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Spatial Distribution of Diatoms and Nutrients in a Mangrove Swamp of Eastern Obolo, Niger Delta

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Authors' contributions

This work was carried out in collaboration between both authors. Author AII designed the study, wrote the protocol and wrote the first draft of the manuscript. Author KSE managed the literature searches, analyses of the study performed and the experimental process. Author AII identified the species of diatoms. Both authors read and approved the final manuscript.

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ABSTRACT

The spatial distribution of diatoms and nutrients concentration in a mangrove swamp of Eastern Obolo was investigated during dry and wet seasons. This research was to establish the distribution pattern of diatom at ten stations with nutrients level, salinity, TDS (Total Suspended Solid), conductivity, pH across the coastal water, and to evaluate centric/pennate diatom's ratio in the system. It was observed that during dry period, the salinity, conductivity, TDS and pH level increased progressively toward the Atlantic Ocean. The species taxa encountered at respective station could be affected by TDS, conductivity and salinity level as it correlated significantly with these variables, TDS (r = .929**), conductivity (r = .889**) and salinity (r = .760**). The species diversity during dry season correlates significantly with TDS (r = .700**), conductivity (r = .658*) and salinity (r = 0.545). Reactive phosphate peaked 0.038 mg/L at S9 during wet season and dropped to 0.002 mg/L at S2 during dry season, whereas reactive nitrate recorded a higher value of 1.10 mg/L at S5 during dry season and lower value of 0.018 mg/L at S4 & S6 during wet season. During wet season, salinity level affects diatom density positively as it responded significantly (r = .795**). TDS showed a strong significant correlation with reactive nitrate (r = .810**), reactive phosphate (r = .728*) and with SDI (r= 0.265) during wet period. The ratio of centric to pennate

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diatom recorded a lower value of 0.41 and 0.37 at S1 & S2 during wet season, and 0.47 and 0.47 at S1& S2 during dry season. The following species of diatoms showed a wider range of distribution during wet and dry period; *Coscinodiscus centralis* Ehrenberg, *Ditylum brightwelli* (T. West) Grunow, *Biddulphia mobiliensis* (J.W. Bailey) Grunow, *Thalassiothrix frauenfeldii* (Grunow) Grunow and *Asterionella japonica* Cleve. The centric to pennate diatom ratio could be used to quantify the degree of disturbance of benthic environment. The distribution and composition of the diatom species in the coastal water was affected by salinity level, conductivity, pH and TSD for the seasons majorly, and least by the nutrient level.

Keywords: Centric diatom; mangrove swamp; nitrate; species diversity.

1. INTRODUCTION

Diatom are unicellular (but often live in colonies and some form chains), microalgae with membrane-bound cell organelles and which have a siliceous cell wall or frustule, which is made up of two parts (known as valves) the hypotheca and epitheca. The structure and patterns and processes of the cell wall form the basis for the two major groups within the diatoms namely: pennate and centric diatoms. Pennate diatoms are elongate and usually bilaterally symmetrical, with up to 800 marine species identified, dominating benthic environment. Centric diatoms are usually round or ''radially symmetrical" and there are up to about 1000 species dominating marine planktonic environment [1]. In the coastal waters, limiting factors such as silicate and other nutrient availability, water stability, light climate, parasitism and grazing affects some species which are present in the water column at a particular time. Diatom bloom often occur along coastal waters when episodic upwelling brings nutrient-rich water to the surface, where there is better access to light and subsequent increased production. Diatoms are the most abundance group of phytoplankton in aquatic ecosystem. Their usefulness in the coastal water is because of its extreme sensitivity to changes in salinity, temperature, total dissolved solids (TDS), nutrient supply and other environmental factors. Because their cell wall is composed of hydrated silica [Si(H2O)*n*], they are well preserved in the sediments. Diatoms contribute more than 70% of the primary production in Southern Ocean and play a major role in global silica and carbon cycling [2] and a major group of primary producers in most aquatic ecosystem [3, 4]. Because of its sensitivity to variations in the environment, diatoms can be used to indicate the intensity of human activity and climate change in aquatic ecosystem [5,6].

However, diatom community composes of many planktonic species and benthic species as well. Their size ranges from 2 to 200 μm and they exhibit a wide variety of shapes. Their distribution is chiefly influenced by the presence of nutrients like silicate, nitrate, phosphate [7], SST (Sea Surface Temperature) [7,8] and the stability of the water column [9]. [10] reported that the spatial distribution of sediment diatom assemblage are clear markers of current water levels within Lake Lugu and represent a benchmark for evaluating paleolimnological changes in water levels, which can be an indirect proxy of regional climate change.

Generally, diatoms being part of phytoplankton is the basic biological resources of marine ecosystem. Changes in its population and community structure have a direct impact on the marine ecosystem structure and function. The precise knowledge of its spatial distribution patterns constitutes a powerful tool for an oceanologically-based dynamic coastal management and must be integrated in marine water quality monitoring procedures.

The coastal water of Eastern Obolo is characterized with human activities such boat transport, fishing, sand dredging, logging, and deforestation of mangrove. Therefore the objective of this work is to evaluate the ratio of centric to pennate diatoms in the water column in respect to hydraulic conditions, to assess the natural distribution of diatom base on nutrient level. However, this work will serve as baseline information for diatoms composition in this ecosystem since no such research has been done in this water.

2. MATERIALS AND METHODS

2.1 Study Area

Coastal water of Eastern Obolo drains into Atlantic Ocean and is connected to Qua Iboe River estuary at the east and Imo River estuary at the west. It is located at 4033′ N – 4050′ N;

7045′ E – 7055′ E and about 650m above sea level in the tropical mangrove forest belt east of the Niger Delta, Fig. 1. The tidal regime here is semidiurnal and has a range of about 0.8m at neap tides and 2.20 m during spring tides with little fresh water input joined by numerous tributaries [11]. Eastern Obolo is an area blessed with many communities with diver socio-economic activities such as artisanal fishing, logging and boat transportation. The water is fringed with diversity of floral such as *Rhizophora mangle* L., *R*. *racemosa* (G.F.W. Meyer), *Avicennia africana* (P. Beauv.), *Avicennia marina* (Forssk) Vierh., *Phoenix reclinata* (Jacq.) and *Nypa fruiticans* (Wurmb) and *Sargassum* sp that normally found during wet season. Oil palm (*Elaeis guineensis* Jacq.) and coconut palm (*Cocoa nucifera* L.) are also widely distributed in the villages. The area is an oil-producing area with several oil wells and many fishing communities. Nypa palm and red mangrove are the dominant species of flora. The area is characterized by an extensive mudflat at Iko Creek and others dotted all over the environment. A large sand bar is also found at Etizar during neap low tide. As part of tropics, this area experience two seasons, the dry (October to May) and wet (April to October) with an annual rainfall averaging about 2500 mm [12].

