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The influence of environmental variables on algal pigment in the western Lagos lagoon, Nigeria

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Abstract

Algal pigments are useful in the estimation of primary production and phytoplankton biomass. Chlorophyll a, chlorophyll b and phaeophytin a are notable algal pigments in this regard. Open lagoon are coastal environments known to exhibit continuous environmental gradients daily and seasonally. Algal pigments and environmental variables of the western parts of the Lagos Lagoon were investigated for six month at seven stations (November, 2015 – April, 2016). The environmental indices reflected seasonal changes related to rainfall distribution pattern and tidal sea water incursion. Air temperature (25 - 35 ^{0}C), water temperature (26 – 32.5 ^{0}C), total dissolved total (656 – 19611.31 mg/L), dissolved oxygen (4.15 - 6.83 mg/L), transparency (22.5 and 135cm), pH (6.73 - 7.59), salinity (23.24‰) and calcium (4.69 - 258.17mg/L) recorded increased values in the dry than wet season. On the other hand biological oxygen demand (1 - 4mg/L), chemical oxygen demand (4 – 18mg/L), total suspended solids (1 - 38mg/L), nitrate (0.19 - 12.85mg/L), copper (0.002- 0.004mg/L), zinc (0.01 and 0.057) and cadmium (0.0006 - 0.0018mg/L) recorded higher values in the wet season. Chlorophyll a, chlorophyll b and pheophytin a values were higher in the dry season. Notable correlation coefficient (r) was recorded between chlorophyll a and nitrate ($r = 0.73, p < 0.05$), phosphate ($r = -0.82, p < 0.01$), chemical oxygen demand ($r = -0.35, p < 0.01$), biochemical oxygen demand ($r = 0.22, p < 0.01$) and copper ($r = -.387, p < 0.01$). On another hand correlation between chlorophyll b and rainfall ($r = 0.62, p < 0.01$), pH ($r = -0.31, p < 0.05$), zinc ($r = 0.44, p < 0.05$), manganese ($r = 0.36, p < 0.05$) and cadmium ($r = 0.33, p < 0.05$) were noteworthy. Furthermore phaeophytin a showed a correlated relationship with rainfall ($r = 0.39, p < 0.01$), dissolved oxygen ($r = 0.31, p < 0.05$) and cadmium ($r = -0.36, p < 0.05$). Recorded chlorophyll a values place the western Lagos Lagoon between the mesotrophic and eutrophic status. Increasing nitrate (nutrient) levels coupled with the reduced rainfall events led to the development of more algal cells (phytoplankton) thus higher algal pigments level within the western Lagos lagoon ecosystem.

Keywords: Physico-chemical parameters; estuarine lagoon; Algal pigment; Lagos**.**

Introduction

An open lagoon ecosystem is a dynamic and complex ecotype and is influenced largely by the inflow from the sea and adjacent fresh waters (Onyema, 2009). Coastal Lagoons also inadvertently serve as sinks for the disposal of domestic, municipal and industrial wastes in Lagos and the environs. With regards to literature, there are ten lagoons in South-western Nigeria namely: Yewa, Ologe, Badagry, Iyagbe, Lagos, Kuramo, Onijegi, Epe, Lekki and Mahin lagoons from the west to the east (FAO, 1969; Webb, 1958; Afinowi, 1972; Yoloye, 1974, 1976; Nwankwo, 2004; Onyema, 2008) with two of them (Kuramo and Onijegi lagoons) currently described as "dying" lagoons (Onyema, 2013).

Planktons are drifting organisms (animals, plants or bacteria) that inhabit the pelagic zone of the aquatic ecosystems and the phytoplankton are the foundation of the aquatic food chain. Phytoplankton species are key aquatic primary producer and provide food for higher trophic level organisms by an autotrophic process of photosynthesis. Each phytoplankton cell contain algal pigments such as chlorophylls. (Lee, 2008) There are six different chlorophylls that have been identified (Wetzel, 2001). The different forms (*a, b, c, d, e* and *f*) each reflect slightly different ranges of green wavelengths. Chlorophylls *a* have been widely reported as the primary molecule responsible for photosynthesis (Hakanson, 2005) and present in all photosynthesizing organisms, from land plants to algae and cyanobacteria. The dynamics of algal pigment concentrations reflect the same for the level of primary production in the environment especially in the aquatic environment. In natural situations in plants chlorophyll, the Chlorophyll *a* and *b* appears in a ratio of 3:1 respectively. This molecule is used in photosynthesis, as a photoreceptor as they absorbed light energy (Hakanson, 2005).

Connectedly, algal studies in the Lagos area have indicated high levels of phytoplankton production in terms of individual cell biomass especially for the Lagos lagoon (Nwankwo, 1988, 1996, 2004). Changing hydro-environmental characteristics are the determinants of the phytoplankton standing crop at any time (Onyema, 2013). According to Onyema (2007), phytoplankton satisfy conditions to qualify as suitable indicators in that they are simply capable of qualifying changes in water quality, applicable over large geographical areas and can also furnish data on background conditions and natural variability.

However, the levels of algal pigments in water are influence by environmental variables such as temperature, salinity, conductivity, biochemical oxygen demand, chemical oxygen demand, dissolved oxygen, pH, alkalinity, acidity, nitrite, sulphate, phosphate, zinc, manganese, cadmium and copper, to mention few. According to Lee (1999), higher Phytoplankton biomass would directly reflect in a higher level of chlorophyll *a* in such regions. Thus, chlorophyll concentration can be used to estimate the total quantity of plant material or biomass (Sverdrup *et al*., 2006).

