻¹). Nitrite (0.32 ± 0.65 mg·L⁻¹) and nitrate (18.16 ± 4.32 mg·L⁻¹) concentrations showed no significant differences between the two areas ($p > 0.05$).

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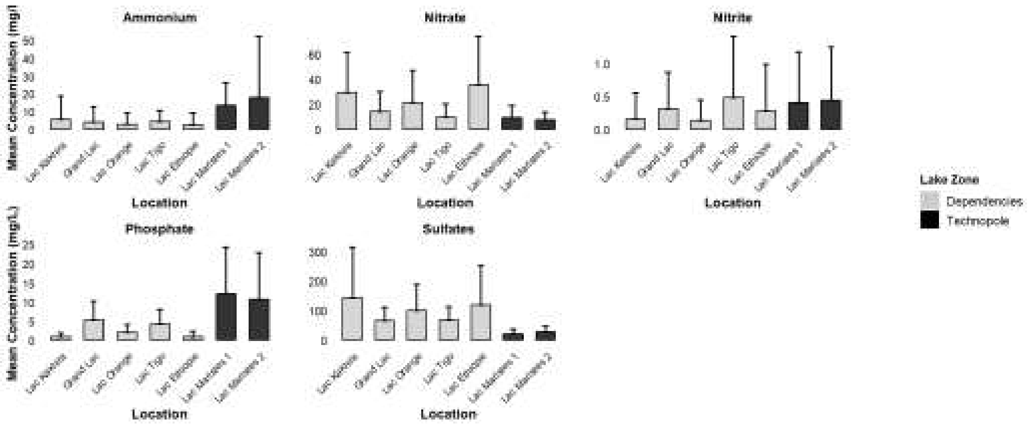

Figure 3: Spatial variations of nutrient concentrations in the UNRGNPD.

b. Temporal variations of environmental parameters

BOD_5 showed significant variations across the years ($p < 0.05$). The mean concentrations observed were 29.90 ± 22.81 mg·L⁻¹ in 2021, 9.24 ± 3.19 mg·L⁻¹ in 2022, 12.16 ± 13.11 mg·L⁻¹ in 2023, 37.45 ± 40.03 mg·L⁻¹ in 2024, and 28.04 ± 25.95 mg·L⁻¹ in 2025 (Figure 4). The Kruskal–Wallis test revealed significant differences in BOD_5 concentrations between years ($p = 0.0107$). However, post hoc multiple comparisons did not reveal significant differences between individual pairs of years ($p > 0.05$).

Dissolved oxygen concentrations also differed significantly between years ($p < 0.05$). The recorded means were 4.36 ± 1.95% in 2021, 27.91 ± 30.77 % in 2022, 93.98 ± 22.47 % in 2023, 58.71 ± 7.10 % in 2024, and 69.79 ± 15.77 % in 2025. The Dunn test revealed significant differences between 2022 and 2023, and between 2023 and 2024 ($p < 0.05$).

The mean seasonal values of BOD_5 were 24.74 ± 30.30 mg·L⁻¹ during the wet season and 21.97 ± 21.41 mg·L⁻¹ during the dry season, with no significant difference between seasons ($p > 0.05$). In contrast, dissolved oxygen concentrations varied significantly with season ($p < 0.05$), with mean values of 63.83 ± 38.16 % during the wet season and 38.07 ± 30.31 % during the dry season.