2.2 Collection of Sample

Samples were taken from ten stations along Okoromokho Creek, Iko River, Iko Creek and Iko River Estuary. To assess the spatial distribution of diatoms per season, samples were collected between 9 a.m to 1 p.m at ten stations across the coastal water of Eastern Obolo, once in dry season and once in wet season. February was selected for dry season and August for wet season. Surface water was collected and analyzed insitu for the following parameters: Conductivity, salinity, pH and TDS (total dissolved solids). Simultaneously, 250 ml water sample was collected and taken to the laboratory for the analysis of nutrients. Thereafter, 50 ml each was subsampled to analyze reactive nitrate, reactive phosphate, silicate and ammonia as described by APAH, [13].

2.3 Diatom Sample

Plankton net with a mesh size of 55 µm was tied unto a motorized boat and dragged back and forth just below the water surface for 10 minutes at a low speed (4 knots) per station. Plankton sample was preserved immediately by fixing in 4% unbuffered formalin solution. The density of diatoms was determined using the sedimentation

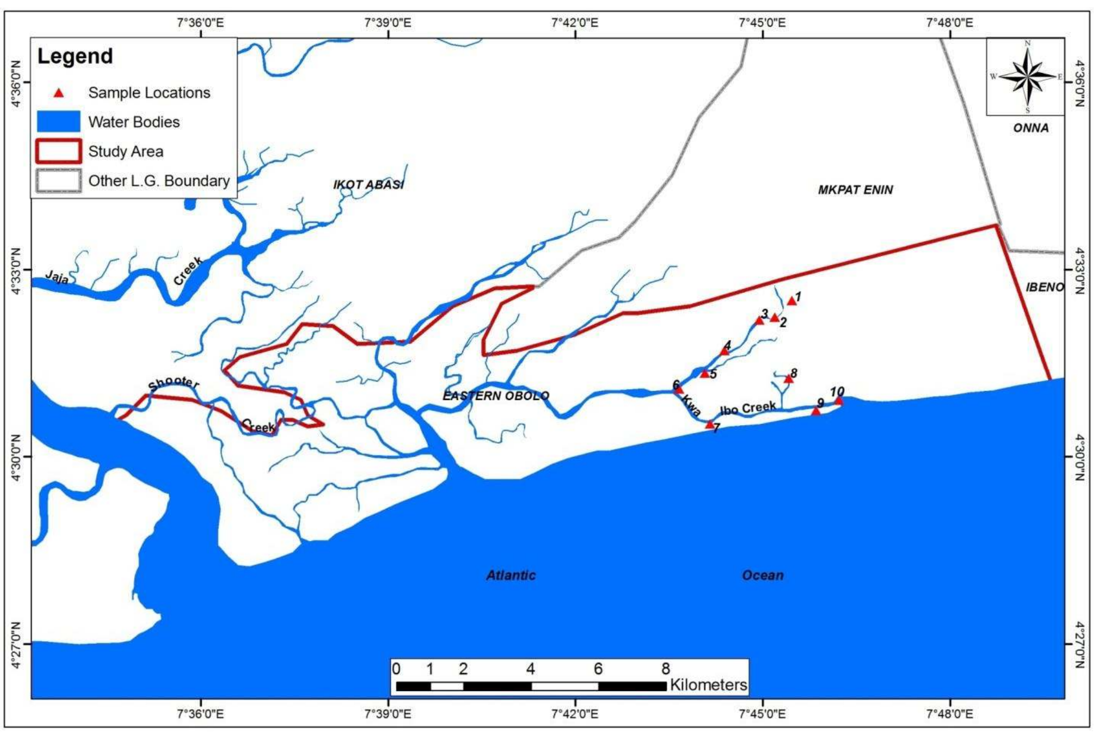

Fig. 1. Map of the coastal water of Eatern Obolo showing the study stations

technique as described by, [14]. One millimeter each of shakened sample was examined using a CHA and CHB binocular light microscope with a calibrated eye piece, using the x160 and x640 fields. Diatoms species were identified using relevant texts [15 – 21]. The Diatoms count was expressed as units per ml (filaments or single cells).

2.4 Statistical Analysis

PAST 3.0 statistical tool was used to analyzed the biological indexes such as Shannon-Wiener diversity index (Hs), Species diversity index is express as Simpson (1 – D) index and Evenness (e^H/S) index and Pearson Correction coefficient. Minitab 17 was used to evaluate multivariate relationship between the diatom community and the environmental variables.

The ratio of centric to pennate is express as

$$\frac{\text{Centric}}{\text{Pennate}} \tag{1}$$

This was used to quantify the degree of variations in diatoms community in respect to hydraulic conditions of the area.

3. RESULTS

3.1 Physicochemical Indices

The results for physicochemical parameters for dry season are given in Figs. 5 and 6. During this season, the surface water salinity range from 16‰ at S1 to 32‰ at S7. The salinity content correlate significantly with conductivity (r = .852**) and pH (r = .834**). The pH value varied across the stations but remained ≤ 8.7 and showed positive correlation with TDS and conductivity, Table 4. The total dissolved solids and conductivity peaked 308 mg/L and 675 µs/cm respectively at S10 with progressive increase in levels toward the Ocean. TDS level showed a strong significant correlation relationship with conductivity (r = .974**) and salinity (r = .871**), Table 4. The nutrients showed a great variation across the stations with high level of reactive nitrate and silicate in the water, Fig. 6. The reactive nitrate concentration showed a strong significant relationship with evenness index (r = .763*) and species taxa (r = -.635*). The silicate level correlate weakly with diatom individuals (r = 0.284) and negatively with pH level (r = -0.603). The reactive phosphate correlates weakly with species diversity index (SDI) (r = 0.442), Table 4. The reactive nitrate level showed a significant correlation with TDS (r = -.715*) and with conductivity (r = -.748*), and negatively correlate with salinity (r = -0.601).

