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The phytoplankton, photosynthetic pigments, nutrients and heavy metals in the dry season of an estuarine Lagoon, Lagos, Nigeria

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Abstract

The Agboyi creek is one of the two tributaries of the Ogun River as it enters Lagos state and the Atlantic Ocean through the Lagos lagoon. It serves as a major drainage channel receiving domestic and industrial wastes from nearby industries at Maryland, Isheri, Bariga, Magodo and Ogudu areas of the Lagos metropolis. Sand mining, mangrove cuttings for fuel wood and brush parks (Acadja) as well as unregulated waste discharges are also rampant in the area. Water chemistry, photosynthetic pigment and microscopic analyses on water and plankton samples from these parts of the Lagos lagoon were carried out in the dry season (Nov. 2015 to Apr. 2016). The water climate showed marked effects of reduction in floodwater incursions and the increased influx of tidal sea water into the Lagos lagoon. The Phytoplankton population was represented by four divisions namely; Bacillariophyta (60.16%), Chlorophyta (4.15%), Cyanophyta (34.03%) and Euglenophyta (1.66%). The bacillariophyta (diatoms) was the most frequently occurring and numerically more important group of species. Additionally, higher photosynthetic pigments values were directly connected to the high microalgal biomass. Elevated saline conditions encouraged the development of marine phytoplankton taxa such as *Odontella, Pleurosigma, Nitzschia* and *Oscillatoria* spp. Comparative to previous studies, the reduction in algal species diversity is possibly linked to the increasingly limiting effect of heavy metals on the expression and utilization of nutrients by phytoplankton species.

Keywords: Chlorophyll *a*, Chlorophyll *b*, Phaeophytin *a*, Nitrate, Heavy metals.

Introduction

Creeks and associated wetlands are quite productive coastal ecosystems that receive floodwaters and pass them on to estuaries and or lagoons in coastal areas. The dry and wet seasons are ecologically different in coastal wetland ecology with the former being more brackish while the latter season is usually characterized with reduced salinities associated with increased rainfall during the period (Nwankwo and Adesalu, 2005; Ibanga *et al,* 2020). In between the seasons, there is the breakdown of environmental gradients which becomes more pronounced in the dry season (Nwankwo, 1988; 1993). The effect of tidal inflow and outflow can be significant in these parts and more evident in the dry season (Onyema and Akanmu, 2017). Tidal oscillations in the creeks around Lagos follow the semi-diurnal tidal regime.

Phytoplankton is an important microscopic organism that synthesizes and sustains majority of aquatic life forms thus, the pioneer of an aquatic food chain. The primary productivity of an aquatic ecosystem directly depends on the density of phytoplankton. Additionally, the phytoplankton species composition gives a reflection of the character of the aquatic ecosystem **(**Onyema and Omokanye, 2016**).** There are a number of factors chiefly among them are nutrients that limit phytoplankton development and hence aquatic productivity (Akanmu and Onyema, 2020).

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 concentration of algal pigments recorded per time (Roy *et al.,* 1996; Wu *et al*., 2014: Onyema *et al*., 2017).

High levels of nutrients, vegetation and biomass are common in creeks. Additionally, phytoplankton diversity and abundance vary from region to region. Notably, the Lagos lagoon area provides the nursery, breeding and spawning ground for aquatic animals from connected inland waters on one side and the adjoining sea, on the other side.

Hitherto, a large number of researches on phytoplankton community have been carried out by using microscopy alone especially in Nigeria since the middle of the last century (Onyema, 2018). These studies were conducted by using microscopes to investigate phytoplankton communities and spectra variations. This method requires key taxonomic expertise to be effective and successful. However, the observance of very small phytoplankton forms or groups is a limitation to this method. On the other hand, algal or phytosynthetic 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, 2018).

Here we attempt to investigate the influence and monthly variation of the key phytoplankton species, their photosynthetic pigment concentration and in connection with nutrients and heavy metals at the mouth of the Agboyi creek and Oworonshoki areas of the Lagos lagoon.

Materials and Methods

Description of Study Sites

The Agboyi creek is one of the two tributaries of the Ogun River as it enters Lagos state and the Atlantic Ocean through the Lagos lagoon. Much of the area for this study is part of the lower Ogun River flood plain as well as wetlands of the north-west part of the Lagos lagoon. The area serves as a major drainage channel for the region, receiving domestic and industrial wastes, which are discharged from nearby industries at Maryland, Isheri, Bariga, Magodo and Ogudu areas of the Lagos metropolis. Sand mining, mangrove cuttings for fuel wood and brush parks (Acadja) as well as unregulated waste discharges are also rampant in the area.

