EVALUATION OF PHYSICOCHEMICAL PARAMETERS AND PHYTOPLANKTON ASSEMBLAGE OF LAKE ASA, ILORIN, NIGERIA

[1]MUHIBBU-DIN, Iysa Olorunshina and [2]OLADIPO, Segun Olayinka
[1]Department of Zoology, Kwara State University, Malete, Kwara State, Nigeria.
[2]Department of Biology, Howard University, Washington, D.C., USA.

Corresponding Author: Muhibbu-Din, I. O. Department of Zoology, Kwara State University, Malete, Kwara State, Nigeria. **Email:** iysa-muhibbudin@kwasu.edu.ng **Phone:** +234 703 475 3918

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ABSTRACT

A limnological investigation of Lake Asa was conducted from November 2023 to October 2024, encompassing three sampling stations, to assess its physicochemical properties and phytoplankton composition. Measured values of physicochemical parameters were evaluated against established water quality standards. The lake's water quality was assessed through three analytical approaches: (1) analysis of phytoplankton taxonomic structure; (2) multimetric assessment using diversity indices; and (3) multivariate ordination of taxonomic group distribution to environmental variables. Thirteen physicochemical parameters were analyzed. Comparative analysis revealed that nine parameters met acceptable limits for domestic water supply and aquaculture, while four parameters were deemed unsuitable. Specifically, transparency, total nitrogen, organic matter, total organic carbon, and total phosphorus concentrations indicated a hypereutrophic state across all sampling stations, a hallmark of eutrophication. However, taxonomic analysis suggested a mesotrophic status for the lake. Phytoplankton community composition consisted of six taxonomic groups, with Cyanophyta dominating (83.20%). Other groups present, in descending order of abundance, were Bacillariophyta (diatoms 8.4%), Dinophyta (4.20%), Chlorophyta (2.70%), Euglenophyta (1.00%), and Chrysophyta (0.41%). Phytoplankton diversity indices ranged as follows: Shannon-Wiener (H = 0.26 – 0.98), Simpson (D = 0.46 – 0.90), and Pielou's evenness (J = 0.22 – 0.44). Canonical Correspondence Analysis (CCA) demonstrated the influence of environmental variables on phytoplankton assemblage structure, while Non-metric Multidimensional Scaling (NMDS) revealed spatial and temporal differences in phytoplankton assemblages. The observed Cyanophyta dominance and low diversity index values collectively indicate that Lake Asa is heavily polluted and in poor ecological condition.

Keywords: Lake Asa, Limnology, Physicochemical parameter, Phytoplankton composition, Ecological diversity indices

INTRODUCTION

A critical component of environmental conservation and ecosystem monitoring efforts is the assessment of biodiversity, which includes the detailed analysis of community structure at various trophic levels (Risch and Parks, 2017; Al-Qadami *et al.*, 2024). The lake's ecological status assessment should include biological indicators, specifically the composition and abundance of aquatic organisms (Brucet *et al.*, 2013). This approach recognises the inherent ecological value of water bodies, acknowledging them not merely as human resources but as integral components of functioning ecosystems. Consequently, evaluations must encompass not only physicochemical water quality parameters but

also the broader ecological health of the entire aquatic ecosystem (Pasztaleniec, 2016).

River Asa, a significant tributary of the Niger River, is the primary watercourse of the Federal Republic of Nigeria which plays a crucial role in the hydrology of Ilorin, a city in North-Central Nigeria. River Asa was dammed in 1977 by the Kwara State Government. The Lake Asa is fed by four river tributaries with the River Asa being the major river. The lake occupies 302 hectares of surface area (Araoye, 2009). However, the lake is subject to both direct and indirect anthropogenic pollution, overtime the lake has been greatly modified. A preliminary survey carried out identified several pollution sources, including agricultural runoff containing pesticides and herbicides, industrial effluents, domestic waste, and wastewater discharge from fish farms along its catchment. Over 80% of its catchment area consists of a mix of disturbed and undisturbed vegetation, while approximately 47% of the sublittoral zone is covered by macrophytes (water hyacinth).

One of the dominant features of the Ilorin metropolis is the Lake Asa system. It occupies 302 hectares of surface area. Lake Asa has been greatly modified by human activity. This lake system has natural and cultural values. The lake is used mainly for water and fish supply. Therefore, evaluation and monitoring of the lake is important.

Phytoplankton communities offer significant potential as bioindicators in aquatic ecosystems. However, their application in water quality assessments of Lake Asa remains underutilized. Comprehensive investigations of Lake Asa's phytoplankton assemblages are notably scarce in the existing literature. In previous works, researchers examined phytoplankton community structure in specific lake segments impacted by human activities. However, understanding the variability of phytoplankton across the entire lake course presents a more complex and less explored. The current limnological study is designed to examine the phytoplankton structure of the whole Lake Asa system, the physicochemical parameters influencing its distribution and determine its suitability for domestic water supply and aquaculture.

The basic aim of this study is to characterise physicochemical parameters compare the findings with standard reference values recommended for aquaculture, and water supply and identify the phytoplankton assemblages inhabiting the Lake Asa ecosystem.

MATERIALS AND METHODS

Study Area: Lake Asa, situated in Ilorin, Kwara State, Nigeria, is located at 8°20'N, 4°33'E, encompassing a surface area of 302 hectares and reaching a maximum depth of 14 meters. Ilorin's climate is classified as humid tropical, characterized by distinct wet (March to October) and dry (November to February) seasons (Ogundiran and Fawole, 2014). The annual rainfall is 1150 ± 250 mm, and the annual temperature ranges from 25 to 28.9°C, with relative humidity of between 65 and 80%.

Sampling was conducted bi-monthly from November 2023 to October 2024 at three stations along Lake Asa (Figure 1) to collect water samples and phytoplankton for the assay of physicochemical parameters, plankton compositions and diversity.