However, in the wet season, the physicochemical parameters results are given in Figs. 7 and 8. During this time, the salinity value range from 0‰ at S1, 2 & 3 to 17‰ at S10. Salinity showed a strong significant correlation with conductivity (r = .816**), Table 5. TDS varied across the water surface with highest value of 404 mg/L at station 9 and the lowest value of 178 at station 10. TDS showed a strong significant correlation with reactive nitrate (r = .810**) and reactive phosphate (r = .728**). Reactive silicate peaked 0.79 mg/L at S9 and dropped to 0.40 mg/L at S4. Reactive nitrate showed a strong significant correlation with reactive phosphate (r = .929**), while reactive phosphate correlate positively with conductivity (r = 0.405) and salinity (r = 0.497).

3.2 Diatom Community

The spatial distribution of diatom community is given in Tables 7 and 8, for dry and wet season respectively. *Coscinodiscus centralis* Ehrenberg, *Ditylum brightwelli* (T. West) Grunow, *Biddulphia mobillensis* (J.W.Bailey) Grunow and *Thalassiothrix frauenfeldii* (Grunow) Grunow showed a good distribution across the water during dry season, Table 6. In the wet season, *Ditylum brightwelli*, *Biddulphia mobillensis* and *Asterionella japonica* Cleve showed a good distribution pattern across the water. The diatom community was grouped into centric and pennate, group. During dry season, centric diatoms had a highest percentage occurrence than pennate diatom, Fig. 2. The percentage abundance for centric diatoms in the wet season is given as 57% while pennate diatoms as 43%, Fig. 2. It was observed that the percentage abundance for pennate diatoms is high in wet season than dry season. The spatio-distribution abundance for central and pennate diatoms across Eastern Obolo coastal water is given at Figs. 3 and 4. This showed that during wet season pennate diatoms were high at S1, 2 & 3 than centric counterpart. The centric to pennate ratio are given in Table 1. During wet season, this ratio range from 0.22 at S2 to 2.70 at S7, and in dry season, the ratio peaked 6.69 at S10 and dropped to 0.47 at S1 & 2. The centric diatoms correlate significantly with salinity (r = .928**) and conductivity (r = .823**) during wet period, and with TDS (r = .691*) during dry season whereas the pennate diatoms correlate positively with TDS (r = 0.551), conductivity (r = 0.423) and salinity (r = 0.395) during dry season and negatively with TDS (r = -0.360), conductivity (r = -0.133) and salinity (r = 0.231) during wet season, Table 6.

Table 1. Shows the ratio distribution of centric: Pennate diatoms across Eastern Obolo coastal water in 2015

Centric: Pennate		
Location	**Wet season**	**Dry season**
Utebette	0.41	0.47
Okorombokho Bridge	0.37	0.47
Okoroette Comm.	0.22	1.78
Ayama	0.39	2.88
Etizar	1.22	4.56
Atoajgi Fishing Comm.	11.5	2.79
Okoroette Fishing Port	2.13	3.76
Iko Creek	2.70	3.00
Iko Fishinf Port	2.45	3.17
Iko Estuary Mouth	1.70	6.69

However, the biological indexes for both dry and wet seasons are given in Tables 2 and 3 respectively. During dry season, the species diversity index (SDI) peaked 0.925 at S7 and dropped to 0.657 at S2. The SDI correlate significantly with TDS (r = .700*), conductivity (r = .658*), and a positive correlation with salinity (r = 0.545). S2 recorded the lowest number of diatom cells as 44 cells/ml, whereas S9 recorded 2519 cells/ml as the highest individuals. The diatoms cells correlate significantly with TDS (r = .663*), species taxa (r = .760*), and a strong positive correlation with salinity (r = 0.522) and conductivity (r 0.563). The even distribution was high at S2 (0.986) with a total number of individual as 44 cells/ml and low at S9 (0.641) with a total number of individual as 2519 cells/ml, Table 2. The evenness index showed a strong negative significant correlation with TDS (r = -.886**), conductivity (r = -.874**), salinity (r = -.766**), species taxa (r = -.860**), individual (r = -.737*) and with Shannon-wiener index (r = -.740*). The Shannon-wiener index showed that S2 has the lowest value as 1.084 while S7 has the highest value as 2.826, Table 2. The Shannon-wiener index correlate significantly with TDS (r = .837**), conductivity (r = .791**), salinity (r = .703*), SDI (r = .970**), dominant index (r = -.969**), and a strong positive correlation with species taxa (r = 0.924), individual (r = 0.557) and negatively with reactive nitrate (r = -0.581). The species taxa showed a strong significant correlation with TDS (r = .929**, P ≤ 0.01), conductivity (r = .886**), salinity (r = .790**) and reactive nitrate (r = -.635*), Table 4.

In the wet season, the evenness index was high at S2 (0.996) with a total number of individual as 56 cells/ml and low at S10 (0.427) with a total number of individual as 451 cells/ml. The evenness index showed a strong negative

Table 2. Biological indexes for diatom density observed in Eastern Obolo coastal water during dry season in February, 2015

	St 1	**St 2**	**St 3**	**St 4**	**St 5**	**St 6**	**St 7**	**St 8**	**St 9**	**St 10**
Taxa_S	5	3	10	12	12	13	23	20	25	21
Individuals	101	44	160	224	234	481	1000	349	2519	766
Dominance_D	0.219	0.343	0.107	0.114	0.129	0.162	0.076	0.078	0.079	0.096
Simpson_1-D	0.782	0.657	0.893	0.884	0.871	0.838	0.925	0.922	0.921	0.905
Shannon_H	1.562	1.084	2.269	2.326	2.295	2.215	2.826	2.792	2.774	2.626
Evenness_e^H/S	0.954	0.986	0.967	0.853	0.827	0.705	0.734	0.816	0.641	0.658

Table 3. Biological indexes for diatom density observed in Eastern Obolo coastal water during wet season in August, 2015

