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Chlorophyll *a* measurement as an index of phytoplankton bloom and primary production in the Gulf of Guinea, Nigeria, West Africa

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Abstract. Chlorophyll *a* levels of oceanic waters in Nigeria located in the Gulf of Guinea and adjoining water bodies were investigated in this study. Sample collections were done at quarterly intervals from March 2014 to January 2015 from fifty-five sites and spanned over eight coastal states. Integrated water sample for chlorophyll analysis was taken from a depth of 10m to the surface using a silicone hose. Determination of chlorophyll was done by a combination of filtration, extraction, homogenization, centrifugation and spectrophotometry using the trichromatic method. The range of chlorophyll *a* concentration was 27.5 – 1419.35 μgL^{-1} in oceanic waters and 32.79 – 1649.64 μgL^{-1} in adjoining water bodies. Chlorophyll a concentrations varied spatially and temporally, with a general observation of higher concentrations in the south-west oceanic locations in the Bight of Benin axis of the Gulf of Guinea, compared to the south-south oceanic locations in the Bight of Bonny axis of the Gulf of Guinea In the adjoining coastal waters, the Gbaji River in Badagry, Lagos, located in the South-West, had the highest overall total chlorophyll a concentration while the Brass River in Bayelsa, located in the South-South had the lowest overall total chlorophyll *a* concentration throughout the study period. The mean primary production, ranging from 439.85 μgL^{-1} to 1051.89 μgL^{-1}, were included in six categories of <500 μgL^{-1}; 600-699 μgL^{-1}; 700-799 μgL^{-1}; 800-899 μgL^{-1}; 900-999 μgL^{-1} and >1000 μgL^{-1}. Principal component analysis showed strong positive correlations of chlorophyll *a* with total biomass of major phytoplankton groups (Bacillariophyta, Dinophyta and Cyanophyta) and dissolved oxygen levels; negative correlation of chlorophyll *a* with Fe, NO_3, PO_4, TDS, SiO_3 and turbidity.

Keywords: algal bloom, chlorophyll *a*, Gulf of Guinea, Nigeria, primary production.

Introduction

Chlorophyll *a* is a universal photosynthetic pigment found in plants, cyanobacteria and algae. It occurs as the primary photosynthetic pigment in all autotrophic and mixotrophic phytoplankton and its concentration can be used as a proxy for total phytoplankton biomass. Chlorophyll *a* concentration is one of the key indices in the study of the health status of any aquatic ecosystem (Boyer *et al*., 2009; Jamshidi *et al*., 2010; Jamshidi and Abu Bakar, 2011). Therefore, the investigation on variations of chlorophyll *a* is very important in the study of water quality and pollution in the aquatic environments. Additionally, chlorophyll is an indicator of productivity, an indicator of algal abundance in aquatic environment, and an effective measure of trophic status of waterbodies (Kadiri 1993). The application of chlorophyll *a* as an index of the productivity and trophic condition of estuaries, coastal and oceanic waters is age long (Boyer *et al.,* 2009). Chlorophyll *a* connotes the instantaneous (standing stock) or net matter of both growth and loss processes of autotrophic organisms in the pelagic ecosystems.

Variability of chlorophyll *a* concentrations determines the ecological conditions of marine systems such as the changes in the physical and chemical characteristics of the environment, aquatic systems health, composition, and ecological status (Rakocevic-Nedovic and Hollert, 2005). Phytoplankton requires an array of macro and micronutrients for growth; the most important being nitrogen and phosphorus. However excess nutrients inputs into coastal waters which mainly arise from anthropogenic sources can cause algae to bloom, resulting in a myriad of effects including toxicity, hypnoxia, increased turbidity, low light intensity, impairment of aquaculture production, degradation of recreational amenities, ecological problems like fish kill~~,~~ and community structure alteration (Anderson *et al*., 2002).

In recent decades, coastal areas have undergone considerable development and increased utilization and this trend is expected to continue (Neumann *et al.,* 2015). As consequence of this development, there is increased population growth and development which are important drivers of changes in coastal areas through high increased utilization and pollution (Hardy and Patterson 2008; Crossland *et al.,* 2005).

