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Responses of Phytoplankton Community Structure to Polycyclic Aromatic Hydrocarbon Constituents in Imo River, Oyigbo, Niger Delta, Nigeria

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Abstract

Phytoplankton perform a pivotal role in the food chain and serve as indicator species in environmental studies. Polycyclic aromatic hydrocarbons (PAHs) are toxic group of divergent chemicals with two or more aromatic rings coalesce side by side representing serious persistent organic contaminants posing environmental risk to aquatic life and human. Imo River receive contaminants from illegal oil refinery. The study was conducted to assess the responses of phytoplankton community structure to polycyclic aromatic hydrocarbon (PAHs) constituents in Imo River, Oyigbo, Niger Delta, Nigeria. Phytoplankton and water samples were collected from three (3) stations between January and March 2022 following standard methods. A total of 327 phytoplankton consisting of 5 taxa, 34 genera and 60 species were recorded in the study. Cyanophyceae (28 species), Chlorophyceae (14 species), Bacillariophyceae (15 species), Chrysophyceae (2 species), xanthophytes (1 species). PAHs constituent ranged between Acenaphthene (1.56±1.15 ppm) and Benzo (k) fluoranthene (0.54±0.10 ppm). Benzo (a) anthracene, chrysene, Benzo (b) fluoranthene, Benzo (k) fluoranthene and benzo (a) pyrene were higher than USEPA (1996) standard for aquatic environments. PCA revealed Bacillariophyceae, Chlorophyceae and Cyanophyceae were lover of Benzo (k) fluoranthene, Flourene, Flouranthene, Acenaphthylene, Acenaphthene and Anthracene while Xanthophyceae and Chrysophyceae was weakly associated with pH, dissolved oxygen, nitrate and phosphate. Thus, high molecular weight PAHs are rampant in the study area, which suggests that the environment poses a mutagenic, teratogenic, and carcinogenic risk due to biotransformation in the food chain.

Keywords: Phytoplankton community, PAHs, illegal artisanal refinery, Imo River, Nigeria

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1 INTRODUCTION

Phytoplankton is the cornerstone of the nibbling food chain and food web in aquatic ecosystem **[1]**. Since phytoplankton maintain chief source of food in all aquatic ecosystems, its abundance increases the amount of bio-output. In river ecosystem, species composition and abundance of phytoplankton proximity linked to an array of physical, chemical, and biological factors as well as their interactions. The phytoplankton composition turns out via the proportion of wins to attrition amongst the species that became accustomed to live in that environment **[2]**. In addition to providing evidence of the underlying causes of any notable changes in an aquatic ecosystem, phytoplankton approach can notify researchers of any such changes. In a stressed or impure river system, separate phytoplankton groups have multiple degrees of natural tolerance, leading to an uneven species succession **[3]**. The sturdier species might ultimately take over the less forbearing ones that may have once superseded the region, and the latter may even go extinct. When less vulnerable species are eliminated, they compete for food and sunlight, which could lead to the cooperative groups hitting their maximum reproductive capacity and exhibiting an increase in population.

The aquatic setting is exclusively exposed to PAHs from a spectrum of sources and in intricate combinations [4, 5]. It is believed that polycyclic aromatic hydrocarbons (PAHs) prove particularly counterproductive due to their mutagenic and carcinogenic properties [6]. Aquatic life in the water column may suffer once PAHs are redistributed by both natural and man-made mechanisms [7, 8]. In general, disproportionate wreckage occurs for low molecular weight compounds such as anthracene, benzene, and naphthalene [9], and microalgae in aqua-ecosystem use high-molecular weight, more riskier PAHs chemicals such as fluoranthene and pyrene [10]. The form of picking out stolen crude oil and purifying it using made in-country refineries, as well as local resources and skills, is recognized as illegal artisanal refining. Illegal artisanal refineries emerged a variety of sizes; small-scale platforms often charm women and others with limited financial resources, while large-scale builders usually run by business people due to their high budgetary needs [11]. The Imo River emerges in southern Nigeria and plunges into the Atlantic Ocean. It comes in contact with several creeks that were contaminated by sand quarrying operations, waste from road and bridge construction, artisanal refineries that were illegally contextualized along the river's path, and wooden boat manufacturing and repair projects.

