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Assessment of Surface Water Quality using Phytoplankton as Base-line Indicator Organisms in Ilorin, Kwara State, Nigeria

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Abstract

Timely and accurate water quality monitoring is crucial to ensure their sustainable use and safeguard public health. Therefore, this study assessed surface water quality in Mubo River (SP1) and Sobi Dam (SP2) in Ilorin, using phytoplankton as base-line indicator organisms. Water samples were collected on July 20th (rain season) and December 20th (dry season), 2023, at 0.3 meters from the mid-water column. The physicochemical parameters of the water samples were determined using standard methods. The standard microscopic techniques were used to enumerate and identify phytoplankton genera. The findings showed that the pH and DO (mg/l) levels were within the permissible limit stipulated by the National Environmental Standard and Regulation Enforcement Agency for Surface Water in Nigeria (NESREA). The BOD (mg/l) and COD (mg/l) levels were above the permissible limit for SP1 for both seasons. The 8 genera of pollution-tolerant phytoplankton recorded were Cyclotella, Chlorella, Closterium, Chlamydomonas, Micractinium, Microcystis, Euglena, and Phacus, with Chlorella having the highest abundance percentage in all the sampling sites. The Shannon diversity indices values indicate lower phytoplankton species diversity (H ≤ 1.99) in all the water samples. The Palmer's pollution index (PPI) scores ranged from 14 to 18 in the sampling sites. Palmer's index suggests likely high organic pollution in Mubo Rivers' in both sampling periods. A notable high level of organic pollution was recorded in Sobi Dam only during the rainy season. The relatively high turbidity, BOD (mg/l), and COD (mg/l) values support the index pollution scores and confirm the suitability of phytoplankton as baseline indicators for organic pollution assessment in surface water.

Keywords: Phytoplankton, Surface water, Palmer's index, Pollution-tolerant, Chlorella

INTRODUCTION

Surface waters, like rivers, lakes, and streams, are important components of the environment, supporting ecosystem functioning, human communities, vital economic activities, and environmental sustainability. However, these invaluable resources are increasingly threatened by various forms of pollution and environmental degradation (Aborisade *et al.*, 2023). Assessing the quality of water systems in a timely and accurate manner is crucial for ensuring their sustainable use and safeguarding public health (Onu *et al.*, 2023). Assessing surface water quality using phytoplankton as baseline indicators could provide a rapid and standard technique crucial for environmental monitoring and management (Nguyen and Huynh, 2023).

Phytoplankton are an ecological group of microalgae adapted to live in the well-illuminated surface part of the aquatic environment (Tambaru *et al.*, 2021; Naselli-Flores and Padisak, 2023). They are oxygenic photosynthetic organisms and play a fundamental role in aquatic ecosystems (Enawgaw and Wagaw, 2023). They are the primary producers and facilitate the process of carbon fixation through photosynthesis, thereby serving as primary energy sources within aquatic food ecosystems (Okere *et al.*, 2020). The sensitivity of phytoplankton to environmental changes makes them ideal bioindicators for monitoring water quality (Gabyshev *et al.*, 2022). Likewise, phytoplankton responds rapidly to nutrient level fluctuation, pH, temperature, and other environmental factors (Filiz *et al.*, 2020). Their characteristically short life cycles and rapid population response to environmental changes could provide timely insights into water quality variations. Their ubiquitous nature also offers comprehensive coverage for monitoring water quality across diverse ecosystems (Grob *et al.*, 2021). With numerous species exhibiting distinct features, their presence and abundance can reveal specific pollutants or environmental stresses (Okoye and Ogbebor, 2023).

Water quality assessment involves the evaluation of physicochemical parameters (inorganic nutrients, organic pollutants, heavy metals, acidity, and salinity) in water samples (Boudeffa *et al.*, 2020; Roy *et al.*, 2021). While regular evaluation of water quality based on physicochemical characteristics is preferable, biological monitoring that uses phytoplankton evaluation can offer a quicker, more reliable, and cost-effective method for pollution monitoring in aquatic environments. It can reflect the overall quality of water and offer direct insights into the ecological effects of environmental conditions on aquatic life.