In Nigeria, about 20 million people live along the coastal zone and depend directly on the coastal waters for their nutritional and economic sustenance. Because phytoplankton is the first link in food chain of most aquatic ecosystems, its productivity affects organisms that feed on them directly or indirectly and thus can impart fishery resources which many coastal communities in Nigeria rely on.

Research on chlorophyll *a* in Nigerian waterbodies are not only generally very few, such information on coastal waters is exceptionally very rare. The few studies that exist are mainly restricted to small inland waterbodies and they include reports of (Nwadiaro and Oji, 1985; Kadiri, 1993; Nwankwo *et al.,* 2013; Onyema and Akingbulugbe, 2017; Ayeni and Adesalu, 2018). Additionally, no information on chlorophyll *a* exists in the Atlantic Ocean of Nigeria, coupled with the lack of comprehensive study in the entire coast of Nigeria. Therefore this study represents the first comprehensive study of this nature in the entire coast, spanning the Bight of Benin to the Bight of Bonny, Gulf of Guinea.

The objectives of the study was to investigate the concentrations, seasonal and spatial profile of chlorophyll *a* in the Atlantic oceanic, Gulf of Guinea and adjoining waters of coastal waters of Nigeria and establish relationship between environmental variables and chlorophyll *a*.

Materials and methods

The study was carried out in the Nigerian Coast-Atlantic Ocean, from the Bight of Bonny to Bight of Benin with 55 sampling sites located in Cross River, Akwa-Ibom, Rivers, Bayelsa, Delta, Ondo, Ogun, Lekki, Bar Beach, and Badagry (Lagos) States (Fig. 1). Geographically, the Nigerian costal states are divided into two regions namely: South-South region and the South-West region. The South-South consists of five states namely: Cross River, Akwa Ibom, Rivers, Bayelsa and Delta. Three stations were sampled in each of these locations and the mean value was taken.

There are two main seasons in the area, namely the rainy (wet) season spanning from May to October and dry season which extends from November to April. The coastal area is humid with a mean average temperature of 24°C to 32°C and an average annual rainfall ranging between 1,500 m to 4,000 m (Kuruk, 2004).

Sampling was done in March, 2014, July 2014, October, 2014 and January, 2015, corresponding to dry-wet, wet, wet-dry and dry seasons respectively.

Integrated water sample of the water column was taken from a depth of 10 m to the surface using a silicone hose with an inner diameter of 2.5 mm and provided with a heavy-weight, into clean 1litre sample containers. The samples were immediately stored in ice-chests and transported to the Limnology and Algology laboratory of the University of Benin, Nigeria within 6 hours of collection. Determination of chlorophyll a concentration was done according to the trichromatic method of Vollenweider (1974), using the combined procedures of filtration, extraction, homogenization, centrifugation and spectrophotometry.

Two-Way Analysis of Variance (ANOVA) and Principal Component Analysis (PCA) was done using Paleontological Statistics *Software* Package (PAST), Version 3.26 (Ogbeibu, 2005). Principal Component Analysis was done to determine environmental and biological relationships with chlorophyll *a* concentrations while ANOVA was employed to test differences between means of chlorophyll concentrations in the study area.