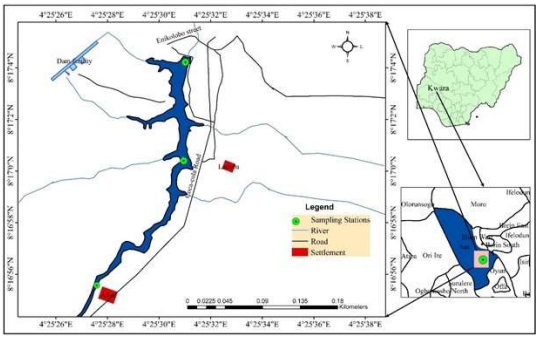


Figure 1: Map of Lake Asa and location of the sampling stations

The coordinates of the sampling stations are as follows: Dam Station (lacustrine) – 8°24'42.25"N, 4°33.45"E; Laduba Station (transitional) – 8°20'42.93"N, 4°33'19.76"E; and Afon Station (inlet) – 8°26'25.29"N, 4°31'1.01"E. Sampling was stratified by season, encompassing both the dry season (November 2023 – February 2024) and the wet season (March – October 2024). Sampling sites at each station were determined by the presence or absence of significant anthropogenic influence.

Sampling Stations: Three sampling stations were strategically selected along the lake, as depicted in Figure 1. The upstream station (Afon) is located 2.5 kilometres from the midstream station (Laduba). The intervening catchment area is characterized by a mosaic of disturbed and undisturbed vegetation, with prominent human activities such as water abstraction, fishing, and cattle grazing. The midstream Laduba Station is situated 2.0 kilometres upstream of the downstream Dam Station. The catchment areas of both the Dam and Laduba Stations are subject to a range of anthropogenic pressures, including fish farming, fishing activities, cattle rearing, domestic waste disposal, and agricultural runoff.

Field Sampling Procedure: Sampling was conducted between 9 – 11 am, bi-monthly from November 2023 to October 2024 at three stations in Lake Asa (Figure 1) to collect phytoplankton and water samples for the analysis of physicochemical parameters. 1 litre of water sample was collected at each sampling in a clean plastic bottle. The plastic was rinsed with lake water before sampling. Water quality parameters were analyzed according to the standard methods outlined in Standard Methods for the Examination of Water and Wastewater (APHA, 2005). Thirteen parameters were assessed: pH, water temperature, electrical conductivity (EC), total dissolved solids (TDS), and dissolved oxygen (DO) were measured *in situ* using a Combo pH, EC, TDS, DO and temperature meter (HI 98129), HANNA Instruments, USA. Water transparency and depth were determined using a Secchi disk and an anchored calibrated rope. Water samples for the determination of chemical oxygen demand (COD), total nitrogen (TN), total phosphate (TP), sulphate, total organic carbon (TOC), and organic matter (OM) were collected in 2-litre plastic bottles, while samples for biological oxygen demand (BOD) were collected in 250 ml dark glass bottles. Before sample collection, each bottle was meticulously rinsed several times with distilled water. At each sampling station, the water column was allowed to stabilize before collecting samples. Bottles were then rinsed thrice with lake water, followed by the collection of water samples from a depth of 10 cm below the water surface. Collected samples were appropriately labelled, sealed airtight, and transported to the laboratory in insulated containers with ice packs.

Physicochemical Parameters Analysis: BOD was determined by the titrimetric method following a 5-day incubation period in dark bottles. Total nitrogen and phosphate concentrations were quantified using a portable spectrophotometer (721 LCD) at wavelengths of 480 nm and 740 nm, respectively. COD and OM concentrations were determined by the titrimetric method, employing potassium dichromate as the oxidizing agent and ferrous ammonium sulphate as the reducing agent. Sulphate concentrations were determined using the turbidimetric method. All physicochemical assays were done as described in APHA (2005).

Phytoplankton Analysis: Phytoplankton samples were collected using a 150 µm mesh plankton net, towed horizontally for 100 meters at a depth of 10 cm below the water surface at each sampling station, effectively filtering 1200 litres of lake water. Collected samples were immediately preserved in a 4% buffered formalin solution, with the addition of two drops of Lugol's iodine solution for concentrate precipitation. Three replicate 1 mL subsamples were then examined using a camera-equipped binocular light microscope. Phytoplankton identification followed established taxonomic keys (Guo and Qian, 2003; Hu and Wei, 2006; Li and Qi, 2010). The relative abundance of each taxon was calculated using the formula: $N = (a/b)n$, where N represents the estimated number of genera per sample, *a* is the volume of the water sample (mL), *b* is the volume of the subsample (mL), and *n* is the number of phytoplankton cells in the subsample (Moncheva and Parr, 2010). Phytoplankton diversity was assessed using the Shannon-Wiener index (H) (Shannon and Weaver, 1949), evenness (J) was calculated according to Pielou (1975), species richness was determined using the Margalef index (Margalef, 1957), and the Simpson's index (1-*D*) (Simpson, 1949) was employed to evaluate species diversity and dominance (D).

Data Analysis: Descriptive statistics were generated for all measured physicochemical and biological parameters for each station and season. The one-way analysis of variance (ANOVA) was used for spatial variation (interstation comparison) and t-test for seasonal variation of physicochemical parameters and plankton. Canonical Correspondence Analysis (CCA) (Ma *et al.,* 2021) was employed to investigate the relationships between environmental variables (physicochemical parameters) and phytoplankton taxonomic group composition across stations and seasons, aiming to elucidate the influence of these variables on phytoplankton distribution and occurrence. Non-metric Multidimensional Scaling (NMDS) was utilized to assess similarities and dissimilarities in phytoplankton community structure across stations and seasons. All diversity metrics and analyses exploring the relationships between phytoplankton group biomass and environmental variables were done using the paleontological statistics software PAST v4.03.