Thus, as unapproved refinery ventures were set up by indigenous peoples in Nigeria to make ends meet, the country's unemployment rate grows. As a result, irritants substance was discharged into the Niger Delta's rivers. In relation to pollutants made up of residues from crude oil, previous studies reveal that phytoplankton growth responses vary, as some studies find growth increases while others find growth decreases in their presence. Varying petroleum hydrocarbons have varying effects on how sensitive certain phytoplankton species are in terms of their ability to develop and assimilate carbon from the environment [12]. In the event of a spill, phytoplankton makeup may change as a result of some species seeing a rise relative to abundance, while other algal population group often decreases [13]. Phytoplankton community structure is known to shift with response to changes in environmental conditions such as temperature, nutrient availability, and grazing pressure [14]. In Nigeria several studies have been reported but few to be mentioned Bubu-Davies *et al.* [5] reported on the effects of PAHs in sediments, water and fishes, Kpikpi *et al.* [8] documented work on temporal pollution load index and ecological risk evaluation of some heavy metals. Little or no knowledge to the best of my literature search based on this study. Hence, to fill the knowledge gap, the study aims to investigate the responses of phytoplankton to PAHs constituents in Imo River, Oyigbo, Nigeria.

MATERIALS AND METHODS

Study area

The research was carried out in Imo River, Oyigbo and in Oyigbo local government area of Rivers State, Nigeria. In terms of ecology, the area comprises of mangroves vegetation, freshwater swamps, and rain forests. The study area is located between 6˚52′19″N and 3˚43′41″E (Table 1).

Table 1. Description of sampling stations and locations.

Stations	Geographical co-ordinates	Descriptions
1.	6˚34′24″N, 3˚31′52″E	Dredged sand deposit for sales, wooden boats constructions and repairs, receiving wastes from the occupants around the area.
2.	6˚47′36″N, 3˚27′29″E	Previous loading site for crude oil exploitation and installment of illegal artisanal refinery
3.	6˚52′19″N, 3˚43′41″E	Sand mining, buying and selling of crude oil products by vendors

Water analysis

Water samples were collected monthly for three months between January and March, 2022. Samples for physico-chemical analysis (temperature (°C), salinity (ppt), electrical conductivity (EC), total dissolved solids (TDS) and pH were analyzed in-situ except for Dissolved Oxygen (DO), biochemical oxygen demand (BOD), Nitrate and Phosphate that was analyzed in the laboratory following standard method.

Collection of Plankton Samples

Phytoplankton net of 55 µm mesh size with 50ml sample collection vial bottle attached at the base was dragged against the water current at low tide in each station just below the water surface for five minutes. After which, the water samples were transferred into a sterilized sample bottles and fixed with 5% formalin. Organism/mL method as described by **[15]** for enumeration of phytoplankton.

Identification of Plankton

The following plankton keys Patrick and Reimer **[16]**, Prescott **[17]** were consulted as identification guides.

PAHs sample Collection and Determination

PAHs water samples were collected in all three stations in an amber bottle of 500ml and placed in an ice cooler box and transported to the laboratory for analyses. GC-MS was used to determined PAHs samples using established method and procedures as described by **[18]**.

Data Analyses

One-way Analysis of variance (ANOVA) for samples were performed at ($p < 0.05$) with Statistical Package for the Social Sciences (SPSS Version 26).

