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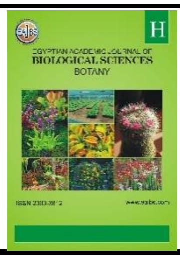

Water Chemistry, Microscopy and Algal Pigment Concentration Analyses of Phytoplankton in the Western and Eastern Parts of the Lagos Lagoon.

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ABSTRACT

The phytoplankton community using microscopy and algal pigment concentrations at the western and eastern parts of the Lagos lagoon were monitored from November, 2015 to April, 2016 in relation to water chemistry changes. The phytoplankton spectrum and water quality parameters showed monthly variations linked with flood water inflow connected to the rainfall distributive pattern and tidal water incursion into the lagoon. Whereas salinity, total dissolved solids, conductivity, acidity, dissolved oxygen, total hardness and sulphate generally increased from November to April during the study period, total suspended solids, silica, pH and biological oxygen demand reduced likewise for both parts of the Lagos lagoon. Microscopy revealed a total of 17 phytoplankton species that consisted of three (3) major divisions. Diatoms (93.88%), blue-green algae (5.91%) and green algae (0.21%). Notable species were *Aulacoseira granulata* var. *angustissma*, *Coscinodiscus radiatus*, *Thalassionema nitzschioides* and *Oscillatoria sancta*. The occurrence of *Aulacoseira granulata* var. *angustissma* and *Oscillatoria sancta* clearly defined the low salinity period (wet season effect) in November within the lagoon at both the western and eastern portions. On the other hand the occurrence of *Coscinodiscus radiatus*, *Thalassionema longissima* and *Thalassionema nitzschioides* recorded in brackish water conditions reflected a period of increased salinity (dry season effect). Chlorophyll *a* estimates ranged between 8 and 19 µg/L, chlorophyll *b* was from 0.5 to 2.8 µg/L and phaeophytin *a* levels were between 0.1 and 0.4 µg/L. For the western part of the Lagos lagoon, chlorophyll *a* was positively correlated with chlorophyll *b* and phaeophytin *a*, whereas for the eastern part, phaeophytin *a* was positively correlated with chlorophyll *a* but negatively correlated with chlorophyll *b*. Present species diversity and number of individuals (as determined by microscopy) show an obvious reduction in these parameters compared to previous studies. The negative correlation effects of heavy metals especially in the western axis of the lagoon are possibly limiting primary productivity in the phytoplankton crop. Nutrients are probably not readily bioavailable for commensurate photosynthetic processes.

INTRODUCTION

Phytoplankton contributes at least twenty-five percent of the world's vegetation and constitutes the base of the food web in aquatic ecosystems (Jeffrey and Vesk, 1997). The phytoplankton constitutes plant drifters of the aquatic environment, which are usually microscopic. They form the first step in the aquatic food chain with the zooplankton forming the second step (Onyema and Okedoyin, 2017). Diatoms, dinoflagellates, blue-green algae, chlorophytes and so on are some important groups of phytoplankton in brackish and marine ecosystems. Nutrients and other chemical characteristics are important in the occurrence, growth and development of phytoplankton forms in water (Agribas *et al*., 2017). Spatio-temporal or seasonal variations and regimes of these environmental factors are crucial in the levels and estimates of phytoplankton diversity, abundance or density of individuals as well as estimated levels of algal pigments recorded per time (Onyema *et al*., 2017). Algal pigment concentrations are currently applied to quantify and qualify phytoplankton communities (Wu *et al*., 2014).

Hitherto, a large number of research on phytoplankton assemblages have been carried out by using microscopy especially in Nigeria since the middle of the last century (Fox, 1957; Hendey, 1958; Nwankwo, 1988; Onyema, 2008a, b; Onyema, 2017). These studies were conducted by using microscopes to investigate the diversity and variations in phytoplankton communities. This method requires key taxonomic expertise to be effective and successful. However, the observance of very small phytoplankton forms or groups such as the femto, pico and nanoplankton is a limiting reality to this method. On the other hand, algal pigments types and concentrations are known to be useful in qualifying and quantifying phytoplankton communities successfully in recent years (Wu *et al*., 2014; Onyema *et al*., 2016; Agribas *et al*., 2017; Onyema and Akanmu, 2017). Photosynthetic pigments are also indicators of specific groups and this method apart from microscopy is known to have the advantage of processing a large number of samples per time and easily too.

