PHYTOPLANKTON COMMUNITY STRUCTURE IN RELATION TO PHYSICAL AND CHEMICAL PARAMETERS IN PARTS OF THE LAGOS HARBOUR, SOUTHWEST, NIGERIA

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Abstract
The activities and growing population in the coastal areas of Lagos have increased the anthropogenic influence on the Lagos harbour. The aim of this study was to assess the phytoplankton assemblages in parts of the Lagos harbour and their relationship with some water quality parameters. Three stations (Badagry, Five cowries and Ijora creeks) were selected for this study. Using standard methods, the diversity of phytoplankton and changes in water quality indices were studied for three months, from November 2022 to January 2023 (Dry season). During the study period, some parameters were observed, and fluctuations ranged from slight to significant. The pH of the surface water ranged from 7.35 to 7.89, and the temperature was between 30 and 31 °C. Salinity ranged between 15 and 24.8 ‰, transparency ranged between 60.5 and 126 cm, and conductivity ranged between 19, 220 and 40,100 µS/cm. Total dissolved solids ranged from 15.1 to 42.8 mg/L, and total suspended solids ranged from 0.0019 to 0.0139 mg/L. The ranges for dissolved oxygen, biochemical oxygen demand, phosphorus and nitrate were 9.54–17.13 mg/L, 3.33–13.8 mg/L, 0.3 to 1.3 mg/L and 2.7–7 mg/L, respectively. A total of 40 phytoplankton taxa belonging to three classes were recorded for this study. Bacillariophyceae (Diatoms) comprised 30 taxa (86.5 %), Cyanophyceae (blue-green algae) were represented by 7 taxa (9.92 %), and Fragilariophyceae had 3 taxa (3.57 %). Species of high economic significance and environmental bio-indicators including Navicula sp, Nitzschia sp, Synedra ulna and Coscinodiscus sp, were recorded in this study. Canonical correspondence analysis revealed that chlorophyll a, salinity, and nitrate were significant factors that influenced the distribution of the phytoplankton species within the sampled stations. Carlson's trophic state index (TSI), used to analyze trophic state, showed that the study sites were oligotrophic. The nutritional stoichiometry showed an explicit nitrate limitation. It may be exacerbated by the scarcity of nitrate-rich freshwater sources. The considerable impact of phosphate in November was reflected in the abundance of cyanobacteria and might be linked to sediment re-suspension as a result of extensive dredging and sand mining operations at the Lagos harbour. However, to improve the water quality in the Lagos harbor, better management techniques are necessary. Future monitoring of the harbour should continue to be of concern to researchers as Lagos is continuously affected by rapid economic development and pressures on aquatic resources.

Keywords: Harbour, Nutrient, Phytoplankton, Stoichiometry

Introduction

The creeks and lagoons in South-western Nigeria play a crucial role both ecologically and economically. The rising human activities and population along the coast are intensifying the human impact on Lagos harbour. Chukwu and Nwankwo (2004) highlight the significant stress on the Lagos lagoon and adjacent creeks due to human activities. The occurrences and density of different types of phytoplankton species in the bodies of water are usually affected by water quality, as noted by Elegbeleye and Onyema (2019). Key water quality parameters affecting phytoplankton growth, abundance, and diversity include water temperature, salinity, dissolved oxygen, critical nutrient levels (nitrate, phosphate, sulphate), light availability, pH, and conductivity. These parameters serve as indicators of the water body's productivity status. Changes in temperature, light, nutrients, and discharge contribute to the distribution of phytoplankton (Montesanto *et al*., 1999; Phillips *et al*., 2000; Sullivan *et al*., 2001). However, phytoplankton communities are not solely responsive to natural aquatic environment changes; they can also exhibit variations due to human interventions affecting the water body, either directly or through activities in the entire basin. Indiscriminate dredging, sand mining operations, and extensive land reclamation for the construction of Eko Atlantic City are increasingly straining the Lagos harbour. Despite land reclamation's impact on phytoplankton species assemblages, the harbour has received limited attention in the checklist. This study aims to investigate phytoplankton assemblages in relation to water quality parameters at the Lagos harbor

Materials and Methods

Description of study sites

The designated sampling stations include Badagry creek, Ijora, and the Five cowries creek within the Lagos Harbour. The Five Cowries Creek, stretching approximately 7 km, extends from latitude 6° 26' N and longitude 3° 24' E to latitude 6° 26' N and longitude 3° 27' E. According to Hill and Webb (1958), the tidal flow in the Five Cowries Creek is noted as the fastest in the entire Lagos Lagoon system.
Situated in the upper part of the Lagos Harbour, the Ijora Creek (6.4626541ºN, 3.3765639ºE) remains open to the sea throughout the year. It displays semi-diurnal tidal oscillations and is characterized as shallow and protected, as described by Olaniyan (1975). Badagry Creek, located between longitude (2°421; 3°231E) and latitude (6°231; 6°281N), initiates the Barrier Lagoon Complex positioned in eastern Lekki town, Nigeria, between Badagry and Ajumo. It is estimated to be situated over 51 km away from Lagos