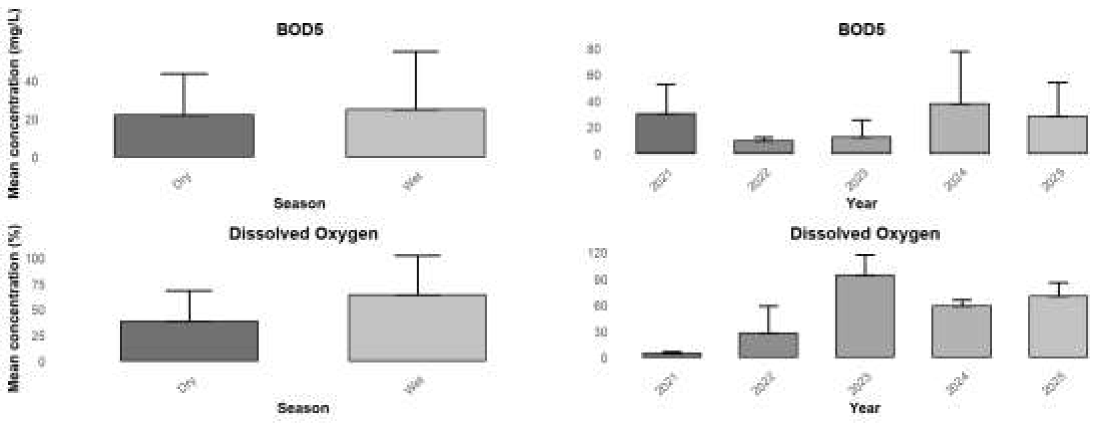

Figure 4: Seasonal and annual variations of BOD_5 and dissolved oxygen levels in the UNRGNPD.

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Volume 9, Issue 2, 2026 (pp. 124-140)

The combined analysis of interannual and seasonal variations in nutrient concentrations in the UNRGNPD revealed differences among parameters. Ammonium (NH_4^+) concentrations showed interannual variability, with a maximum recorded in 2021 followed by a gradual decrease until 2025, although no significant differences were observed between years ($p = 0.713$). Seasonally, concentrations were higher during the dry season than during the wet season, but this difference was not statistically significant ($p = 0.088$). In all cases, values exceeded the recommended threshold (0.3 $mg \cdot L^{-1}$).

Nitrate (NO_3^-) concentrations exhibited significant interannual variability ($p < 0.001$), characterized by a marked peak in 2024 followed by a decrease in 2025. No significant seasonal variation was observed ($p = 0.888$). Some values approached or exceeded the recommended limit (50 $mg \cdot L^{-1}$).

Nitrite (NO_2^-) concentrations also showed significant interannual variations ($p < 0.001$), with a progressive increase until 2024 followed by a decline in 2025. Higher concentrations were observed during the dry season, although the difference was not statistically significant ($p = 0.071$). Values frequently exceeded the reference threshold ($mg \cdot L^{-1}$).

Phosphate (PO_4^{3-}) concentrations varied significantly between years ($p < 0.001$), with a marked decrease in 2023 followed by an increase in 2024 and 2025. Seasonally, concentrations were significantly higher during the wet season ($p = 0.042$). Overall, concentrations remained above the recommended threshold (0.1 $mg \cdot L^{-1}$).

Finally, sulfate (SO_4^{2-}) concentrations showed significant variations both interannually ($p = 0.010$), with a peak in 2022, and seasonally, with higher values during the dry season ($p = 0.046$). However, measured levels remained below the standard limit of 500 $mg \cdot L^{-1}$.