Studies from the Lagos lagoon from at least the last seven decades have been chiefly by microscopy (Fox, 1957; Hendey, 1958; Nwankwo, 1988; Onyema, 2008a). More recently in the coastal region are studies related to the use of photosynthetic pigments or algal markers. These studies include Kadiri (1993); Ogamba *et al*. (2004); Nwankwo *et al*. (2012); Onyema and Omokanye (2017); Onyema *et al*. (2016); Onyema and Akanmu (2017; 2018); Akanmu (2018 in press). Additionally, algal pigments especially chlorophyll *a* are generally used as a convenient proxy for phytoplankton biomass (Onyema, 2016). Photosynthetic pigments are also considered as indicators for the physiological conditions of a phytoplankton community (Agirbas *et al*., 2017). They also indicate environmental conditions and trophic status for a given area (Roy *et al*., 2006).

The aim of this study was to investigate the phytoplankton at the western and eastern part of the Lagos lagoon using microscopy and pigment concentration analyses.

MATERIALS AND METHODS

Description of Study Site:

Lagoons represent 15% of the world coastal zone and their productivity results from the interaction between oceanic and continental inputs, which enable them to play a considerable biological and economical role, far beyond their seemingly limited geographical extent (Onyema, 2017). The creeks and lagoons of southwestern Nigeria, apart from their ecological and economic significance, serve also as sites for the disposal of an increasing array of waste (Onyema, 2007a). They are often highly productive habitats for a variety of plants and animals and serve as nurseries for prawns and shrimps and also sites for harbours, wharfs, agriculture, industries, and recreation (Akpata *et al*., 1993).

The Lagos lagoon is located in Lagos state, Nigeria. It has a surface area of 208km^2 (FAO, 1969), and an average depth of about 1.5 m. It is open all through the year to the Atlantic Ocean via the Lagos harbour and experiences semi-diurnal tidal regime. Tidal Sea water incursion and fresh water from adjourning rivers determine the lagoonal environment. Owing to the dynamic inflow of river and seawater incursion, the Lagos lagoon experiences brackish conditions. Brackish water conditions in the lagoon are higher in the dry season and decreases inland (Onyema, 2007b).

It is possible to hypothetically divide the Lagos lagoon into two, notably the western and eastern parts. Whereas the western part of the Lagos lagoon contains more industrialized communities and companies and receives more unregulated waste discharges and other anthropogenic stressors as compared to the eastern part of the lagoon. The eastern part of the lagoon at low tide receives water inflow from the Epe and Lekki lagoon areas of Lagos. On the other hand the Majidun, Ogudu, Agboyi, Abule eledu, Abule agege and Makoko creeks empty into the western part of the Lagos lagoon for this study. The division between the western and eastern part of the Lagos lagoon is a straight line south of the Ofin area of Ikorodu in Lagos (Longitude 6°32′0″ and Latitude 3°30′38″). Whereas the western station for collection of samples was located at Longitude 6°31′6″, Latitude 3°25′25″, the eastern part was located in Longitude 6°32′0″, Latitude 3°30′38″ (Fig. 1).