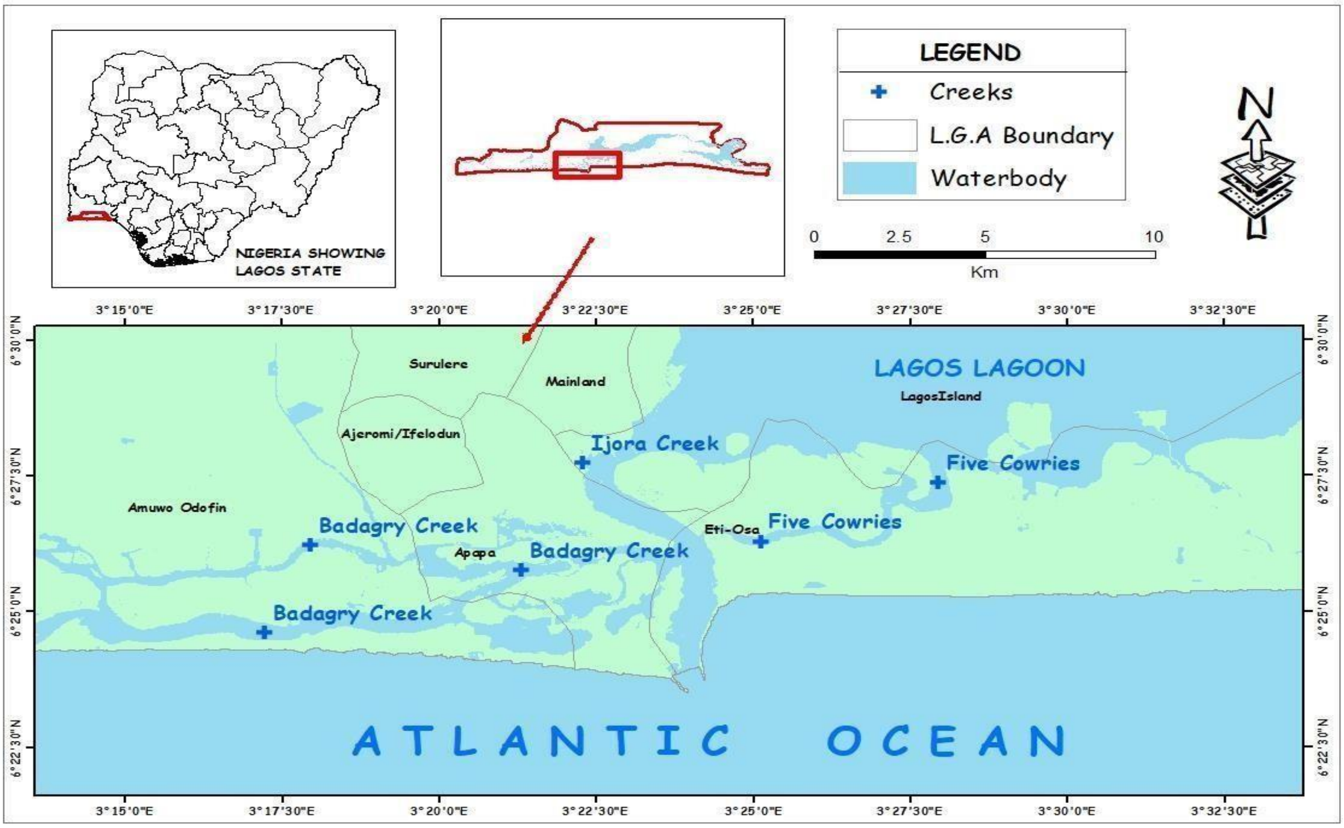


Figure 1: The Lagos harbour showing the study sites

Collection of Water Samples

Monthly sampling was conducted and water samples were collected for a period of three months from November 2022 to January 2023 (Dry season) between 09.00 and 11.00 hrs each day. Triplicate samples were collected at every site on each occasion for the analyses of nutrients, heavy metals and all other water quality parameters. Integrated surface water samples were collected between 0 –1 m depth surface water. Samples for dissolved oxygen were fixed in-situ with Winkler's reagents (APHA, 2005).

Collection of Plankton Samples

The phytoplankton samples were collected using standard plankton net of mesh size 55 µm. The plankton net was towed horizontally from a motorized boat at low speed (< 4 knots) for 5 minutes and the filtered plankton were emptied into well-labelled plastic container with a screw-cap. The plankton samples were preserved with 4 % formalin and transferred to the laboratory for further analysis as described by Nwankwo (2004); Julius and Theriot (2010).

Physical and Chemical Analysis

Water and air temperatures were measured using mercury-in-glass thermometer. Secchi disc was used to estimate transparency. Methods described by APHA (2005) were employed in estimating conductivity, salinity, dissolved oxygen, biological oxygen demand, total suspended solids, pH, total dissolved solids, Nitrate, Phosphate, Calcium and Magnesium.

Phytoplankton identifications and cell counts

Plankton sample was allowed to settle in the lab for 2hrs and concentrated to 20ml. For each settled sample, 2drops of well mixed sample was investigated. On each occasion, one drop of sample was thoroughly investigated using the Drop Count Method .Onyema (2007). For each drop five transect were investigated by moving the stage at different positions under a light microscope. Phytoplankton species were observed, identified and drawn using text. Several relevant keys and illustrations: (Newell and Newell, 1966; Wimpenny, 1966; Olaniyan, 1975; Waife and Frid, 2001; Lange-Bertalot, 2001; Witkowski *et al*., 2000; Siver, 2003; Rosowski, 2003; Nwankwo, 2004) were adequately consulted to confirm identification.

Community Structure Analysis

Determination of Species Diversity Index (d)

This is also known as the species diversity index. The species richness Margalef (1951) was given by the equation.

$$d = \frac{S-1}{\ln N}$$

Where d = Margalef richness index or species diversity index S= Number of species in the population,
N=Total number of individuals in species.

Determination of Shannon and Wiener Diversity Index (Hs)

This was proposed by Shannon and Wiener (1963) and it is given by the equation:

$$Hs = \frac{N \log N - (\sum Pi \log Pi)}{N}$$

Where Hs =Shannon-Wiener diversity index,
Σ = Summation I = count denoting ith species ranging from 1 to n.

Pi = proportion that the ith species represent to the total number of individuals in the sampling space.

Determination of Menhinick Index (D): This was determined by the equation:
$D=S/\sqrt{N}$

Where D = Menhinick index S
= Species total
$\sqrt{N}$ = Abundance

Determination of Equitability (j): Species equitability or evenness (Pielou, 1996) was determined by the equation: j = Hs/Log2S

Where j = Equitability index
Hs = Shannon and weaver index
S = Number of species in a population

Statistical Analyses

Relevant statistical tests, such as one-way analysis of variance (ANOVA), were applied to identify the levels of variation in water quality parameters across different stations. Statistical hypothesis testing was utilized to assess the significance of the results, employing a 95% confidence interval, where a significance level (P) less than 0.05 was considered statistically significant. Principal components analysis (PCA) was employed to identify major controlling water quality indices, while Canonical Correspondence Analysis (CCA) and Pearson's correlation coefficient were used to determine the water quality indices influencing monthly and spatial phytoplankton occurrences. All statistical analyses were conducted using Excel, Paleontological Statistics (PAST) by Hammer *et al*. (2001), and the Statistical Package for Social Sciences (SPSS).

Trophic Status Evaluation

The trophic state index (TSI) developed by Carlson (1977) was adopted for this study. Mean values of three variables: chlorophyll a (chl a), phosphate (TP) and secchi depth (SD) were used to calculate TSI. The formulae for calculating TSI values for chlorophyll a, reactive phosphorus and secchi depth are stated below;

TSI chlorophyll a = 9.81 1n (chl) + 30.6;
TSI reactive phosphorus =14.42 1n (TP) + 4.15;
TSI secchi depth = 60-14.41 1n (SD).
Therefore; $\text{Carlson's TSI} = \dfrac{\text{TSI (Chla)} + \text{TSI (TP)} + \text{TSI (SD)}}{3}$

Stoichiometric Nutrient Limitation

The Redfield Nitrate: Phosphate ratio of 16:1 was used as a benchmark for differentiating Nitrate limitation from Phosphate-limitation. This ratio assumes that phytoplankton is Nitrate- limited (N - limited) at N: P < 16 and that it is Phosphate limited (P - limited) at N: P > 16.