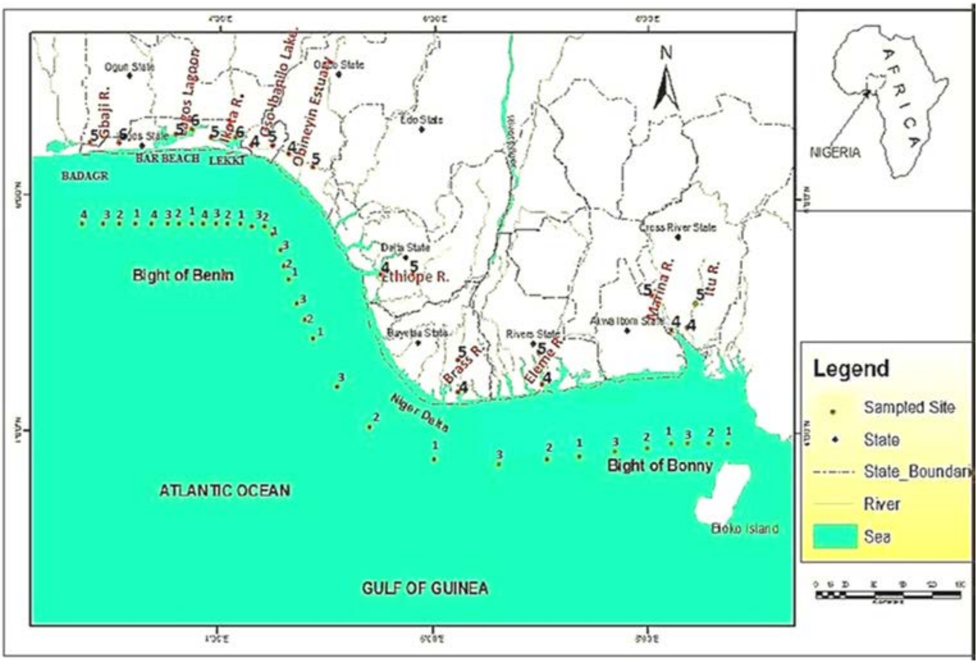

Figure 1. Coastal map of Nigeria showing the study area

Results and discussion

The total chlorophyll *a* concentrations of oceanic waters of Nigeria is presented in figure 2. The concentration values ranged from 27.5 – 1419.35 μgL^{-1}, with the minimum recorded in Ogun in July and maximum obtained in Lekki also in July. Chlorophyll *a* exhibited significant spatial and temporal variations. Generally, the chlorophyll *a* levels of July were the lowest and those of January were the highest. A deviation from this trend was noted where minimum and maximum values were recorded respectively in March and July (Lekki, Bar Beach and Badagry areas), in March and October (Ondo); a maximum in July (Lekki, Lagos) and minimum value obtained in October in Bayelsa oceanic water. Spatial comparison revealed overall that Lekki had the highest and Bayelsa had the lowest annual total chlorophyll *a* concentration throughout the entire period.

A horizontal gradient was observed. Generally, the South-West oceanic areas were higher in chlorophyll *a* than the South-Southern ones.

Statistically, the results for the two-way ANOVA indicated a significant main effect for season, *F* (3, 132) = 52.341, $p < 0.001$ and a significant main effect for sampling locations, *F* (9, 132) = 7.202, $p < 0.001$. Additionally, the results show a significant interaction between season and location, *F* (27,132) = 9.873, $p < 0.001$, an indication that seasonal variations in chlorophyll *a* were dependent upon the spatial variations in chlorophyll *a* in the oceanic waters of the Nigerian coast. Also, 83.8 % ($R^2 = 0.838$) of the total variance of chlorophyll *a* was attributed to the interaction of season and location of sampling. Post hoc analyses using *DMR* test for seasonal variation of chlorophyll *a* showed that the mean value for January was highest and differed significantly from October, July and March seasons. Post hoc analyses using *DMR* test for determination of spatial variation in chlorophyll *a* concentrations showed that mean chlorophyll *a* values were in a descending order of Lekki >Badagry> Ondo> Bar Beach >Ogun> Akwa Ibom> Rivers > Cross River >Delta > Bayelsa.