Water quality monitoring is important because of the link between the overall quality of water and people's health (Luvhimbi *et al.*, 2022). Maintaining high-quality water is a global necessity. Contaminants such as hazardous chemicals and pathogenic microorganisms can cause waterborne illnesses, emphasizing the importance of protecting water sources and maintaining effective system monitoring (Nguyen and Huynh, 2023).

The comprehensive evaluation of phytoplankton could serve as an indispensable tool for evaluating water quality. Evaluating the community composition of phytoplankton may provide clear insights into water pollution levels, their impacts on aquatic communities, and the resilience of aquatic ecosystems. The initial attempt to utilize the phytoplankton species for water pollution assessment was made by Palmer (Salem *et al.*, 2017; Ray *et al.*, 2023). Subsequently, along with other indices, Palmer pollution indices are being used to monitor organic and inorganic pollution because it is thought to be a rapid, dependable, and cost-effective method of evaluating pollution levels in aquatic ecosystems (Labib *et al.*, 2023).

Employing phytoplankton as reference indicators to assess surface water quality represents a multifaceted approach essential for preserving aquatic ecosystems, protecting public health, and promoting sustainable resource management (Enawgaw and Wagaw, 2023). Evaluating surface water quality using phytoplankton can provide a swift and cost-effective tool to safeguard our water resources. By integrating phytoplankton analysis with other water quality parameters and adhering to rigorous scientific methodologies, a holistic and comprehensive understanding of the health of aquatic ecosystems can be attained. Therefore, this study assesses surface water quality using phytoplankton as baseline indicator organisms.

MATERIALS AND METHODS

Study Site

The selected surface waters used for the study were Mubo River and Sobi Dam. Mubo River is a part of Asa River that flows through Royal Valley Estate and lies within the latitude 8° 30' North and longitude 4° 34' East (Aborisade *et al.*, 2023). While the Sobi Dam is located on River Moro and lies within a latitude 9º 58' North and longitude 8° 25' East (Ogunkunle *et al.*, 2016).

Water Samples Analysis

Water samples were aseptically collected from the mid-water column at a depth of 0.3m below the water surface. The samples were collected into 1000 ml screwed cap amber-colored sampling bottles and immediately transported to the laboratory for analysis. The water samples were collected on July 20th and December 20th, 2023, to account for the wet and dry season periods of the year. Three samples each were collected from the sampling point, making a total of 12 samples for the sampling period.

The dissolved oxygen (DO) and the pH variables of the samples were determined on-site with a water multiparameter analyzer (Model YSI-Pro1020). The biological oxygen demand (BOD) was evaluated from the differences in the first-day DO value and the fifth-day DO (DO_1 - DO_5) values (Aborisade *et al.*, 2023). The chemical oxygen demand (COD) was determined through the oxidation of organic matter contents of the water with potassium dichromate ($K_2Cr_2O_7$) and catalyzed by Ag_2SO_4. The turbidity of water samples was determined in the laboratory with a benchtop turbidity meter (Infitek BEP-TB4000E Model).

The samples were analyzed for heavy metals content (cadmium, chromium, copper, zinc, and lead) spectrophotometrically with an atomic absorption spectrophotometer (AAS_Agilent 200AA model).

Enumeration and Identification of Phytoplankton

The standard microscopic technique using a conventional hemocytometer counting method of the UNESCO-Intergovernmental Oceanographic Commission, as described by Isichei *et al.* (2020) with slight modifications, was used to enumerate phytoplankton contents of the water samples. Each sample was agitated to distribute organisms evenly, and 1 ml was placed on a hemocytometer with a dropping pipette and examined under a microscope. The phytoplankton was counted, and the identification was based on morphological features in line with the identification keys by Janse-van *et al.* (2006).