Results

Physical and Chemical Analysis

Air temperature ranged from 30 °C to 32 °C at the three stations during the study. Surface water temperature ranged from 30 °C to 31 °C. There were no significant difference between air and surface water temperatures at both stations (p>0.05). Alkaline pH was estimated throughout the sampling period (7.35 and 7.89). Dissolved oxygen values ranged between 9.54 and 17.13 mg/L and biological oxygen demand ranged 3.33 and 13.8 mg/L. Salinity values were high in January (between 15 and 24.8 ‰ at the three Stations) Conductivity values were low in November. Nitrate levels ranged between 2.7 and 7 mg/L. From 0.3 to 1.3 mg/L, phosphorus was present.

Table 1: ANOVA of Mean ± SE Values of some physical and chemical parameters of surface water at the Lagos harbour (November 2022 – January 2023)

		Sum of Squares	Df	Mean square	F	Sig.
Air Temperature	Between Groups	4.222	2	2.111	4.750	.058
	Within Groups	2.667	6	.444		
	Total	6.889	8			
Water Temperature	Between Groups	.222	2	.111	.500	.630
	Within Groups	1.333	6	.222		
	Total	1.556	8			
Transparency	Between Groups	280.167	2	140.083	.152	.862
	Within Groups	5536.333	6	922.722		
	Total	5816.500	8			
PH	Between Groups	.034	2	.017	.543	.607

	Within Groups	.189	6	.032		
	Total	.223	8			
Conductivity	Between Groups	116631992.000	2	58315996.000	1.320	.335
	Within Groups	265080096.000	6	44180016.000		
	Total	381712088.000	8			
Total suspended Solid	Between Groups	.000	2	.000	1.282	.344
	Within Groups	.000	6	.000		
	Total	.000	8			
Total Dissolved Solids	Between Groups	663.229	2	331.614	8.906	.016
	Within Groups	223.420	6	37.237		
	Total	886.649	8			
Salinity	Between Groups	71.716	2	35.858	11.296	.009
	Within Groups	19.047	6	3.174		
	Total	90.762	8			
Dissolved Oxygen	Between Groups	67.695	2	33.848	50.042	.000
	Within Groups	4.058	6	.676		
	Total	71.753	8			
Biochemical Oxygen demand	Between Groups	110.574	2	55.287	46.480	.000
	Within Groups	7.137	6	1.189		
	Total	117.711	8			

Table 2: ANOVA of Mean $\pm$ SE Values of some physical and chemical parameters of surface water at the Lagos harbour (November 2022–January 2023) (CONTD).

		Sum of squares	Df	Mean square	F	Sig.
Nitrate	Between Groups	3.387	2	1.693	.933	.444
	Within Groups	10.893	6	1.816		
	Total	14.280	8			
Phosphate	Between Groups	.025	2	.012	.093	.912
	Within Groups	.797	6	.133		
	Total	.822	8			
Sulphate	Between Groups	2067822.222	2	1033911.111	207.243	.000
	Within Groups	29933.333	6	4988.889		
	Total	2097755.556	8			
Magnessium	Between Groups	2112750.435	2	1056375.218	3.845	.084
	Within Groups	1648645.633	6	274774.272		
	Total	3761396.068	8			
Zinc	Between Groups	.012	2	.006	3.267	.110
	Within Groups	.011	6	.002		

	Total	.024	8			
Iron	Between Groups	.160	2	.080	.673	.545
	Within Groups	.714	6	.119		
	Total	.874	8			
Calcium	Between Groups	202130.096	2	101065.048	23.188	.002
	Within Groups	26151.321	6	4358.554		
	Total	228281.418	8			
Manganese	Between Groups	.027	2	.013	5.610	.042
	Within Groups	.014	6	.002		
	Total	.041	8			
Nickel	Between Groups	.161	2	.080	1.493	.298
	Within Groups	.323	6	.054		
	Total	.483	8			
Chromium	Between Groups	.536	2	.268	61.546	.000
	Within Groups	.026	6	.004		
	Total	.562	8			
Chlorophyll a	Between Groups	3.236	2	1.618	.340	.725
	Within Groups	28.567	6	4.761		
	Total	31.802	8			

The Principal Component Analysis

The PCA explained 98.74% for component 1 and 1.3% for component 2 of the total variation of the studied ecosystems, while the Eigen values are 1.9916 and 253477 respectively. The data was analyzed using paleontological and statistical software (PAST).