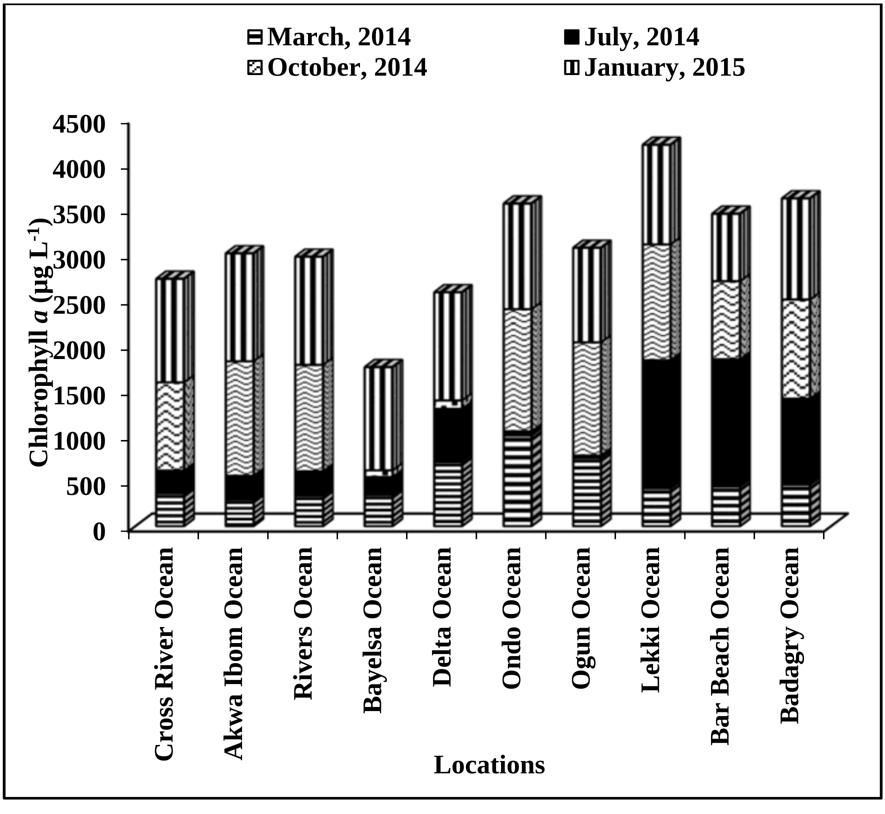

Figure 2. Total seasonal chlorophyll *a* concentration of Atlantic oceanic waters of Nigeria

The total chlorophyll *a* values of adjoining water bodies of oceanic waters of Nigeria is represented in figure 3. The range was 32.79 – 1647.64 μgL^{-1}, with minimum recorded in July in Oso-Ibanilo Lake and maximum obtained in the Gbaji River in July. The trend in adjoining rivers was more variable than in the oceans. The minimum and maximum chlorophyll values were recorded in only 50% of the locations in July and October, respectively. Divergence from this trend was observed in the Itu, Ethiope and Brass Rivers where maximum chlorphyll *a* concentration was recorded in January while Lagos Lagoon and the Gbaji River had maximum chlorophyll *a* values in July. In contrast with the general trend, minimum chlorophyll *a* values were recorded in March for the Ikota River, Lagos Lagoon and the Gbaji River while the Brass and Ethiope Rivers had minimum chlorophyll *a* cocentrations in October.

Spatial comparison revealed that the Gbaji River in Badagry, Lagos State had the highest overall (total) chlorophyll *a* while the Brass River in Bayelsa recorded the lowest overall (total) chlorophyll *a* throughout the entire period. Generally, chlorophyll levels in the South-West Rivers were higher than the South-Southern ones.