Data Analysis

The data were subjected to descriptive analysis on IBM SPSS version 25. The means and standard errors of the data were presented in Table format.

The mean value of physicochemical parameters was compared with the standard permissible limit of the National Environmental Standards and Regulation Enforcement Agency for Nigeria's fisheries and recreation surface water quality (NESREA, 2011). Shannon-Weiner diversity index (H) was used to estimate the diversity of phytoplankton on an online Statology calculator (https://www.statology.org/shannon-diversity-index-calculator/). The water pollution status was classified based on Palmer's index.

RESULTS

Physiochemical Parameters of the Water Samples.

The results for the physicochemical parameters of the surface water samples are presented in Table 1.

The average pH values of the surface water samples were 6.62 and 6.97 (SP1) and 7.02 and 6.69 (SP2) for the rain and dry seasons, respectively. The average dissolved oxygen values DO (mg/l) were 6.83 and 6.49 (SP1) and 6.99 and 6.65 (SP2) for the rainy and dry seasons, respectively. The mean turbidity values (NTU) were 13.05 and 9.03 (SP1) and 11.12 and 5.67 (SP2) for the rain and dry season, respectively. The mean BOD (mg/l) values were 8.23 and 5.24 (SP1) and 4.49 and 3.62 (SP2) for the rainy and dry seasons, respectively. The average COD (mg/l) was 50.03 and 38.05 (SP1) and 35.62 and 23.83 (SP2) for the rainy and dry seasons, respectively.

The cadmium (mg/l) and chromium (mg/l) were below the detectable limit (BDL) of the analytical instrument used for SPI and SP2, respectively. The average copper (mg/l) content values were 0.058 and 0.047 for the rain and dry seasons, respectively, at SP1. The Zinc content (mg/l) values were 0.004 and 0.003 for the rain and dry seasons, respectively, at SP1. The average Pb (mg/l) contents values were 0.007 and 0.002 for the rain and dry seasons, respectively, at SP1. At the sampling site2 (SP2), the Cu (mg/l), Zn (mg/l), and Pb (mg/l) were below the detectable limit (BDL).

The pH and DO (mg/l) values for the sampling sites (SP1 and SP2, respectively) do not exceed the specified standard range of the National Environmental Standard and Regulations Enforcement Agency (NESREA) for fisheries and recreation surface water standards (Table 1).

The turbidity values (NTU) during the rainy season for SP1 and SP2 were higher than the standard value recommended by NESREA (Table 1). The BOD (mg/l) and COD (mg/l) values at sampling point 1 (SP1) in both rainy and dry seasons were higher than the specified limit values of NESREA (Table 1).

The heavy metals (Cd (mg/l), Cr (mg/l), Cu (mg/l), Zn (mg/l), and Pb (mg/l)) were within the recommended safe range of NESREA for surface water quality (Table 1).

Relative Abundance of Phytoplankton from Surface Water Samples

The relative abundance of phytoplankton genera observed from the surface water samples is presented in Table 2. A total of 8 phytoplankton genera (*Chlamydomonas*, *Chlorella*, *Closterium*, *Cyclotella*, *Euglena*, *Micractinium*, *Microcystis*, and *Phacus*) were recorded in the sample sites (Table 2). *Chlorella* had the highest abundance percentage in all the sampling sites (Table 2).

Palmer's Pollution Index Scores of Surface Water Samples

Palmer's pollution index of phytoplankton genera of all the 8 observed algal genera (*Chlamydomonas*, *Chlorella*, *Closterium*, *Cyclotella*, *Euglena*, *Micractinium*, *Microcystis*, and *Phacus*) were considered as pollution tolerant and Palmer's pollution index scores were assigned (Table 2).

The total scores recorded in surface water samples from sample site 1 (SP1) were 18 and 17 for the rain and dry season, respectively. (Table 3). At sample site 2 (SP2), the total scores recorded were 17 and 14 for the rain and dry season, respectively (Table 3).