Aquatic ecosystems have been suffering significant changes due to anthropogenic activities which eventually reduce biodiversity. Lagoons also inadvertently serve as sinks for the disposal of domestic, municipal and industrial wastes in the region. The Lagos lagoon is notable in this regard and its western more industrialized area are known to be subjected to generally more pollutants per unit time than the Eastern axis.(Ajao,1996; Onyema, 2009)

Here we attempt to investigate the seasonality of algal pigments in the western part of the Lagos lagoon and to provide relevance insight on the influence of environmental variables on algal pigments namely chlorophyll *a*, chlorophyll *b* and phaeophytin *a* dynamics.

Materials and methods

Description of study site

The Lagos lagoon is a large expanse of shallow water which covers for about 208km^2 with an average depth of 1.5m.The Lagos lagoon system is permanently connected to the sea; it is tidal and the largest of the four lagoon systems of the Gulf of Guinea (Webb 1958). This study was majorly carried out in the western transit (Fig 1) of the Lagos Lagoon. The locations and coordinates for sampled stations are highlighted in Table 1.

Collection of water samples

The Lagos lagoon was sampled for six months (November, 2015 – April, 2016). Water samples were collected each month using 75cl plastic containers with each indicating the month of collection at the study site. Sampling was carried out between 08.00am and 12.00pm on each sampling day. The plastic bottles were dipped into the water to collect the water samples and were taken to the laboratory for physical and chemical analysis.

Table 1: Sampling Location and the GPS coordinates in Lagos Lagoon

Image here

S/N	Name	Latitude	Longitude
1.	Agboyi	6° 33' 51.12"	3° 24' 18.72"
2.	Oworoshoki	6° 32' 29.76"	3° 24' 26.28"
3.	Mid Lagoon	6° 31' 15.24"	3° 24' 39.24"
4.	Moba	6° 27' 59.04"	3° 23' 11.04"
5.	Ilubirin	6° 27' 55.8"	3° 23' 48.84"
6.	Makoko	6° 28' 54.12"	3° 23' 37.68"
7.	Okobaba	6° 29' 43.8"	3° 23' 26.52"

Fig. 1: The Lagos Lagoon showing sampling stations

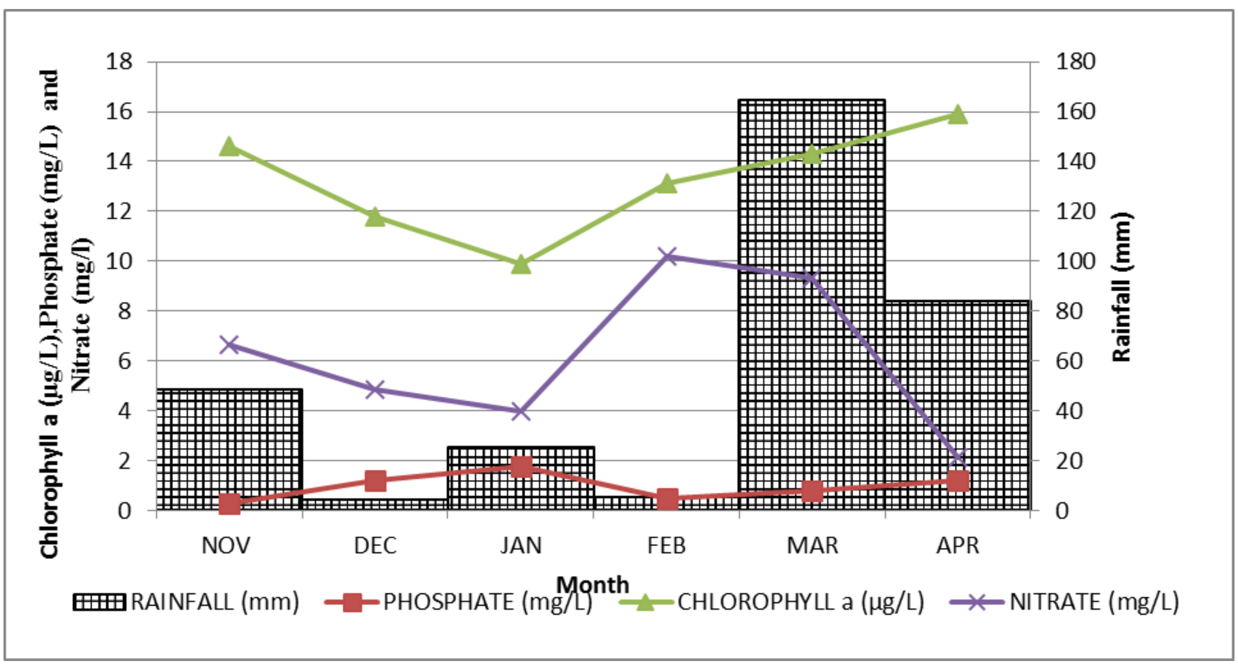

Fig 3: Monthly variations in Rainfall, Phosphate, Nitrate and Chlorophyll *a* at Station 7, (Ilubirin) Lagos Lagoon, (November, 2015 – April, 2016).