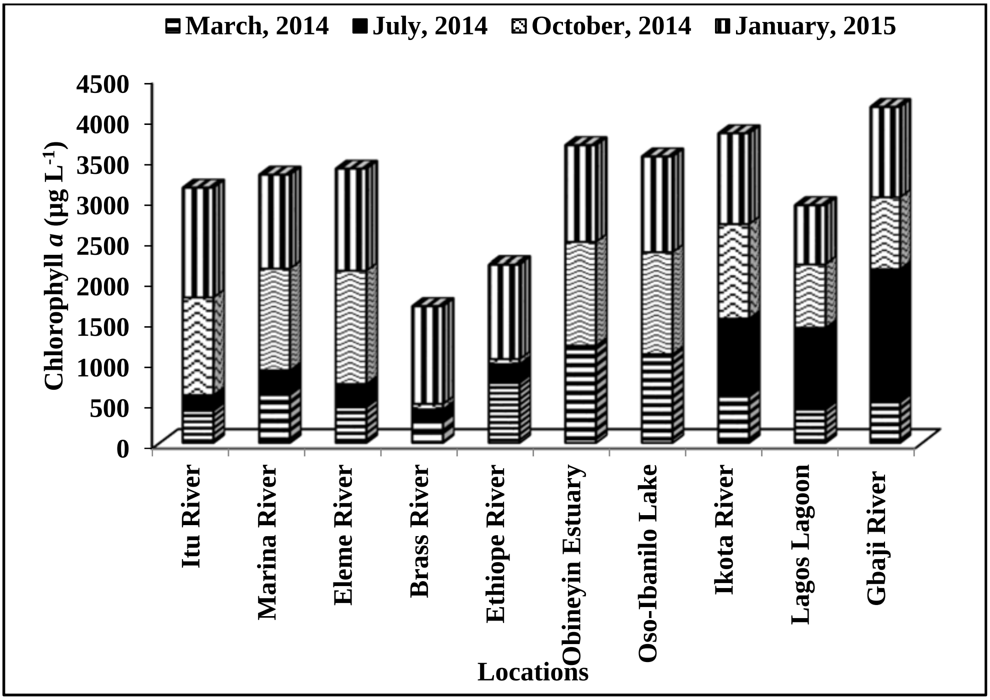

Figure 3. Total Seasonal Chlorophyll *a* concentration of adjoining coastal waterbodies of Nigeria

Similarly, for the adjoining water bodies, the results for the two-way ANOVA indicated a significant main season effect, $F\ (3, 80) = 36.685$, $p > 0.001$ and a significant main effect for location, $F\ (9, 80) = 60.724$, $p > 0.001$. Furthermore, the results showed a significant interaction between season and location, $F(27, 80) = 9.177$, $p > 0.008$. It could be an indication that seasonal variations in chlorophyll *a* of the water samples were dependent upon the spatial variations in chlorophyll *a* in the various adjoining rivers from South-West to South-South locations. Also, 95.8 % of the total variance in chlorophyll *a* was attributed to the interaction of season and location. Post hoc analyses using *DMR* test for seasonal variation of chlorophyll *a* showed that the differences in mean values were in the following order January >March>July and October.

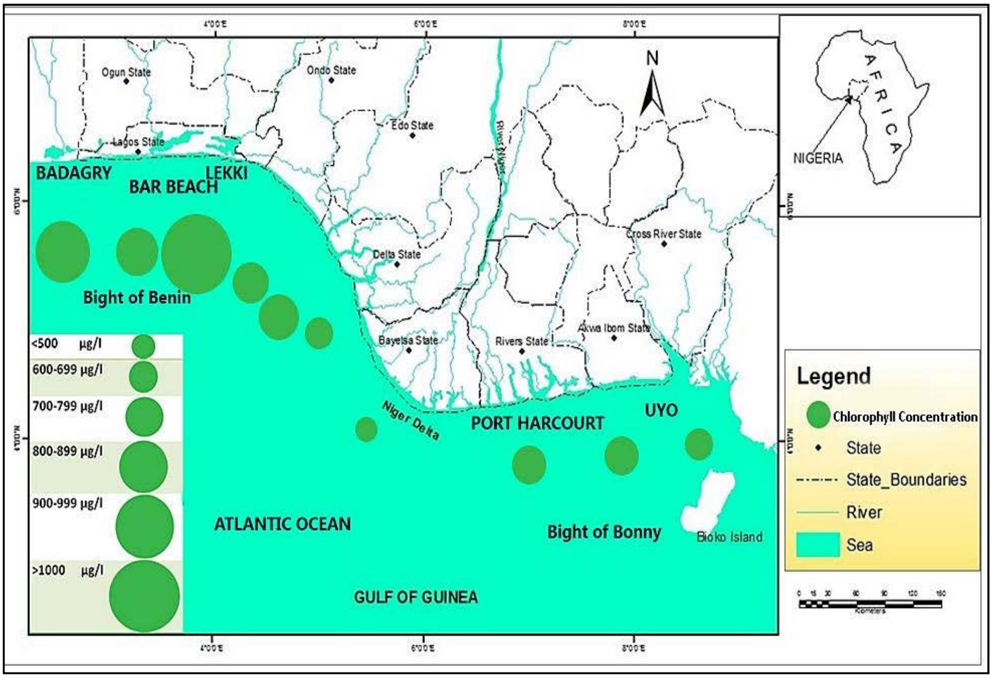

Figure 4. Mean primary production of Atlantic Ocean, Gulf of Guinea, Nigeria

Primary production as a function of mean chlorophyll *a* concentration is depicted in figure 4. There was considerable regional variability in the mean primary production. In this study, mean chlorophyll *a* concentrations varied between 439.85µg L^{-1} and 1051.89µg L^{-1}, and six categories were observed: <500µg L^{-1}; 600-699 µg L^{-1}; 700-799 µg L^{-1}; 800-899 µg L^{-1}; 900-999 µg L^{-1} and > 1000µg L^{-1}.

