Journal of Forestry Research and Management. Vol. 21(3).52-62; 2024, ISSN 0189-8418

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ENVIRONMENTAL DRIVERS OF PHYTOPLANKTON ABUNDANCE AND DISTRIBUTION IN A FRESH WATER ECOSYSTEM

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ABSTRACT

The distribution of phytoplankton in an aquatic ecosystem is dependent on the environmental conditions. Likewise, the quality and quantity of phytoplankton in an environment is used to determine its pollution status. This study investigates the distribution and abundance of phytoplankton in Ikere-gorge, with a focus on understanding the influence of various water quality parameters. Monthly phytoplankton samples were randomly collected from four out of twelve fishing villages in Ikere-gorge with the aid of plankton net from January 2017 to December 2018 and analyzed using canonical correspondence analysis (CCA) to examine the relationships between phytoplankton genera and environmental variables. A total of 55 phytoplankton genera were identified, with *Microcystis*, *Gloeotrichia*, and *Calothrix* being the most abundant. The CCA revealed that water quality parameters such as temperature, dissolved oxygen, pH, conductivity, and nutrient concentrations significantly affect phytoplankton distribution and abundance. Specifically, distinct phytoplankton communities were found to be associated with different environmental conditions, indicating that abiotic factors play a critical role in shaping the structure of phytoplankton populations in Ikere-gorge. These findings highlight the importance of monitoring water quality to ensure the ecological health of freshwater ecosystems. The study provides valuable insights into the complex interactions between phytoplankton and their environment, emphasizing the need for ongoing research to develop effective strategies for managing aquatic biodiversity.

Keywords: Phytoplankton, Canonical correspondence analysis, Environmental variables

Introduction

Canonical Correspondence Analysis (CCA) is a valuable tool in aquatic studies, particularly for examining fish, phytoplankton, zooplankton, and other aquatic organisms. It enables the estimation and statistical testing of the impacts of environmental and explanatory variables on biological communities, even when these effects are not immediately apparent (Ter Braak and Verdonschot, 1995). As a multivariate extension of weighted averaging ordination, CCA is effective for arranging species along environmental gradients (Ter Braak, 1987).

Phytoplankton, the microscopic plant life found in aquatic environments, play a crucial role as primary producers by synthesizing the basic food necessary for nearly all aquatic organisms. They are fundamental to the food chain in aquatic ecosystems, acting as energy transducers that convert solar energy into chemical energy (Basu and Mackey, 2018). This energy is then passed on to zooplankton and larval forms of crustaceans, mollusks, and finfish. Key components of phytoplankton include diatoms (Bacillariophyceae), dinoflagellates (Dinophyceae), blue-green algae (Cyanophyceae), phytoflagellates (Xanthophyceae, Chrysophyceae, Haptophyceae, Cryptophyceae), and nannoplankters (such as *Chlorella* and *Nannochloropsis*). Silicoflagellates and coccolithophores are also considered part of the phytoplankton community. The abundance of these phytoplankton is a critical determinant of the productivity of aquatic environments (Narasimha and Bernarjee, 2013; Jakhar, 2013; Gopinathan *et al*., 2018).

Phytoplankton are primarily photosynthetic organisms and serve as the initial link in the aquatic food chain. They are categorized under the class Algae, which, in addition to chlorophylls, contain other distinctive pigments. Most phytoplankton species are unicellular, though some exhibit colonial and filamentous forms. While the majority of phytoplankton are harmless, a few can be detrimental to other aquatic organisms. The quality of the water is directly related to phytoplankton production, growth, and diversity (Schabhuttl *et al*., 2013). Different phytoplankton species have varying preferences and tolerances for water quality parameters, which influence their distribution and abundance (Rusanov *et al*., 2012). This study aims to evaluate the impacts of water quality parameters on the distribution and abundance of phytoplankton in Ikere-gorge.

Materials and Methods

Ikere-gorge (Figure 1) is a 565 million cubic meters (mcm) multipurpose dam located at Ikere village, between longitudes 8°10' and 8°20' N and latitudes 3°40' and 3°50' E. It is about 28 km, North East of Iseyin in Oyo State. Ikere-gorge has 12 fish landing sites or fishing villages and four fishing villages were randomly selected for this study. The selected villages are Asamu (Site A), Agatu (Site B), Spillway (Site C) and Irawote (Site D). The selected sampling sites were sampled monthly for a period of twenty-four months (January 2017 to December 2018).