RESULTS AND DISCUSSION

Physicochemical Parameters of Lake Asa: The analysis of freshwater physicochemical parameters is a crucial initial step in determining its optimal utilization and provides insights into the complex interplay between climatic and biological processes within the aquatic environment. Table 1 presents the spatial and temporal variations of these parameters, including descriptive statistics and comparison with established water quality standards for domestic water supply and aquaculture. A clear seasonal variation in these parameters was observed.

Water temperatures observed during this study ranged from 27.0°C to 28.2°C in the dry season and from 24.03°C to 24.9°C in the wet season. Dry season temperatures at all sampling stations fell within the optimal range of 25°C to 30°C recommended by the FAO (2006) for fish productivity. Conversely, wet season temperatures were consistently below this recommended range. These seasonal variations in water temperature may be attributed to factors such as increased solar radiation and the influence of the harmattan wind during the dry season, as previously reported (Niyoyitungiye *et al.,* 2019).

Water transparency in Lake Asa exhibited a marked seasonal variation. During the dry season, transparency values ranged from 138.00 to 196.00 cm, while in the wet season, they decreased significantly, ranging from 35.46 to 47.33 cm. The lowest transparency (35.00 cm), recorded at the Laduba Station during the wet season, is likely attributable to increased tributary input of suspended materials and surface runoff from surrounding agricultural lands, aquaculture facilities, and other effluent sources. Water transparency is influenced by a complex interplay of factors, including phytoplankton biomass, inorganic and detrital turbidity, and the presence of dissolved coloured substances. While Bhatnagar and Devi (2013) suggest a transparency range of 30 – 80 cm as suitable for fish health, the higher transparency values observed during the dry season in Lake Asa indicate conditions conducive to both water supply and the lake's trophic functioning.

The pH of Lake Asa exhibited seasonal variation, ranging from 8.33 to 8.93 pH during the dry season and 6.40 to 6.80 pH during the wet season. These results indicate alkaline conditions during the dry season and slightly acidic conditions during the wet season. The elevated pH values observed in the dry season may be attributed to increased photosynthetic activity by both micro and macrophytes, which shifts the carbonate equilibrium towards alkalinity (Howland *et al.*, 2000), or potentially to lower water levels and increased nutrient concentration. Conversely, the lower pH values in the wet season may be a consequence of the lower pH of rainwater and runoff from tributaries (Ling *et al.*, 2017). The pH range (6.40 – 8.93) suggests some influence from anthropogenic acidification in accordance with Johannesson *et al.* (2023) indicating minimal influence from atmospheric acidification. The high pH values recorded in the lake may likely reflect elevated photosynthetic rates during daylight hours (Fondriest, 2013). Importantly, the pH levels observed across all stations throughout the study period remained within the acceptable water quality standards for both aquaculture and water supply, as recommended by PHILMINAQ (2006) and Francis-Floyd *et al.* (2024).

Table 1: Spatial-temporal distribution of physicochemical parameters of Lake Asa

Season	Nov-Feb (dry season)			Mar-Oct (wet season)			Water quality standard
Parameters/ Station	**Dam**	**Laduba**	**Afon**	**Dam**	**Laduba**	**Afon**	
Temperature (^{0}C)	28.20 ± 0.57^c	27.50 ± 0.00^b	27.00 ± 0.21^a	24.76 ± 0.57^b	24.03 ± 0.51^a	24.90 ± 0.00^c	25^{0}C-30^{0}C (FAO, 2006)
Transparency (cm)	196.00 ± 0.00^c	176.00 ± 0.00^b	138.00 ± 0.00^a	41.13 ± 0.25^b	35.46 ± 0.05^a	47.33 ± 0.28^c	30-40 (Santhosh and Sing, 2007)
pH	8.33 ± 0.00^a	8.45 ± 0.00^b	8.93 ± 0.00^c	6.80 ± 0.00^c	6.40 ± 0.30^a	6.53 ± 0.57^b	6-9 (PHILMINAQ, 2006)
TDS (mgL^{-1})	275.00 ± 1.57^c	270.00 ± 0.31^b	261.00 ± 4.32^a	33.03 ± 3.57^a	71.53 ± 5.48^b	101.20 ± 3.29^c	<500 (USEPA, 2006)
TP (mgL^{-1})	1.45 ± 0.00^c	0.68 ± 0.00^a	1.00 ± 0.00^b	0.01 ± 0.00^a	0.30 ± 0.00^c	0.15 ± 0.00^b	0.01-3 (Piper *et al,* 1982)
DO (mgL^{-1})	8.12 ± 0.00^b	9.20 ± 0.00^c	7.33 ± 0.00^a	9.30 ± 0.00^c	8.10 ± 0.02^b	7.30 ± 0.10^a	≥ 4 (Santhosh and Sing, 2007)
BOD (mgL^{-1})	11.30 ± 0.00^c	9.90 ± 0.00^b	6.36 ± 0.00^a	2.90 ± 0.00^a	6.70 ± 0.00^c	5.10 ± 0.00^b	3-20 (Boyd, 2003)
COD (mgL^{-1})	72.00 ± 0.00^b	106.50 ± 0.00^c	36.10 ± 0.00^a	35.10 ± 0.00^a	118.50 ± 0.00^b	228.50 ± 0.00^c	< 50 (Santhosh and Sing, 2007)
EC (µS/cm)	411.00 ± 1.43^c	402.00 ± 0.04^b	389.00 ± 0.02^a	66.50 ± 0.40^a	151.36 ± 0.55^b	201.46 ± 1.68^c	1000 (FEPA,1991)
SO_4^{-2} (mgL^{-1})	14.50 ± 0.00^a	16.00 ± 0.00^b	18.20 ± 0.00^c	7.30 ± 0.00^a	53.50 ± 0.10^b	71.80 ± 0.00^c	250 (WHO, 2011)
TN (mgL^{-1})	0.68 ± 0.21^a	0.84 ± 0.01^c	0.78 ± 0.00^b	1.90 ± 0.00^c	1.24 ± 0.00^b	1.12 ± 0.00^a	0.1 (FEPA, 1991)
OM (mgL^{-1})	22.70 ± 0.00^a	23.20 ± 0.00^b	25.40 ± 0.00^c	33.10 ± 0.12^c	24.30 ± 0.01^b	15.20 ± 0.01^a	>4 (BCMECCS, 2019)
TOC (mgL^{-1})	13.10 ± 0.00^a	13.40 ± 0.00^b	14.70 ± 0.00^c	19.20 ± 0.21^c	14.10 ± 0.11^b	8.80 ± 0.02^a	>4 (BCMECCS, 2019)