	St 1	**St 2**	**St 3**	**St 4**	**St 5**	**St 6**	**St 7**	**St 8**	**St 9**	**St 10**
Taxa_S	5	4	11	21	8	9	13	11	17	14
Individuals	68	56	207	420	174	223	404	176	361	451
Dominance_D	0.235	0.252	0.096	0.056	0.137	0.121	0.116	0.115	0.108	0.263
Simpson_1-D	0.765	0.748	0.904	0.944	0.863	0.880	0.885	0.885	0.892	0.737
Shannon_H	1.512	1.382	2.371	2.949	2.036	2.155	2.354	2.255	2.514	1.789
Evenness_e^H/S	0.907	0.996	0.974	0.908	0.957	0.959	0.810	0.867	0.727	0.427

Table 4. Pearson correlation values for micronutrients, some selected physicochemical parameters and biological indexes across Eastern Obolo coastal water during dry season in February, 2015

	Nitra	Phosp	Silica	TDS	Cond	Salin	pH	Spp	Ind	Domi	SDI	Shan.
Nitra	1											
Phosp	-0.419	1										
Silica	0.153	0.009	1									
Amm	-0.411	-0.001	0.354									
TDS	-.715*	0.077	0.007	1								
Cond	-.748*	0.085	0.022	.974**	1							
Salin	-0.601	-0.057	-0.388	.871**	.852**	1						
pH	-0.350	-0.206	-0.603	0.608	0.558	.834**	1					
Spp	-.635*	0.205	0.178	.929**	.889**	.790**	0.44	1				
Ind	-0.309	-0.204	0.284	.663*	0.563	0.522	0.214	.760*	1			
Domi	0.477	-0.444	-0.210	-.699*	-.657*	-0.545	-0.356	-.822**	-0.465	1		
SDI	-0.477	0.442	0.215	.700*	.658*	0.545	0.352	.825**	0.466	-1.000**	1	
Shan.	-0.581	0.382	0.135	.837**	.791**	.703*	0.461	.924**	0.557	-.969**	.970**	1
Evenn	.763*	-0.073	0	-.886**	-.874**	-.766**	-0.392	-.860**	-.737*	0.620	-0.622	-.740*

**. Correlation is significant at the 0.05 level (2-tailed).*
***. Correlation is significant at the 0.01 level (2-tailed).*
{Nitra. = Nitrate, Phosp. = Phosphate, Silica. = Silicate, TDS = Total dissolved solid, Cond. = Conductivity, Salin = Salinity, Spp. = Species taxa, Ind. = Individual, Domi. = Dominance Index, SDI = Species diversity index, Shan. = Shanon-Weiner index and Enenn. = Evenness index}

Table 5. Pearson correlation values for micronutrients, some selected physicochemical parameters and biological indexes across Eastern Obolo coastal water during wet season in August, 2015

	Nitra	Phosp	Silica	TDS	Cond	Salin	pH	Spp	Ind	Domi	SDI	Shan.
Nitra	1											
Phosp	.929**	1										
Silica	0.432	0.281	1									
Amm	0.202	0.117	0.421									
TDS	.810**	.728*	0.390	1								
Cond	0.134	0.405	0.180	0.024	1							
Salin	0.224	0.497	-0.143	0.005	.816**	1						
pH	0.131	0.150	0.158	0.054	-0.055	-0.152	1					
Spp	-0.036	0.159	-0.343	-0.058	0.220	0.524	0.109	1				
Ind	-0.079	0.189	-0.356	-0.249	0.503	.795**	0.079	.878**	1			
Domi	0.115	0.101	0.211	-0.267	0.083	-0.056	0.181	-0.600	-0.335	1		
SDI	-0.118	-0.102	-0.213	0.265	-0.082	0.057	-0.183	0.599	0.336	-1.000**	1	
Shan.	-0.110	-0.011	-0.298	0.119	0.041	0.275	-0.055	.858**	.635*	-.924**	.924**	1
Evenn	-0.164	-0.426	-0.106	0.205	-.710*	-.726*	-0.342	-0.425	-.679*	-0.348	0.349	0.02

**. Correlation is significant at the 0.05 level (2-tailed).*
***. Correlation is significant at the 0.01 level (2-tailed).*
{Nitra. = Nitrate, Phosp. = Phosphate, Silica. = Silicate, TDS = Total dissolved solid, Cond. = Conductivity, Salin = Salinity, Spp. = Species taxa, Ind. = Individual, Domi. = Dominance Index, SDI = Species diversity index, Shan. = Shanon-Weiner index and Enenn. = Evenness index}

significant correlation with conductivity (r = -.710*), salinity (r = -.726**) and with individual (r = -.679*). The species diversity index, peaked 0.944 at S4 and dropped to 0.737 at S10 whereas Shannon-wiener index was low at S2 (1.382) and high at S4 (2.949), Table 3. Shannon-wiener index showed a strong significant correlation with species taxa (r = .858**), species diversity index (r = .924**), dominance index (r = -.924**) and with individual (r = .635*), Table 5.

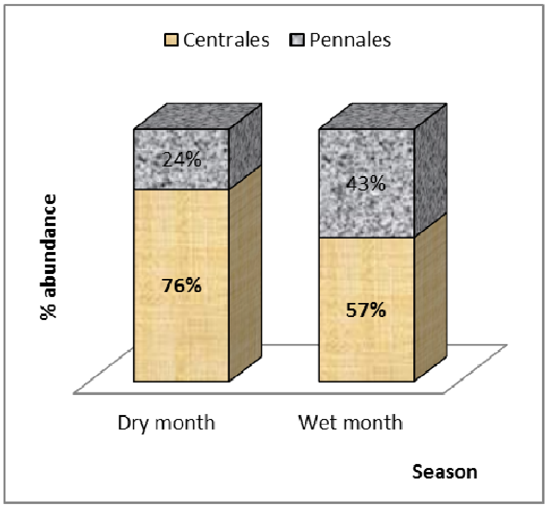

Fig. 2. Histogram of % abundance for Centric and pennate diatoms during dry and wet season across Eastern Obolo coastal water in 2015

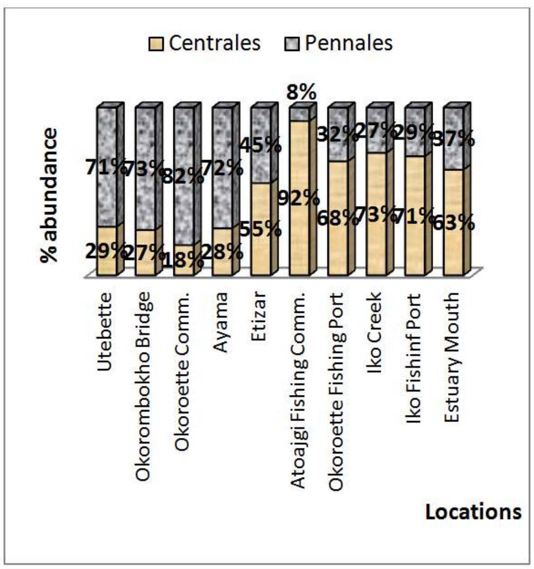

Fig. 3. Histogram of % abundance for centrales and pennales during wet season across Eastern Obolo coastal water in August, 2015