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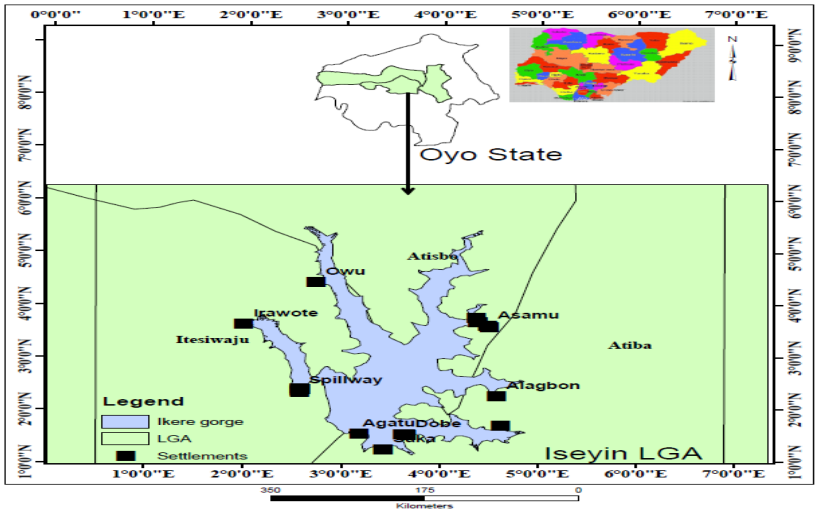


Figure 1: Map of Ikere-gorge dam (showing some fishing villages), Oyo State, Nigeria (Ajagbe *et al.* 2021)

Water sampling techniques

Water samples were collected with water sampling bottles and some parameters were determined *in-situ*. Air temperature was measured in degree Celsius (ºC) *in-situ* with mercury – in – glass thermometer. Water temperature (ºC), pH, electrical conductivity (µS/cm) and total dissolved solids (mg/l) were also measured *in-situ* with a combined probe (Hanna, Model HI 98129). Dissolved oxygen samples were fixed *in-situ* with 2 ml each of manganese sulfate, alkali-iodide azide and concentrated sulfuric acid. In the laboratory Azide-Winkler titration method was used to analyze dissolved oxygen. Water transparency was determined by the use of a Secchi disc, with a method described by Michaud, (1991) and Offem *et al.* (2011). Titrimetric method was used to analyse total alkalinity (APHA, 1989). Vanado-molybido-phosphoric acid colorimetric method was used to measure the concentration of phosphate (mg/l) while solution salicylate (colorimetric) method was used to measure the concentration of nitrates (mg/l) in the water samples (Odulate, 2010).

Phytoplankton sampling

Phytoplankton samples were collected monthly between January 2017 and December 2018, during the hours of 11:00 am and 02:00 pm. A plankton net with a 25 cm diameter and a 50 µm mesh size was utilized for sample collection, as most microplankton, such as protozoa and rotifers, range between 20 – 200 µm in size (Shiel, 1995). The net was towed horizontally for a distance of 100 meters in the water column. The collected phytoplankton samples were concentrated and transferred into 50 ml plastic bottles, then preserved with 4% formalin. Each sample was carefully labeled and recorded before being transported to the Biotechnology Centre at the Forestry Research Institute of Nigeria (FRIN), Ibadan, for further analysis.

In the laboratory, phytoplankton species were identified using a Celestron LCD digital microscope II, operating at magnifications

between 100x and 400x. Identification was facilitated using several identification keys, including those by Needham and Needham (1962), Belcher and Swale (1978), Findlay and Kling (1979), Huynh and Serediak (2006), Taylor *et al*. (2007), Janse van Vuuren *et al*. (2006), and Suthers and Rissik (2009). Images of the identified phytoplankton were captured, recorded, and stored for further analysis. The Lackey drop count method (Lackey, 1938) was employed for counting phytoplankton cells, with 28 drops of the concentrated sample corresponding to 1 ml.

Relative Abundance

It is the proportion contribution of individual aquatic species to the total population in the sample. It was computed with the formula:

$$RA = \frac{S_i}{N \times 100} \quad \text{---------- (1)}$$

Where:

RA – Relative Abundance
Si – Population of individual species
N – Total population of species

Data analysis

The analysis variables included phytoplankton genera, water quality parameters, and sampling sites. Phytoplankton genera with a relative abundance of less than 0.15 were excluded from the analysis. Multivariate analysis was conducted using the Palaeontological Statistics (PAST) software package (Hammer *et al.*, 2001; Odulate *et al*., 2014).A Monte Carlo permutation test was used to assess the statistical significance of the effects of water quality parameters on phytoplankton abundance in Ikere-gorge.