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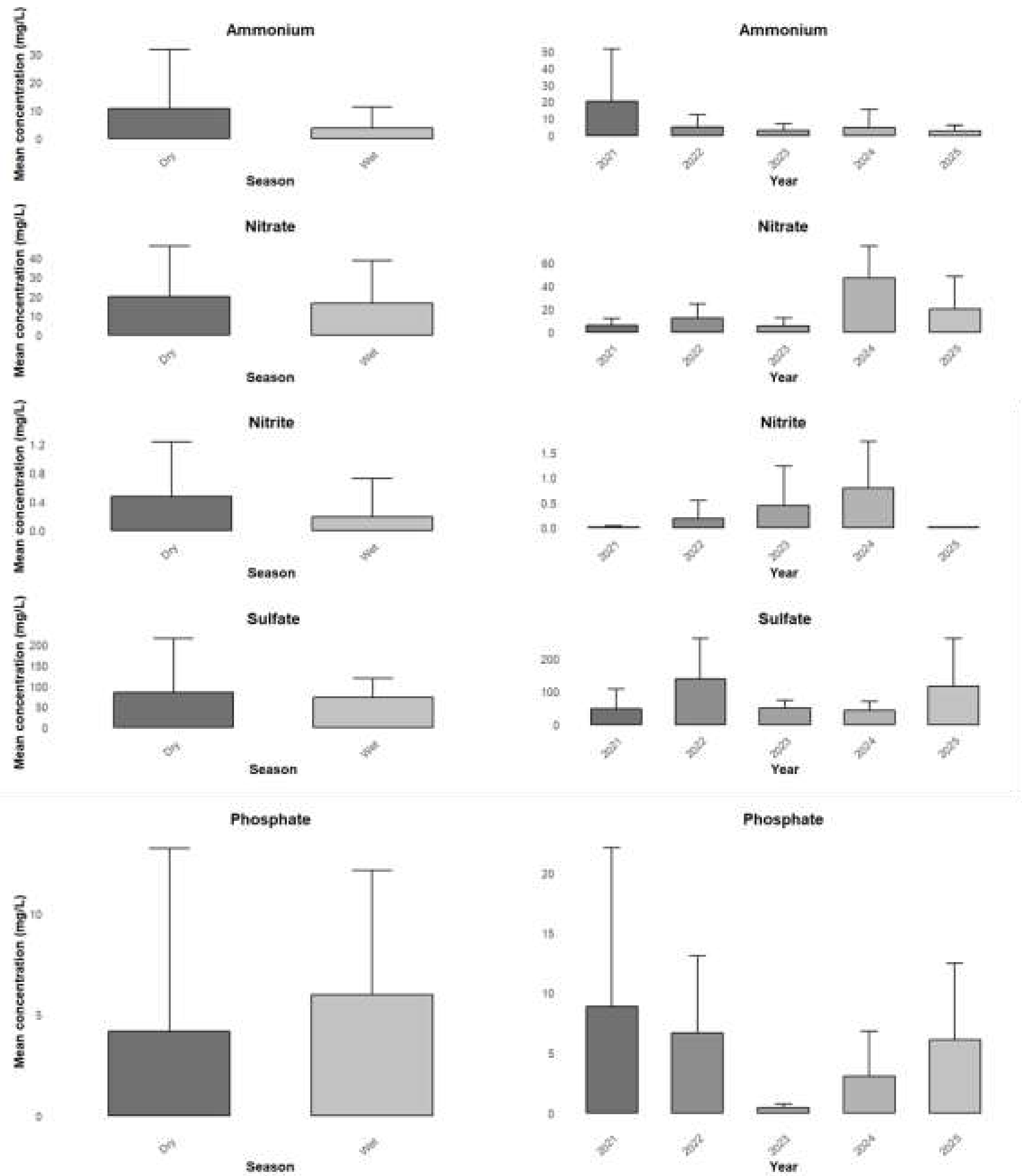

Figure 5: Seasonal and annual variations of mineral elements in the UNRGNPD.

c. Correlation analysis of environmental parameters

The Pearson correlation matrix reveals several significant relationships among the physicochemical parameters measured in the studied lakes. Strong positive correlations were observed between phosphate and ammonium ($r = 0.88$), as well as between nitrate and sulfate ($r = 0.90$). In contrast, marked negative correlations were recorded, particularly between phosphate and nitrate ($r = -0.82$), and between phosphate and sulfate ($r = -0.95$). A negative correlation was also noted between nitrite and sulfate ($r = -0.78$). Overall, these results highlight significant statistical relationships among the analyzed nutrients.

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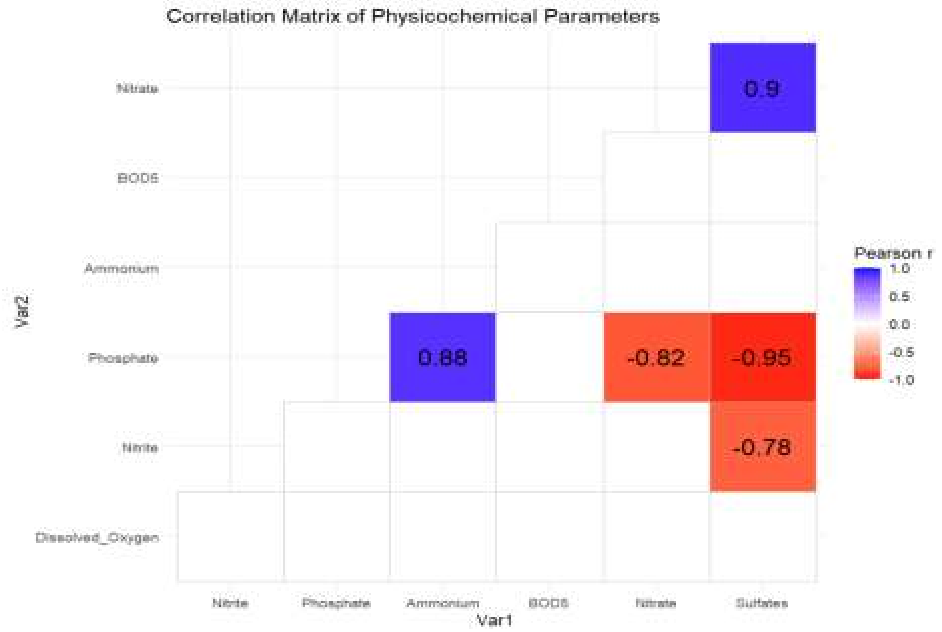