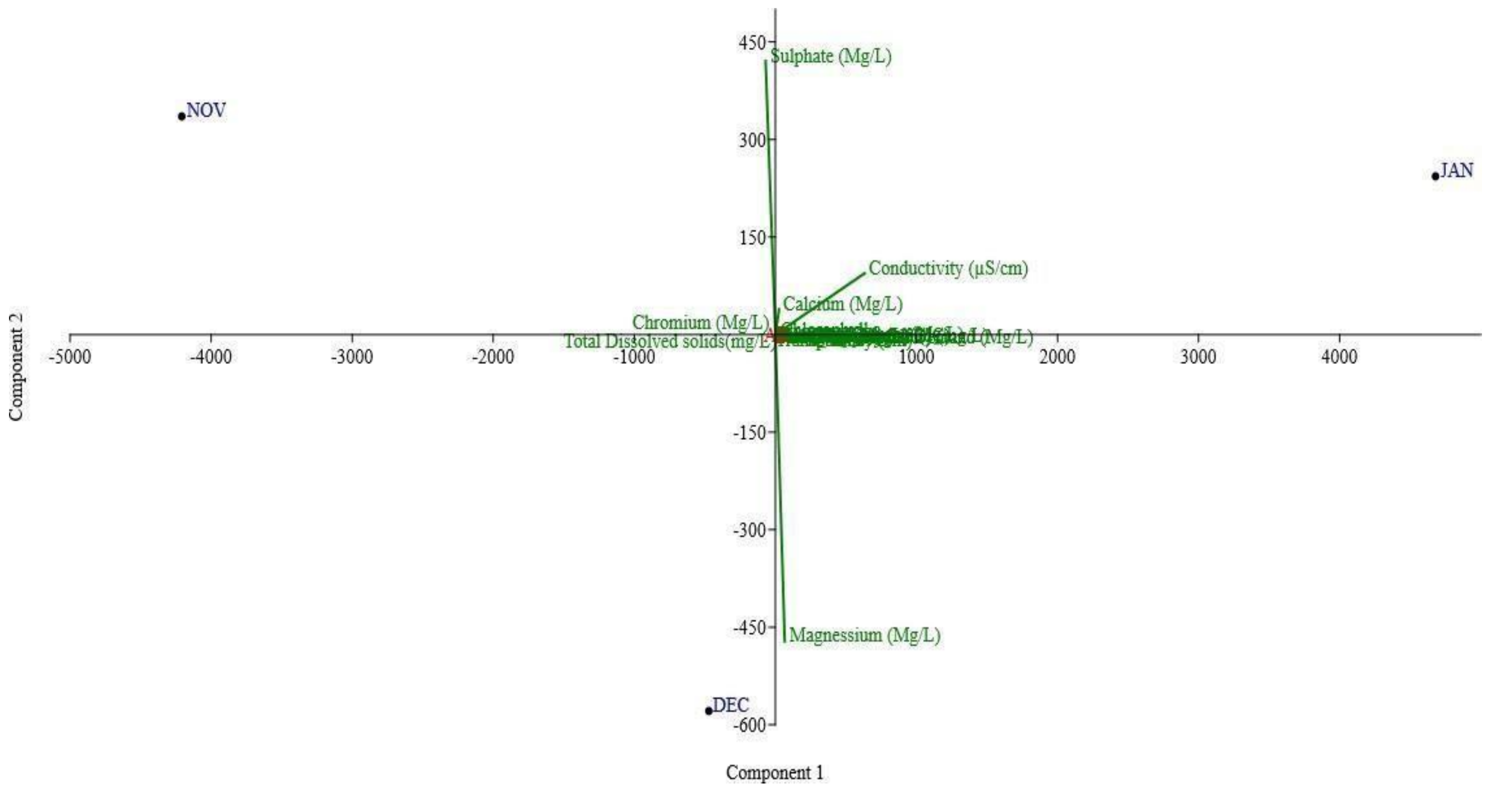


Figure 1: PCA score plot of physical and chemical parameters operating in the Lagos harbour, South-west, Nigeria

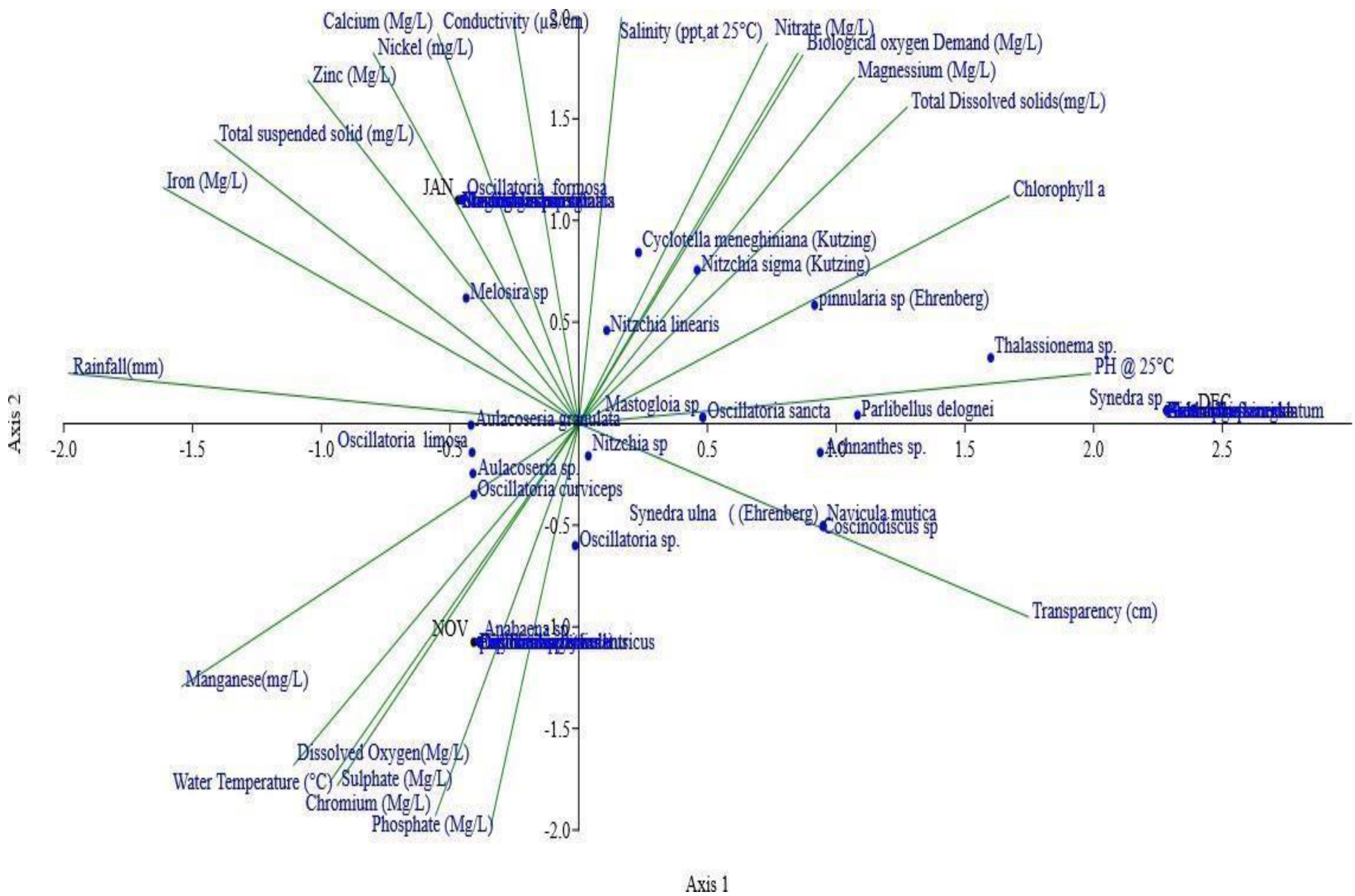


Figure 2: Canonical correspondence analysis of physical and chemical parameters influence on the distribution of phytoplankton species in parts of Lagos harbour, South-west, Nigeria

Phytoplankton Communities

The diversity and abundance of phytoplankton in parts of the Lagos harbour, South-west Nigeria was recorded between November 2022 and January 2023 (Dry season). A total of 40 phytoplankton taxa belonging to three classes were recorded for this study. Bacillariohyceae (diatoms) comprised 30 taxa (86.5%), Cyanophyceae (blue-green algae) were represented by 7 taxa (9.92%), and Fragilariophyceae had 3 taxa (3.57%).