OM- Organic Matter; TP- Total Phosphorus; TN- Total Nitrogen; TOC- Total Organic Carbon; SO_4^{-2}- sulphate; EC- electrical conductivity; DO- dissolved oxygen; BOD- biological oxygen demand; TDS- total dissolved solids; COD- chemical oxygen demand. Table 1 shows the (mean ± standard error) values for each physicochemical parameter for each season and station, compared with acceptable standards for aquaculture and domestic water supply. $^{a-c}$ means on the same row the different letter superscript are significantly different ($p<0.05$)

pH is a critical variable in aquatic ecosystems, influencing numerous biological and chemical processes. pH is notably sensitive to both acidification, which lowers pH, and eutrophication, which often increases pH (Flynn *et al.*, 2015).

Total Dissolved Solids (TDS), determined by evaporating water samples and drying the resultant residue to a constant weight at 103 – 105°C, exhibited seasonal fluctuations in Lake Asa. TDS concentrations ranged from 261 to 275 mg/L during the dry season and from 33.03 to 101.20 mg/L during the wet season. The highest TDS concentration was measured at the Dam Station during the dry season, while the lowest was recorded at the same station during the wet season. Across all sampling stations and seasons, TDS levels remained below the 500 mg/L threshold established by the US Environmental Protection Agency for optimal fish culture (Charkhabi and Sakizadeh, 2006).

Total phosphorus (TP) concentrations in Lake Asa exhibited marked seasonal variation, ranging from 1.00 to 1.45 mg/L during the dry season and 0.01 to 0.30 mg/L during the wet season. The highest and lowest TP concentrations were both observed at the Dam Station, with averages of 1.45 and 0.01 mg/L, respectively. Bhatnagar and Devi (2013) recommend an optimal range of 0.05 to 0.07 mg/L for productive fish farming, the concentrations observed in this study, though higher, fall within the broader range of 0.10 to 2.0 mg/L deemed suitable for aquaculture by Abedin *et al.* (2017). TP is a crucial nutrient for algal growth and plays a significant role in lake eutrophication. Potential sources of elevated TP in Lake Asa include surface water runoff, agricultural runoff, and washing activities. However, the values obtained at all stations complied with the levels reported by Abedin *et al.* (2017), indicating suitability for both fish culture and irrigation water supply. TP was selected for analysis over soluble reactive phosphorus due to the latter's lability and significant diurnal variability. TP concentrations can fluctuate due to various factors. Heavy rainfall can lead to temporary increases in TP as suspended particles and soluble forms are transported into the lake, or through sediment resuspension during windy conditions. Conversely, TP can also increase during dry periods due to phosphate release from sediments under plant beds, even under conditions of good or high ecological status.

Dissolved oxygen (DO) in Lake Asa ranged from 7.33 to 9.20 mg/L during the dry season and 7.30 to 9.30 mg/L during the wet season. These findings align with established ecological DO for lakes. Wetzel and Likens (2000) observed a correlation between higher DO concentrations and increased chlorophyll and water transparency, typically observed in drier periods. Conversely, lower chlorophyll concentrations are often associated with reduced DO levels. Furthermore, the influence of high flood events on DO concentrations, as reported by Araoye (2009), is consistent with the observed data. Increased turbidity resulting from flooding can decrease DO availability. In the context of aquaculture, Santhosh and Singh (2007) recommend a minimum DO level of 4 mg/L for fish culture. The DO values recorded in Lake Asa during this study period consistently exceeded this threshold, indicating suitable conditions for fish health.

Biochemical oxygen demand (BOD) in Lake Asa exhibited seasonal variation. During the dry season, BOD ranged from 6.36 to 11.30 mg/L; in the wet season, it ranged from 2.90 to 6.70 mg/L. All recorded BOD values fell within the 3 – 20 mg/L acceptable range for aquaculture (Boyd, 2003). However, it is important to note the more granular classification of water quality based on BOD: unpolluted water typically has a BOD below 1 mg/L, moderately polluted water exhibits BOD levels between 2 and 9 mg/L, and heavily polluted water has a BOD exceeding 10 mg/L (Adakole, 2000). In the present study, the majority of stations fell within the moderately polluted category. Notably, the Dam Station during the dry season registered BOD levels indicative of heavy pollution. BOD is a recognized indicator of pollution from sewage and industrial sources.

Chemical oxygen demand (COD) in Lake Asa exhibited seasonal variation. During the dry season, COD values ranged from 36.10 to 106.50 mg/L; in the wet season, they ranged from 35.10 to 228.50 mg/L. The Afon Station during the dry season and the Dam Station during the wet season had lower COD values (36.10 and 35.10 mg/L, respectively). These low values fall within

acceptable aquaculture and domestic water supply standards (Santhosh and Sing, 2007). Conversely, the remaining stations exhibited elevated COD levels, indicative of organic matter pollution, thus rendering them unsuitable for these purposes. COD, a measure of the oxygen required to chemically oxidize both biodegradable and non-biodegradable organic matter in water (Mahananda *et al.*, 2010), provides insight into the extent of sewage and industrial pollution. For optimal fish culture, COD levels should ideally remain below 50 mg/L (Santhosh and Singh, 2007).