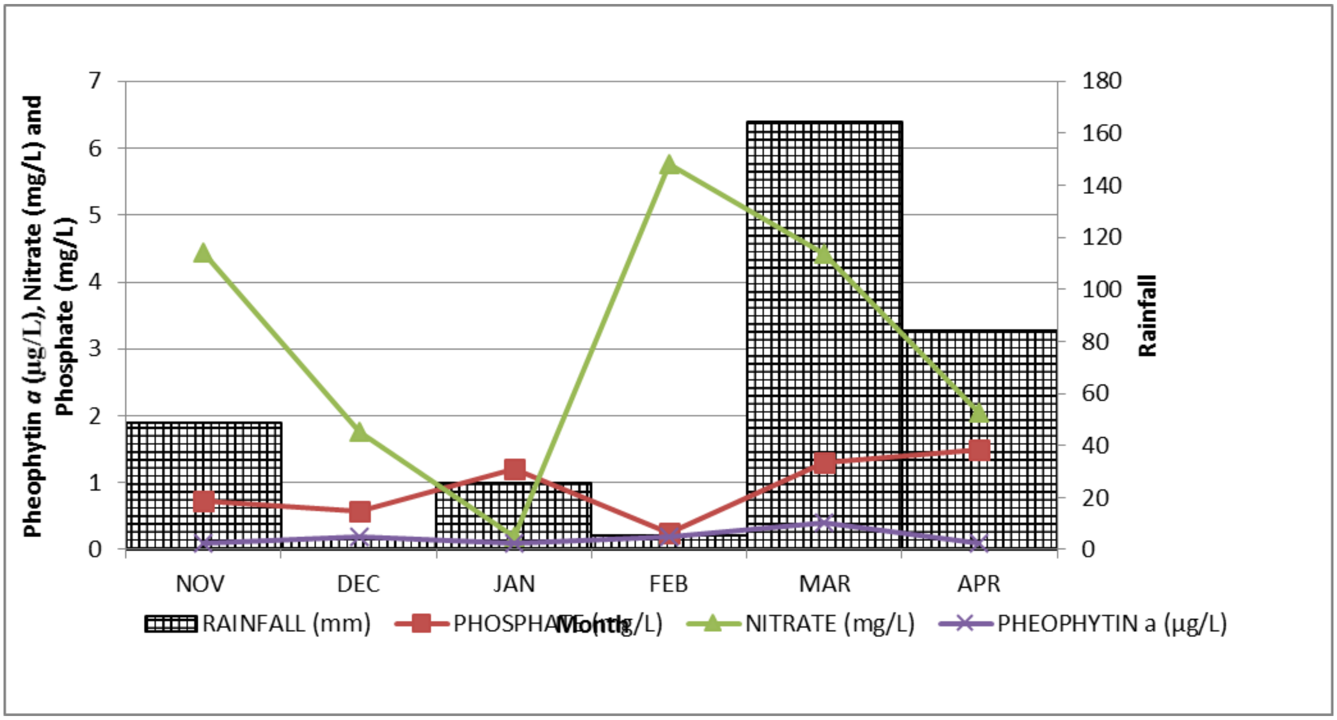

Fig 4: Monthly variations in Rainfall, Phosphate, Nitrate and Pheophytin *a* at Station 4, (Moba) Lagos Lagoon, (November, 2015– April, 2016).

Analysis of environmental variables.

The environmental characteristics were estimated using methods in APHA (1998) and nutrient related parameters were measured with the different HACH Methods.

Algal Pigments Estimation

200 mL, each of deionized water (blank) and samples (Vfiltered) were filtered through 0.45 µm glass fiber filters. Each filter was removed and placed in labeled polypropylene tubes. To each tube was added 3 ml 90% acetone solution, and macerated at 500rpm for 1 min, steeped in the dark for 2 h at 4oC and clarified by filtration and then adjusted to 20 ml (Vextract) with 90% acetone solution. The extract was capped and then store in the dark until analysed. 3ml of the clarified sample extract was transferred to a cuvette and the absorbance measured at 750, 665, 664, 647 and 630nm, using a spectrophotometer (HACH DR 3900). Thereafter, the extract in the cuvette was acidified with 0.1ml of 0.1M HCl solution, gently agitated and allowed to stand for 90sec. The absorbance of the acidified extract was read at 750 and at 665nm. Test results were validated with chlorophyll calibration standards (5-20ug/L). The pigments concentrations were calculated as follows:

1. Chlorophyll-a [corrected; (µg/L)] = 26.7 * (A664b – A665a) * Vextract
   Vfiltered * L
2. Pheophytin-a (µg/L) = 26.7 * [1.7(A665a) – A664b] * Vextract
   Vfiltered * L
3. Chlorophyll-b (µg/L) = 21.03 * (A647b) – 5.43*(A664b) – 2.66*(A630b) * Vextract
   Vfiltered * L

Where:
Vextract = volume of extract (mL)
Vfiltered = volume of sample filtered (L)
L = light path length or width of cuvette, cm
664b, 647b, 630b = corrected absorbance of extract before acidification
665a = corrected absorbance of extract after acidification
The value 26.7 is the absorbance correction factor (A × K)
A = absorbance coefficient for chlorophyll a at 664 nm = 11.0
K = ratio expressing correction for acidification = 2.43

Determination of Statistical Analysis
This was determined by the equation;

$$\sqrt{\frac{\sum (x-\bar{x})^2}{(n-1)}}$$

Determination Of Correlation Coefficient (r)

The correlation between Algal Pigment (chlorophyll a, chlorophyll b and Pheophytin a) abundance and some environmental variable (Temperature, salinity, total, rainfall and nutrient levels [phosphorus and nitrates] was determined by using Spearman Rank correlation analysis (Ogheibu, 2005) and it is given by the equation:

$$r = N\Sigma XY - (\Sigma X)(\Sigma Y)/\sqrt{[N\Sigma X^2 - (\Sigma X)^2][\Sigma Y^2 - (\Sigma Y^2)]}$$

Where r = Correlation coefficient

N= Number of pairs of Scores

ΣXY = Sum of production

ΣX = Sum of X scores

Determination Of Cluster Analysis (CA)

Cluster Analysis (CA), is a statistical tool using PAST (paleontological Statistics), free software for scientific data analysis with function for data manipulation, plotting, univariate and multivariate statistics, ecological analysis, time series and spatial analysis, morphometric and stratigraphy. The variables objects are grouped into classes (Cluster) on the basis of similarities within a class and dissimilarities between different classes. It also helps in interpreting the data and indicates the spatial and temporal patterns. In hierarchical clustering, cluster are formed sequentially by starting with the most similar pair of object and forming higher clusters step by step.