Palmer's pollution classification index scores for SP1 are probably high organic pollution for the rainy and dry seasons (Table 3). For SP2, the pollution classification was probable high organic and moderate organic pollution for the rainy and dry seasons, respectively (Table 3).

Table 1: Physicochemical Parameters and Heavy Metals Content of Water Samples

Parameter / Period	Sampling Sites				NESREA Permissible Limit
	SP1		SP2		
	Rain Season	Dry Season	Rain Season	Dry Season	
pH	6.62 ± 0.07	6.97 ± 0.02	7.02 ± 0.03	6.69 ± 0.07	6.5 - 8.5
DO (mg /l)	6.83 ± 0.02	6.49 ± 0.01	6.99 ± 0.04	6.65 ± 0.17	≥ 6.0
Turbidity (NTU)	13.05* ± 0.38	9.03 ± 0.76	11.12* ± 0.17	5.67 ± 0.43	≤ 10
BOD (mg /l)	8.23* ± 0.21	5.24* ± 0.27	4.49 ± 0.15	3.62 ± 0.00	≤ 3.0
COD (mg /l)	50.03* ± 0.23	38.05* ± 0.18	28.62 ± 0.06	23.83 ± 0.10	≤ 30.0
Cd (mg /l)	BDL	BDL	BDL	BDL	≤ 0.005
Cr (mg /l)	BDL	BDL	BDL	BDL	≤ 0.5
Cu (mg /l)	0.058 ± 0.04	0.047 ± 0.01	BDL	BDL	≤ 0.001
Zn (mg /l)	0.004 ± 0.05	0.003 ± 0.29	BDL	BDL	≤ 0.01
Pb (mg /l)	0.007 ± 0.19	0.002 ± 0.04	BDL	BDL	≤ 0.01

Key: All the values were presented in mean plus or minus standard error of the mean; The values with an asterisk (*) are not within the NESREA surface water's standard for fisheries and recreation, NSEREA is the National Environmental Standard and Regulation Enforcement Agency; BDL is below the detection limit of 0.00003 mg/l; SP1 is Mubo water; SP2 is Sobi Dam.

Table 2: Relative Abundance of Phytoplankton in the Study Sites

Phytoplankton genera	Sampling Sites			
	SP1		SP2	
	Rain Season (%)	Dry Season (%)	Rain Season (%)	Dry Season (%)
Chlamydomonas	3 (8.6)	5 (25)	5 (13.9)	3 (16.7)
Chlorella	12 (34.2)	6 (30)	10 (27.8)	8 (44.4)
Closterium	2 (5.7)	1 (5)	3 (8.3)	0 (0)
Cyclotella	2 (5.7)	2 (10)	3 (8.3)	2 (11.1)
Euglena	7 (20.0)	2 (10)	5 (13.9)	4 (22.2)
Micractinium	3 (8.6)	2 (10)	5 (13.9)	0 (0)
Microcystis	3 (8.6)	0 (0)	0 (0)	1 (5.6)
Phacus	3 (8.6)	2 (10)	5 (13.9)	0 (0)
Total	35 (100)	20 (100)	36 (100)	18 (100)
H Index	1.86	1.78	1.87	1.39

Key: H is Shannon's diversity index; If H value ≥ 3.50 indicates Very high; H value 3.00 - 3.49 High; H value 2.50 - 2.99 indicates moderate; H value 2.00 - 2.49 indicates low; H value ≤ 1.99 indicates Very low diversity (Baliton *et al*., 2020).