Results and Discussion

This study identified 55 genera of phytoplankton in Ikere-gorge (Table 1). The most dominant genus was *Microcystis* (6.7%), followed by *Gloeotrichia* (3.8%) and *Calothrix* (3.3%). For the multivariate analysis, only the 28 genera with a relative abundance greater than 1.5% were included. In a similar study, Yana *et al*. (2012) identified 34 phytoplankton genera during an autumn survey in the Xiaoqing River estuary, including 32 genera in the analysis based on their abundance and frequency. The hierarchical classification grouped the phytoplankton genera into three distinct clusters at a Bray-Curtis similarity index of 0.74 using UPGMA. This clustering occurred at the point of highest homogeneity. The clusters formed included *Microcystis spp.*, *Crucigenia spp*., and *Pleodorina spp.* (Figure 2) with genera showing similar relative abundances clustering together. This finding contrasts with Abdul *et al*. (2015), who reported five distinct groups. The environmental variables used in the analysis was presented in Table 2.

The triplot diagram illustrates the distribution of phytoplankton species as scattered points, with water quality parameters represented by arrows and the sampling sites clearly marked (Figure 3). This approach aligns with Ter Braak and Verdonschot's (1995) report that canonical correspondence analysis diagrams typically feature points for species, sites, and qualitative environmental variables, alongside arrows for quantitative environmental variables.

Table 1: Assemblage of phytoplankton in Ikere- gorge, Iseyin, Oyo State, Nigeria

Phytoplankton Species	CODE	Mean	%RA
Microcystis	Micro	5516	6.68
Gloeotrichia	Gloe	3122	3.78
Calothrix	Cal	2828	3.43
Aulacoseira	Aul	2709	3.28
Oscillatoria	Osci	2688	3.26
Volvox	Vol	2646	3.21
Gonatozygon	Gon	2597	3.15
Synedra	Syn	2492	3.02
Spirogyra	Spir	2366	2.87
Chroococcus	Chro	2261	2.74
Oocystis	Ooc	2247	2.72
Pleodorina	Pleo	1974	2.39
Drapanaldia	Drap	1519	1.84
Chlamydomonas	Chla	1491	1.81
Oedogonium	Oed	1484	1.80
Dinophysis	Dino	1386	1.68
Crucigenia	Cruc	1379	1.67
Stigeoclonium	Stig	1351	1.64
Cyclotella	Cyc	1330	1.61
Hydrodictyon	Hyd	1323	1.60
Mougeotia	Mou	1316	1.59
Heamatococcus	Hea	1295	1.57
Mesotaenium	Mes	1295	1.57
Merismopedia	Mer	1281	1.55
Fragillaria	Frag	1274	1.54
Chromulina	Chr	1260	1.53
Closterium	Clos	1246	1.51
Dinobryon	Din	1239	1.50
Cocconeis	Coc	1225	1.48
Surirella	Sur	1211	1.47
Melosira	Melo	1204	1.46
Microspora	Mic	1197	1.45
Encyonema	Ency	1190	1.44
Ulothrix	Ulo	1183	1.43
Characium	Cha	1176	1.43
Navicula	Nav	1169	1.42

Nitzchia	Nitz	1162	1.41
Lemanea	Lema	1162	1.41
Tribonema	Trib	1148	1.39
Frustulia	Frus	1141	1.38
Vauchena	Vau	1099	1.33
Pleurotaenium	Pleu	1050	1.27
Pinularia	Pin	1036	1.26
Palmodictyon	Pal	1022	1.24
Germirella	Ger	1001	1.21
Cryptomonas	Cry	994	1.20
Ankistrodesmus	Ank	980	1.19
Diatoma	Dia	959	1.16
Bulbochaete	Bul	889	1.08
Ochroomonas	Och	805	0.98
Aphanocapsa	Aph	770	0.93
Bacillaria	Baci	749	0.91
Gomphonesis	Gom	749	0.91
Tetraedron	Tet	721	0.87
Rhopalodia	Rho	630	0.76
Total		82537	100

* Percentage relative abundance in parenthesis

Table 2: Mean monthly water quality parameters of Ikere-gorge, Oyo State, Nigeria

Parameters	**Values**
Air Temperature (°C)	27.46±1.82
Water temperature (°C)	28.14±1.57
pH	6.50±0.63
Transparency (m)	1.34±0.12
Dissolved oxygen (mg/L)	5.93±0.29
Conductivity (µS/cm)	130.59±7.59
Total dissolved solids (mg/L)	67.67±4.37
Total hardness (mg/L)	56.70±15.76
Total alkalinity (mg/L)	58.97±9.53
Phosphate (mg/L)	2.22±0.67
Nitrate (mg/L)	2.90±1.23