RESULTS

A total of 327 phytoplankton consisting of 5 taxa, 34 genera and 60 species were recorded in the study. Cyanophyceae (28 species), chlorophyceae (14 species), bacillariophyceae (15 species), chrysophyceae (2 species), xanthophytes (1 species). Highest species densities 1818.18 org/mL were implicated for *Anabaena flos-aquae, Lyngbya spiralis, Microcystis aeruginosa, M. flos-aquae* and *Oscillatoria curviceps* (station 2) and lowest densities 227.27org/ml (station 2) were obtained for *Aphanocapsa biformis, Nostoc commume, Oscillatoria princeps, Phormidium inundatum, Spirulina sp* and *Synechococcus elongatus* were all (Cyanophyceae) respectively (Table 2).

Temperature ranges between 30.47ºC (Station 3) and 31.72ºC (Station 1), pH range from 5.82 (Station 3) to 7.08 (Station 1), salinity range from 9.50 ‰ (Station 2) to 9.71 ‰ (Station 3), electrical conductivity (EC) ranged from 16.58 µs/cm (Station 3) to 45.27 µs/cm (Station 1), total dissolved solids (TDS) ranged between 7.47 mg/L (Station 3) and 21.78 mg/L (Station 1) while dissolved oxygen (DO) ranged from 7.14 mg/L (Station 1) to 7.35 mg/L (Station 2) (Figure 1).

The nutrients showed that nitrate range between 0.0012 mg/L (Station 2) and 0.0036 (Station 1) while phosphate range between 0.0045 mg/L (Station 3) and 0.0085 (Station 1) (Figure 2).

A total of ten (10) Polycyclic aromatic hydrocarbons (PAHs) constituents were recorded in this study. In descending order, PAHs from 1-3 was high in the month of January and lowest in the month of March. The results showed significant differences ($p<0.05$) with months.

Though, Acenaphthene, flourene, anthracene and fluoranthene showed deviation from CCME **[19]**, then benzo (a) anthracene, chrysene, Benzo (b) fluoranthene, Benzo (k) fluoranthene and benzo (a) pyrene were higher than recommended USEPA **[20]** for aquatic environments (Table 3).

Table 2. Phytoplankton species composition and density of Imo River, Port Harcourt, Nigeria

Phytoplankton	Density		
CYANOPHYCEAE (46.78%) (n=153)	***STN 1***	***STN 2***	***STN 3***
Anabaena flos-aquae	-	1818.18	909.09
" fertilissima C.B.Rao	-	454.54	-
" orientalis S.C.Dixit	-	-	454.54
" variabilis Kuetz ex Bornet	-	227.27	0
Anabaenopsis circularis	-	454.54	454.54
Aphanocapsa biformis A.Br.	454.54	227.27	227.27
Aphanothece sp	227.27	-	-
Entophysalis sp	-	909.09	454.54
Gomphosphaeria aponina Kuetz.	227.27	454.54	227.27
Lyngbya spiralis Geitler	-	1818.18	454.54
Merismopedia elegans Lemm	227.27	909.09	-
" minima Beck.	454.54	454.54	-
Microcystis aeruginosa Kuetz.	-	1818.18	909.09
" flos-aquae (Wilttra) Kirchner	-	1818.18	909.09
Nostoc commume Vaucher ex Born. Et Flah.	454.54	227.27	-
Nostoc muscorum Ag.	909.09	909.09	454.54
" punctiforme Hariot	227.27	454.54	227.27
Oscillatoria curviceps C.Agardh ex Gomont	227.27	1818.18	909.09
" formosa Bory ex Gomont	227.27	909.09	454.54
" limosa Ag. Ex Gomont	454.54	454.54	227.27
" princeps Vaucher ex Gomont	227.27	227.27	227.27
Phormidium fragile (Meneghini) Gomont	454.54	454.54	454.54
" inundatum Kutzing ex Gomont	227.27	227.27	227.27
" tenue Gomont	227.27	909.09	454.54
Rivularia aquatica De Wilde.	227.27	454.54	227.27
Spirulina sp.	-	227.27	227.27
Synechococcus elongatus Nag	-	227.27	227.27
" sp	227.27	454.54	454.54
CHLOROPHYCEAE (25.07%) (n=82)	***STN 1***	***STN 2***	***STN 3***
Ankistrodesmus falcatus (Corda.)	227.27	227.27	227.27
Chlorella vulgaris Bayernick	227.27	454.54	227.27
Chlorococcum humicola (Nageli) Rabenhorst	227.27	909.09	454.54
Cladophora glomerata (L.) Kutzing	454.54	454.54	909.09
Closterium acerosum (Schrank.) Ehr.	454.54	227.27	227.27
Closterium ehrenbergii (Menegh.) ex Ralfs.	1818.18	227.27	0
Closterium incurvum Brebisson	909.09	227.27	454.54
Chaetophora flocossa	454.54	0	0
Cosmarium granatum Brebisson ex Ralfs	227.27	227.27	227.27
Cosmarium turgidum Ralfs	909.09	0	227.27
Crucigenia quadrata Morren	1818.18	227.27	454.54
Crucigenia tetrapedia Kirchner	909.09	0	909.09
Microsphora flocossa	909.09	227.27	454.54
Pseudendoclorium subrrarium	454.54	227.27	227.27
BACILLARIOPHYCEAE (22.01%) (n=72)			
Cyclotella meneghiniana Kutzing	454.54	909.09	0
Cymbella lanceolata Breb	227.27	454.54	227.27
Fragillaria sp.	0	909.09	227.27
Gyrosigma acuminatum (Kutzing) Rabenhorst	227.27	454.54	227.27
Gyrosigma rautenbachiae Cholnoky	227.27	454.54	454.54
Melosira pusilla	227.27	909.09	454.54
Melosira varians C.Agardh	227.27	454.54	0