Table 3: Palmer's Pollution Index Scores of Surface Water Samples

Phytoplankton genera	Sampling Sites				Palmer Index (PPI)
	SP1		SP2		
	Rain Season	Dry Season	Rain Season	Dry Season	
Ankistrodesmus	-	-	-	-	2
Chlamydomonas	4	4	4	4	4
Chlorella	3	3	3	3	3
Closterium	1	1	1	-	1
Cyclotella	1	1	1	1	1
Euglena	5	5	5	5	5
Gomphonema	-	-	-	-	1
Lepocinclis	-	-	-	-	1
Melosira	-	-	-	-	1
Micractinium	1	1	1	-	1
Microcystis	1	-	-	1	1
Navicula	-	-	-	-	3
Nitzschia	-	-	-	-	3
Oscillatoria	-	-	-	-	4
Pandorina	-	-	-	-	1
Phacus	2	2	2	-	2
Phormidium	-	-	-	-	1
Scenedesmus	-	-	-	-	4
Stegioclonium	-	-	-	-	2
Synedra	-	-	-	-	2
Total	18	17	17	14	
Pollution Status	**C**	**C**	**C**	**B**	

Key: PPI score values between **A**: 0-10 = lack of organic pollution, **B**: 10-15 = moderate pollution, **C**: 15-20 = probable high organic pollution, and **D**: ≥ 20 = confirmed high organic pollution (Zaky *et al.*, 2018).

DISCUSSION

Timely and accurate monitoring of water quality is crucial to ensure its sustainable use and safeguard public health (Onu *et al.*, 2023). Therefore, this study assesses the quality of Mubo and Sobi Dam surface water using phytoplankton as baseline indicator organisms.

The findings showed that the pH and DO (mg/l) levels were within the permissible limit stipulated by Nigeria's National Environmental Standard and Regulation Enforcement Agency for surface water (NESREA, 2011). The pH, a measure of the concentration of protons in the water, has been reported to have a major impact on the toxicity and solubility levels of chemicals and heavy metals in aquatic environments (Mishra *et al.*, 2023). Research has shown that pH could disrupt the photosynthetic activities of phytoplankton communities by affecting their inherent physiological carbon uptake (Masuda *et al.*, 2021; Liu *et al.*, 2022).

The biological oxygen demand is one of the crucial indicators that could indicate the level of organic pollution in the aquatic environment (Mishra *et al.*, 2023). It measures the amount of dissolved oxygen necessary for the biodegradation of organic matter in the water system (Lemessa *et al.*, 2023). The BOD (mg/l) levels for Mubo River were higher than the recommended range for both sampling periods. While at the Sobi Dam sampling sites, the BOD (mg/l) and the COD (mg/l) were within the permissible values (NESREA, 2011). The higher BOD (mg/l) and COD (mg/l) values recorded in the free-flowing Mubo River compared to the comparatively static Sobi Dam could be attributed to several factors, including its higher flow rate, shorter residence time for organic matters and susceptibility to non-point pollution sources (Moses *et al.*, 2019).

Turbidity is one of the effective indicators of water quality monitoring because a sudden change in turbidity has been ascribed to the presence of a new pollution source in the water system (Zaghloul *et al*., 2019; Kusari *et al*., 2022). Therefore, the higher turbidity levels above the permissible limit of NESREA recorded in the rainy season in this study could be ascribed to the non-point sources of surface water pollution from flood water during the rainy season. However, the water quality turbidity level was within the recommended limit in the dry season.

The high levels of heavy metals in aquatic environments are considered harmful due to their hazardous and toxic effects on aquatic organisms and the human community (Zhang *et al*., 2023). However, the heavy metals evaluated in this study (Cd (mg/l), Cr (mg/l), Cu (mg/l), Zn (mg/l), and Pb (mg/l)) were within the recommended safe range of NESREA for surface water quality (NESREA, 2011).