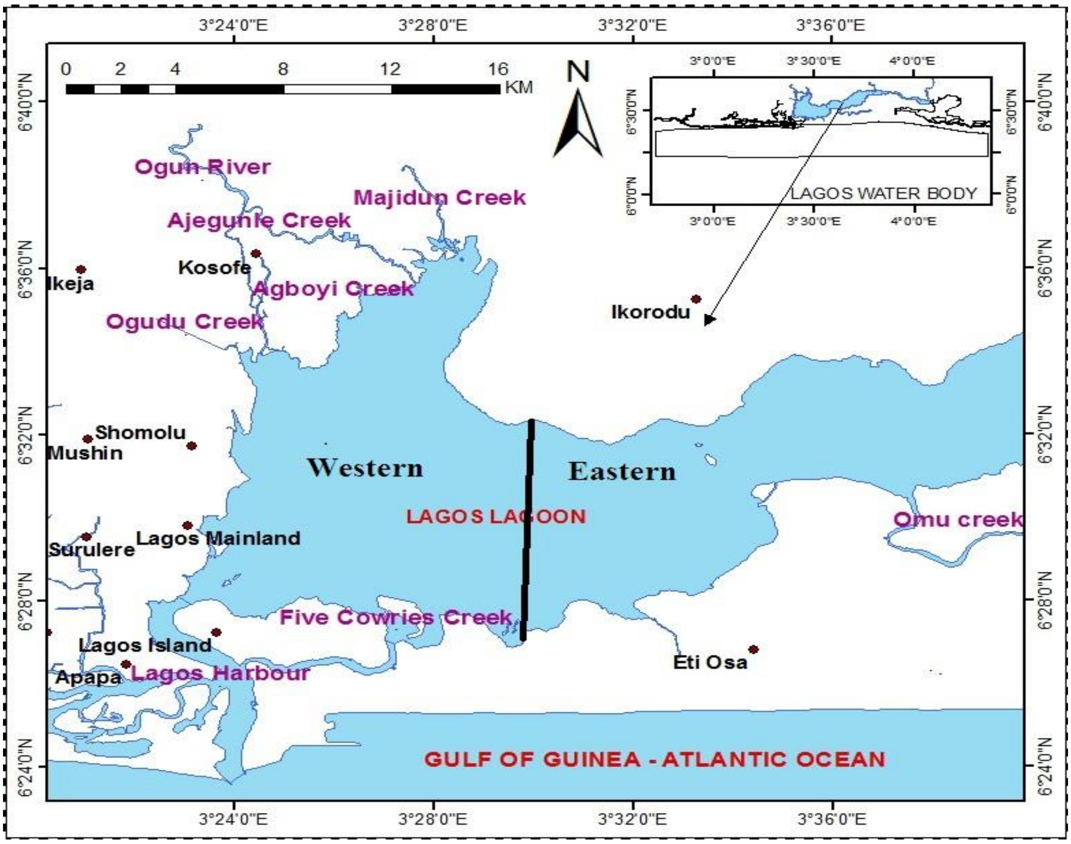

Fig. 1: The Lagos lagoon showing the Western and Eastern part of the study areas

Collection of Samples:

The western and eastern parts of the Lagos Lagoon were sampled for six months (November, 2015 – April, 2016). Water sampling was carried out between 9.00 and 11.00 am each sampling day. Plankton sampling was also collected. Water samples were collected for each month using 75cl plastic containers with each container indicating the sample area and month of collection. Plankton samples were collected by hauling a standard plankton net of 55 µm mesh size horizontally with a sample bottle attached to a motorized boat at low speed (<4 km/h) for 5mins. The filtrate in the attached sample bottle was transferred into a well-labeled plastic container with screw caps, indicating the name of the site, date of collection and the period on the attached label. Samples were preserved in diluted 10% formalin and transported to the laboratory for further analysis of the plankton samples.