Navicula cuspidate Kuetz	227.27	454.54	227.27
Navicula rosetellata	0	227.27	227.27
Navicula gastrum	0	227.27	454.54
Navicula viridula Kuetz	227.27	0	227.27
Nitzschia palea (Kutzing) W.Smith	227.27	227.27	0
Nitzschia sigma	1818.18	454.54	909.09
Asterionella gracillima	909.09	454.54	227.27
Tabellaria binalis	454.54	227.27	227.27
CHRYSOPHYCEAE (4.28%) (n=14)			
Mallomonas litomesa	227.27	454.54	909.09
Mallomonas helvetica	227.27	454.54	909.09
XANOPHYCEAE (1.83%) (n=6)			
Botryococcus branunii	454.54	454.54	454.54
Total No. of Individual species	**97**	**137**	**93**
Total No. of species	**327**		

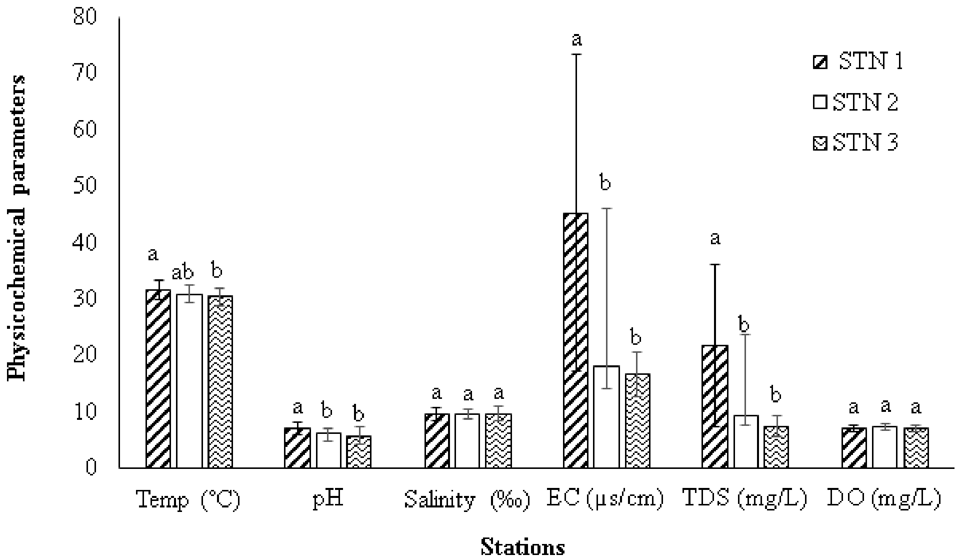

Figure 1. Physico-chemical parameters of Imo river, Oyigbo, river state.