Two stations were selected as sampling points for this study. They are the Oworonshoki (St. 1) and Agboyi (St. 2) areas of the Lagos lagoon located in Kosofe Local Government Area of Lagos State. Oworonshoki is a rapidly urbanizing district of the metropolis. Urbanization has led to intense reclamation of the lower Ogun river wetlands. These wetlands which occupied 82.45 % of the area in 1965 had reduced to 36.31 % in 2005 mostly due to anthropogenic actions (Odunuga and Oyebande, 2007) and has presently reduced further. Parts of the area are also among the districts frequently afflicted with flooding and exhibiting signs of degraded environmental quality.

Collection of Water and Plankton Samples

Surface water and plankton samples were collected from the Oworonshoki and Agboyi stations in the Lagos lagoon for six months (November, 2015 to April, 2016) to cover the dry season between 09.00 and 12.00 hours on each sampling day. Water samples were collected at the study site using 75 cl plastic containers with each indicating the month of collection. Plankton samples were collected by hauling horizontally standard plankton net of 55 μm mesh size with a sample bottle attached to a motorized boat at an interval of 5 minutes at low speed (≤4 km/h). The filtrate in the attached sample bottle was transferred into a well labeled plastic container with screw caps preserved in diluted 4 % formalin. The water samples were transported to the laboratory for immediate chemical and microscopic analyses. Rainfall values were obtained from the Nigerian Meteorological Agency, Lagos (NIMET).

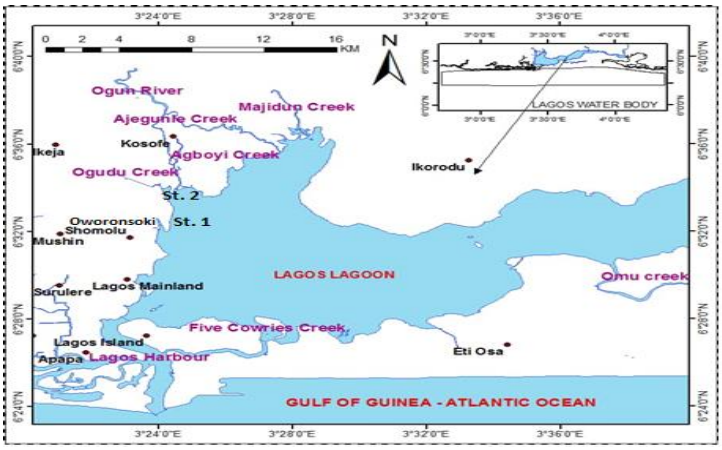

Fig. 1: The Lagos lagoon showing the sampling sites at Oworonshoki (St. 1) and Agboyi (St. 2) areas

Laboratory Analyses

Total suspended solids, salinity, dissolved oxygen, nitrate, phosphate, sulphate and silica were measured using methods according to American Public Health Association (APHA, 2012) for water analysis. Calcium, magnesium, sodium, potassium, copper, iron, zinc, manganese and cadmium were estimated using inductively coupled plasma, optical emission spectrometer (Agilent ICP-OES 710 Axial). Photosynthetic pigments (Chlorophyll *a, b* and Pheophytin *a*) (µg/L) were analyzed using spectrophotometric determination of chlorophylls in water samples. The photosynthetic pigments were determined using different computational formulae as reported in Onyema and Akanmu (2017).

Statistical analysis

Standard deviation and Pearson rank correlation on a normally distributed data was used to treat the nutrients, heavy metals and photosynthetic pigments.