Figure 6: Correlation of environmental parameters.

The PCA results show a clear structure in the physicochemical data. The first two axes explain 86.1% of the total variance (Dim1 = 66%, Dim2 = 20.1%), providing a good summary of the relationships between variables and sites.

Dim1 mainly contrasts nitrate and sulfate (negative side) with ammonium, phosphate, and nitrite (positive side), while dissolved oxygen is also positively associated but to a lesser extent. Dim2 is mainly defined by dissolved oxygen (positive) and BOD_5 (negative), reflecting an opposition between oxygenation and organic pollution.

The ordination of sites shows different patterns: Maristes 1 and Maristes 2 are associated with higher nutrient levels and oxygen (especially Maristes 1), Kakhira and Ethiopie are linked to higher nitrate and sulfate levels, Grand Lac is characterized by high organic load (high BOD_5), Lac Orange shows generally low concentrations, and Lac Tigo occupies an intermediate position with moderate conditions.

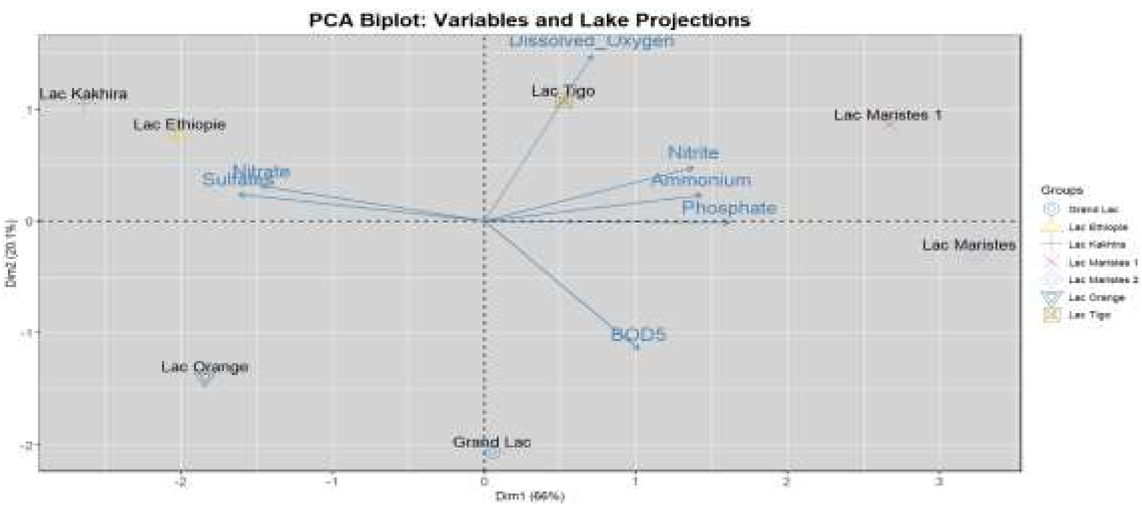

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Figure 7: Correlation circle of variables and lakes.

d. Organic Pollution Index (OPI)

The Organic Pollution Index (OPI) was assessed in seven lakes of the RNUGNPD based on 70 samples (Table 2). The results indicate that all studied lakes fall within the same pollution category, classified as very high organic pollution, with OPI values ranging from 1.00 to 1.75. Despite slight variations between sites, these values consistently reflect severe organic contamination across the entire system.

These findings suggest a generalized degradation of water quality in the RNUGNPD, where even lakes still supporting fish populations such as Grand Lake, Lake Ethiopie, Lake Orange, and Lake Kakhira are subjected to very high levels of organic pollution.

Table 2: Mean Organic Pollution Index (OPI) and water quality class in the seven lakes.