3.3 Multivariate Analysis

Dendrogram was used to evaluate further the relationship between the measured variables and the biological indexes. This evaluation is given in Figs 9 and 10 for wet and dry season respectively. In the wet season, reactive nitrate and reactive phosphate showed a high level of similarity with TDS. Reactive silicate and TDS showed similar correlation. Conductivity and salinity showed a similar correlation with species taxa, individual, SID and Shannon-wiener, Fig. 9. During dry season, a high level of similarity correlation was found between TDS and conductivity with species taxa, species diversity index and Shannon-wiener index, salinity and pH, reactive nitrate and evenness index. Diatom density showed a correlation similarity with TDS and conductivity, Fig. 10.

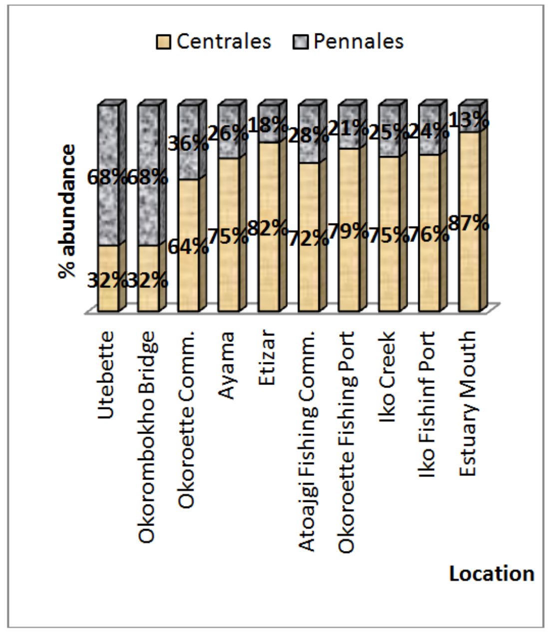

Fig. 4. Histogram of % abundance for centrales and pennales during dry season across Eastern Obolo coastal water in February, 2015

Table 6. Pearson correlation results between silicate, TDS, Conductivity, salinity and, pennales and centrales for both seasons across Eastern Obolo coastal water during wet season in August, 2015

	Dry season	
Variables	**Pennate**	**Centric**
Silicate	0.319	0.272
TDS	0.551	.691*
Conductivity	0.423	0.600
Salinity	0.395	0.556
	Wet season	
Silicate	-0.343	-0.189
TDS	-0.360	-0.037
Conductivity	-0.133	.823**
Salinity	0.231	.928**

4. DISCUSSION

The progressive increase in salinity, conductivity, TDS and pH level toward the ocean as being observed during the dry season was due to the strong influence of saltwater incursion, less dilution effect of the rain water and high evaporation. The strong significant correlation among these variables is an indication of absence of surface water dilution by rain. [22], reported that seasonality in the tropic influences the hydrological factors and, that conductivity is TDS dependent factor. In the wet season, the salinity level was low with a progressive increase toward the ocean. This mark a clear effect of precipitation in the dilution process of many parameters measured during this season. The salinity level at station 1, 2 and 3 were 0‰ compared with the dry season observations as 16‰, 25‰ and 24‰ respectively. This indicated that these stations have received a high volume to freshwater from storm water and other inlets to cushion the effect of saltwater. The observed correlation between salinity level and the diatom

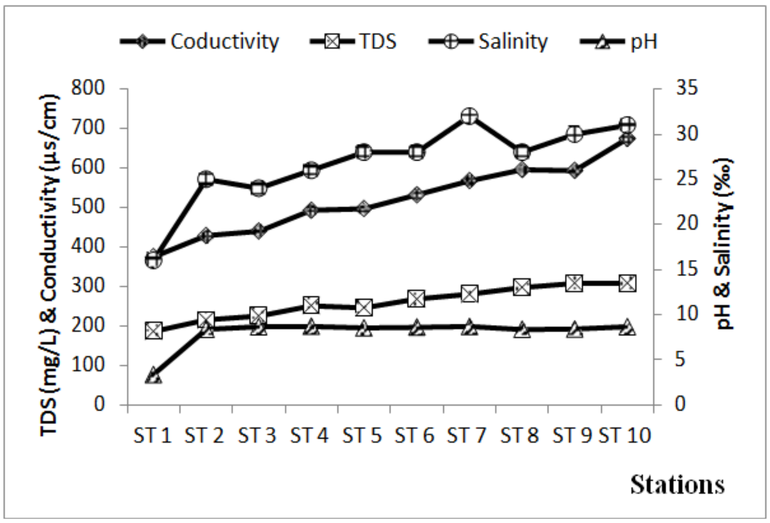

Fig. 5. Variation in the physicochemical indices across Eastern Obolo coastal water during dry season in February, 2015

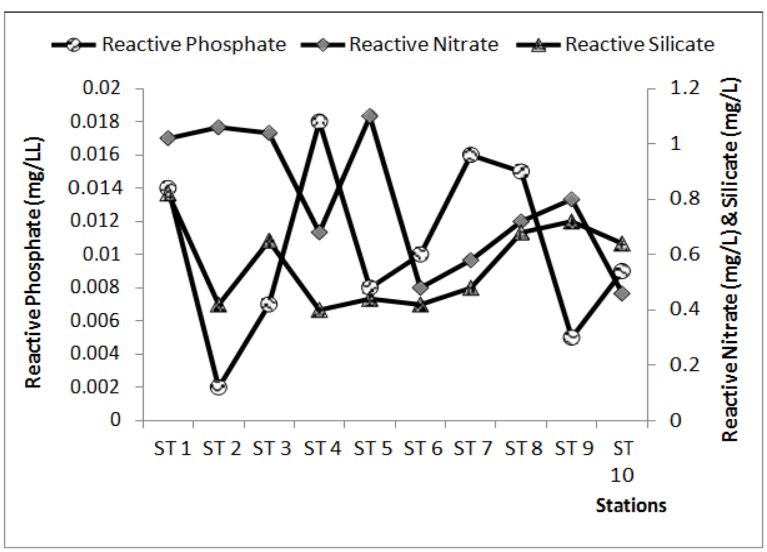

Fig. 6. Variation in the micronutrient level across Eastern Obolo coastal water during dry season in February, 2015