Results

The data obtained for the mean variations in nutrients, heavy metals and photosynthetic algal pigments concentration parameters are presented in Table 1 and graphically in Figures 2 and 3. Rainfall data ranged from 4.1 to 164.4 mm. The ranged of the mean values for parameters were transparency (46.75 - 109.75 cm); total suspended solids (1 - 28 mg/L); salinity (0.50 – 16.91 ‰); conductivity (1010.6 – 29150.0 mg/L); dissolved oxygen (4.39 – 6.71 mg/L); biochemical oxygen demand (1 – 3 mg/L) and chemical oxygen demand (5 – 17 mg/L). The ranged of nutrients were nitrate (1.67 – 9.09 mg/L); phosphate (0.54 – 1.36 mg/L) and silica (1.25 – 4.55 mg/L). The heavy metals were zinc (0.0135 – 0.0535 mg/L); iron (0.0825 – 0.1600 mg/L); copper (0.0025 -0.0040 mg/L); cadmium (0.00085 – 0.00120 mg/L) and manganese (0.0240 – 0.0605 mg/L). The biological variables were algal pigments (chlorophyll *a* 12.15 – 17.00 µg/L; chlorophyll *b* 0.55 – 2.70 µg/L and phaeophytin *a* 0.25 – 0.45 µg/L) as well as phytoplankton. Heavy metals concentration was negatively correlated with chlorophyll *a* (Fe = -0.369, Cu = -0.72, Cd = -0.582 and Mn = -0.72). Chlorophyll *b* was also negatively correlated with Fe (r = -0.6.7) and Cd (r=-0.749). Additionally, Zn was negatively correlated with Species diversity (S) (r = -0.662) and Number of individuals (N) (r = -0.534).

Table 2 presented the diversity and abundance of phytoplankton species at an estuarine creek of the Lagos lagoon. The Phytoplankton population was represented by four divisions namely; Bacillariophyta (60.16 %), Chlorophyta (4.15 %), Cyanophyta (34.03 %) and Euglenophyta (1.66 %) in terms of abundance. Bacillariophyta was more abundant and was represented by the Order Centrales and Pennales. Table 3 shows the phytoplankton community structure values for the phytoplankton species recorded.

Table 1: **Mean Variations in the Nutrients, Heavy Metals and Algal Pigments Concentration at an estuarine lagoon in Lagos, Nigeria**

S/N	PARAMETERS	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	MEAN	±S.D.
		2015		2016					
1	**Rainfall (mm)**	48.7	4.1	25.6	5.4	164.4	84	55.37	61.26
2	**Transparency (cm)**	52.75	46.75	109.75	76.75	56.75	76.25	69.83	23.14
3	**Conductivity (µS/cm)**	1010.6	15675.2	25100.1	29150.0	28200.1	22700.0	20306.00	10611.36
4	**Total Suspended Solids (mg/L)**	28	2.5	2.5	1	1	1	6.00	10.80
5	**Salinity (‰)**	0.50	8.76	14.62	16.91	16.57	14.72	12.01	6.36
6	**Acidity (mg/L)**	1.25	1.65	1.75	1.70	0.95	1.20	1.42	0.33
7	**Alkalinity (mg/L)**	89.35	93.15	96.45	92.20	92.70	91.55	92.57	2.32
8	**Dissolved Oxygen (mg/L)**	4.39	5.86	5.92	5.88	6.70	6.71	5.91	0.85

9	**Biochemical Oxygen Demand$_5$ (mg/L)**	3	2	3	1.5	1	2	2.08	0.80
10	**Chemical Oxygen Demand (mg/L)**	17	13	13	8	5	8.5	10.75	4.36
11	**Chloride (mg/L)**	250.75	4818.3	8030.2	9438.5	9115.9	8095.3	6624.83	3525.68
12	**Nitrate (mg/L)**	6.43	1.67	2.88	6.20	9.09	2.84	4.85	2.84
13	**Sulphate (mg/L)**	29.50	681.85	1119.75	1319.90	1293.00	1147.20	931.87	497.88
14	**Phosphate (mg/L)**	0.60	1.08	1.36	0.54	0.62	0.52	0.79	0.35
15	**Silica (mg/L)**	4.55	2.15	2.15	2.30	1.25	1.90	2.38	1.13
16	**Calcium (mg/L)**	5.90	100.63	162.41	187.73	185.65	164.93	134.54	70.48
17	**Magnesium (mg/L)**	18.92	341.26	566.59	667.19	647.69	573.36	469.17	249.20
18	**Sodium (mg/L)**	158.05	2660.00	4436.76	5196.60	5037.42	4473.30	3660.36	1938.40
19	**Potassium (mg/L)**	6.26	92.95	148.86	172.57	170.55	149.06	123.38	64.18
20	**Zinc (mg/L)**	0.02	0.0135	0.02	0.0155	0.04	0.0535	0.03	0.02
21	**Iron (mg/L)**	0.16	0.117	0.117	0.1065	0.0825	0.1035	0.11	0.03
22	**Copper (mg/L)**	0.003	0.0035	0.0035	0.0025	0.003	0.004	0.00	0.00
23	**Cadmium (mg/L)**	0.0011	0.0012	0.0012	0.0012	0.00085	0.0012	0.00	0.00
24	**Manganese (mg/L)**	0.0465	0.0455	0.027	0.024	0.043	0.0605	0.04	0.01
25	**Chlorophyll *a* (µg/L)**	14.7	12.15	12.9	17	17	14.1	14.64	2.03
26	**Chlorophyll *b* (µg/L)**	0.95	1.5	0.9	0.55	2.7	1.8	1.40	0.78
27	**Phaeophytin *a* (µg/L)**	0.25	0.45	0.4	0.3	0.3	0.45	0.36	0.09