The eight genera of phytoplankton recorded from the surface water under investigation belong to four major divisions of algae group; viz, Bacillariophyta (*Cyclotella*), Chlorophyta (*Chlorella*, *Closterium*, *Chlamydomonas* and *Micractinium*), Cyanophyta (*Microcystis*) and Euglenophyta (*Euglena* and *Phacus*) (Janse-van *et al*., 2006). The Shannon Diversity Index (H) is widely used in evaluating the community species diversity status as influenced by environmental pollution levels. According to Al-Tamimi and Al-Jumaily (2021), there is a clear correlation between aquatic ecosystems' species richness and pollution levels, with a lower diversity index indicating highly polluted water. The diversity of phytoplankton in the surface water samples under investigation was very low (H ≤ 1.99) following the Shannon diversity index classification (Baliton *et al*., 2020). This affirmed the work of Nwonumara *et al*. (2022), who reported that Shannon-Weiner diversity indices within the range of 1.50-3.40 signify low diversity richness. This implies a relatively high pollution level of the surface waters under investigation, which might account for the dominance and proliferation of a few phytoplankton species adapted to such conditions.

According to Palmer's index, surface water samples from the free-flowing Mubo Rivers were estimated to probably contain high levels of organic pollution during the two sampling periods (Zaky *et al*., 2018). However, only in the rainy season did Sobi Dam exhibit notable levels of organic pollution. This is corroborated by the physicochemical analysis of the water, which showed high levels of BOD (mg/l) and COD (mg/l) to indicate a probable high level of organic pollution level (Aguilar-Torrejon *et al*., 2023).

Conclusion

The Shannon diversity index and Palmers' pollution index scores for phytoplankton assessment of the surface waters' pollution status showed that the water samples from the free-flowing Mubo Rivers contained high levels of organic pollution in both sampling periods. While the relatively static Sobi Dam exhibits notable levels of organic pollution only during the rainy season. The relatively high turbidity, BOD (mg/l), and COD (mg/l) values support the index pollution scores and confirm the suitability of phytoplankton as baseline indicators for organic pollution in water.

REFERENCES

Aborisade, W. T., Ajao, A. T. and Idemudia, I. B. (2023). Water quality assessment and bacteriological evaluation of fishpond in Ilorin. *Aswan University Journal of Environmental Studies*, 4(4), 248-260. **[Crossref]**.

Aguilar-Torrejon, J. A., Balderas-Hernandez, P., Roa-Morales, G., Carlos Eduardo Barrera-Diaz, C. D., Rodriguez-Torres, I. and Torres-Blancas, T. (2023). Relationship, importance, and development of analytical techniques: COD, BOD, and TOC in water - an overview through time. *SN Applied Sciences*, 5:118-131. **[Crossref]**.

Al-Tamimi, A. M. and Al-Jumaily, I. S. A. (2021). Planktonic Diatoms as Bio Indicators of Water Quality of Euphrates River between Saqlawiah and Amiriat Al-Fallujah - Iraq. *Annals of the Romanian Society for Cell Biology*. 25(3): 6799 – 6813. https://annalsofrscb.ro/index.php/journal/article/download/2195/1823.

Baliton, R. S., Landicho, L. D., Cabahug, R. E. D., Paelmo, R. F., Laruan, K. A., Rodriguesz, R. S., Visco, R. G. and Castillo, A. K. A. (2020). Ecological services of agroforestry systems in selected upland farming communities in the Philippines. *Biodiversitas*, **21**: 707-717. **[Crossref]**.

Boudeffa, K., Fekrache, F. and Bouchareb, N. (2020). Physicochemical and biological water quality assessment of the Guebli River, North-Eastern Algeria. *Rasayan Journal of Chemistry*, 13(1): 168 – 176. https://www.rasayanjournal.co.in/admin/php/upload/855_pdf.pdf.

Enawgaw, Y. and Wagaw, S. (2023). Phytoplankton communities and environmental variables as indicators of ecosystem productivity in a shallow tropical lake. *Journal of Freshwater Ecology*, 38:1-14. [Crossref].

Filiz, N., Iskin, U., Beklioglu, M., Oglu, B., Cao, Y., Davidson, T. A., Sondergaard, M., Lauridsen, T. L. and Jeppesen, E. (2020). Phytoplankton community response to nutrients, temperatures, and a heat wave in shallow lakes: an experimental approach. *MDPI Journal of Water*, 12(12): 3394 - 3415 [Crossref].