Electrical conductivity (EC) in Lake Asa demonstrated seasonal variation. During the dry season, EC values ranged from 389 to 411 µS/cm, while in the wet season, they ranged from 66.5 to 201.46 µS/cm. The observed EC values of 101 – 800 µS/cm suggest that Lake Asa's water originates from base-rich peat or soil overlying calcareous rocks, consistent with the findings of Nykänen *et al.* (2005). This EC range is also indicative of a mesotrophic state, which typically supports a diverse array of aquatic organisms. EC serves as a useful proxy for assessing the degree of mineralization and salinity in water. While the recorded EC values are within the acceptable limits for aquaculture (1000 µS/cm) established by the Federal Environmental Protection Agency (FEPA, 1991), they exceed the recommended limit of 70 µS/cm for direct domestic water use (Odume *et al.*, 2024), thus rendering Lake Asa unsuitable for untreated water supply.

Sulphate concentrations in Lake Asa exhibited both spatial and seasonal variations. Concentrations ranged from 14.5 to 18.2 mg/L during the dry season and 7.3 to 71.8 mg/L during the wet season. All recorded sulphate levels were well below the acceptable standard of 250 mg/L. Furthermore, the sulphate concentrations observed at all locations in this study were lower than the tolerance limits established by both Nigerian standards (100 mg/L) (FEPA, 1991) and the World Health Organization (200 mg/L) (WHO, 2004). Therefore, the sulphate concentrations in Lake Asa are within acceptable limits for both aquaculture and domestic water supply.

Total nitrogen concentrations in Lake Asa water ranged from 0.68 to 0.84 mg/L during the dry season and 1.12 to 1.90 mg/L during the wet season. These concentrations exceed acceptable limits, rendering the lake water unsuitable for both aquaculture and direct domestic use (WHO, 2003). The elevated total nitrogen levels observed may be attributed to increased microbial activity, resulting in the decomposition of aquatic plants (e.g., lotus) and the excretion of waste products by aquatic animals. A likely contributing factor to the high nitrate-nitrogen concentrations is the leaching of excess fertilizers into shallow groundwater. This aligns with the findings of Bijay-Singh (2021), who reported that the application of substantial amounts of organic manure, inorganic fertilizers, and agrochemicals to crops can lead to elevated nitrate-nitrogen concentrations in surface and groundwater. While nitrogen is a vital nutrient, its bioavailable forms (primarily nitrate and ammonium) are highly labile and subject to fluctuations, particularly with infrequent sampling. Furthermore, nitrogen levels are readily influenced by anthropogenic activities, including catchment vegetation disturbance and atmospheric pollution.

Organic matter (OM) concentrations in Lake Asa varied seasonally, ranging from 22.7 to 25.4 mg/L during the dry season and 15.2 to 33.1 mg/L during the wet season. Based on the criteria established by BCMECCS (2019), these OM concentrations classify Lake Asa as moderately polluted. Furthermore, given that all recorded values exceed the 10 mg/L threshold, the lake water is deemed unsuitable for both aquaculture and direct domestic water supply.

Total organic carbon (TOC) concentrations in Lake Asa exhibited seasonal variation, ranging from 13.1 to 14.7 mg/L during the dry season and 8.8 to 19.2 mg/L during the wet season. Based on the criteria established by BCMECCS (2019), Lake Asa can be classified as moderately polluted due to TOC concentrations exceeding the 10 mg/L threshold, rendering the water unsuitable for both aquaculture and direct domestic use. The elevated TOC levels suggest that catchment runoff is influencing Lake Asa's biogeochemical nutrient and energy cycling, as previously observed (Heinen and McManus, 2004; Oni *et al.*, 2013).

Phytoplankton Structure and Diversity in Lake Asa: The phytoplankton community of Lake Asa comprised six taxonomic groups: Cyanophyta, Chlorophyta, Euglenophyta, Chrysophyta, Dinophyta, and Bacillariophyta (diatoms). A total of 37 taxa were identified, consisting of 13 Cyanophyta, 9 Chlorophyta, 5 Dinophyta, 5 Bacillariophyta, 3 Euglenophyta, and 2 Chrysophyta, representing an estimated population of 40,845 individuals. Cyanophyta dominated in both seasons, constituting 83.20% of the total phytoplankton count. Bacillariophyta (8.40%) and Dinophyta (4.20%) were more prevalent during the dry season, while Chlorophyta (2.70%) were present in both seasons. Euglenophyta (1.00%) were more common in the wet season, whereas Chrysophyta (0.41%) were rare in both seasons. A detailed spatial and temporal distribution and composition of the identified phytoplankton taxa is presented in Table 2. Within the Cyanophyta, *Anabaena* spp. and *Microcystis* spp. accounted for 73.00 and 11.00% of the seasonal Cyanophyta community in the dry season, respectively, and 22.10 and 14.20% in the wet season, respectively. *Cylindrospermopsis* spp. dominated the wet season Cyanophyta community, representing 52.40% of the total as observed by Poniewozik and Leonard (2022).

Variables of Importance in the Structural Analysis of the Lake Asa Phytoplankton Community: This analytical approach generates an ordination diagram where points represent both phytoplankton groups and sampling stations, while vectors depict environmental variables. This visualization effectively illustrates patterns of variation in community composition that are best explained by the measured environmental variables. Furthermore, it provides an approximation of the distribution centres of each taxon along the gradient of each environmental variable. Figures 2 and 3 summarize the relationships between the phytoplankton community and environmental variables (physicochemical) for the dry and wet seasons, respectively, along the established pollution gradient (Senouci *et al.,* 2023). Furthermore, Figure 2 showed that the first axis (Axis 1) has an eigenvalue of 0.08, explaining 92.96% of the variance. The dry season ordination biplot, with a trace value of 0.33 and a p-value of 0.08, suggests statistical significance at the conventional alpha level of 0.05. This indicates a distinct relationship between taxonomic group composition and the environmental gradient during the dry season (Ter Braak and Schaffers, 2004).