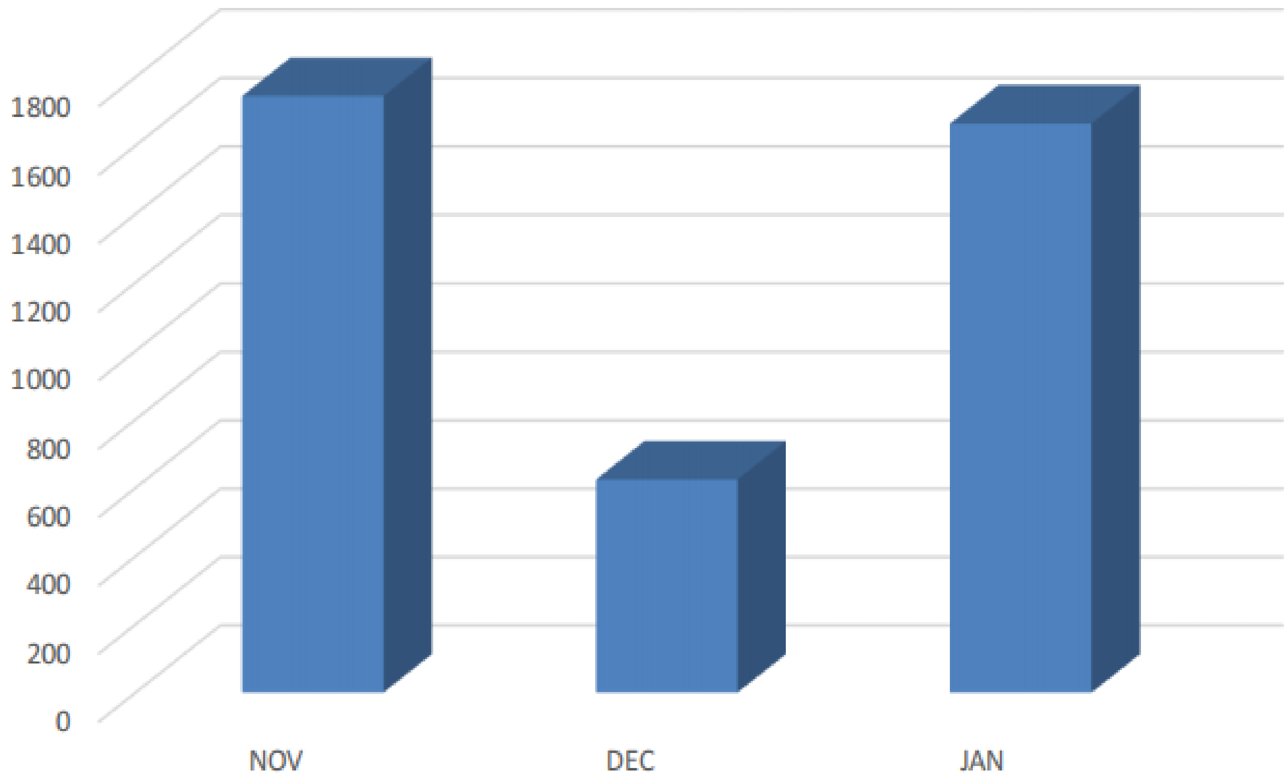


Figure 3: Monthly variations in phytoplankton abundance in parts of the Lagos harbour (November 2022 - January 2023)

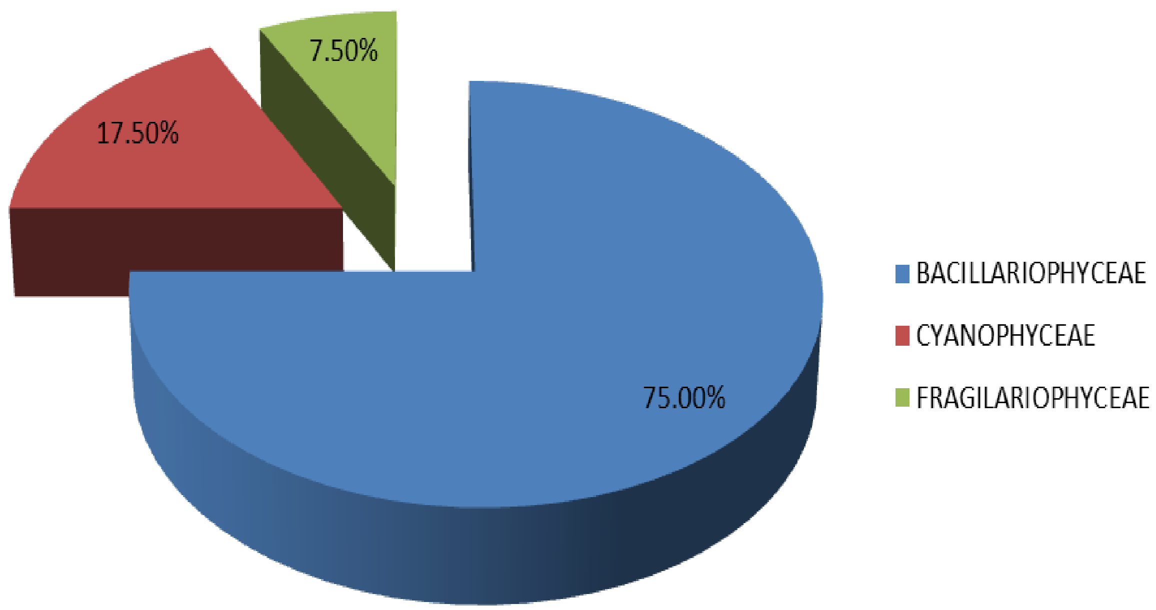


Figure 4: Percentage composition of phytoplankton in parts of the Lagos harbour (November 2022 - January 2023)

Table 3: Diversity indices at sampled stations in the Lagos harbour (November 2022 - December 2023)

	BC	FC	IJ
Total species richness (S)	17	22	25
Total abundance (N)	1680	896	1456
Log of species richness (LogS)	1.23	1.34	1.40
Log of species abundance (LogN)	3.23	2.95	3.16
Shannon-Wiener Index (Hs)	0.05	0.09	0.07
Menhinick Index (D)	0.41	0.73	0.70
Margalef Index (d)	2.15	3.09	3.30
Equitability index(j)	0.04	0.07	0.05
Simpson Dominance Index (D)	0.999	0.999	0.999

BC - Badagry creek FC - Five cowries creek IJ - Ijora creek

Trophic State Index
Trophic state index (TSI) using Carlson's indices revealed oligotrophic condition across the stations.