Lakes	**Grand Lac**	**Ethiopie**	**Orange**	**Tigo**	**Kakhira**	**Mariste1**	**Mariste2**
IPO	1,25	1,5	1,25	1,25	1,75	1	1
Classe	1	1	1	1	1	1	1
Quality	Very high	Very high	Very high	Very high	Very high	Very high	Very high

DISCUSSION

The data analysis highlights marked spatial heterogeneity between the water bodies of the Technopole and Dependency. Ammonium (NH_4^+) and phosphate (PO_4^{3-}) concentrations are significantly higher in these areas, reflecting a major influence of untreated domestic discharges and agricultural inputs associated with fertiliser and pesticide use. Such levels are characteristic of waters under strong anthropogenic pressure, as previously reported by Gueye et al. (2022) and Ameen et al. (2023). Conversely, the higher sulfate (SO_4^{2-}) concentrations observed at the Technopole appear primarily linked to effluents from the wastewater treatment plant (WWTP) and evapoconcentration processes, a phenomenon also described in other urban wetlands (Bop et al., 2021; Prost-Boucle et al., 2022). Extreme NH_4^+ levels, sometimes exceeding 100 $mg \cdot L^{-1}$, far surpass surface water quality standards (< 0,3 $mg \cdot L^{-1}$) and indicate intense episodic inputs. These levels are far higher than those reported in the Ebrié Lagoon in Côte d'Ivoire (Koné et al., 2022) but comparable to those of the Massili River in Burkina Faso (Idrissa et al., 2023), where high nutrient loads were attributed to uncontrolled sludge spreading and animal waste carried by runoff. These observations confirm that the absence of efficient sanitation systems in large African cities promotes rapid contamination of aquatic environments.

Temporally, interannual analyses reveal that BOD_5 decreased in 2022 before rising again in 2023 and 2024, while dissolved oxygen (DO) peaked in 2023 and then sharply declined in 2024. These fluctuations reflect the combined effects of anthropogenic inputs and hydrometeorological conditions on biogeochemical cycles, as also shown by Tampo et al. (2021) and Zhi et al. (2023). At the seasonal scale, DO is significantly higher in the wet season

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than in the dry season. This trend can be explained by dilution and mixing due to rainfall, photosynthetic supersaturation during periods of high biological productivity, and lower water temperatures, which enhance oxygen solubility. Conversely, high temperatures in the dry season accelerate organic matter decomposition and reduce dissolved oxygen. Similar results were reported by Gouton et al. (2025) in the Okpara River (Benin).

Nutrients also exhibit contrasting seasonal dynamics: ammonium is more concentrated in the dry season due to stagnation and limited dilution of discharges, whereas sulfates are more abundant in the wet season due to runoff. Similar observations were made by Houssou et al. (2017) and Agblonon Houelome et al. (2016) confirming that the combination of external inputs and the release of pollutants accumulated in sediments largely explains seasonal variations.

Correlation analysis among chemical parameters highlighted several noteworthy relationships. A strong correlation between NH_4^+ and PO_4^{3-} suggests a common origin, primarily domestic and agricultural, as observed in other highly anthropised wetlands (Amieur et al., 2025). A positive correlation between NO_3^- and SO_4^{2-} suggests joint mobilisation via urban runoff and industrial or WWTP effluents (Gana and Draoui, 2023). Finally, negative correlations between PO_4^{3-} and oxidised forms of nitrogen (NO_3^-, NO_2^-) indicate distinct biogeochemical processes, likely related to denitrification or differentiated pollution sources. These results confirm the complexity of interactions between anthropogenic inputs, internal cycles, and ecological processes.

Assessment of water quality through the Organic Pollution Index confirms that all the studied lakes in the reserve exhibit very high organic pollution. These findings are consistent with those from other West African systems under strong anthropogenic pressures, such as Lake Nokoué (Agbohessi et al., 2023). However, some lakes, such as Ethiopie, Orange, Grand Lac and Kakhira, still maintain notable fish biodiversity, highlighting the importance of preserving these still-functional environments.

Lake Tigo is particularly concerning: despite its small size, it exhibits a very high OPI, which may be attributed to the massive proliferation of *Phragmites australis*. This invasive plant, although sometimes beneficial for water purification, promotes biomass accumulation at high densities, whose decomposition increases eutrophication and biological oxygen demand. This phenomenon illustrates the ambivalent role of macrophytes in water quality regulation and explains why Lake Tigo reaches pollution levels comparable to Maristes 1 and 2, despite a less pronounced chemical signature.