Result

Monthly variations in environmental variables at the upper Lagos Lagoon between November, 2015 and April, 2016 are presented in Table 1-7

Air temperature ranged from 25^{0}C in December to 35^{0}C February while surface water temperature ranged from 26^{0}C in December to 32.5^{0}C in November (fig 2). Rainfall value was low in December (4.1mm) and highest in March (164.4mm) as rainfall exhibited a strongly significant correlation with nitrate ($r = 0.378$; $p < 0.05$). Transparency ranged between 22.5cm (November) and 135.5cm (April), while Total Suspended Solids varied between 1 and 38mg/L with the highest in November. Total Dissolved Solids varied between 656 and 196131.1 mg/L with highest recorded in April and lowest recorded in November and mean value was 2140.57±31093.60 mg/L (fig 3). Total dissolved solid showed positive correlation with dissolved oxygen ($r = 0.316$; $p < 0.05$).

Alkaline conditions, were recorded throughout the study, pH values fluctuated (6.73-7.59) while Alkalinity ranged between 54.7 and 130.7mg/L. correspondingly low acidity was recorded (2.4mg/L). The highest value was recorded in January and lowest in March. Typical of region subjected seasonal tidal inundation, salinity values ranged between 0.40 and 23.24‰ with the highest value recorded in February and lowest value recorded in November; the mean value was 14.13 ‰ ± 6.95. Conductivity recorded during the period ranged between 308.9 and 38800µS/cm. Conductivity mean value during this study was 23803.12 µS/cm ±11518.32.

Total hardness of water ranged between 76.2 and 4217.8 mg/L; the highest value was recorded in February and the lowest value was recorded in November. Recorded chloride values ranged between 201 and 1290.78. Calcium ranged between 4.69mg/L in November to a maximum of 258.17mg/L in February with a mean value of 158.34 ±77.06 mg/L. Magnesium ranged between value of 15.6mg/L in November and high value of 912.01mg/L in February at station 7. The mean value was 512.7±40.64 mg/L.

Dissolved oxygen ranged between 4.15 and 6.83mg/L, highest was recorded in April and lowest was recorded in November, with a mean value of 5.95 ±076 mg/L. Biological Oxygen Demand ranged between 1 and 4mg/L, while Chemical oxygen demand value ranged between 4 and 18mg/L. A strong significant relationship exist between dissolved oxygen and pheophytin a ($r = 0.316$, $p<0.05$) was noted. However, a strong inverse relationship was observed between Biochemical oxygen demand and chlorophyll a ($r = -0.351$, $p<0.05$). Similarly, Chemical oxygen Demand correlated negatively with chlorophyll a ($r = -0.365$, $p<0.05$).

Nutrient regime of the water during showing seasonal trends (Fig 2 and 3) with Nitrate ranging from 0.19 mg/L in January to 12.85 mg/L in March with mean values was 5.17±3.09mg/L. There is a strong inverse correlation between nitrate and biochemical oxygen demand ($r = -0.325$, $p<0.05$). Phosphate concentration ranged from 0.08 mg/L in December at (Station 2) and 1.8 mg/L in February at (Station 4), with mean values of 0.82 ±0.43 mg/L while Silica ranged between 1.2 and 5.3 mg/L with an average mean value was 2.32±1.12 mg/L. Chemical constituent of the water shows Sulphate concentration ranged between 22.9 and 18047mg/L (Fig 2) and Copper values generally low with range between 0.002 and 0.004mg/L. Iron ranged between 0.18 and 0.062 mg/L. The mean value was 0.1748±0.02 mg/L. Other heavy metals such as Zinc ranged between 0.01 and 0.057 mg/L, between 0.0006 and 0.0018mg/L, and Manganese values ranged between 0.011mg/L in February and 0.07mg/L in April.

Phytoplankton biomass as estimated by chlorophyll a show slight variation with values ranging between 8µg/L in January and 19.6µg/L in in February. The average chlorophyll a value was 14.20 ± 2.54µg/L (fig 3) while Chlorophyll b valued ranged between 0.3µg/L in February and 3.3µg/L in March recorded. The mean Chlorophyll b value was 1.16±0.69. Chlorophyll a and copper exhibited a strong inverse relationship indicative of the possible influence of heavy on phytoplankton dynamics (r = -.038, $p < 0.05$). Chlorophyll b and magnesium were negatively correlation (r = -.0.361, $p<0.05$). Pheophytin a showed a similar pattern like other Algal pigment and ranged between 0.1µg/L in January and 0.6µg/L in January (fig 4). The mean pheophytin a values were 0.25±0.16 µg/L. Pheaophyin a and cadmium were, poorly positively correlated (r = -0.364, $p<0.05$).

TABLE 3: THE MINIMUM AND MAXIMUM VALUE OF ALGA PIGMENT ACROSS ALL THE STATION FROM NOVEMBER 2015 - DECEMBER 2016

	ST. 1		**ST. 2**		**ST. 3**		**ST. 4**		**ST. 5**		**ST. 6**		**ST. 7**	
	Min	**Max.**	**Min.**	**Max.**	**Min.**	**Max.**	**Min.**	**Max.**	**Min.**	**Max.**	**Min.**	**Max.**	**Min.**	**Max.**
Chloropyll *a*	9.6	17	11.8	17.5	8.0	14.9	12.6	19.6	9.9	15.9	10.0	16.8	12.8	17.4
Chlorophyll b	1.1	2.1	0.4	3.3	0.7	2.8	0.4	0.9	0.4	2.7	0.3	2.1	0.3	1.4
Pheophytin *a*	0.2	0.6	0.2	0.5	0.1	0.2	0.1	0.4	0.1	0.5	0.1	0.4	0.1	0.6

TABLE 4: Pearson correlation coefficient matrix between environmental variables and Pigments characteristics from stations 1 to 7 in the western Lagos Lagoon.