Spatially, highest values of primary production as particulate chlorophyll *a* were associated with Lekki and Badagry axis of Lagos, falling within the range of 900 μgL^{-1} to >1000 μgL^{-1}, whereas the lowest was recorded in Bayelsa State (<500 μgL^{-1}). In general primary production was higher and more variable in South-West locations (600 μgL^{-1} - >1000 μgL^{-1}) compared to the South-South locations where mean primary production was <500 μgL^{-1} to 799 μgL^{-1}.

Relationship between chlorophyll *a* concentration and environmental variables

Principal Component Analysis was performed using 17 environmental and biological variables. The results as shown in figure 5 illustrate the PCA biplot of some divisions of algae (Bacillariophyta, Dinophyta and Cyanophyta) and environmental variables in the Nigerian coastal waters. The first two components accounted for approximately 40% of the total variance and displayed moderate phytoplankton-environmental variables correlation. Bacillariophyta, Dinophyta,

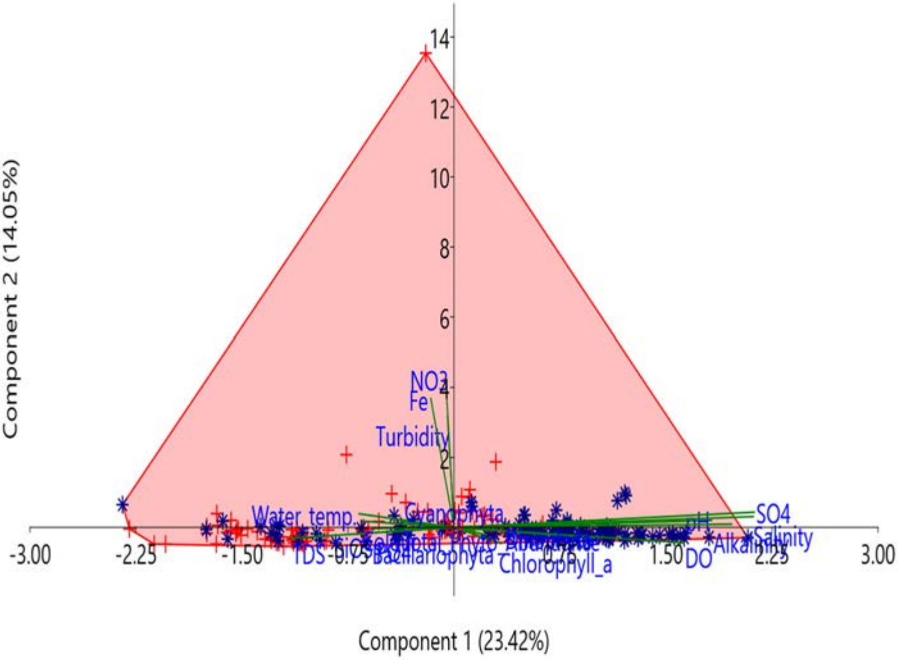

Figure 5. PCA biplot of environmental variables, chlorophyll *a* and phytoplankton divisions in the Nigerian coast.

Cyanophyta, chlorophyll *a*, pH, alkalinity, salinity, dissolved oxygen (DO), and SO_4 correlated and contributed positively to principal component 1 (PC1) while turbidity, water temperature, colour, Fe, NO_3, PO_4, TDS and SiO_3 correlated and contributed negatively to PC1. However, Fe, NO_3 and turbidity contributed and correlated positively to principal component 2 (PC2). Overall, the result revealed that the phytoplankton present in sites with low turbidity in the water column and nutrients had little or no effect in the distribution of phytoplankton communites. Additionally, DO, chlorophyll *a* and the phytoplankton biomass of Cyanophyta, Dinophyta and Bacillariophyta correlated positively. Furthermore, the South-West region of the Nigerian coast had high phytoplankton density when compared to the South-South region.