Table 2: **The Composition and Abundance (Individuals per ml) of Phytoplankton at an estuarine lagoon in Lagos, Nigeria**

PHYTOPLANKTON TAXA	Nov.		Dec.		Jan.		Feb.		Mar.		Apr.	
	2015				2016							
	ST.1	ST.2	ST.1	ST.2	ST.1	ST.2	ST.1	ST.2	ST.1	ST.2	ST.1	ST.2
DIVISION: BACILLARIOPHYTA												
CLASS: BACILLARIOPHYCEAE												
ORDER 1: CENTRALES												
Aulacoseira granulata var. *angustissima*	10	-	-	-	-	-	-	-	-	-	-	-
Chaetocerus sp.	-	-	-	-	-	-	10	-	-	-	-	-
Coscinodiscus radiatus Ehrenberg	-	-	10	5	-	-	10	15	-	15	-	-
Cyclotella meneghiniana Kutzing	5	-	-	-	-	-	-	-	-	-	-	-
Skeletonema costatum (Greville) Cleve	-	-	5	-	-	-	-	-	-	-	-	-
ORDER 11: PENNALES												
Bacillaria paxillifer (O. F. Muller)	-	-	-	60	-	-	-	-	-	-	-	-
Gyrosigma balticum (Her.) Rabenhorst	-	-	-	5	-	-	-	-	-	-	-	-
Odontella biddulphiana (J. E. Smith) Boyer	-	-	95	-	-	-	-	-	-	-	-	-
Odontella sinensis (Greville) Grunow	-	-	5	-	-	-	-	-	-	-	-	-
Pleurosigma angulatum (Quekett) Wm	-	-	-	105	-	-	-	-	-	-	-	-
Pleurosigma elongatum Wm. Smith	-	-	5	-	-	-	-	-	-	-	-	-
Navicula mutica Kutzing	-	-	15	5	-	-	-	-	-	-	-	-
Nitszchia bicapitata Cleve	-	-	-	5	-	-	-	-	-	-	-	-
Nitszchia closterium (Ehrenberg)	-	-	30	-	-	-	10	-	-	-	-	-
Nitszchia palea (Kutzing)Wm. Smith	40	-	-	-	-	-	-	-	-	-	-	-
Nitszchia perminuta (Grunow)	-	-	-	95	-	-	-	-	-	-	-	-
Nitszchia sigmoidea (Witesch) Wm. Smith	-	-	135	-	-	-	-	-	-	-	-	-
Synedra crystallina (Ag.) Kutzing	5	-	-	5	-	-	15	-	-	-	-	-
Synedra ulna (Nitzsch) Ehrenberg	-	5	-	-	-	-	-	-	-	-	-	-
DIVISION: CHLOROPHYTA												
CLASS: CHLOROPHYCEAE												
ORDER I: DESMIDIALES												
Closterium minimac (O. F. Muller)	-	-	5	-	-	-	-	-	-	-	-	-
ORDER II: SPHAEROPLEALES												
Microspora sp.	-	-	-	-	-	15	-	-	20	-	-	-
ORDER III: ULOTRICALES												
Spirogyra africana (Fritsch) Czurda	-	-	-	-	10	-	-	-	-	-	-	-
DIVISION: CYANOPHYTA												
CLASS: CYANOPHYCEAE												
ORDER I: CHROOCOCALES												
Lyngbya limnetica Lemermann	-	-	-	-	-	-	-	10	-	10	-	10
ORDER II: HOMOGONALES												
Oscillatoria limnetica Lemermann	75	60	65	10	5	5	-	5	30	15	10	20
Oscillatoria lacustris (Klebahn)	-	-	-	-	60	-	15	-	-	-	-	-
Oscillatoria santa (Kutzing)	-	5	-	-	-	-	-	-	-	-	-	-
DIVISION: EUGLENOPHYTA												
CLASS: EUGLENOPHYCEAE												
ORDER I: EUGLENALES												
Euglena sp.	10	-	-	5	-	-	-	-	-	-	-	-
Trachelomonas hispida (Perty) F. Stein	5	-	-	-	-	-	-	-	-	-	-	-
Phytoplankton Diversity (S)	**7**	**3**	**10**	**10**	**3**	**2**	**5**	**3**	**2**	**3**	**1**	**2**
Number of individuals (N)	**15**	**70**	**370**	**300**	**75**	**20**	**60**	**30**	**50**	**40**	**10**	**30**