Gabyshev, V., Barinova, S., Ivanova, A., Gabysheva, O. and Curtean-Banaduc, A. (2022). The indicator role of algae in assessing the organic pollution in the Lena River Delta, the Russian Arctic. *Frontier in Environmental Science*, 10: 1-11. [Crossref].

Grob, E., Boersma, M. and Meunier, C. L. (2021). Environmental impacts on single-cell variation within a ubiquitous diatom: The role of growth rate. *PLoS ONE*, 16(5): 1-17. [Crossref].

Isichei, C. T., Adeniyi, I. F., Ogbuenunu, K. E. and Enordiana, I. O. (2020). Taxonomic composition and assessment of phytoplankton flora in Esa-Odo Reservoir, Osun State, Nigeria. *Direct Research Journal of Biology and Biotechnology*, 6(5): 64-74. [Crossref].

Janse-van V. S., Taylor, J., Gerber, A. and Van-Ginkel, C. (2006). Easy identification of the most common freshwater algae. A guide for the identification of microscopic algae in South African freshwaters. p.212.

Kusari, L. (2022). Turbidity as a Surrogate for the determination of total phosphorus, using relationship based on sub-sampling techniques. *Ecological Engineering and Environmental Technology*, 23(4): 88-93. [Crossref].

Labib, W., El-Dahhar, A. A., Shahin, S. A., Ismail, M. M., Hosny, S. and Diab, M. H. (2023). Water quality indices as tools for assessment of the Eastern Harbor's water status (Alexandria, Egypt). *Springer Nature Journal of Applied Sciences*, 5: 89-99. [Crossref].

Lemessa, F., Simane, B., Seyoum, A. and Gebresenbet, G. (2023). Assessment of the Impact of Industrial Wastewater on the Water Quality of Rivers around the Bole Lemi Industrial Park (BLIP), Ethiopia. *MDPI Journal of Sustainability*, 15(5): 4290-4308. [Crossref].

Liu, F., Gledhill, M., Tan, Q. G., Zhu, K., Zhang, Q., Salaun, P., Tagliabue, A., Zhang, Y., Weiss, D., Achterberg, E. P. and Korchev, Y. (2022). Phycosphere pH of unicellular nano- and micro-phytoplankton cells and consequences for iron speciation. *Multidisciplinary Journal of Microbial Ecology*, 16: 2329–2336. [Crossref].

Luvhimbi, N., Tshitangano, T. G., Mabunda, J. T., Olaniyi, F. C. and Edokpayi, J. N. (2022). Water quality assessment and evaluation of human health risk of drinking water from the source to point of use at Thulamela municipality, Limpopo Province. *Scientific Reports*, 12: 6059-6076. [Crossref].

Masuda, T., Prasil, O., Villafane, V. E., Valinas, M. S., Inomura, K. and Helbling, E. W. (2021). Impact of increased nutrients and lowered pH on photosynthesis and growth of three marine phytoplankton communities from the Coastal Southwest Atlantic (Patagonia, Argentina). *Frontiers in Marine Sciences*, 8: 1-20. [Crossref].

Mishra, A. P., Kumar, S., Patra, R., Kumar, A., Sahu, H., Chandra, N., Pande, C. B. and Alshehri, F. (2023). Physicochemical parameters of water and its implications on avifauna and habitat quality. *MDPI Journal of Sustainability*, 15(12): 9494-9511. [Crossref].

Moses, S., Wyasu, G. and Moses, Titus. Y. (2019). Physicochemical and bacteriological quality of water collected from dams and rivers along gold mining sites in Zamfara State. *Science World Journal*, 14(1): 148-155. https://www.ajol.info/index.php/swj/article/view/208524.

Naselli-Flores, L. and Padisak, J. (2023). Ecosystem services provided by marine and freshwater phytoplankton. *Hydrobiologia*, 850(13): 2691-2706. [Crossref].