The high organic and nutrient load measured in the UNRGNPD exposes aquatic ecosystems to major ecological risks, including hypoxia, anoxic events, phytoplankton blooms, and fish mortality. These phenomena have been widely documented in other eutrophic tropical ecosystems (Levain et al., 2021). Beyond ecological impacts, the combination of runoff, domestic discharges, agricultural inputs, and dysfunctions at the ONAS (National Sanitation Office of Senegal) WWTP compromises the sustainability of local socio-economic uses, particularly artisanal fishing, market gardening, and ecosystem services related to water quality regulation.

To mitigate these impacts, several management strategies should be considered, including improving treatment of domestic and industrial effluents, reducing agricultural inputs through

Article DOI: 10.52589/AJENSR-EMVUSD3B
DOI URL: https://doi.org/10.52589/AJENSR-EMVUSD3B

rational fertilisation and adoption of agroecological practices, ecological restoration of lakes through control of invasive macrophytes and establishment of vegetated buffer zones, and the implementation of regular environmental monitoring based on integrated indicators such as the OPI.

IMPLICATIONS FOR RESEARCH AND PRACTICE

This study provides important implications for both research and environmental management of urban wetlands, particularly in rapidly urbanizing regions of West Africa. From a research perspective, the findings highlight the need for long-term and high-resolution monitoring of nutrient dynamics and organic pollution in urban aquatic systems. The strong correlations observed between key parameters (ammonium–phosphate and nitrate–sulphate) emphasize the importance of integrated approaches combining physicochemical analyses and pollution indices such as the Organic Pollution Index (OPI) to better identify and quantify anthropogenic pressures. Furthermore, the study underscores the value of incorporating seasonal and interannual variability into future research to improve the understanding of climate–pollution interactions in tropical wetland ecosystems.

From a practical standpoint, the results demonstrate the urgent need for improved management of wastewater discharges, agricultural inputs, and urban runoff affecting the UNRGNPD. The identification of critical pollution hotspots, such as the Technopole and the Dependency, provides a basis for targeted intervention strategies. Policymakers and environmental managers should prioritize the regulation of effluents, the promotion of sustainable agricultural practices, and the implementation of nature-based solutions, including phytoremediation and wetland restoration. In addition, strengthening environmental monitoring programs and fostering community engagement are essential to ensure the long-term protection of ecosystem services, biodiversity, and local livelihoods.

Overall, this study contributes to bridging the gap between scientific assessment and practical decision-making, offering a framework applicable to other urban wetlands facing similar environmental pressures in developing countries.

CONCLUSION

This study revealed concerning organic and nutrient pollution in the UNRGNPD, characterised by high concentrations of ammonium and phosphates, elevated BOD_5, and an Organic Pollution Index indicating severe degradation, particularly at the Technopole and Dependency. Correlations among nutrients confirm the anthropogenic origin of these inputs, which increase the risk of eutrophication and threaten both fish biodiversity and local socio-economic activities. Implementing corrective measures such as regulating effluents, reducing chemical fertilisers, managing invasive species, and enhancing environmental monitoring appears essential. In the long term, an integrated management approach combining scientific monitoring, ecological restoration, and community involvement represents the most sustainable way to preserve the ecosystem services of the UNRGNPD and similar urban wetlands in West Africa.

Article DOI: 10.52589/AJENSR-EMVUSD3B
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FUTURE RESEARCH

Future research should aim to expand the scope of this study by investigating the impact of pollution on local human populations living in proximity to the UNRGNPD, particularly in terms of potential health risks associated with exposure to contaminated water and aquatic resources. In addition, further studies should focus on the assessment of contamination in avian species inhabiting the reserve, given their ecological importance and their role as bioindicators of environmental quality.

Moreover, it would be relevant to extend the analysis of pollutants by exploring the presence and distribution of other heavy metals within this ecosystem, beyond those currently studied. Such investigations would provide a more comprehensive understanding of contamination pathways, bioaccumulation processes, and ecological risks. These perspectives would contribute to strengthening environmental monitoring and improving risk assessment and management strategies for urban wetlands.

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