	RAINFALL	SALINITY	pH @ 25	TOTAL SUSPENDED SOLID	TOTAL DISSOLVED SOLID	SULPHATE	NITRATE	PHOSPHATE	CHEMICAL OXYGEN DEMAND	BIOCHEMICAL OXYGEN DEMAND	DISSOLVED OXYGEN	CHLOROPHYLL *a*	CHLOROPHY *b*	PHEOPHYTIN *a*
RAINFALL (mm)	1													
SALINITY (‰)	0.19	1												
pH@ 25	-0.28	0.345*	1											
TOTAL SUSPENDED SOLID (mg/L)	0.323	-.791*	-0.30	1										
TOTAL DISSOLVED SOLID (mg/L)	0.055	0.256	-0.30	-0.38	1									
SULPHATE (mg/L)	0.201	1.000**	0.344*	-.796	0.254	1								
NITRATE (mg/L)	0.378*	-0.026	0.069	0.392	-0.19	-0.02	1							
PHOSPHATE (mg/L)	-0.16	0.049	0.241	-0.39	0.117	0.044	-.452	1						
CHEMICAL OXYGEN DEMAND (mg/L)	-.567	-.666*	-0.03	0.547**	-0.28	-.676	-0.26	-0.00	1					
BIOCHEMICAL OXYGEN DEMAND (mg/L)	-.487	-.533*	-0.03	0.263	-0.25	-.545	-.325	0.139	0.888**	1				
DISSOLVED OXYGEN (mg/L)	0.480**	0.799**	0.052	-.818	-.316	0.808**	-0.05	0.059	-.760	-.590	1			
CHLOROPHYLL *a* (µg/L)	0.279	-0.004	-0.06	0.223	-0.02	0.002	0.735**	-.382	-.365	-.351	0.029	1		
CHLOROPHY *b* (µg/L)	0.627**	-0.144	-.319	0.127	-0.1	-0.13	0.222	-0.21	-0.22	-0.28	0.185	0.114	1	
PHEOPHYTIN *a* (µg/L)	0.395**	0.029	-0.21	-0.25	0.14	0.039	0.083	-0.05	-0.27	-0.15	0.316*	0.205	0.462**	1

TABLE 5: Pearson correlation coefficient matrix between physico-chemical parameters and Pigments characteristics from Stations 1 to 7 in Lagos Lagoon.

	CALCIUM	MAGNESIUM	SODIUM	POTASSIUM	ZINC	IRON	COPPER	MANGANESE	SILICA	CADMIUM	LEAD	CHROMIUN	NICKEL	CHLOROPHYLL *a*	CHLOROPHYLL *a*	PHEOPHYTIN *a*
CALCIUM (mg/L)	1															
MAGNESIUM (mg/L)	**.954****	**1**														
SODIUM (mg/L)	**.937****	**.987****	**1**													
POTASSIUM (mg/L)	**.995****	**.950****	**.934****	**1**												
ZINC (mg/L)	**.324***	**.324***	**.318***	**.339***	**1**											
IRON (mg/L)	**-.472****	**-.432****	**-.461****	**-.489****	**-.418****	**1**										
COPPER (mg/L)	**-0.242**	**-0.232**	**-0.235**	**-0.271**	**0.282**	**0.158**	**1**									
MANGANESE (mg/L)	**-0.173**	**-0.204**	**-0.235**	**-0.153**	**.370***	**-0.035**	**.504****	**1**								
SILICA (mg/L)	**-.841****	**-.825****	**-.820****	**-.841****	**-.364***	**.497****	**0.002**	**0.007**	**1**							
CADMIUM (mg/L)	**-0.115**	**-0.093**	**-0.13**	**-0.139**	**-.378***	**.342***	**0.033**	**-.322***	**0.195**	**1**						
LEAD (mg/L)	**.a**	**.a**	**.a**	**.a**	**.a**	**.a**	**.a**	**.a**	**.a**	**.a**	**.a**					
CHROMIUN (mg/L)	**.a**	**.a**	**.a**	**.a**	**.a**	**.a**	**.a**	**.a**	**.a**	**.a**	**.a**	**a**				
NICKEL (mg/L)	**.a**	**.a**	**.a**	**.a**	**.a**	**.a**	**.a**	**.a**	**.a**	**.a**	**.a**	**.a**	**.a**			
CHLOROPHY*a* (mg/L)	**-0.011**	**0.111**	**0.114**	**0.021**	**0.174**	**-0.087**	**-.387***	**-0.168**	**0.096**	**-0.142**	**.a**	**.a**	**.a**	**1**		
CHLOROPHY*b*	**-0.137**	**-0.162**	**-0.151**	**-0.115**	**.440****	**-0.1**	**0.248**	**.361***	**0.05**	**-.331***	**.a**	**.a**	**.a**	**0.114**	**1**	
PHAEOPHYTIN *a*	**0.037**	**0.047**	**0.04**	**0.063**	**.385***	**-0.22**	**0.062**	**0.222**	**-0.17**	**-.364***	**.a**	**.a**	**.a**	**0.205**	**.462****	**1**

**. Correlation is significant at the 0.01 level (2-tailed). *. Correlation is significant at the 0.05 level (2-tailed). a. Cannot be computed because at least one of the variables is constant.