Chlorophyll concentration is often used as an indicator of algal biomass in aquatic ecosystems. In this study, highest chlorophyll *a* concentrations were recorded in South-West locations where higher phytoplankton biomass of major phytoplankton groups was also recorded. As a measure of trophic state, chlorophyll *a* levels in this study were high based on Horne and Goldman's (1994) trophic categorization of chlorophyll *a* of <8 μgL^{-1} for oligotrophic, 8-25 μgL^{-1} for mesotrophic, 26-75 μgL^{-1} for eutrophic and >75 μgL^{-1} for hypereutrophic waters. Following this classification, all the locations in the Gulf of Guinea, Nigeria studied are considered hypereutrophic. High chlorophyll *a* concentration is considered to signal eutrophication and as an indication of areas affected by eutrophication (HELCOM 2009). Also, employing the criteria of Havens (1994) which stipulates that algal bloom corresponds to 40 $\mu g\ L^{-1}$ of chlorophyll *a*, all the locations studied produced algal bloom. Chlorophyll *a* concentrations can act as an indicator of phytoplankton abundance and biomass in the coastal waters. The results obtained in the Atlantic ocean, Nigeria are quite higher than those reported elsewhere (maximum chlorophyll *a* level of 2 μgL^{-1}) in the Gulf of Guinea by Lefèvre (2009) and Caspian Sea (1.3–2.1 mg m^{-3} by Jamshidi and AbuBakar (2011) and maximal and surface chlorophyll *a* concentrations are 0.15-2.5 and 0.015-2.0 mg m^{-3} respectively, off North West African upwelling areas (Agusti and Duarte, 1999).

Chlorophyll *a*, which is a measure of phytoplankton population density, is influenced by a multitude of intrinsic and extrinsic factors such as internal and external nutrient fluxes, grazing etc. The negative correlation of, water temperature, colour, Fe, NO_3, PO_4, and SiO_3 to chlorophyll *a* observed in this study has been reported by some authors (Gnanamorthy *et al*., 2013; Chen *et al*., 2018). Chlorophyll *a* concentrations in aquatic environments is affected by the seasonal and spatial variations of the sea surface temperature (Jouanno *et al.,* 2011); trace metals like iron (Mills *et al.,* 2004), hydrographic features such as residence time and upwelling (Wieters *et al.,* 2003), nutrients load, bioavailability and form (Heisler *et al.,* 2008), pH (Hinga 2002), grazing rates and selectivity (Irigoien *et al.,* 2005), salinity (Chan and Hamilton, 2001) and light availability (Spilling *et al.*, 2015). The above factors interact in a very complex manner at influencing phytoplankton and chlorophyll *a*. Even when physical and chemical conditions are conducive, intrinsic factors like certain anatomical or metabolic adaptations confer competitive advantage on some phytoplankton species, enabling proliferations and bloom formation. The differential chlorophyll levels in the oceanic waters and adjoining rivers is ascribable to the meso-and macro-tidal systems with strong tidal flushing and micro-tidal coastal systems with limited flushing (Canavate *et al.,* 2015). The observation of the negative correlation between water temperature and chlorophyll *a* in this study negates the findings of Grodsky *et al*. (2008) of the congruence between temperature and chlorophyll *a* trends in the Gulf of Guinea, suggesting that a common process of South Equatorial Current (SEC), and of the Guinea Current takes cool and nutrient-rich waters to the surface (Jouanno *et al.,* 2011).

Conclusions

The study investigated the chlorophyll *a* levels in the Bights of Bonny and Benin in the Gulf of Guinea, Nigeria and some adjoining coastal waterbodies. Results revealed spatio-temporal variation and influence of nutrients. The spatio-temporal distribution of pigment profiles consequent on phytoplankton groups can influence aquatic ecosystem structure and functioning. Chlorophyll *a* is sensitive to ecosystem drivers (stressors, particularly nutrient load) and its measurement is useful for the screening, monitoring, early detection and warning of harmful algal bloom. Routine monitoring of chlorophyll *a* levels can thus provide very useful information about the productivity, water quality, nutrient load and fisheries potential of Nigerian coastal waters. In view of the dynamics of the Gulf of Guinea region, coupled with scarcity of measurements of this nature in this region, the present study has provided a pivot for subsequent future studies in chlorophyll *a,* production and algal blooms in the area.

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