National environmental standard and regulation enforcement agency (NESREA): 2011. In: Federal Government of Nigeria NESREA Gazette for surface and groundwater quality control." Lagos Nigeria Printed and Purchased by the Federal Government Printer Lagos pp. B 693-727.

Nguyen, T. G. and Huynh, N. T. H. (2023). Evaluating surface water quality using indexes of water quality and plankton diversity. *Civil Engineering Journal*, 9(5): 1187-1202. [Crossref].

Nwonumara, G. N., Elebe, F. A. and Nwibo, O. D. (2022). The physicochemical variables and phytoplankton of Ufiobodo and Ebonyi reservoirs, Ebonyi State, Nigeria. *The Zoologist*, 21: 41-48. [Crossref].

Ogunkunle, C. O., Mustapha, K., Oyedeji, S. and Fatoba, P. O. (2016). Assessment of metallic pollution status of surface water and aquatic macrophytes of earthen dams in Ilorin, North-Central of

Nigeria as indicators of environmental health. *Journal of King Saud University of Science*, 28(4): 324-331. **[Crossref]**.

Okere, M. C., Davies, I. C. and Okonkwo, S. E. (2020). Seasonal variation of the hydro-environmental factors and phytoplankton community around waters in Tincan Island, Lagos State, Nigeria. *Journal of Applied Science and Environmental Management*, 24(10) 1739-1746. https://www.ajol.info/index.php/jasem/article/view/201253/189766.

Okoye, G. U. and Ogbebor, J. U. (2023). Evaluation of the organic pollution status of some rivers in Edo State using Palmer's Pollution Index. *Journal of Science and Technology Research*, **5**(4): 97-105. **[Crossref]**.

Onu, M. A., Ayeleru, O. O., Oboirien, B. and Olubambi, P. A. (2023). Challenges of wastewater generation and management in sub-Saharan Africa: a review. *Environmental Challenges*, 11: 1-21. **[Crossref]**.

Ray, A., Mondal, D., Chakraborty, N. and Ganguly, S. (2023). Phytoplankton diversity in wastewater impacted Indian Ramsar site: a study from East Kolkata Wetland. *Environmental Monitoring and Assessment*, 195(8):938. **[Crossref]**.

Roy, M., Shamim, F. and Chatterjee, S. (2021). Evaluation of Physicochemical and Biological Parameters on the Water Quality of Shilabati River, West Bengal, India. *Water Science*, 35(1): 71-81. **[Crossref]**.

Salem, Z., Ghobara, M. and El-Nahrawy, A. A. (2017). Spatio-temporal evaluation of the surface water quality in the middle Nile Delta using Palmer's algal pollution index. *Egyptian Journal of Basic and Applied Sciences*, 4(3): 219-226. **[Crossref]**.

Tambaru, R., Burhanuddin, A. I., Massinai, A. and Amran, M. A. (2021). Detection of marine microalgae (phytoplankton) quality to support seafood health: A case study on the west coast of South Sulawesi, Indonesia. *Biodiversitas* 22(11): 5179-5186. **[Crossref]**.

Zaghloul, A., Saber, M. and Abd-El-Hady, M. (2019). Physical indicators for pollution detection in terrestrial and aquatic ecosystems. *Bulletin of the National Research Centre*, 43: 120-126. **[Crossref]**.

Zaky, S. K., Ezra, A. G., AbdulHameed, A., Nayaya, A. J. and Okpanachi, I. Y. (2018). Use of algae as a bio-friendly means to determine the water quality of Romi River in Kaduna, Nigeria. *Science World Journal*, 13(1): 65 -69. https://www.scienceworldjournal.org/article/view/18373/11926.

Zhang, P., Yang, M., Lan, J., Huang, Y., Zhang, J., Huang, S., Yang, Y. and Ru, J. (2023). Water quality degradation due to heavy metal contamination: health impacts and eco-friendly approaches for heavy metal remediation. *MDPI Toxics*, **11**(10): 828-848. **[Crossref]**.