<u>Algal pigments and environmental variables</u>

In respect to the similarity that existed between the observed variables, Cluster analysis using the dendrogram tree diagram shows descending pattern of similarity with Dissolved oxygen - Salinity - Sulphate; Nitrate - Chlorophyll a; Chlorophyll b - Rainfall and chemical Oxygen demand - Biological oxygen demand all merge together to form a clusters at a similarity level ranges from 0.64 to 0.9, in the Fig (4) indicating a strong relationship (the higher the similarity level the stronger the relationship).

Algal pigment, Chlorophyll *b*, Pheophytin *a* and Rainfall further merge at a similarity level of 0.4 in the Fig. 4, while Total dissolved solid and Chemical oxygen demand - Biological oxygen demand further merge at a similarity level of 0.5 (moderately related). Further down the cluster chain, Total dissolved solid, Phosphate, pH and Pheophytin *a* all merge to form a bigger cluster at a level of similarity slightly higher than -0.16 indicating poor relationship and finally the two cluster merge at similarity level of -0.32 indicating a strongly poor relationship.

From the dendrogram, Chemical oxygen demand and Biochemical oxygen demand showing strong relationship at a value of 0.86 and Chlorophyll *a*, Chlorophyll *b*, Pheophytin *a* and dissolved oxygen form a cluster at a level less than -0.16 (poor relationship) in Fig. 5 possibly suggestive of pollution.

Heavy metals homogeneity in this study shows classic case of higher level of similarity at 0.9, indicating a stronger relationship while Copper, Zinc, Cadmium, Potassium Calcium, Sodium, Chromium, Lead, Iron, Chlorophyll *b* and Pheophytin *a* merge to form a cluster at a similarity level range from 0.2 – 0.42 (Moderately related). Chlorophyll *a*, Calcium, Potassium, Magnesium, Sodium all form a cluster at similarity level of -0.1 in the Fig. 6 and Iron and Copper shows similar poor relationship as it co-join the bigger Cluster at a similarity level slightly greater than -0.16 (poor relationship).

However, Manganese and Copper shown in the Fig. 7 have a relationship with Chlorophyll *b* and Pheophytin *a* at a similarity level of 0.48 (moderately related) and Cadmium Chlorophyll *a* further merge with the cluster at a similarity level of -0.16 (poorly related).

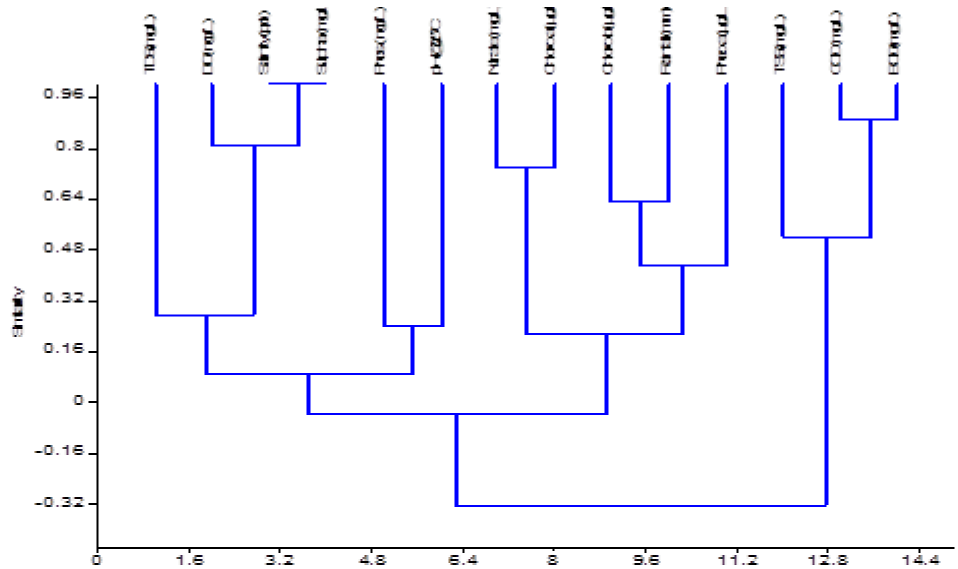

Fig. 5: Environmental parameters and algal Pigments across the sampling stations (November, 2015 – April, 2016).