Table 3: Phytoplankton Community Structure at an estuarine lagoon in Lagos, Nigeria.

PARAMETERS	NOV.		DEC.		JAN.		FEB.		MAR.		APR.		Min	Max
	2015				2016									
	ST.1	ST.2	ST.1	ST.2	ST.1	ST.2	ST.1	ST.2	ST.1	ST.2	ST.1	ST.2		
Phytoplankton Diversity (S)	7	3	10	10	3	2	5	3	2	3	1	2	1	10
Number of Individuals (N)	150	70	370	300	75	20	60	30	50	40	10	30	10	370
Shannon-Wiener Index (Hs)	0.61	0.22	0.73	0.68	0.27	0.24	0.69	0.44	0.29	0.47	0.00	0.28	0.00	0.73
Menhinick Index (D)	0.57	0.36	0.52	0.58	0.35	0.45	0.65	0.55	0.28	0.47	0.32	0.37	0.28	0.65
Margalef Index (d)	1.20	0.47	1.52	1.58	0.46	0.33	0.98	0.59	0.26	0.54	0.00	0.29	0.00	1.58
Equitability Index (j)	0.72	0.46	0.73	0.68	0.57	0.81	0.99	0.92	0.97	0.99	0.00	0.92	0.00	0.99
Simpson's Dominance Index (C)	0.33	0.74	0.23	0.27	0.66	0.63	0.18	0.39	0.52	0.34	1.00	0.56	0.18	1.00

Discussion

The introduction of floodwaters associated with the rains entry into the Oworonshoki and Agboyi creeks from the preceding months before the study period commenced, might have resulted in the dilution and possible scouring and stirring up of detritus and organic matter. This probably accounted for the high total suspended solids value as well as reduced salinity (by dilution), transparency, conductivity, alkalinity, chloride, calcium and magnesium values in November than at other times. However, the increase in all these parameters subsequently may be due to the absence or reduction of floodwater inflow and the increased influx of tidal sea water into the Lagos lagoon. Similar observations were made by Adesalu and Nwankwo (2008) at the Abule-Eledu Creek, Nwankwo *et al.* (2012) at the creeks of the Lagos Harbour, Onyema and Akanmu (2018) at a Mangrove swamp and creek and Onyema (2016), Onyema *et al.*, (2016), Lawal-Are *et al.* (2019) at other mesohaline creek areas connected to the Lagos lagoon.

The nutrient values (nitrate, phosphate and silica) were higher as the study stretched possibly because of the increased oxidation of materials owing to higher temperatures of the dry season. These organic matter derivatives would have originally come in with flood waters as allochthonus materials. This increase in nutrients level may have additionally accounted for the corresponding increase in photosynthetic pigment levels. The presence of *Euglena* sp. and *Trachelomonas hispida* in this study have been previously reported to indicate very high nutrients environment and from sewage or high biodegradable waste contamination (Onyema, 2013). Furthermore, the higher chlorophyll *a*, *b* and phaeophytin *a* values in this study is connected to the high microalgal biomass at this period. This confirms earlier reports by Onyema and Omokanye (2016) at the western as well as Onyema (2018) at the eastern and western parts of the Lagos lagoon for such periods. The impact and strength of positive correlation between nutrients such as nitrate, salinity and chlorophyll *a* was noteworthy. Additionally, phytoplankton species diversity, its number of individuals and the total suspended solids (nutrients / detritus) were also positively related.

Photosynthetic pigments have strong chemotaxonomic associations that maybe exploited to map the coastal abundance and composition of the phytoplankton community (Onyema, 2018). The elevated saline/marine condition encouraged the development of estuarine/marine phytoplankton species such as *Cosinodiscus, Odontella* and so on. The comprehensive monitoring of phytoplankton community composition using microscopy and pigments analysis is required to ensure sustainable management of fisheries resources (Agribas *et al*., 2017).