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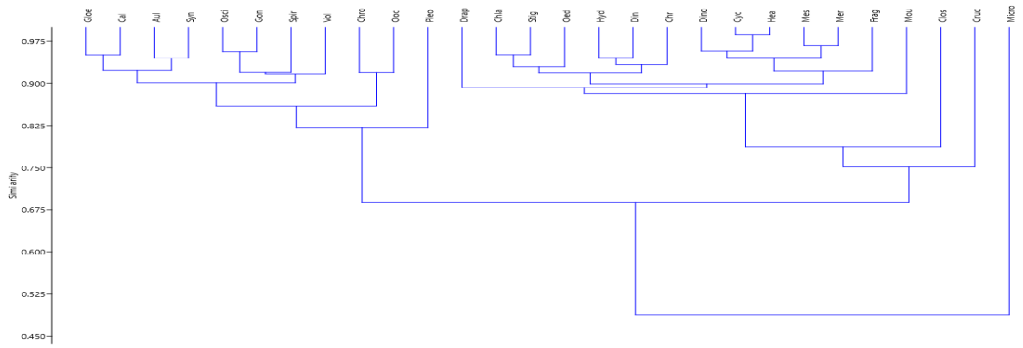


Figure 2: Hierarchical clustering of phytoplankton species in Ikere-gorge, Oyo State, Nigeria

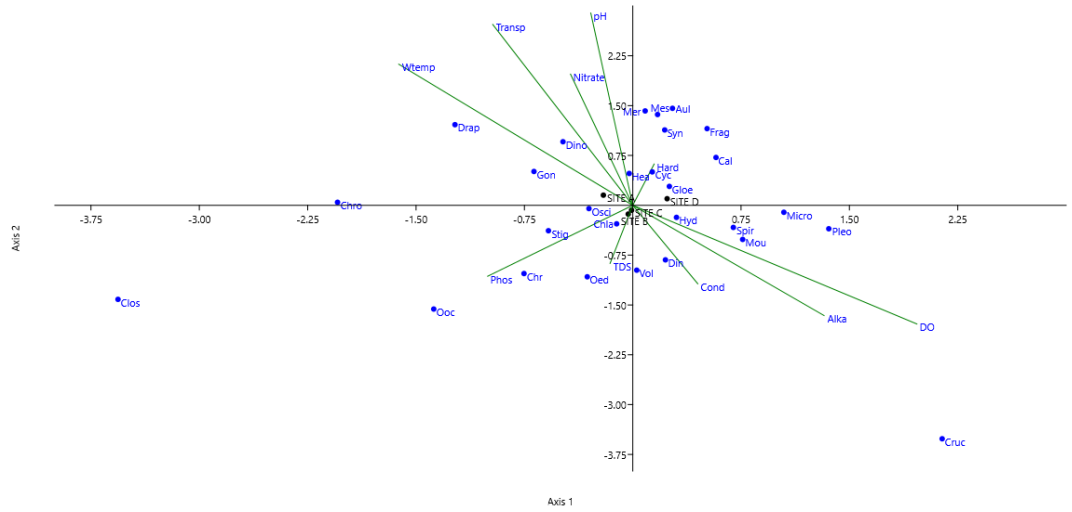


Figure 3: Triplot diagram of canonical correspondence analysis (CCA) of phytoplankton species in Ikere-gorge, Oyo State, Nigeria

Axes 1 and 2 of the canonical correspondence analysis explained 87.45% of the variance in phytoplankton species abundance in Ikere-gorge, with Axis 1 accounting for 54.38% (Eigen value: 0.0223) and Axis 2 accounting for 33.07% (Eigen value: 0.0136). Axis 3 explained an additional 12.54% of the unexplained variance (Eigen value: 0.0051). Given that the variance of the eigenvectors exceeded 40% of the total variance, these results are considered both valid and significant. Similar findings have been reported in other studies; for instance, Li *et al*. (2017) found that the first two axes were sufficient to reflect the relationship between biological and environmental factors. Gast *et al*. (2014) reported that axes 1 and 2 explained 97.4% of the variability in biotic data, indicating a strong correlation between phytoplankton species density and abiotic

variables in the Mundaú reservoir, Brazil. Çelekli *et al.* (2014) also reported that the first two axes explained 91.2% of the correlation between phytoplankton species and environmental variables.