The Canonical Correspondence Analysis (CCA) ordination biplot presented in Figure 2 illustrates the distribution and occurrence of phytoplankton groups across the three sampling stations during the dry season, as influenced by environmental variables. Dissolved oxygen (DO) and chemical oxygen demand (COD) exhibited a positive correlation and influenced the occurrence of Cyanophyta at the Laduba Station. Electrical conductivity (EC), TDS, water transparency, and temperature were also strongly and positively correlated, influencing the distribution and occurrence of Chrysophyta, Euglenophyta, and Cyanophyta at the Dam Station. Total phosphorus (TP) and total nitrogen (TN) showed a negative correlation. TP weakly influenced the occurrence of Dinophyta and Bacillariophyta (diatoms) at the Afon Station, while strongly influencing Euglenophyta at the Dam Station. TN weakly influenced the distribution of Cyanophyta at the Laduba Station. Sulfate, pH, organic matter (OM), and total organic carbon (TOC) were positively correlated, exerting a strong influence on the distribution of Chlorophyta, Bacillariophyta, and Dinophyta at the Afon Station. The ordination presented in Figure 2 suggests that, during the dry season sampling period, TN and TP may have had limited influence on the overall distribution and occurrence of phytoplankton groups within Lake Asa (Ter Braak and Schaffers, 2004).

Figure 3 illustrates that the eigenvalue for Axis 1 is 0.67, accounting for 87.6% of the variance. The ordination biplot, with a trace value of 0.08 and a p-value of 0.32, indicates that the overall model lacks statistical significance at the conventional 0.05 alpha level. This suggests a potentially weak or indistinct relationship between taxonomic group composition and the environmental gradient during the wet season (Ter Braak and Schaffers, 2004).

Table 2: Taxonomic composition of phytoplankton and its spatial-temporal distribution in Lake Asa

Season	Nov-Feb (dry season)			Mar-Oct (wet season)		
Taxon/Station	**Dam**	**Laduba**	**Afon**	**Dam**	**Laduba**	**Afon**
Cyanophyta						
Oscillatoria spp.	+	+	+	+	+	++
Chlorococcus spp.	+	+	+	+	++	-
Stigonema spp.	+	-	+	-	-	-
Woronichinia spp.	++	+	+	-	+	+
Anabaena spp.	+++	+++	+++	+++	+++	+++
Aphanizomenon spp.	++	+	++	-	-	++
Aphanotheca spp.	++	++	++	+	++	+
Aphanocapsa spp.	+	++	+	+	-	+
Syechococcus spp.	+	+	+	+	+	+++
Gomphosphaeria spp.	++	+	-	-	++	+
Microcystis spp.	+++	+	+++	+++	++	+++
Merismopedia spp.	+	+	-	+	-	++
Cylindrospermopis spp.	-	-	-	++++	++	+
Chlorophyta						
Pandorina spp.	-	+	+	++	-	-
Gonium spp.	-	-	-	-	++	+
Ankistrodesmus spp.	-	-	+	++	+	+
Eudorina spp.	+	-	+	+	+	-
Sphaerocystis spp.	-	-	-	+	-	+
Volvox spp.	-	+++	++	+	-	++
Cosmarium spp.	-	+	-	-	-	-
Scenedesmus spp.	+	+	-	+	+	-
Staurastrum spp.	-	+	-	++	++	-
Euglenophyta						
Euglena spp.	+	-	+	++	+	++
Phacus spp.	+	+	+	+	+	-
Trachelomonas spp.	+	+	+	-	-	+
Chrysophyta						
Dinobryon spp.	+	+	-	-	-	+
Synura spp.	-	-	-	+	++	-
Dinophyta						
Dinophysis spp.	++	+	++	-	-	-
Akashiwo spp.	++	+	-	-	-	-
Gymnodinium spp.	-	+	+	+	+	-
Lingulodinium spp.	-	-	+	-	-	-
Ceratium spp.	+++	+++	+	++	+	+
Bacillariophyta						
Pseudonitzchia spp.	+++	+++	+++	-	++	-
Nitzchia spp.	++	+	++	+	-	+
Navicula spp.	-	-	-	-	+	++
Thalassiosira spp.	-	+	+	-	-	-
Tabellaria spp.	+	-	+	+	-	-

Keys:(-) absent; (R +) rare 0–100 ind.m^{-3}; (C ++) common 100–1000 ind.m^{-3}; (A +++) abundant 1000–10,000 ind.m^{-3}; (V ++++) very abundant > 10,000 ind.m^{-3}

During the wet season, Figure 3 illustrates the influence of environmental variables on phytoplankton group distribution and occurrence. Cyanophyta distribution was influenced by a suite of variables across all sampling stations. At the Afon Station, Euglenophyta occurrence was associated with a cluster of positively correlated variables: TDS, EC, sulfate, water temperature, and water transparency. TP, BOD, TDS, EC, and sulfate also exhibited positive correlations and influenced the occurrence of Bacillariophyta (diatoms), Chlorophyta and Chrysophyta. At the Dam Station, a group of positively correlated variables (TN, DO, OM, TOC, and pH) influenced Dinophyta distribution. As in the dry season, TN and TP showed a negative correlation in Opa Reservoir (Akindele and Adeniyi, 2013).