Phytoplankton Analysis (Microscopy):

Plankton sample was first gently mixed and the sample inverted for at least 60 seconds. Samples were then concentrated to 10 ml. Five drops (using a long nose disposable pipette / dropper) of the concentrated sample (10 ml) were investigated differently at different magnifications (50X, 100X and 400X) using an OLYMPUS CH binocular microscope with calibrated eyepiece (X10) and the average recorded. To create a suitable plankton sample mount, a disposable pipette / dropper was used to take in at least 1.5ml of the sample after gently shaking properly again. This was then allowed to stand for at least 5 minutes. One or two drops of sample with the dropper was then gently dropped on a glass-slide (7.5 cm by 2.5 cm) while placed on a flat laboratory table and covered with a cover glass-slide (2 cm by 2 cm). The mount was then placed on the microscope stage, fitted in and all transects (views) thoroughly observed and counted for phytoplankton (cells, filaments, colonies). The drop count microscope analysis method was used to count and estimate the total number of phytoplankton (algal) individuals against the different species present. Each sample drop from the dropper accounts to 0.1ml. Outcomes are evaluated as cells, filaments, colonies per ml. The values were recorded as numbers of organisms per ml. Final data were presented as number of organisms (cells, filaments, colonies and whole organism) per ml.

Algal pigment Analysis:

Chlorophyll concentration in water samples was determined using a spectrophotometer with a 2 nm spectral bandwidth. This method is prepared in conjunction with guidelines from EPA Method 446.0, Revision 1.2, 1997 and Standard Methods for the Examination of Water and Wastewater, 20th Edition, Method, 10200H (APHA, 2012). A 200 mL aliquot of the water sample is filtered, in a dark room, through a membrane filter. The pigment is extracted from the filter through maceration, and centrifugation in 90% acetone. The extract is then analyzed, before and after acidification, using a spectrophotometer. The algal pigments were determined using different computational formulae as reported in Onyema and Akanmu (2017).

Statistical Analysis:

Standard deviation on a normally distributed data was used to treat the water chemistry and other data. Pearson rank correlation was used on normally distributed data set of water chemistry parameters, algal pigments, species diversity and abundance data from both parts of the lagoon.

RESULTS

Physico-chemical Parameters:

The minimum, maximum, mean and standard deviation values at the Western and Eastern axis of the Lagos lagoon between November, 2015 and April, 2016 are presented in Table 1. Within the Lagos lagoon and for the western and eastern axis, the surface water temperature ranged between 26 and 33 ^{0}C and rainfall volumes during the period was between 17.4 and 202.0 mm. The highest value was recorded in March and the lowest was recorded in December. Total suspended solids varied between 1 and 22 mg/L with the highest in November (Western) and lowest in April (Western). Total dissolved solids varied between 82.0 and 18024.5 mg/L while pH ranged between 6.94 and 7.36 with lowest recorded in March in the Western axis as against the highest in December and recorded for the Eastern part. The salinity values ranged between 0.08 and 17.32 $^0/_0$, with the highest value recorded in March in the Western axis and the lowest value was recorded in November and in the Eastern side. Conductivity recorded during the period ranged between 149.3 and 29500 µS/cm. While acidity ranged between 0.8 and 2.4 mg/L. Alkalinity was between 54.7 and 99.9 mg/L whereas total hardness ranged between 15.2 and 3292.9 mg/L. The highest value was recorded in March (Western). Dissolved oxygen ranged between 4.6 and 6.75 mg/L. The highest was recorded in March (Western) while the lowest was recorded in November (Eastern), with a mean value of 5.98 mg/L, 5.93 mg/L for the Western and Eastern axis respectively. Biological oxygen demand values were between 1 and 4 mg/L while and chemical oxygen demand was between 4 and 18 mg/L. Calcium concentration varied monthly and recorded a minimum of 1.12 mg/L in November at Eastern axis and a maximum of 194.16 mg/L in March at the Western part. Nitrate varied between 0.19 and 9.74 mg/L, phosphate ranged from 0.22 and 3.34 mg/L with the highest in January and the lowest in March. The sulphate concentration ranged between 4.9 and 1352 mg/L with the highest concentration recorded in March (Western) and the lowest concentration was recorded in November (Eastern). Silica values ranged between 1.3 and 5.3 mg/L. Copper values were between 0.003 and 0.005mg/L, zinc was ranged between 0.01 and 0.062 mg/L, lead values were constant all through the sampling period (<0.001mg/L) for both stations. The iron value showed fluctuation between 0.1 and 0.18 mg/L, while cadmium ranged between 0.001 and 0.0017 mg/L with the highest value recorded in February in the Western axis. On the other hand, manganese values ranged between 0.022 and 0.062 mg/L.