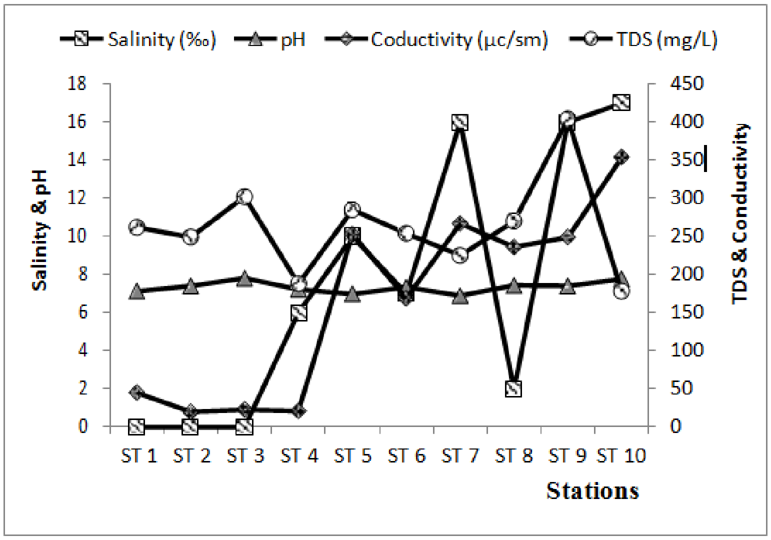

Fig. 7. Variation in the physicochemical indices across Eastern Obolo coastal water during wet season in August, 2015

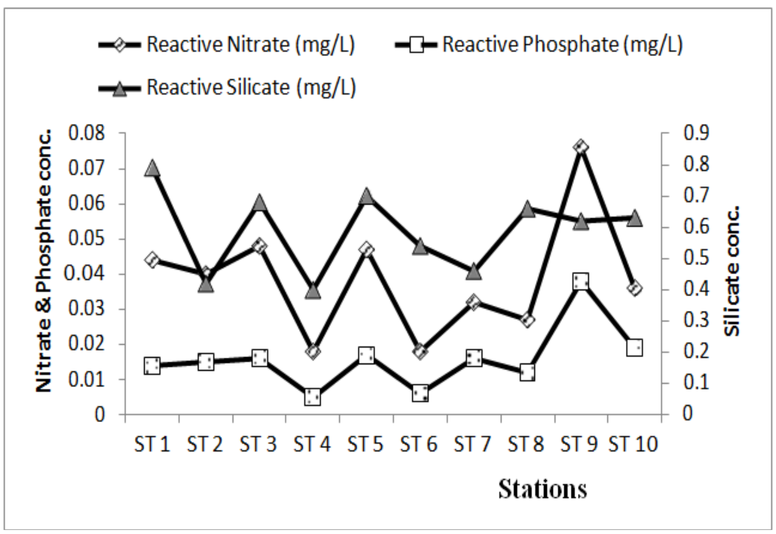

Fig. 8. Variation in the micronutrient level across Eastern Obolo coastal water during wet season in August, 2015

individuals for dry and wet seasons suggested the important of this parameter in the diatom species composition, abundance and distribution in this environment. [23], reported a similar correlating effect of salinity on phytoplankton distribution in Bhavanapadu Creek, Srikakulam District, South India. The non-progressive increase in pH level toward the ocean as was observed during wet season could be as a result of biological activities and surface water contamination by pH raising substances from the mangrove swamp. These substances could be brought into the water by storm water. [24], reported that pH could be controlled by swamp exudates that regulate the acidity of the water body. [25], stated that pH levels depend on the amount of carbonate present in the water and often considered it as indicator of the aquatic chemical environment. Factors such as photosynthesis, which removes CO_2 through bicarbonate degradation; freshwater input, which causes dilution of seawater and reduction in salinity and temperature; and decomposition of organic matter, can contribute to the fluctuations in pH in the study area.

Table 7. Spatial distribution of diatom cells across Eastern Obolo coastal water during dry season in February, 2015

Phytoplankton taxa	ST 1	ST 2	ST 3	ST 4	ST 5	ST 6	ST 7	ST 8	ST 9	ST 10	Total
Phylum: Bacillariophyta											
Class: Bacillariophyceae											
Order 1: Centrales											
Coscinodiscus centralis Ehrenberg	20	14	21	46	66	167	161	65	442	115	1117
Coscinodicus stellaris Roper				15		18		23	162	118	336
Coscinodiscus concinus W. Smith				42	23		81		124	44	314
Coscinodiscus nitidus W. Gregory							32	12	57		101
Coscinodiscus granii L. F. Gough						15	98	32	124	84	353
Cocconies scutellum Ehrenberg	12	15					102				129
Hyalodiscus stelliger J.W.Bailey		11		15	16						42
Encyonema prostratum Kutzing		15		15							30
Cyclotella kuetzingiana Thwaites				18			29	13	30		90
Actinocyclus octonarius Ehrenberg									12		12
Bacteriastrum delicatulum Cleve					18						18
Bacteriastrum hyalinum Lauder						35	69	8	100		212
Chaetoceros decipiens Cleve					12		12	12		25	61
Leptocylindrus danicus Cleve							18	12			30
Hemidiscus cuneiformis Wallich					14	23	40		145		222
Hemidiscus hardmanianus (Greville) Mann							11				11
Hemiaulus hauckii Grunow ex Van Heurck							18			15	33
Triceratium Ehrenberg						18	15		25		58
Ditylum sol Cleve						13	13		41		67
Ditylum brightwelli (T. West) Grunow		15		8	15	25		24	203	115	405
Rhizosolenia setigera Brightwell										13	13
Biddulphia alternans Bail									12		12
Biddulphia granulata Roper								14	179		193
Biddulphia sinensis Grev.							15		12	37	64
Biddulphia arctica (Brightwell) Bory					12			15			27
Biddulphia mobillensis (Bail) Grun.				10	15	32	76	32	212		377
Biddulphia ragia (Schuitze) Ostenfeld									45	25	70