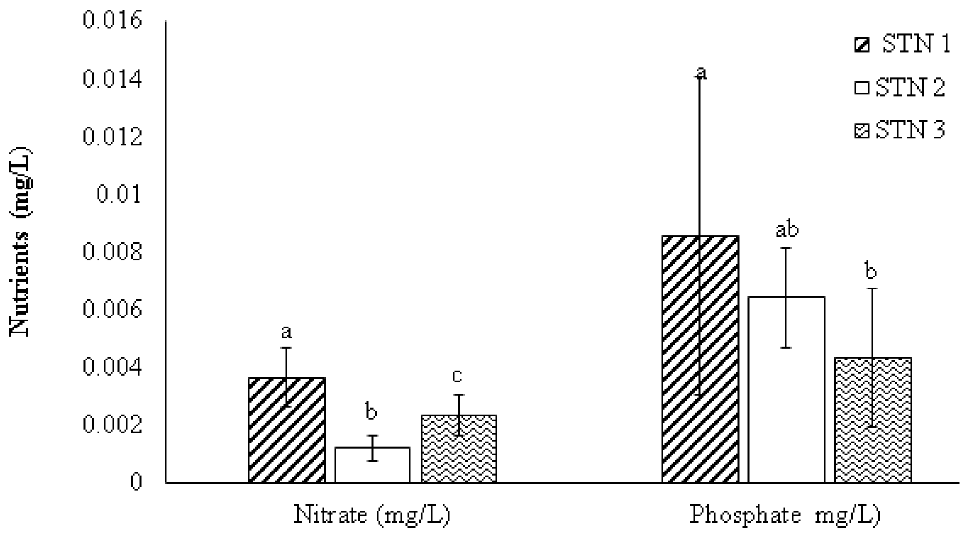

Figure 2. Nutrient status of imo river, Oyigbo, river state.

Table 3. Monthly PAHs concentration in Imo River, Oyigbo, Rivers State, Nigeria.

PAHs constituents (ppm)	Months			Overall mean	CCME 2008	Standard
	Jan	*Feb*	*Mar*			
Acenaphthylene, HMW	1.63±0.65[a]	0.84±0.46[b]	0.21±0.05[c]	0.89±0.74	N/A	60 USEPA [20]
Acenaphthene, HMW	2.80±0.65[a]	1.63±0.46[b]	0.24±0.19[c]	1.56±1.15	0.58	60 USEPA [20]
Flourene, HMW	2.63±0.61[a]	1.43±0.46[b]	0.09±0.09[c]	1.38±1.14	0.3	300 WHO [21]
Anthracene, HMW	2.32±0.94[a]	1.04±0.75[b]	0.49±0.35[c]	1.28±1.04	0.012	2000 WHO [21]
Flouranthene, LMW	2.14±0.44[a]	0.96±0.43[b]	0.22±0.18[c]	1.11±0.88	0.4	300 WHO [21]
Benzo (a) anthracene, LMW	1.76±0.59[a]	0.58±0.44[b]	0.40±0.19[b]	0.91±0.75	0.018	0.1 USEPA [20]
Chrysene, LMW	1.91±0.07[a]	0.82±0.62[b]	0.82±0.62[b]	1.18±0.93	N/A	0.2 (USEPA, [20]
Benzo (b) fluoranthene, LMW	1.73±0.76[a]	0.02±0.01[b]	0.02±0.01[b]	0.59±0.17	N/A	0.2 USEPA [20]
Benzo (k) fluoranthene, LMW	1.18±0.50[a]	0.30±0.16[b]	0.13±0.09[b]	0.54±0.10	N/A	0.2 USEPA, [20]
Benzo (a) pyrene, LMW	1.24±0.61[a]	0.30±0.18[b]	0.27±0.28[b]	0.65±0.11	0.15	0.2 USEPA, [20]