Algal Pigments (Chlorophyll *a*, *b* and Phaeophytin *a*, µg/L):

The chlorophyll estimated levels ranged between 8 and 19.9 µg/L. The highest value was recorded in February (Eastern portion) while the lowest value was recorded in January (Western portion). The mean values were 12.62 and 14.58 µg/L, standard deviation values were ±2.62 and ±3.47 for the Western and Eastern axis respectively. The chlorophyll *b* values ranged between 0.5 and 2.8 µg/L. The highest value was recorded in November in the Western part while the lowest value was recorded in January in the Eastern part of the lagoon. The mean values were 1.32 and 1.18 µg/L and standard deviation values were ±0.83 and 0.80 µg/L for the Western and Eastern axis of the Lagos lagoon respectively. The phaeophytin *a* estimates ranged between 0.1 and 0.4 µg/L. The highest value was recorded in March (Western part) and February (Eastern part) while the lowest value was recorded in November, 2015, January and April, 2016 (Eastern part) and November, January and March (Eastern part). The mean values were 0.18 and 0.2 µg/L, and standard deviation values were ±0.12 and 0.13 µg/L for the Western and Eastern axis of the Lagos lagoon respectively.

In the western axis iron, copper, cadmium and manganese were notably negatively correlated with phaeophytin *a* (r = -0.63, -0.47, -0.53 and -0.34) respectively. Cadmium and manganese were also negatively correlated with chlorophyll *b* (r = -0.39 and -0.25), whereas chlorophyll *a* was negatively correlated with Manganese (r = -0.43).

For the eastern part, chlorophyll *a* was negatively correlated with all the heavy metals investigated notably zinc, iron, copper, cadmium and manganese and recorded r = -0.47, -0.67, -0.65, -0.12, -0.44 respectively. However, Chlorophyll *b* was negatively correlated with iron, copper and cadmium by r = -0.37, -0.04, and -0.37. Phaeophytin *a* was additionally negatively correlated with zinc, iron and copper (r = -0.20, -0.08 and -0.25).

Table 1:Mean and standard deviation values of water chemistry for the Western and Eastern axis of the Lagos lagoon (November, 2015 – April, 2016).

PARAMETERS	Minimum		Maximum		Mean		±STD	
	Western	Eastern	Western	Eastern	Western	Eastern	Western	Eastern
WATER CHEMISTRY								
Water temperature (°C)	26	27.5	30.8	33	29.3	30.33	1.8	2.36
Rainfall (mm)	17.4	17.4	202	202	99.43	99.43	68.37	68.37
pH @ 25°C	6.94	7.16	7.31	7.5	7.11	7.34	0.14	0.11
Conductivity (µS/cm)	1211.4	149.3	29500	28300	21118.6	16398.27	10978	10410.2
Total Suspended Solids (mg/L)	1	1	22	22	7.25	7.5	9.91	9.81
Total Dissolved Solids (mg/L)	665.1	82	18024.5	17377	13062.85	10074.27	6749.54	6383.09
Salinity (‰)	0.62	0.08	17.32	16.7	12.26	9.4	6.49	6.13
Acidity (mg/L)	0.8	0.8	2.4	1.7	1.5	1.07	0.6	0.34
Alkalinity (mg/L)	54.7	61.2	99.9	99.5	86.2	89.62	16.36	14.33
Total Hardness (mg/L)	117.6	15.2	3292.9	2665.5	2317.43	1499.6	1226.41	944.06
Dissolved Oxygen (mg/L)	4.7	4.6	6.75	6.73	5.98	5.93	0.74	0.79
Biological Oxygen Demand (mg/L)	1	1	4	3	2.33	2	1.37	0.89
Chemical Oxygen demand (mg/L)	5	4	18	18	12	10.83	5.59	5.46
Nitrate (mg/L)	0.19	3.87	5.77	9.74	3.11	6.33	2.1	2.55
Sulphate (mg/L)	38	4.9	1352	1280	946.8	724.13	505.81	471.51
Phosphate (mg/L)	0.22	0.22	1.2	3.34	0.55	1.17	0.38	1.18
Silica (mg/L)	1.3	1.5	5.3	5.2	2.45	2.72	1.46	1.29
Zinc (mg/L)	0.01	0.014	0.056	0.062	0.03	0.03	0.02	0.02
Iron (mg/L)	0.074	0.092	0.18	0.18	0.11	0.13	0.04	0.03
Copper (mg/L)	0.003	0.003	0.004	0.005	0	0	0	0
Cadmium (mg/L)	0.0007	0.0008	0.0017	0.0017	0	0	0	0
Manganese (mg/L)	0.022	0.016	0.062	0.058	0.04	0.04	0.01	0.01
ALGAL PIGMENTS								
Chlorophyll *a* (µg/L)	8	10.1	14.9	19.9	12.62	14.58	2.62	3.47
Chlorophyll *b* (µg/L)	0.7	0.5	2.8	2.7	1.32	1.18	0.83	0.8
Phaeophytin *a* (µg/L)	0.1	0.1	0.4	0.4	0.18	0.2	0.12	0.13