The phytoplankton community shift from predominantly freshwater to marine forms is a reflection of the shift in the hydroclimatic condition of the lagoon ecosystems from freshwater to sub-marine conditions. Dominant species recorded during the study period include *Odontella, Pleurosigma, Nitzschia* and *Oscillatoria.* The phytoplankton is the base 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 of phytoplankton within this area of the Lagos lagoon was the Cyanophyceae. Some *Lyngbya* and *Oscillatoria* spp. have been reported as indicators of brackish water conditions and organic pollution in surface waters in the region (Nwankwo, 2004; Onyema, 2017).

The limiting effects of heavy metals on the absorption of available nutrients were clearly shown by the strong and negative relationship between heavy metal and photosynthetic pigment levels.

According to Onyema *et al.,* (2019) in their study, low levels of photosynthetic pigments reported was due to the depressing effect of pollution including heavy metals from the surrounding solid waste site.

This then impacted aquatic life. As reported by a number of authors (Ajao *et al*., 1996; Chukwu, 2010; Otitoloju, 2018; Ali *et al*., 2020; Fawape *et al,* 2020), the deleterious effects of excessive nutrients from domestic and industrial waste concerns, as well as heavy metal enrichment from small and medium scale industries that are poorly monitored with regards to their waste discharges have now risen to levels of high ecological concerns.

It is important to note that the reduction in algal species diversity comparison to other studies (Adesalu and Nwankwo, 2008; Nwankwo *et al.* 2012; Onyema *et al*., 2016; Onyema, 2018; Onyema and Akanmu, 2018; Akanmu and Onyema, 2020) for the region and the proliferation of tolerant species is currently of concern. The limiting effect of heavy metals on the expression and utilization of excessive nutrients load from domestic and industrial waste by algal species is also increasingly noteworthy.

Conclusion

This study highlights the impact of the hydro environmental factors and phytoplankton in the study area especially the clear impact of nutrients and the limiting effects of heavy metals. There is the need for further studies on the transfer of energy from the phytoplankton to higher trophic levels such as zooplankton, benthos and the fish community among other.

Table 4: **Correlation Matrix in the Nutrients and Biological Parameters at an Estuarine Creeks in Lagos, Nigeria (November, 2015 – April, 2106)** * P < 0.05; **P < 0.01