Table 4: Monthly variations showing the Carlson's tropic state index in parts of the Lagos harbour, South-west, Nigeria. (November 2022 - January 2023)

	November	December	January
TSI of (Chla)	53.29	54.62	54.03
TSI of TP	-5.42	-6.43	-4.33
TSI of SD	-1.62	-3.96	-4.47
CTSI	15.42	14.74	15.08

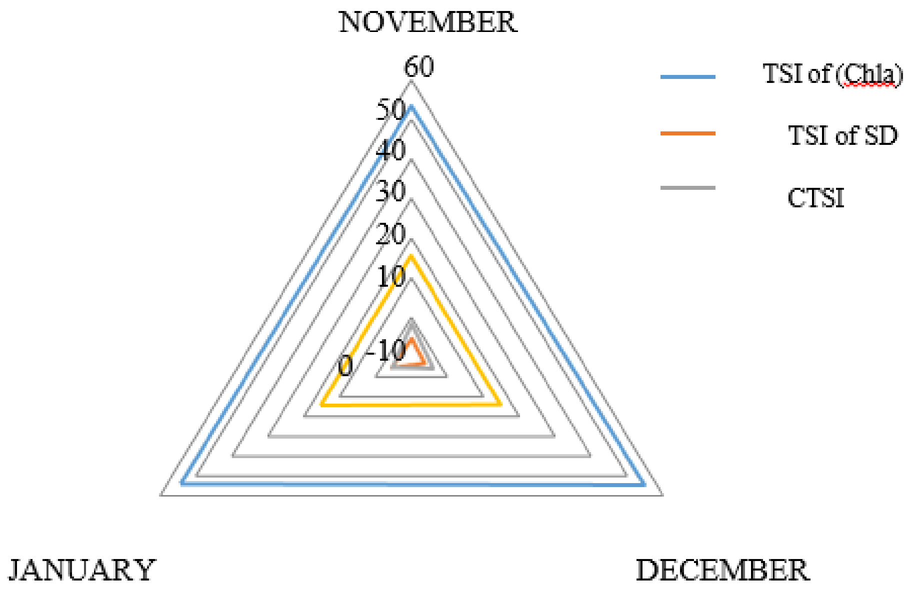


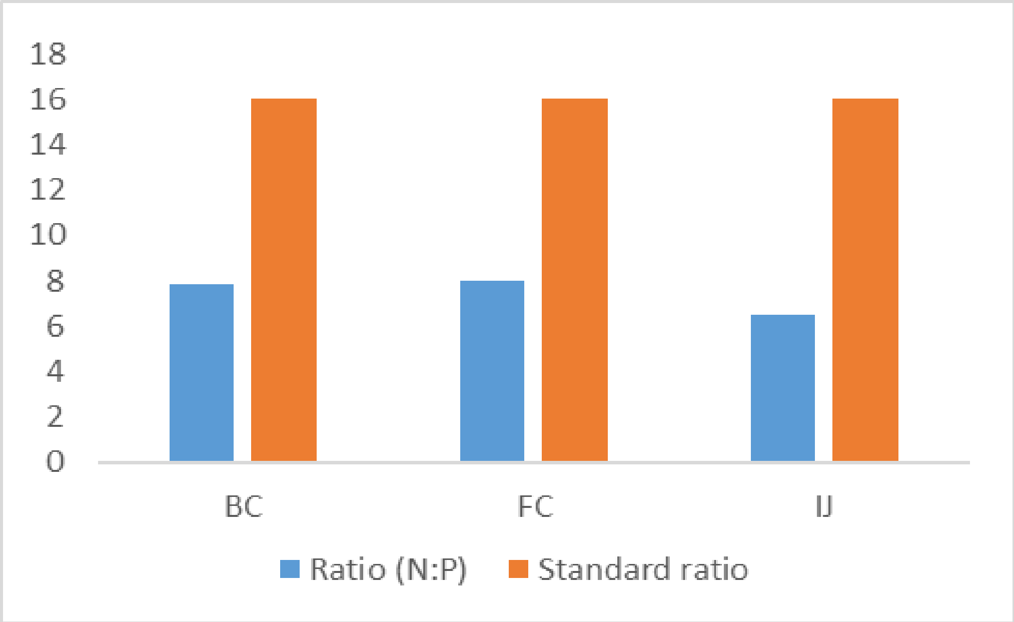
Figure 5: Radar showing the Carlson tropic state index at the (CTSI) in part of the Lagos harbour, South-west, Nigeria. (November 2022 – January 2023)

Stoichiometric Nutrient Limitation

Table 5: Stoichiometric Nutrient limitations in Part of the Lagos harbour, South-west, Nigeria. (November 2022 - January 2023)

	Nitrate	Phosphate	Ratio	Standard ratio
BC	5.5	0.7	7.86:1	16
FC	3.43	0.43	7.98:1	16
IJ	4.27	0.66	6.47:1	16

Figure 6: Comparison between standard ratio and stoichiometric nutrient ratio in parts of Lagos harbour,



Southwest, Nigeria. (November 2022 – January 2023)