Phytoplankton (Microscopy):

Microscopic examination revealed a total of 17 phytoplankton species belonging to diatoms (11 taxa from seven genera) as presented in Table 2, blue-green algae (three taxa from two genera) and green algae (two taxa from two genera). Whereas the diatoms recorded 93.88%, the blue-green algae recorded 5.91% and the green algae contributed 0.21% in terms of numbers of organisms per ml. *Aulacoseira granulata* var. *angustissma* was recorded only in November, 2015 and was more at the eastern than the western part of the lagoon. On the other hand, the dry season months (December - April) recorded species such as *Coscinodiscus radiatus* which was more prevalent at the western than the eastern part of the lagoon. *Oscillatoria sancta* represented periods of low salinity at both stations within the lagoon for November and December, 2015.

The western part of the Lagos lagoon recorded more phytoplankton cells in terms of number in the low salinity (wet) month (November) while the eastern part recorded more phytoplankton cells and more diversity in the brackish water (dry) months (December - April). Higher phytoplankton taxa were recorded in the dry than in the wet season at both parts of the Lagos lagoon.

Table 2: The Composition and Abundance of Phytoplankton at the Western and Eastern parts of the Lagos Lagoon, Lagos (November, 2015 - April, 2016).

PHYTOPLANKTON TAXA	NOV.		DEC.		JAN.		FEB.		MAR.		APR.	
	2015				2016							
	W	**E**	**W**	**E**	**W**	**E**	**W**	**E**	**W**	**E**	**W**	**E**
DIVISION: BACILLARIOPHYTA												
CLASS: BACILLARIOPHYCEAE												
ORDER I: CENTRALES												
Aulacoseira granulata var. *angustissma* Muller	10	3870	-	-	-	-	-	-	-	-	-	-
Coscinodiscus radiatus Ehrenberg	-	-	15	15		10	25	20	150	35	185	10
Coscinodiscus centralis Ehrenberg	5	-	-	-	-	-	-	-	15	10	-	-
Coscinodiscus stellaris Grunow	-	-	5	-	-	-	-	-	-	-	-	-
Coscinodiscus lineatus Ehrenberg	-	-	-	5	-	-	-	-	-	-	-	5
ORDER II: PENNALES												
Biddulphia sinensis Greville	-	-	-	-	-	-	-	-	-	-	-	5
Asterionella formosa Hassal	-	5	-	-	-	-	-	-	-	-	-	-
Nitszchia longissima Ehrenberg	-	-	-	-	-	-	-	-	-	-	-	5
Synedra crystallina Kutzing												
Thalassionema longissima Cleve and Grunow	5	-	10	-	10	-	-	-	-	-	-	-
Thalassionema nitzschioides Cleve and Grunow	-	-	-	-	50	5	-	15	15	-	-	-
ORDER III:CYMBELLALES												
Cymbella sp.	-	-	-	-	-	5	-	-	-	-	-	-
DIVISION: CHLOROPHYTA												
CLASS: CHLOROPHYCEAE												
ORDER I:VOLVOCALES												
Volvox sp.	-	5	-	-	-	-	-	-	-	-	-	-
ORDER 11: CLADOPHARALES												
Cladophora glomerata Linnaeus Kutzing	-	-	-	-	-	-	5	-	-	-	-	-
DIVISION: CYANOPHYTA												
CLASS: CYANOPHYCEAE												
ORDER I: HOMOGONALES												
Anabaena spiriodes Klebahn	-	20	-	-	-	-	-	-	-	-	-	-
Oscillatoria limnetica Bory	-	-	-	-	10	-	-	-	-	-	-	10