Means that share different superscripts within the rows are significant at $p<0.05$
Note: HMW- High molecular weight, LMW – low molecular weight, N/A – not available

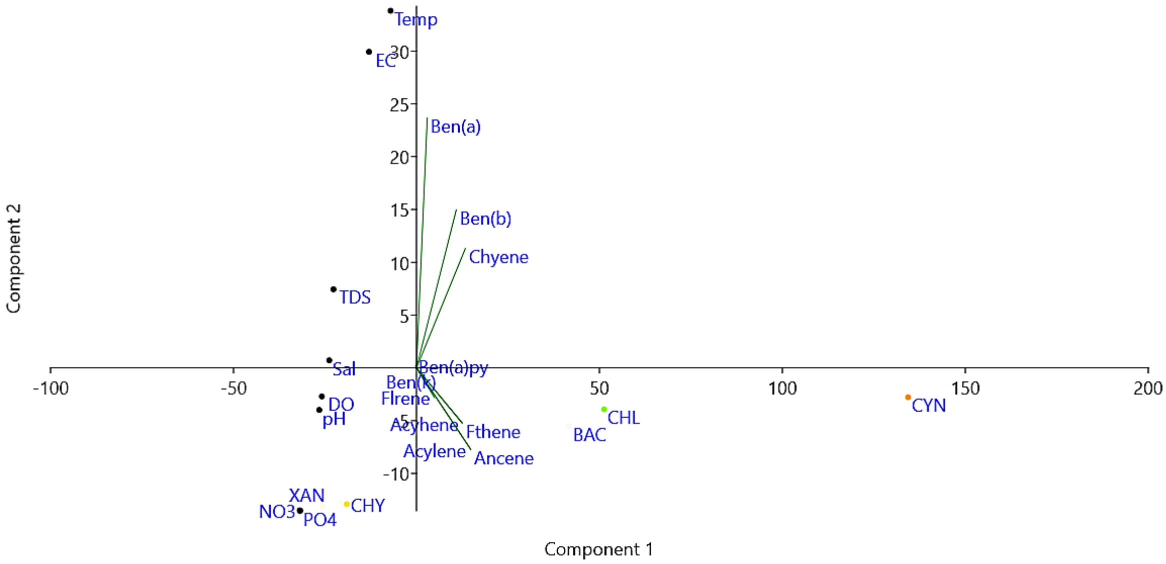

Figure 3. Principal component Analysis (PCA) correlation for environmental variables and phytoplankton.
Note: *(BAC – bacillariophycea, CHL- chlorophycea, CHY- chrysophycea, CYN- cyanophycea and XAN- xanthophycea)*

Bacillariophyceae, Chlorophyceae and Cyanophyceae is a lover of Benzo (k) fluoranthene, Flourene, Flouranthene, Acenaphthylene, Acenaphthene and Anthracene while xanthophyceae and chrysophyceae was weakly associated with pH, dissolved oxygen, nitrate and phosphate (Figure 1). The eigenvalue recorded component 1 (7.77484) and component 2 (1.23059) (Figure 3).

DISCUSSIONS

Phytoplankton as first tropic level organism is greatly influenced by nutrients, physcio-chemical parameters and organic matter in the environment. The present study revealed Chrysophyceae and xanthophyceae lose their dominance of low resistance to PAHs, making it possible for other tolerant groups of phytoplankton Cyanobacteria to proliferate in the ecosystem.

The more tolerant groups, the more the toxin-producing species. Thus, the study supported the findings by Pelletier *et al.* **[22]** who opined widespread of crude oil pollution may influence a detrimental effect on the total phytoplanktonic biomass.

The physicco-chemical parameters (temperature, pH, salinity, electrical conductivity, total dissolved solids and dissolved oxygen) ranges observed in the study favored the composition of phytoplankton species. There were significant differences between the studied stations ($p<0.05$).