DISCUSSION

Phytoplankton have been reported to be a reflection of environmental conditions, pointing to the health of the aquatic ecosystem overtime. Onyema *et al* (2007). Phytoplankton occurrence cannot be considered alone as one must also consider the prevailing environmental conditions mainly the physical and chemical parameters. Kadiri, (2006). The physical and chemical changes observed at the Lagos harbor clearly reflects the influence of seasonal variations and tidal sea conditions in the environment. Onyema and Akanmu (2013). Rainfall pattern in the tropics is responsible for the dry (November-January) season this study was carried out. Brown and Kusemiju (2002). There were minimal to wide variations in air temperature, water temperature and transparency, which could be due to changes in cloud conditions and rainfall patterns Onyema (2008). Temperature values were in the 30 - 31 °C range, which is consistent with the unsettling climate brought on by global warming. The salinity regime of the study sites during this investigation ranged from (15 - 24.8 ‰) a brackish condition. Ajao *et al* (2002). According to Onyema (2008), the Lagos lagoon and its tidal creeks have a salinity gradient that affects the ecology. The pH values ranged between 7.35 and 7.89. It exhibited the usual alkaline properties which could be due to the buffering effect of seawater according to Onyema and Akingbulugbe (2017). The observed biochemical oxygen demand increases with decreasing dissolved oxygen level which is in accordance to a study by Nwankwo (1998). According to Onyema and Nwankwo (2009), Biochemical oxygen demand can be used to determine the pollution status in a water body. During the period of study, high level of conductivity up to 40,100 (µS/cm) was recorded, as a result of intrusion of seawater in proximity of the study area to the sea which is in agreement with Ubong and Emem (2021). The dry season period was associated with reduced volume of freshwater inflow from adjoining river, less perturbation stress related to mixing and reduced flushing. Sandra *et al* (2020). Heavy metals concentration was at trace levels (Zinc 0 - 0.194 Mg/L and Iron 0.553 - 1.559 Mg/L) it appeared to be governed mainly by shipping and sand mining activities that are characteristics of the study sites. Correlation matrix showed that there were significance of correlation between phytoplankton and physical and chemical parameters. Some variables like temperature, salinity, dissolved oxygen and nitrate were the key parameters that are correlated with plankton productivity in the study area. The relative dominance, abundance and diversity of diatoms (Bacillariophyceae) in three months across three stations reported in this study is in agreement with earlier works done in the Lagos lagoon system (Nwankwo, 2004; Onyema, 2007; Balogun and Ladigbolu, 2010; Nwankwo *et al*., 2012). Spatial and temporal sampling was significant in respect of species diversity and abundance. Chlorophyll a value ranged from 9.2 - 15 µg/L, this relatively high value can be attributed to the fact that the study was done during dry season when there is little or no precipitation, reduced suspended particles and increased light penetration which enhances phytoplankton productivity. Chlorophyll a is an indicator of the abundance of phytoplankton that makes an important contribution to overall primary productivity of coastal water bodies. Carlson's trophic state index (TSI), used to analyze trophic state, showed that the study sites were oligotrophic which could be attributed to the water current in proximity to the sea. Few phytoplankton taxa represented could be attributed to the relatively low productivity of the study site during the sampling period. This is in agreement with Idera *et al* (2015). The nutritional stoichiometry showed an explicit nitrate limitation. Reduced rainfall during the study period results in lower freshwater inputs into the harbour. This reduction in freshwater input may lead to less nutrient run-off, including nitrates, from the surrounding land. As a result, nitrate restriction may be exacerbated by the scarcity of nitrate-rich freshwater sources. The considerable impact of phosphate in November was reflected in the abundance of cyanobacteria and might be linked to sediment re-suspension as a result of extensive dredging and sand mining operations at the Lagos harbour. Significant ratio was later compared to standard ratio and it showed a balanced relationship between both nutrients. Canonical correspondence analysis (CCA) showed that Nitrate, chlorophyll a, and salinity are strongly correlated and have similar effects on the distribution of Phytoplankton. Presence of *Nitzchia sp, Achnanthes sp, Synedra ulna* showed a saline condition which can be attributed to the inflow of sea water into the Lagos harbour. The proximity to the sea, dilution by flood waters, and seasonal fluctuations were the main determining elements in the analysis of the physical, chemical and phytoplankton composition of the studied area. The results of the current study further showed that the phytoplankton assemblages in the Lagos harbour are influenced by physical and chemical parameters. Future monitoring of the Lagos harbour should continue to be of concern to researchers as Lagos is continuously affected by rapid economic development and pressures on aquatic resources.Extensive dredging and sand mining operations should be discouraged at the harbour. More effort should be made toward analyzing water quality parameters for future comprehensive sampling examination and a minimum of six month to one year sampling period is encouraged for further studies to provide adequate data for both wet and dry season.

REFERENCES

Ajao, E. A. & Fagade, S. O. (2002). The ecology of *Neritina glabrata* in Lagos Lagoon, Nigeria. _Archive for Hydrobiology_ 119 (3):339-350.

APHA (2005). Standard Methods for the examination of water and waste water analysis, 21st Edition, American water works association /water environment federation, Washington D.C.

Balogun, K. J. & Ladigbolu, I. A. (2010). Nutrients and phytoplankton production. Dynamics of a tropical harbour in relation to water quality indices._ Journal of American Research_ 6 (9): 261-275.

Brown, A. C. & Oyenekan, J. A. (1998). Temporal variability in the structure of benthic macro- fauna communities of the Lagos lagoon and harbour, Nigeria. _Polish Archives Hydrobiology_ 45: 45-54.

Chukwu, L. O. & Nwankwo, D. I. (2004). The impact of land based pollution on the hydrochemistry and macro benthic community of a tropical West African creek. _Ekologia for Hydrobiology_ 119 (3):339-350.

Hammer, O., Harper, D. & Ryan, P. (2001) PAST: Paleontological Statistics Software Package for Education and data Analysis. _Palaeontologia Electronica_ V 4: 1-9

Hill, M. B. & Webb, J. E. (1958).The ecology of Lagos Lagoon II. The topography and physical features of the Lagos harbour and Lagos lagoon. _Transaction of Royal Society_. London. 241: 307 – 417.

Idera, F., Falilu, K., Uyimadu, J. P., Popoola, S., Oyatola, O. & Nwoko, C (2015).On the nutrient profile in the Lagos harbour _Journal of Scientific Research and Reports_ 8 (4):1-13

Julius, M. L. & Theriot, E. C. (2010). The diatoms: a primer. In: The Diatoms: _Applications for the Environmental and Earth Science_ (2nd edition), J.P. Smol and E.F. Stoermer (editors).

Cambridge University Press. pp. 8 – 20.

Kadiri, M. O. (2006). Phytoplankton survey in the Western Niger Delta, Nigeria. _African Journal of Environmental Pollution and Health_ 5 (1): 48-58.

Margalef, R. (1951). Diversidad de species en las comunidales naturales. _Publ. Inst. Biol. Apl_9: 5 – 27.

Newell, G. E. & Newell, R. C. (1966). Marine Plankton: A Practical Guide. Revised Edition. Hutchinson, London. 225pp.

Nwankwo, D. I. (1996). Phytoplankton diversity and succession in Lagos lagoon, Nigeria. _Archive for Hydrobiology_ 135 (4):529-542.

Nwankwo, D. I. (1998). Seasonal changes in Phytoplankton composition and diversity in the Epe Lagoon, Nigeria. _Acta Hydrobiology_ 40 (2):83–92.

Nwankwo, D. I (2004). The Microalgae: Our indispensable allies in aquatic monitoring and biodiversity sustainability. _University of Lagos Press Inaugural Lecture Series_ 44pp.

Nwankwo, D. I., Okedoyin, A. O. & Adesalu, T. (2012). Primary Productivity in tidal creeks of South West Nigeria II. Comparative study of nutrient status and Chlorophyll-a variations in two Lagos harbour creeks. _World Journal of Biological Research_ Vol 5:41-48

Nwankwo, D. I., Onyema, I. C., Adesalu, T. A., Olabode, R. J., Osiegbu, G. O. & Owoseni, T. I. (2003). Additions to a preliminary check-list of planktonic algae in Lagos Lagoon, Nigeria._ Journal of Science, Technology and Environment_ 3 (1-2): 8-12

Olaniyan, C. I. (1975). An introduction to West African Ecology. _ Hienemann Education Books Ltd_ London **170** pp

Onyema, I. C. (2007). The Phytoplankton composition, abundance and temporal variation of a polluted estuarine creek in Lagos, Nigeria. _Turkish Journal of Fisheries and Aquatic Sciences_ **7**: 89-96

Onyema, I. C. & Akaanmu, R. T. (2013). The physical and chemical characteristics, chlorophyll a levels and phytoplankton dynamics of the east mole area of the Lagos harbour, Lagos. _Asian Journal of Scientific Research_ 3 (10):995-1010

Onyema, I. C. & Akingbulugbe, G. E. (2017). Water chemistry and chlorophyll-a variations in a perturbed mangrove ecosystem in Lagos. _National journal of fisheries and Aquaculture_5 (1), 50 – 56

Onyema, I. C., Nwankwo, D. I. & Owolabi, K .O. (2008). Temporal and spatial changes in the phytoplankton dynamics at the tarkwa-bay jetty in relation to environmental characteristics. _Ecology, Environment and Conservation_ 14 (4):1-9

Onyema, I. C., Okpara, C. U., Ogbebor, C. I., Otudeko, O. & Nwankwo, D. I. (2007). Comparative studies of the water chemistry characteristics and temporal plankton variations at two polluted sites along the Lagos lagoon, Nigeria. _Ecology and Environmental Conservation_ 13 (1):1–12.