Phytoplankton taxa	**ST 1**	**ST 2**	**ST 3**	**ST 4**	**ST 5**	**ST 6**	**ST 7**	**ST 8**	**ST 9**	**ST 10**	**Total**
Bidullphia favus Ehrenberg										32	32
Biddulphia biddulphiana (Smith) Boyer										25	25
Terpsinoe americana (Bail.) Grunow		25									25
Detonula schroderi (P. Bergon)										15	15
Order II: Pennales											
Thalassiothrix frauenfeldii (Grunow)		18		12	12	21	51	10	212	17	353
Thalassionema nitzschoides Hustedt						49	22	12	163	13	259
Thalassiosira nordenskioldii Cleve									18		18
Bacillaria paxillifer (O.F. Muller) T. Marsson	15							12			27
Nitzschia vermicularis (Kutz.) Hantzsch										12	12
Pseudo-nitzschia pungens (Grunow ex Cleve) G.R.Hasle							46	5	140		191
Pseudo-nitzschia delicatissima (Cleve) Heiden		14						14	13	4	45
Pseudo-nitzschia australis Frenguelli					10					20	30
Pseudo-nitzschia seriata (Cleve) H. Peragallo									18		18
Nitzschia longissima (Brebisson) Ralf										5	5
Nitzschia frigida Grunow										5	5
Ulnaria ulna (Nitzsch) Ehrenberg				12		43	29		18	27	129
Synedra crystallina (C. Agardh) Kutzing							14				14
Navicula pusilla W. Smith	26	18									44
Navicula crucicula (W. Smith) Donkin								10			10
Cavicula scutiformis Grunow ex A. Schmidt			16					12			28
Pinnularia didyma Ehrenberg	28		10								38
Diploneis elliptica (Kutzing) Cleve		12		15							27
Diploneis didyma (Ehrenberg)							32				32
Pleurosigma strigosum W. Smith				16	21		16	12			65
Cymatopleura elliptica var. *nobilis* (Hantzsch) Hustedt						22			12		34

Table 8. Spatial distribution of diatom cells across Eastern Obolo coastal water during wet season in August, 2015

Phytoplankton taxa	ST 1	ST 2	ST 3	ST 4	ST 5	ST 6	ST 7	ST 8	ST 9	ST 10	Total
Phylum: Bacillariophyta											
Class: Bacillariophyceae											
Order 1: Centrales											
Coscinodiscus centralis Ehrenberg				30	22		86	30	58	17	243
Coscinodiscus kützingii A. Schmidt				35	38		45	22	20		160
Coscinodicus stellaris Roper									5		5
Coscinodiscus concinus W. Smith			15			25		5	17		62
Coscinodiscus nitidus W. Gregory				5		25	30	8	32	6	106
Melosira spaerica Héribaud-Joseph										6	6
Melosira distans var. *lirata* (Ehrenberg) VanLandingham			22						12		34
Melosira moniliformis (O.F.Müller) C. Agardh				8							8
Hyalodiscus stelliger J.W.Bailey		15									15
Stephanodiscus Ehrenberg	20										20
Cyclotella kuetzingiana Thwaites						36	25		10	7	78
Cyclotella striata var. *striata* (Kützing) Grunow										9	9
Bacteriastrum hyalinum Lauder					18	21		21	15		75
Chaetoceros decipiens Cleve								22			22
Leptocylindrus danicus Cleve				9					12		21
Triceratium Ehrenberg							21				21
Ditylum brightwelli (T. West) Grunow				15		16	10	5	12	15	73
Rhizosolenia styliformis T. Brightwell									15		15
Eucampia groenlandica Cleve							17			13	30
Hemiaulus Heiberg							12			182	194
Biddulphia granulata Roper										6	6
Biddulphia mobillensis (Bail) Grun.				12	17	35	28	15	25	22	154
Biddulphia rhombus Ehrenberg						20			25		45
Order II: Pennales											
Encyonema prostratum Kutzing			12								12
Asterionella japonica Cleve				25		15	70	25	81	136	352
Asterionella bleakeleyi W. Smith										8	8

Phytoplankton taxa	**ST 1**	**ST 2**	**ST 3**	**ST 4**	**ST 5**	**ST 6**	**ST 7**	**ST 8**	**ST 9**	**ST 10**	**Total**
Thalassiothrix frauenfeldii (Grunow)				20							20
Frustulia Rabenhorst	16		23	21							60
Thalassionema nitzschoides Hustedt	18		20								38
Bacillaria paxillifer (O.F. Muller) T. Marsson			24	23							47
Nitzschia vermicularis (Kutz.) Hantzsch										7	7
Pseudo-nitzschia australis Frenguelli	9	15		30							54
Nitzschia filiformis (W.Smith) Van Heurck					15						15
Surirella robusta Ehrenberg				15							15
Surirella robusta var. *splendida* (Ehrenberg) Van Heurck			25								25
Nitzschia gracilis Hantzsch				20							20
Nitzschia sublinearis Hustedt				12							12
Ulnaria ulna (Nitzsch) Ehrenberg		12						15	11		38
Synedra acus Kutz.			15								15
Encyonema caespitosum Kützing			21	32	25						78
Cymbella turgida W. Gregory				23	18						41
Placoneis placentula				16							16
Neidium affine (Ehrenberg) Pfitzer			15	30							45
Eunotia Ehrenberg,				27							27
Neidium iridis (Ehrenberg) Cleve		14	15								29
Pleurosigma strigosum W. Smith	5						20		5	17	47
Pleurosigma capense Karsten						21					21
Gyrosigma scalproides (Rabh.) Cleve									8		8
Gyrosigma attenuatum (Kützing) Rabenhorst		12									12
Leptocylindrus danicus Cleve							25				25
Amphora pediculus var. *minor* Grunow							15				15
Amphora ovalis Kutzing										6	6