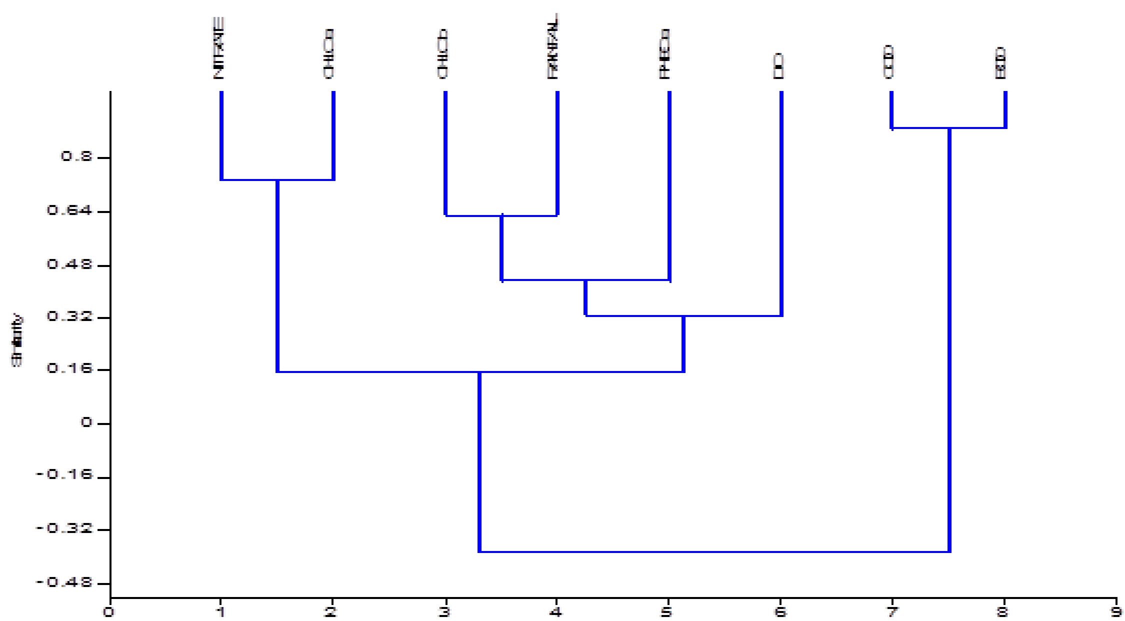

Fig. 6: Environmental Variables (COD, BOD and DO), algal Pigments (Chloropyll *a*, Chlorophyll *b* and Pheophytin *a*) and Rainfall across all the sampling stations (November, 2015 – April, 2016).

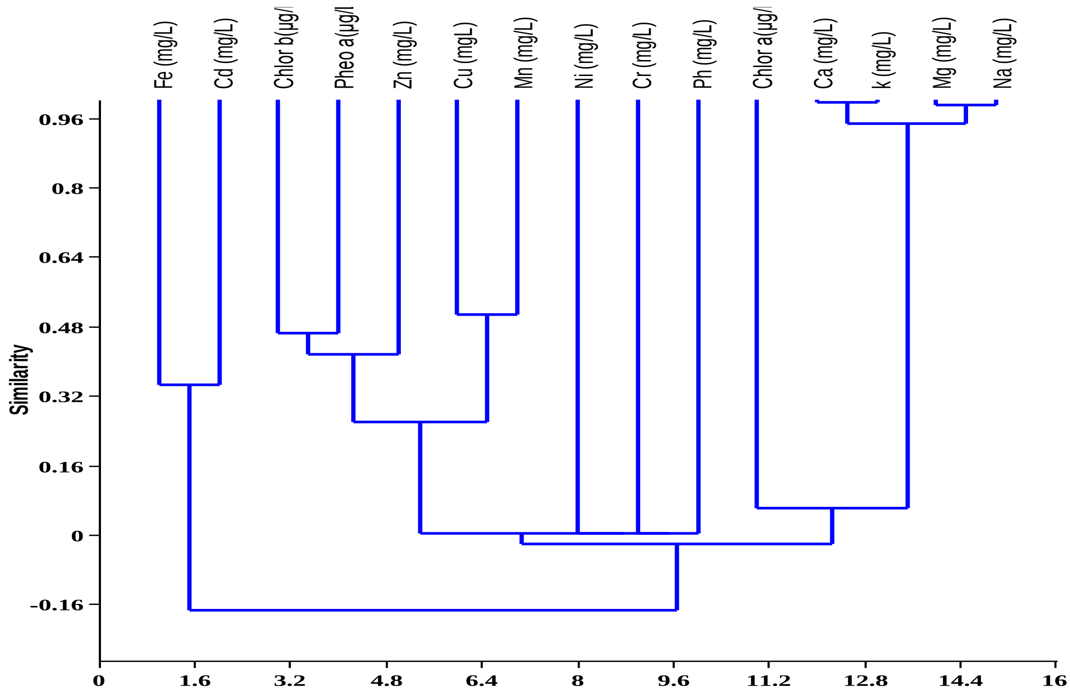

Fig. 7: Heavy Metals and algal Pigments across all the sampling stations within the periods (November, 2015 – April, 2016)

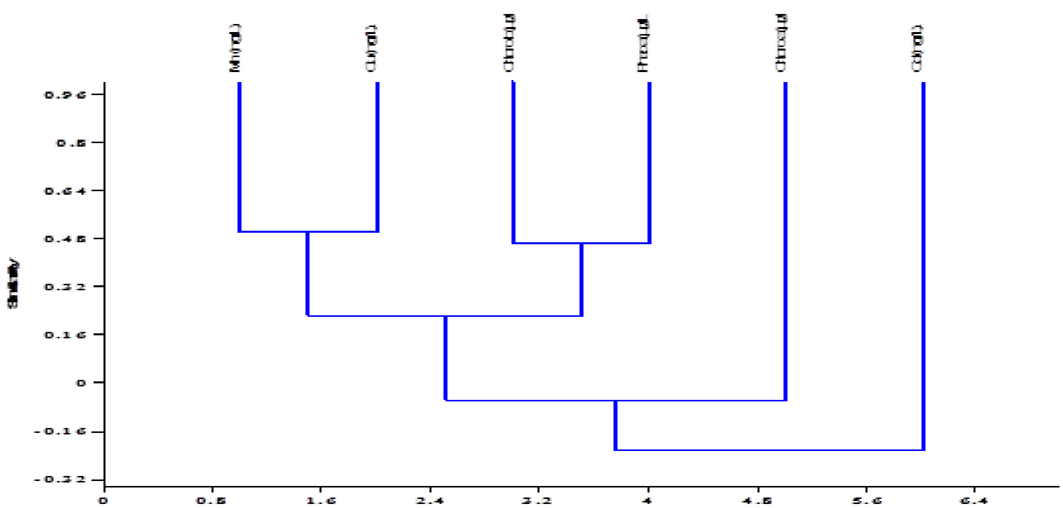

Fig. 8: Heavy Metals (Mn, Cu and Cd), Chlorophyll *a*, Chlorophyll *b* and Pheophytin *a* (November, 2015 – April, 2016).