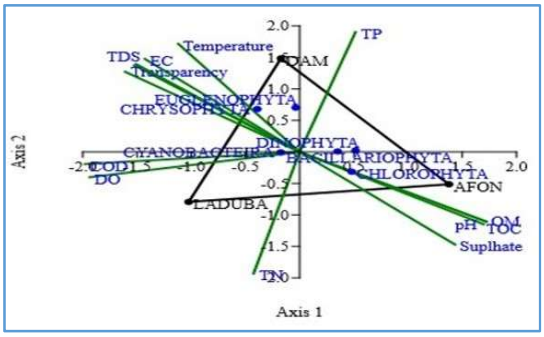


Figure 2: Phytoplankton community-environmental relationships (dry season) plotted in the ordination biplot of CCA analysis. *Phytoplankton groups represented with (•), stations with (•) and environmental variables (green lines pointing blue letters); Axis 1 is horizontal and Axis 2 is vertical*

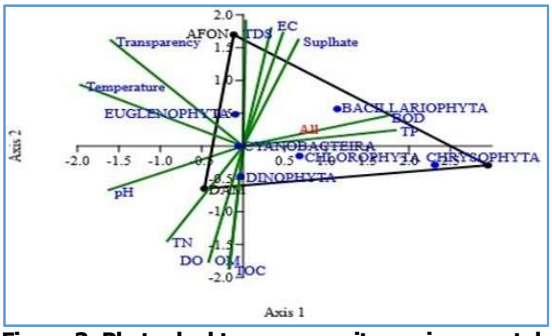


Figure 3: Phytoplankton community-environmental relationships (wet season) plotted in Ordination biplot of CCA analysis. *Phytoplankton groups represented with (•), stations with (•) and environmental variables (green lines pointing blue letters); Axis 1 is horizontal and axis 2 is vertical*

Across both seasons, water temperature and transparency were observed to influence the distribution of Euglenophyta. Total phosphorus (TP) and sulfate levels affected Bacillariophyta (diatom) occurrence. Organic matter (OM), pH, and total organic carbon (TOC) influenced Dinophyta distribution. Cyanophyta distribution was associated with COD, DO, TDS, EC, water temperature, and water transparency in both seasons. TDS and EC were found to influence Chrysophyta distribution, with sulfate and TP also contributing to Chrysophyta occurrence across both seasons (Ter Braak and Schaffers, 2004; Akindele and Adeniyi, 2013).

A point configuration based on differences between the stations according to the proportion of Bray-Curtis. Phytoplankton species composition in both seasons shows high similarity in taxa composition in stations L2, A2, A3 and D2. Whereas, significant differences were noted in stations D3, A2 and L3 as shown in Figure 4. Similarity in taxa composition of phytoplankton had been reported in Opa Reservoir (Akindele and Adeniyi, 2013).

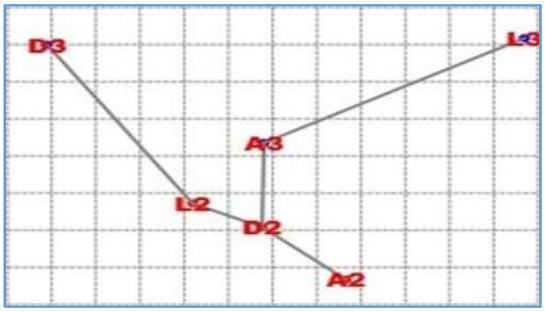


Figure 4: Non-metric Multidimensional Scaling (The stress value is 0.0%) *(Key- Station- D-Dam, L-Laduba, A-Afon, 2- Dry, 3-Wet)*

Phytoplankton Community Structure: Community structure is intrinsically linked to species diversity and abundance, with diversity serving as a key structural component (Table 3). The Shannon-Wiener Diversity Index (H') is a widely adopted metric in environmental monitoring. According to established criteria (Alprol *et al.*, 2021), water bodies exhibiting an algal Shannon-Wiener diversity index of less than 1 are categorized as heavily polluted, those between 1 and 3 as moderately polluted, and those exceeding 3 as indicative of clean water. Based on its phytoplankton H' index score, Lake Asa is classified as heavily polluted. Observed pollution sources include refuse input from adjacent water-related businesses, aquaculture activities within the catchment, and potential nutrient enrichment, possibly attributable to the lake's geological history.

The Margalef index for Lake Asa indicates moderate phytoplankton taxa richness across all stations and seasons. Similarly, the dominance index suggests moderate phytoplankton diversity. Simpson (1949) diversity index (1-D) also reflects a moderate degree of diversity among phytoplankton taxa, except Laduba and Afon Stations during the wet season, which exhibited lower diversity. The Shannon-Wiener index (H), however, classifies Lake Asa as highly to heavily polluted across all seasons and sampling stations, due to the observed low phytoplankton community diversity.

Table 3: Diversity indices of phytoplankton in Lake Asa

Season	Dry			Wet		
Index/Station	**Dam**	**Laduba**	**Afon**	**Dam**	**Laduba**	**Afon**
Margalef	0.57	0.56	0.58	0.53	0.64	0.58
Shannon Wiener *H*	0.88	0.62	0.98	0.26	0.84	0.37
Simpson	0.45	0.30	0.54	0.10	0.40	0.15
Equitability	0.49	0.34	0.55	0.14	0.47	0.21
Evenness *J*	0.40	0.31	0.44	0.22	0.39	0.24
Dominance D	0.55	0.70	0.46	0.90	0.60	0.85
Individuals	6346	7669	5711	13399	2338	5518

H - >4.5; clean, 4.5-3; slightly polluted, 3-2; moderately polluted, 2-1; heavily polluted, <1; highly polluted. J - 0.8; clean, 0.8-0.5; slightly polluted, 0.5-0.3; moderately polluted, 0.3-0.1; heavily polluted, <0.1; highly polluted

Pielou (1975) evenness index (J) further suggests moderate pollution of the lake, indicative of the proliferation of a limited number of species and an uneven distribution of phytoplankton community abundance across stations and seasons as earlier reported for most tropical lakes and Opa Reservoir (Okpiliya, 2012; Akindele and Adeniyi, 2013).

The structure and dynamics of phytoplankton communities in freshwater ecosystems are governed by the complex interactions between phytoplankton and the chemical, physical, and biological characteristics of their environment (Naselli-Flores, 2000). These interactions influence a range of processes, from primary productivity rates to the adaptive strategies employed by phytoplankton to contend with water movement and nutrient availability. Temporal and spatial variations in phytoplankton composition, as observed in Lake Asa, are well-documented phenomena in tropical and subtropical systems (Huszar *et al.*, 2000). This study investigates the influence of abiotic factors on the phytoplankton community of Lake Asa, Ilorin, North Central Nigeria. Specifically, water temperature, transparency, concentrations of total nitrogen and phosphorus, electrical conductivity, total organic matter, dissolved oxygen, chemical oxygen demand, and pH were identified as significant variables associated with variations in the Lake Asa phytoplankton community.