The analysis established relationships between phytoplankton genera and water quality parameters in Ikere-gorge, demonstrating that different environmental variables influence the distribution and abundance of various phytoplankton genera. These relationships are bi-directional; certain environmental factors may either enhance or inhibit the abundance of specific phytoplankton genera. This observation is consistent with Kar *et al.* (2018), who noted that species ordination against environmental factors enables predictions of species-specific relationships to one or more environmental variables. The Monte Carlo permutation test confirmed that water quality significantly affects phytoplankton abundance in Ikere-gorge, corroborating Niyoyitungiye *et al.* (2020), who reported that the abundance and proliferation of phytoplankton species are influenced by the concentration of physico-chemical parameters.

Phytoplankton species with a relative abundance of less than 1.5% were excluded from the triplot diagram, which displays phytoplankton species at the sites of their highest relative abundance. In the triplot, species distribution is indicated by their chi-square distances. Site D, located in the first quadrant of the triplot diagram, showed higher abundances of *Mesotaenium spp.*, *Merismopedia spp.*, *Fragillaria spp.*, *Aulacoseira spp.*, *Calothrix spp.*, *Gloeotrichia spp.*, and *Cyclotella spp.* compared to other sites. These species were positively influenced by total hardness, particularly *Cyclotella spp.*

Sites B and C, located in the third quadrant of the triplot diagram, showed higher abundances of *Oscillatoria spp.*, *Chlamydomonas spp.*, *Oedogonium spp.*, *Stigeoclonium spp.*, *Chromulina spp.*, *Oocystis spp.*, and *Closterium spp.* than other sites. In thisthirdquadrant, phosphate and total dissolved solids (TDS) positively influenced the abundance of these phytoplankton species, with TDS having a more substantial effect on *Oedogonium spp.* and *Chlamydomonas spp.*, while phosphate had a more significant impact on *Chlamydomonas spp.*, *Oscillatoria spp.*, *Stigeoclonium spp.*, and *Chromulina spp.*

Although no site was located in the second quadrant, sites D in the first quadrant and sites B and C in the third quadrant were positioned near this quadrant, suggesting that the species found there could also be found among these sites. The phytoplankton species located in this quadrant included *Hydrodictyon spp.*, *Spirogyra spp.*, *Mougeotia spp.*, *Microcystis spp.*, *Pleodorina spp.*, *Dinobryon spp.*, and *Volvox spp.* The triplot diagram indicated that dissolved oxygen, alkalinity, and electrical conductivity positively influenced the abundance of these species, with dissolved oxygen having the most significant positive impact, as indicated by the longest vector.

Site A, located in the fourth quadrant of the triplot diagram, exhibited higher abundances of *Heamatococcus spp.*, *Dinophysis spp.*, *Gonatozygon spp.*, *Drapanaldia spp.*, and *Chroococcus spp.* The abundance of these species was positively influenced by water temperature, transparency, pH, and nitrate. Environmental variables significantly influence the distribution and abundance of

phytoplankton. This finding is consistent with Çelekli *et al.* (2014), who reported that multiple environmental variables, such as dissolved oxygen, temperature, conductivity, pH, and redox potential, play crucial roles in phytoplankton species distribution in an artificial pond. Species with similar environmental requirements tended to group together within each site and axis, supporting the observation by Ter Braak and Verdonschot (1995) that species in close proximity are likely to have similar distributions across sites, whereas those that are farther apart are expected to differ.

The 999-point random data set generated by random permutation resulted in a p-value of 0.04, which is less than the significance level alpha = 0.05 ($P < 0.05$). This indicates that water quality significantly affects the abundance of phytoplankton species in Ikere-gorge. Therefore, the null hypothesis was rejected, and it was concluded that the abundance of phytoplankton species is not randomly distributed but significantly correlated with water quality parameters.

Conclusion

Based on the findings of this study, it can be concluded that the distribution and abundance of phytoplankton in Ikere-gorge are significantly influenced by various environmental factors, such as water temperature, dissolved oxygen, pH, conductivity, and nutrient levels. The use of canonical correspondence analysis effectively demonstrated the relationships between phytoplankton species and these water quality parameters, highlighting the importance of abiotic factors in shaping phytoplankton communities.

The study also identified specific phytoplankton genera that are closely associated with particular environmental conditions, suggesting that changes in these conditions could significantly impact the composition of phytoplankton communities in the gorge. Overall, these findings underscore the need for continuous monitoring and management of water quality to maintain the ecological health of aquatic systems like Ikere-gorge. Further research is recommended to explore the long-term impacts of environmental changes on phytoplankton dynamics and to develop strategies for preserving biodiversity in freshwater ecosystems.

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