Discussion

The characteristics of environmental variables across all the stations sampled from this study show clearly that the western part of the Lagos lagoon experiences environmental gradients akin to a tropical estuarine aquatic environments. For instance, Rainfall levels varied throughout the sampling period with the highest value in the month of March (164.4mm) and lowest in the month of December (4.1mm) was recorded. The highest rainfall in the month of March seems to be unusual indicating a shift in the seasonal distribution and this might be as a result of climate change.

Salinity ranged from 0.04‰ in November (Agboyi creek area) and highest 23.24‰ in February (Okobaba). The salinity concentration of this environment is strongly determined by the influence of flood waters linked to the distributive pattern rainfall and tidal incursion. According to Nwankwo, (1996) the dynamic interplay between freshwater inflow and tidal seawater incursion determine the Lagos lagoon environment from year to year. Onyema *et. al.*, (2003) also reporting for the Lagos lagoon noted that in wet season there is an increased inflow from rivers which creates freshwater and low brackish water condition in various parts of the lagoon.

As observed using Pearson Correlation Matrix, Rainfall exhibited statistical correlation that is significantly positive with nitrate ($r = 0.378$, $p < 0.05$) and with dissolved oxygen ($r = 0.480$, $p < 0.05$). This may be as a result of heavy influx of water nutrient rich from land and from storm water channels via house hold wastes which usually contain high organic materials. The resultant condition might lead to enrichment of the water body (Eutrophication). In addition, the prevailing Rainfall pattern is strongly related with chlorophyll *b* and recorded an apparent similarity level slightly higher than 0.6 as indicated by cluster analysis. Graphical depiction of environmental trends revealed that as rainfall increases, nitrate level increases correspondingly.

Dissolved Oxygen content indicates the health and ability of the water body to purify itself through biochemical processes. Furthermore, the concentration of the oxygen in aquatic environments is a very important component of water quality. The measurement of the DO concentration of a body of water is often used to determine whether the biological activities requiring oxygen are occurring and consequently, it is an important indicator of pollution. Total suspended solids and dissolved oxygen were negatively correlated ($r = -0.818$, $p > 0.05$). Decrease in concentration of dissolved oxygen (which is the by-product of photosynthesis) could have been as a result of reduction in primary productivity due to the presence of suspended materials which limited light penetration necessary for photosynthesis. Increased total suspended solids inhibit light penetration by reflection. This is in tandem with Nwankwo and Onitiri, (1992) that reported reduced light penetration in Epe Lagoon and suggested that it could have been as a result of increased rainfall, which led to increased presence of suspended solids. Total dissolved solid and dissolved oxygen were negatively correlated ($r = -0.316$, $p > 0.01$). This can be attributed to the effect of rainfall, such that when it rains, already settled materials, such as particulates and sediments are disturbed and then become re-suspended thereby clouding the water column which in turn inhibits sunlight from reaching the phytoplankton. Oxygen being a product of photosynthesis is reduced in the process.

Biochemical Oxygen Demand is a measure of quantity of oxygen used by microorganisms (e.g. aerobic bacteria) in the oxidation of organic matter and; this might be as a result of heavy nutrient released into the lagoon through runoff coupled with abundant sunlight to aid photosynthesis. Hence, dissolved oxygen will be high due to abundance of phytoplankton releasing oxygen which is the end product of photosynthesis. Further analysis using cluster similarity analysis shows that higher similarity level exist between Chemical Oxygen Demand and Biochemical Oxygen Demand.

At this point, it is expected that a coincidental high chlorophyll level would be observed in the water column because of its role in photosynthesis. According to Suzuki (2002), in an investigation of a Mexican lagoon low chlorophyll *a* values reflects a limited phytoplankton growth and was associated to dark water which reduced light penetration and impacted low dissolved oxygen content into the lagoon considerably. Chlorophyll *a* also correlated negatively with Copper ($r = -0.387$ $p<0.01$), chlorophyll *b* correlated positively with Manganese and negatively correlated with Cadmium ($r = 0.364$, $p<0.05$) and ($r = -0.331$, $p < 0.05$) and Phaeophytin *a* correlated negatively with Cadmium ($r = -0.364$, $p < 0.05$). There has been a proliferation of urban settlements and slum in the city of Lagos resulting in the generation of domestic effluent which combines with industrial wastes from facilities, small and medium scale industries and might eventually find their way into the Lagos lagoon that serves as the ultimate sink for the disposal of waste (Onyema *et. al*, 2007). Most reports demonstrated that the inhibitory effect of stress become greater with an increase in metal concentrations and might result to reduced algal growth rate (Bohme, 1998; Cavet *et. al*. 2003; Okmen *et. al*, 2007). Hence the presence of heavy metal in the water reduced the ability of chlorophyll to photosynthesize which in turn reduced primary productivity.

Conclusion

Seasonality of reported physico-chemical parameters in this study shows the important role played by these factors operating in western part of the Lagos Lagoon and their influences on organisms. The value of chlorophyll *a*, chlorophyll *b* and pheophytin *a* are relatively higher in dry season when compared with the wet season which likely indicated high phytoplankton production in the dry season when compared to wet season. In essence, the ample evidence of the observable environmental variables in this part of the lagoon revealed high levels of algal pigments and these had a seasonal trend and is linked to rainfall and nutrient as shown by relatedness, correlations and cluster analysis.

While the presence and levels of heavy metals recorded for this study cannot prove the existence and acute effect of heavy pollution, further investigation on influence of operating environmental condition on phytoplankton should be carried out.

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