PARAMETERS		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
Rainfall (mm)	1	1																												
Transparency (cm)	2	-0.21	1																											
Conductivity (µS/cm)	3	0.22	0.49	1																										
Total Suspended Solids (mg/L)	4	-0.09	-0.349	-.909*	1																									
Salinity (‰)	5	0.26	0.5	.995**	-.908*	1																								
Acidity (mg/L)	6	-.916*	0.459	0.117	-0.206	0.067	1*																							
Alkalinity (mg/L)	7	-0.17	0.691	0.596	-0.639	0.56	0.531	1																						
Dissolved Oxygen (mg/L)	8	0.47	0.226	.835*	-.900*	.867*	-0.22	0.428	1*																					
Biochemical Oxygen Demand$_5$ (mg/L)	9	-0.49	0.35	-0.631	0.601	-0.625	0.374	0.077	-0.674	1																				
Chemical Oxygen Demand (mg/L)	10	-0.58	-0.054	-.845*	0.746	-.861*	0.367	-0.149	-.860*	0.896	1*																			
Chloride (mg/L)	11	0.247	0.498	.995**	-.907*	1.000**	0.074	0.555	.862**	-.628*	-.861**	1																		
Nitrate (mg/L)	12	0.63	-0.278	0.102	0.227	0.083	-0.606	-0.378	-0.047	-0.466	-0.409	0.086	1																	
Sulphate (mg/L)	13	0.258	0.486	0.994	-0.909	1	0.061	0.549	0.87	-0.637	-0.868	1	0.088	1																
Phosphate (mg/L)	14	-0.415	0.447	0.046	-.198*	.000**	0.622	0.824	-0.043	.484*	.397**	-0.006	-0.577	-0.012	1*															
Silica (mg/L)	15	-0.374	-0.229	-.883*	0.951	-.886*	0.063	-0.585	-.959*	0.69	.829*	-0.882	0.042	-.888*	-0.137	1*														
Calcium (mg/L)	16	0.257	0.489	.995**	-.915*	1	0.064	0.561	.874**	-.632*	-0.864	1	0.077	1.000**	.002*	-0.894	1													
Magnesium (mg/L)	17	.252*	0.494	0.995	-0.907	1	.068*	0.552	0.864	-0.632	-0.864	1.000*	0.09	1	-0.009	-0.883	1.000*	1												
Sodium (mg/L)	18	0.25	0.498	0.995	-0.906	1	0.071	0.555	0.863	-0.627	-0.861	1	0.087	1	-0.006	-0.882	1	1	1											
Potassium (mg/L)	19	0.254	0.486	.996*	-.914*	1.000*	0.069	0.564	.870*	-.636*	-.864*	1	0.084	1.000*	.006*	-.893*	1	1	1.000*	1*										
Zinc (mg/L)	20	0.753	0.039	0.269	-0.257	0.355	-0.737	-0.18	0.635	-0.332	-0.552	0.348	0.141	0.359	-0.467	-0.41	0.358	0.351	0.35	0.346	1									
Iron (mg/L)	21	-0.498	-0.149	-.901*	0.894	-.908*	0.211	-0.421	-.950*	0.818	.942*	-0.905	-0.179	-.912*	0.087	.968*	-0.914	-0.907	-.906*	-0.914	-.479*	1								
Copper (mg/L)	22	0.082	0.187	-.070**	-.212*	-.004**	-0.087	0.23	.358**	.298*	.120**	-0.015	-0.707	-.007**	.317*	-.229**	0.004	-0.015	-.013**	-.008*	.521**	-0.065	1							
Cadmium (mg/L)	23	-0.871	0.387	-0.112	-0.059	-0.099	0.781	0.169	-0.209	0.511	0.453	-0.095	-0.822	-0.103	0.314	0.228	-0.101	-0.1	-0.097	-0.106	-0.339	0.367	0.305	1						
Manganese (mg/L)	24	0.427	-0.494	-0.392	0.18	-0.315	-0.652	-0.526	0.156	-0.038	0.015	-0.322	-0.165	-0.308	-0.383	0.051	-0.305	-0.319	-0.321	-0.317	0.678	0.048	0.65	-0.127	1					
Chlorophyll *a*(µg/L)	25	0.487	-0.132	0.373	-.043*	.367**	-0.446	-0.356	0.16	-.641*	-.632**	0.374	0.891	0.374	-.724*	-.131**	0.36	0.377	0.374	.365*	.212**	-0.369	-0.72	-0.582	-.235*	1**				
Chlorophyll *b*(µg/L)	26	0.873	-0.387	.230*	-0.303	.258*	-0.784	-0.04	.621*	-0.585	-.575*	0.249	0.318	.264*	-0.211	-.565*	0.269	0.254	.251*	0.267	.682*	-0.607	0.306	-.749*	0.565	.182*	1			
Pheophytin *a*(µg/L)	27	-0.229	0.235	.243**	-.586*	0.276	0.313	0.484	.520**	.060*	-0.047	0.269	-0.863	.274**	.470*	-0.494	0.286	0.267	.269**	.278*	0.228	-0.296	0.83	.516**	.325*	-0.722	0.142	1		
Species diversity (S)	28	-.535*	-0.595	-0.441	0.158	-0.496	.391*	-0.09	-0.386	0.071	0.457	-.493*	-0.363	-0.491	0.303	0.232	-.485*	-0.493	-0.495	-0.479	-0.662	.335*	-0.077	0.249	0.008	-0.462	-.171*	0.179	1	
Species abundance (N)	29	-0.442	-0.572	-0.42	0.083	-0.464	0.324	-0.003	-0.265	0.084	0.433	-0.464	-0.459	-0.46	0.391	0.127	-0.451	-0.464	-0.466	-0.446	-0.534	0.262	0.122	0.221	0.138	-0.588	-0.025	0.339	0.974	1