Temperature could be influenced by the duration of sunlight exposure and the absorption of solar energy by the river water, which may be heightened due to a reduced presence of standing vegetation to block light rays from reaching the river. For dissolved oxygen, the atmospheric air diffusion was unimpeded due to less standing aquatic vegetation along the shore, the dissolved oxygen detected was thought to be healthier for aquatic life to survive the environment. The pH could result from prior inorganic contamination as well as continuing operations from illicit artisanal refineries, while the salinity varied because of low table water, a lot of evaporation during the dry season, and the migration of inorganic elements from human activities related to the river water under study. This could be attributed to PAHs contamination to aquatic plants that could not withstand the toxic environment from the activities of illicit artisanal refining. Though, high total dissolved solids (TDS) recorded might be linked to sand mining activity and crude oil exploitation along the waterway. The study conformed with report **[5]** that physico-chemical parameters romance with PAHs constituent and increase molecular reaction at the surface water to cause a shift of phytoplankton group to sustain and disintegrate in hash aquatic environment.

Nutrients help in increasing biological productivity to their living standard in an ecosystem **[23]**. The study observed nitrate and phosphate below **[21]** recommended limits. According to Paerl *et al*. **[24]** state that escalated nutrient like nitrate and phosphate may directly increase phytoplankton productivity and can favour blooms of toxic cyanobacteria.

Prince **[25]**, reported 9 species of cyanobacteria and 14 algal genera. Lewis and Pryor **[26]**, reported 53 marine and freshwater species. While, Bretherton *et al.* **[27]** documented 15 marine species. According to Ozhan *et al.* **[28]** suggested that dinoflagellates thrive better than Bacillariophyceae at low concentrations and at higher concentration Bacillariophyceae does better. However, the present study revealed 28 cyanobacterial species appear to be stimulated by crude oil residues with regard to specific oil analytes, whereas others are inhibited. Consequently, phytoplankton species tolerance to crude oil constituents varies with species sensitivity. The observed indicators species in the study were *Anabaena sp*, *Lyngbya spiralis*, *Microcystis sp* and *Oscillatoria sp*. The study revealed that PAHs favored Cyanophyceae disintegration with respect to sensitivity. This could be attributed to the degree of toxicity with regard to the residence time of PAHs to resilient other species composition in the environment. The results disagree with these studies, reported by **[27]** who opined Bacillariophyceae as highest abundance in composition while **[13]**, documented Chlorophyceae.

The study showed phytoplankton species correlated positive with PAHs constituents with high molecular weights (HMW) indicating a polymeric interaction of intracellular substances with phytoplankton and floating solidary substances resulting a shift to the group with more PAHs utilization. The study conformed with report by Jiang *et al.* **[29]** stated that shifts in phytoplankton communities can alter the structure, stability and function of marine ecological systems.

CONCLUSION

Phytoplankton species shown variability in their tolerance to PAHs. The most sensitive phytoplankton were Bacillariophyceae, Chlorophyceae and Cyanophyceae showing upbeat response to PAHs, while xanthophyceae and chrysophyceae seemed to be the least affected group. From the present study, it can be concluded that PAHs can favor Cyanophyceae group of phytoplankton productivity and community structure. With respect to the high molecular weight PAHs (Acenaphthylene, Acenaphthene, Flourene and Anthracene) found rampant in the study area, could suggests that the environment poses unforeseen risk to life in the aquatic environment. However, an insight of residence time of oil spill in surface water could be considered if it will reduce or increase the composition of phytoplankton community as they remain key player in the food chain.

Conflict of Interest

Authors declared no conflict of interest.

Author's Contribution

P. B. Kpikpi initiated experimental design, developed and interpreted the data for the study. Also, Kpikpi is the corresponding author who submitted manuscript to the journal's editor and responsible for correspondences with the editor. The second author **O. A. Bubu-Davies** coordinated the research and edited the manuscript. The third author **L. A. Esaenwi** provided all literatures, compiled the data for the study.

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