Oscillatoria sancta Kutzing	175	25	25	20	-	-	-	-	-	-	-	-
Number of Species (S)	**4**	**5**	**4**	**3**	**3**	**3**	**3**	**2**	**3**	**2**	**11**	**5**
Total Number of Individuals (N)	**195**	**3925**	**55**	**35**	**70**	**20**	**30**	**35**	**180**	**45**	**185**	**35**

***W – Western, E - Eastern**

DISCUSSION

The hydrological characteristics for this study showed trends that were related to seasonal changes in the region and effects of saltier water mixing within the Lagos lagoon. For instance, the inverse relationship between rainfall with salinity observed in the trends of physico-chemical parameters reflected the seasonality of these factors. According to Otitoloju, (2018), chemical measurements reflects water quality at a given time while biological assessment reflects conditions that have occurred in a given environment over a long period of time. The high salinity values during the dry season may be attributed to low rainfall, high evaporation rate coupled with low humidity, increased tidal seawater incursion, reduced flood water and water inflow from associated rivers and creeks. Onyema *et al*. (2003) and Emmanuel and Onyema (2007) are of the view that the salinity regime in the Lagos lagoon is seasonal with high salinities reported from December to April and low salinities observed usually between May and November.

The nature of the water was alkaline which is typical of the marine environment. Most tropical waters have low nutrient values, a feature considered common for natural and polluted waters. The higher levels of nitrate and phosphate in November or wet season may be due to the effect of direct discharges into the lagoon, enrichment from wetlands and subsequent run-offs. This corresponds with the observation of Nwankwo (2004) for coastal waters of Southwestern Nigeria.

The comprehensive monitoring of phytoplankton community composition is required to ensure sustainable management of fisheries resources (Agirbas *et al*., 2017). The photosynthetic pigments have strong chemotaxonomic associations that can be exploited to map the oceanographic abundance and composition of the phytoplankton community. It is also important to note that throughout the study the western axis was always more saline (brackish) than the eastern part. This is largely due to the proximity of the Western part to the Lagos harbour which is the chief source of saline/seawater inflow to the Lagos lagoon. Additionally, the Eastern axis is also close and connected to the Epe and Lekki lagoons which drain fresh/low salinity waters into that axis of the Lagos lagoon regularly. The Lagos lagoon content then drains continually to the Atlantic ocean via the Lagos harbour. The western portion is also known to receive more waste mixed flows and discharges from some of the most concentrated, industrialized and populated parts of the Lagos metropolis.