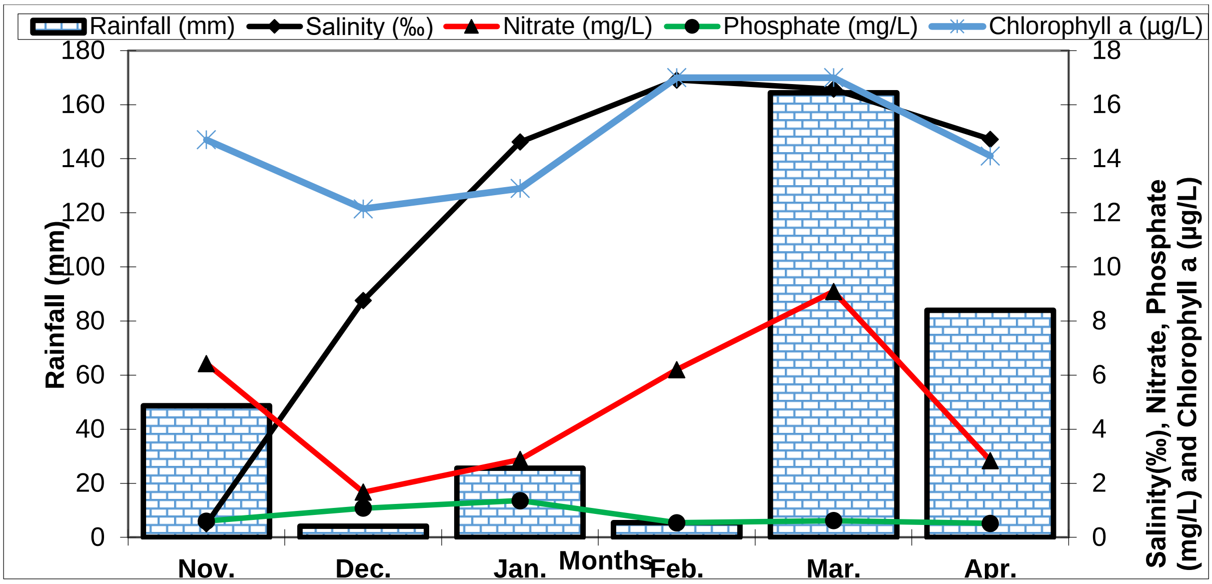

Fig. 2: Mean Variations in Rainfall, Salinity, Nitrate, Phosphate and Chlorophyll *a* at an Estuarine Lagoon in Lagos, Nigeria

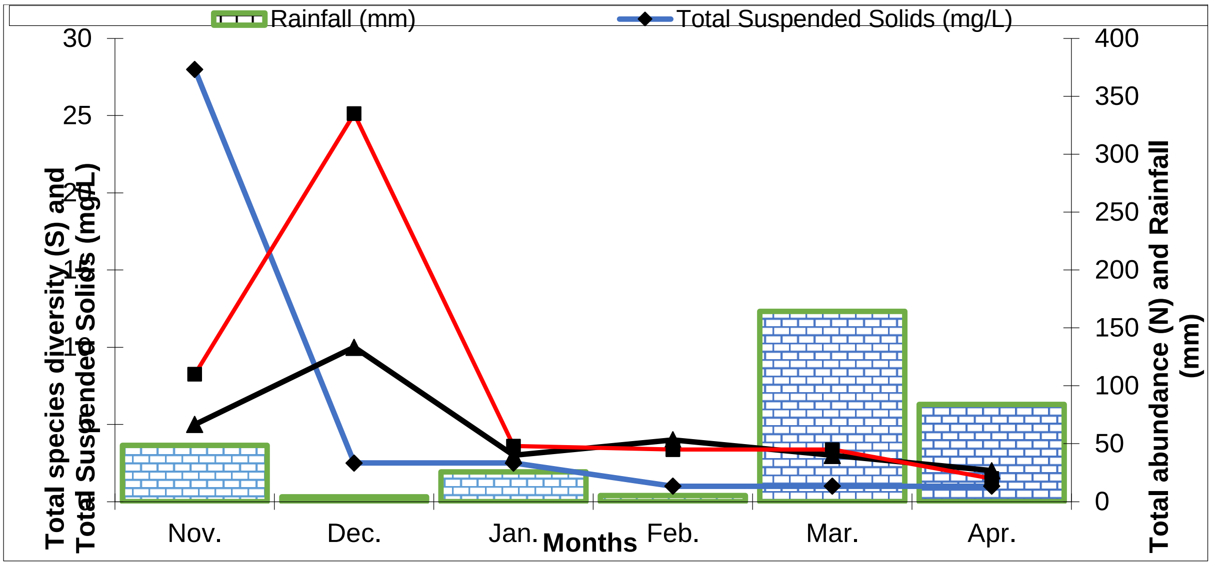

Fig. 3: Mean Variations in Total Suspended Solids, Rainfall, Total species diversity (S) and Total abundance (N) and at an Estuarine lagoon in Lagos, Nigeria

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