This study revealed significant seasonal differences in the biomass of phytoplankton taxonomic groups within Lake Asa. These seasonal biomass patterns were interpreted by considering variations in both taxonomic composition and the life history traits of dominant species. This investigation provides novel insights into the seasonal dynamics of phytoplankton biomass in Lake Asa, Ilorin, Nigeria. Comparison with other regional water bodies indicated that Lake Asa exhibits a notably high phytoplankton biomass. The phytoplankton community in the study area was dominated by Cyanophyta, specifically *Anabaena* sp., *Microcystis* spp., and *Cylindrospermopsis* spp. The dominance of *Cylindrospermopsis* and *Anabaena* spp., as observed in this study, has been previously associated with phosphorus-rich lacustrine environments (Reynolds, 2006), a finding consistent with the total phosphorus concentrations measured in Lake Asa. Many Cyanophyta species possess adaptations that facilitate survival in diverse and often extreme habitats. These adaptations include gas vacuoles for buoyancy regulation, akinetes (dormant resting stages), and heterocysts (specialized nitrogen-fixing cells), which are advantageous in environments with low ammonia and nitrate levels. However, it is important to note that not all cyanobacterial taxa possess these adaptive features.

The resident phytoplankton communities of Lake Asa have adapted not only to water level fluctuations but, more importantly, to the prevailing abiotic variables that constitute the primary driving forces within the ecosystem. These abiotic factors, in conjunction with the inherent biological capabilities of the phytoplankton, can create significant ecological patterns by inducing alterations in local biological communities (Crossetti *et al.*, 2007). Furthermore, wind-driven hydrodynamics can lead to substantial changes in the entire phytoplankton assemblage (Cardoso and Motta Marques, 2003; 2004). Consequently, these systems are often characterized by the dominance of Cyanophyta

and microplanktonic diatoms. Diatoms, being dependent on water column mixing, are well-adapted to tolerate the constant turbulence induced by wind. Conversely, Cyanophyta blooms can develop following periods of wind-induced disturbance or during periods of calm and increased water column stability (Becker and Motta-Marques, 2004; Becker *et al.*, 2009). This observation is consistent with the findings of numerous other studies that have documented the prevalent abundance of Cyanophyta in subtropical lakes (They *et al.*, 2013).

Phytoplankton nutrient acquisition relies on the availability of soluble compounds in the external medium, specifically as diffusible ions or non-dissociated small molecules such as silicic acid (Padisák, 2003). Numerous studies have investigated the influence of nutrient dynamics across the trophic spectrum on phytoplankton community organization (Reynolds *et al.*, 2000; Rojo *et al.*, 2000), highlighting the importance of nutrients in structuring these communities. Phosphorus limitation thresholds for algae typically fall within the nanomolar range, although some research has documented the depletion of soluble reactive phosphorus at concentrations below 10^{-8} M (Reynolds, 2006). This degree of phosphorus limitation is unlikely in Lake Asa, given the observed total phosphorus concentrations ranging from approximately 0.01 to 1.45 mg/L, which are well above this limiting threshold (They *et al.*, 2010; They *et al.*, 2013). Similarly, phytoplankton generally exhibit the capacity for active uptake of dissolved inorganic nitrogen from external concentrations as low as 0.2 – 0.3 mg/L (Reynolds, 2006). In Lake Asa, total nitrogen concentrations, ranging from approximately 0.68 to 1.9 mg/L, also exceed these potentially limiting concentrations (They *et al.*, 2014).

In contrast to the trends observed with other variables, the dominance of Cyanophyta (specifically *Anabaena* spp., *Microcystis* spp., and *Cylindrospermopsis* spp.) was strongly associated with the warm, mixed water column conditions and nutrient limitation observed in Lake Asa (Reynolds *et al.,* 2002). Certain Cyanophyta species are known to produce toxins, which can lead to episodes of severe taste and odour problems in the lake water. The extensive macrophyte coverage in the littoral zone of Lake Asa, along with the aggregation of floating macrophytes in various sections of its open waters, may further contribute to the observed dominance and proliferation of Cyanophyta across seasons and sampling stations. Furthermore, the phytoplankton community in Lake Asa exhibits a high degree of spatial patchiness in its distribution and assemblage.

The evidence presented suggests that the localized distribution of Cyanophyta in Lake Asa can be attributed to the association between Cyanophyta and macrophytes, as well as several key environmental factors, including water temperature, transparency, conductivity, dissolved oxygen, and biochemical oxygen demand. Seasonal trends, conversely, appear to be primarily driven by rainfall patterns and water level fluctuations. While this study may not have exhaustively explored all factors influencing the local distribution of phytoplankton in Lake Asa, it provides essential baseline data for the development of future research programs.

Conclusion: The present study revealed a pattern of high abundance in certain phytoplankton species within Lake Asa, coupled with low species diversity and richness. This low phytoplankton diversity may negatively impact zooplankton survival, with cascading effects on other trophic relationships within the Lake Asa ecosystem. The observed spatial and temporal variations in phytoplankton abundance and distribution were correlated with environmental variables, and diversity indices classified Lake Asa as exhibiting a mesotrophic-eutrophic condition, reflecting the elevated nutrient concentrations measured in the lake. This eutrophic state necessitates the implementation of restoration programs to protect and conserve the lake's ecological resources. Public awareness campaigns and educational programs are recommended to inform the local populace about the appropriate use of the lake's water resources. Macrophyte removal from the Lake Asa system is also warranted. Furthermore, the utilization of phytoplankton as bioindicators of trophic status and environmental parameters could prove valuable in future assessments aimed at evaluating the efficacy of these

restoration efforts in improving the lake's ecological condition.

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