Changes in the phytoplankton spectrum from the western to the eastern parts as well as freshwater/floodwater inflows diluted the lagoon water and resulted in freshwater conditions prior to and in November. This allowed for the development and occurrence of *Aulacoseira*, *Volvox* sp. and so on which are known to exist under freshwater conditions. On the other hand, the tidal seawater inflow through the Lagos harbour into the lagoon increased salinity especially in the dry season (December – April). This increased salinity effect was more pronounced in the western than the eastern part of the lagoon per month. This elevated saline condition encouraged the development of estuarine/marine phytoplankton species such as *Cosinodiscus*, *Thallasionema* and so on. The phytoplankton community shift from freshwater phytoplankton species to marine species is a reflection of the shift in the hydroclimatic condition of the lagoon ecosystem from freshwater to marine conditions. Dominant species recorded during the study period include *Aulacosiera*, *Coscinodiscus* sp. and *Oscillatoria* sp. The phytoplankton is the basis of aquatic productivity and any alteration in their constitution would have a detrimental effect on the food chain and the entire community structure.

After the diatoms, the next dominant group in the lagoon during the study was the Cyanophyceae. *Oscillatoria* and *Anabaena* have been implicated as indicators of organic pollution in surface waters in the region (Nwankwo, 2004, Onyema, 2013). Changes in the biodiversity of these primary producers could make pollution management and environmental biomonitoring a bit difficult because of the role played by these delicate organisms.

Studies into algal pigment analysis such as these and in addition to microscopic examination provide information on phytoplankton assemblages and their physiological status. Algal pigments levels for chlorophyll *a, b* and phaeophytin *a* were generally higher in the east than the western part of the Lagos lagoon suggesting a more biologically richer and healthier ecosystem. As the dry season set in and progresses, the difference in the levels of primary productions showed, with higher levels and estimates from the eastern part of the Lagos lagoon. The eastern region is known to have few or much less human activities, households and industries than the western more populated and industrialized parts. Furthermore, chlorophyll concentrations were also lower in the wet than the dry season months. Higher primary productivity in the dry season months gave rise to higher chlorophyll estimates which lead to a similar trend in dissolved oxygen concentrations since oxygen is a by-product of photosynthesis.

The very low abundance of phytoplankton species in December and February may probably be due to stress conditions as a result of sharp fluctuations in water chemistry conditions. The stress condition might be an explanation for very few species able to tolerate the changes from fresh through brackish water conditions. Chlorophyll levels were higher in the dry season months than in the wet season month of November confirming earlier observations by Kadiri (1993) and Ogamba *et al*. (2004) for some coastal waters of Nigeria. This may be attributed to high light intensity, reduced cloud cover and more stable conditions which permitted maximum use of available nutrients by the phytoplankton, hence an increase in biomass in the dry season. A similar situation has been reported by Onyema and Emmanuel (2009). Furthermore, Onyema *et al.* (2003, 2007) are of the view that higher insolation, increased hydrological stability and marine situation are important encouraging factors for primary production in the Lagos lagoon. Besides the ample availability of nutrients in the study areas, values for chlorophyll *a*, chlorophyll *b* and phaeophytin *a* were comparatively low especially in the rainy periods which likely indicated limited phytoplankton production probably due to increased instability in the hydrological flow conditions.

The limiting effect of heavy metals on primary productivity was evident from this study. For instance the eastern axis with reduced pollution pressure recorded higher concentrations of algal pigments than the Western axis with higher nutrient levels but more pollution from the metropolis. Additionally, the negative effects of manganese, cadmium, iron and copper on algal pigments suggests that it is making the nutrients not bio-available for the physiological processes of phytoplankton cells. A similar situation of heavy metal limiting primary productivity has been suggested by Nwankwo (1993) in his work on cyanobacteria bloom species in southwestern Nigeria. The author was of the opinion that the nutrients may not have reached the algae because of inhibitory effects of heavy metals or due to the formation of complexes which precipitated beyond the reach of the algae. The pollution of the aquatic environment with heavy metals has become a world-wide problem, because they are indestructible and most of them have toxic effects on organisms (Otitoloju, 2018). According to Farombi *et al*. (2007), heavy metal contamination may have devastating effects on the ecological balance of the recipient environment and diversity of aquatic organism.

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