Pielou, E. C. (1969). An introduction to mathematical ecology. John Wiley, New York. 286pp Sullivan, B. E., Small, L. F & Covert, P. (2001). Seasonality of phytoplankton production in the Columbia River: A natural or anthropogenic pattern? _Geochimica et Cosmochimica Acta_ V 65: 1125- 1139

Ubong, G & Emem, M. (2021). Spatial and seasonal variations in water quality parameters of a humid tropical river, Niger Delta, Nigeria. _Researcher_ 13 (4) 31-39

Waife, G. & Frid, C. L. J. (2001). Marine zooplankton of West Africa. Marine Biodiversity Capacity Building in the West African Sub-region. _Darwin Initiative Reports_ 5, Ref. 162/7/451. 120pp.

Wimpenny, R. S (1966). The Plankton of the Sea. _Faber and Faber Ltd_ London. 330 – 373

Appendix 1: Pearson's correlation coefficient matrix among various physic-chemical parameters at the Lagos Harbour, Southwest, Nigeria (November 2022 – January 2023)

	Air Temperature (°C)	Water Temperature (°C)	Rainfall(mm)	Transparency (cm)	PH @ 25°C	Conductivity (µS/cm)	Total suspended solid (mg/L)	Total Dissolved solids(mg/L)	Salinity (ppt at 25°C)	Dissolved Oxygen(Mg/L)	Biochemical oxygen Demand (Mg/L)	Nitrate (Mg/L)	Phosphate (Mg/L)	Sulphate (Mg/L)	Magnessium (Mg/L)	Zinc (Mg/L)	Iron (Mg/L)	Calcium (Mg/L)	Manganese(mg/L)	Nickel (mg/L)	Chromium (Mg/L)	Chlorophyll a
Air Temperature (°C)	1																					
Water Temperature (°C)	0.237595	1																				
Rainfall(mm)	0.032258	0.135769	1																			
Transparency (cm)	0.208153	0.466076	-0.20482	1																		
PH @ 25°C	0.115591	-0.07354	-0.33065	0.559655	1																	
Conductivity (µS/cm)	0.314344	-0.03559	0.144607	0.027834	0.377702	1																
Total suspended solid (mg/L)	-0.17034	-0.56108	0.440663	-0.64522	-0.01934	0.507357	1															
Total Dissolved solids(mg/L)	0.515507	-0.34526	-0.45736	-0.30751	0.204393	0.440256	0.298629	1														
Salinity (ppt at 25°C)	0.642093	-0.32729	-0.2044	0.280033	0.526413	0.561206	0.186083	0.667251	1													
Dissolved Oxygen(Mg/L)	-0.64749	0.389867	0.421947	0.147421	-0.13734	-0.37568	-0.16501	-0.90569	-0.78714	1												
Biochemical oxygen Demand (Mg/L)	0.744948	-0.29363	-0.29955	0.133193	0.453731	0.556911	0.107795	0.762678	0.895148	-0.88308	1											
Nitrate (Mg/L)	0.413376	-0.21217	-0.1546	-0.46547	0.006722	-0.05974	0.285749	0.718255	0.30249	-0.55667	0.346082	1										
Phosphate (Mg/L)	-0.34315	-0.32127	0.036416	-0.04685	-0.40711	-0.58528	-0.03376	-0.32643	-0.15323	0.084127	-0.32431	-0.11032	1									
Sulphate (Mg/L)	-0.68599	0.417645	0.340803	0.023145	-0.27368	-0.41699	-0.18508	-0.84452	-0.88793	0.974725	-0.93858	-0.50592	0.072438	1								
Magnessium (Mg/L)	0.41933	-0.4914	-0.3107	-0.26374	0.174799	0.257164	0.360384	0.869093	0.720153	-0.79536	0.620809	0.759851	-0.06424	-0.78248	1							
Zinc (Mg/L)	0.457104	-0.0792	0.462048	0.360472	0.279005	0.331136	0.147706	-0.11727	0.502434	-0.17811	0.461151	-0.20434	0.118389	-0.35594	-0.0829	1						
Iron (Mg/L)	0.379875	0.397992	0.376614	0.081385	0.439247	0.557234	0.233915	0.121466	0.141644	0.080034	0.216314	0.180304	-0.81558	0.014669	-0.03559	0.233483	1					
Calcium (Mg/L)	0.621305	-0.40656	0.378899	-0.32445	-0.00472	0.46381	0.584433	0.568014	0.68107	-0.62494	0.632942	0.52497	-0.11741	-0.68853	0.68205	0.478349	0.272071	1				
Manganese (mg/L)	-0.31214	0.487061	0.536082	-0.20792	-0.32048	-0.06685	0.006702	-0.56152	-0.7519	0.759915	-0.65745	-0.29926	-0.38953	0.805003	-0.64299	-0.27766	0.437597	-0.32316	1			
Nickel (mg/L)	0.119245	-0.71502	0.297747	-0.33812	-0.07606	0.117564	0.555363	0.279719	0.478418	-0.33411	0.277134	0.307794	0.232436	-0.40621	0.6237	0.242701	-0.16368	0.762362	-0.33161	1		
Chromium (Mg/L)	-0.85188	0.289401	0.140908	0.009232	-0.20806	-0.37675	-0.11436	-0.75127	-0.84345	0.896605	-0.93238	-0.51692	0.18863	0.94057	-0.69934	-0.45896	-0.15017	-0.78478	0.62615	-0.43483	1	
Chlorophyll a	0.571267	0.271716	-0.23721	-0.17434	-0.18004	-0.32332	-0.34745	0.439288	0.029078	-0.3429	0.19893	0.724527	-0.26414	-0.25418	0.382384	-0.32891	0.161455	0.18422	-0.00745	-0.07387	-0.40022	1