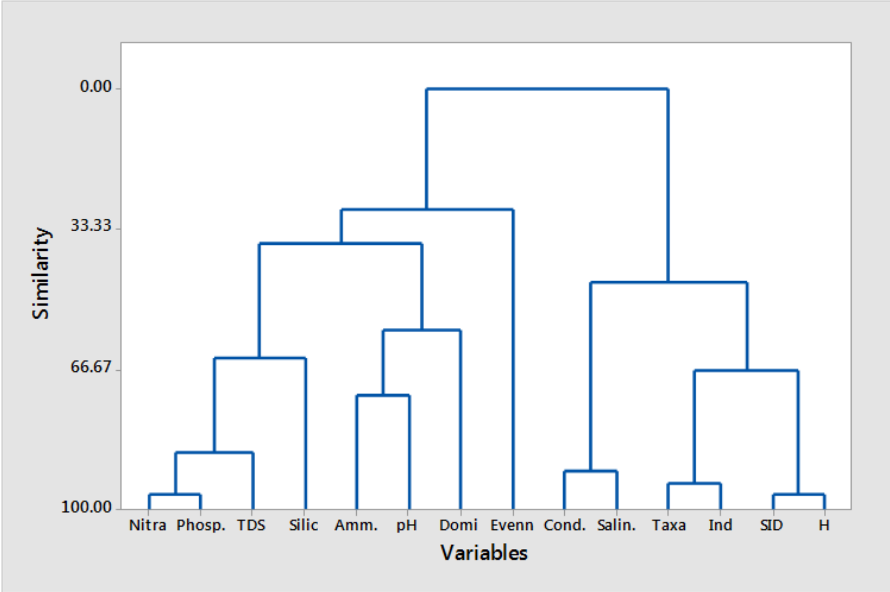

Fig. 9. The dendrogram showing the correlation coefficient distance between the variables during the wet season in August, 2015

{Nitra. = Nitrate, Phosp. = Phosphate, Silic. = Silicate, Amm. = Ammonia, TDS = Total dissolved solid, Cond. = Conductivity, Salin = Salinity, Ind. = Individual, Domi. = Dominance Index, SDI = Species diversity index and H = Shanon-Weiner index}

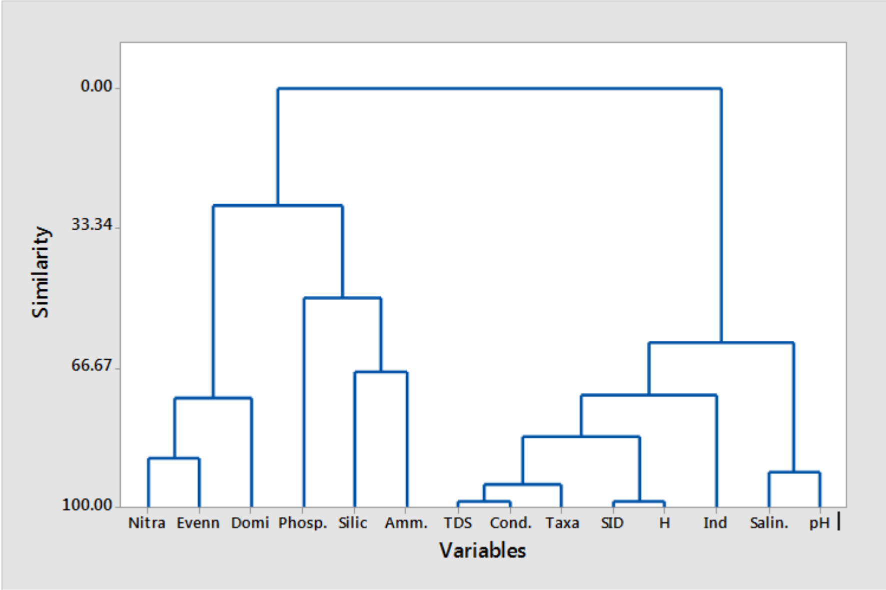

Fig. 10. The dendrogram showing the correlation coefficient distance between the variables during the dry season in February, 2015

{Nitra. = Nitrate, Phosp. = Phosphate, Silic. = Silicate, Amm. = Ammonia, TDS = Total dissolved solid, Cond. = Conductivity, Salin = Salinity, Ind. = Individual, Domi. = Dominance Index, SDI = Species diversity index and H = Shanon-Weiner index}

However, the positive correlation of silicate with diatom individual suggested the significant role it plays in the diatom population. [3], reported that the distribution of diatoms is significantly influenced by nutrient such as nitrate, phosphate and silicate. The silicate level in the surface water maybe season dependent, [26], reported high level of silicate nutrient in Epe lagoon tributary during harmathan period, and the onset of precipitation increased the surface water nutrient level. [27], revealed a high percentage of silicate in harmathan dust of continental West Africa and [28] in Nigeria. Therefore, the high level of silicate observed could be as a result of deposition of dust particles in the coastal area that triggered it concentration in the water and this in turn encourages the developed of diatom cells in the system especially in dry season. Furthermore, the observed significant correlation of diatom cells with nitrate and phosphate during wet and dry season implies the importance of these nutrients on the diatom cells development and growth. [29], reported a seasonal limnological variations and nutrient loads of the River System in Ibadan Metropolis, Nigeria and recorded a high TDS during the rainy season than the dry season.

The diatom species composition revealed a lower percentage ratio of centric to pennate groups during wet season at S1, 2, 3 & 4, with S1 & 2 being the lowest in wet season than dry season. These four stations are characterized with high human activities as they are coastal settlements. Activities such as boast transport, shellfish harvesting during low tide, cutting of rhizophora roots for fish rack production, bioturbation and discharge of storm water during wet season. However, the low value of centric: pennate ratio implies that the station has a higher density of pennate diatoms than centric one. This could be as a result of favourable hydraulic conditions [30] and the fact that centric diatoms prefer saltwater than freshwater [31]. The stations with this low ratio values were found to record 0‰ level of salinity meaning that the water surface were fresh during this period as a result of dilution by freshwater. The input of freshwater from storm water and river water discharge could add an epiphytic diatom cells to pennate diatom population in the system thereby enhancing its density. Generally, across the coastal water, the centric diatoms had a high population density than pennate for the both seasons. This demonstrated that, this group of diatoms plays a vital role in primary productivity of this area.

Furthermore, the even distribution of these diatoms *Coscinodiscus centralis* Ehrenberg, *Ditylum brightwelli* (T. West) Grunow, *Biddulphia mobillensis* (Bail) Grun, *Asterionella japonica* Cleve and *Thalassiothrix frauenfeldii* (Grunow) could signify favorable conditions and a wider range of tolerant. The positive respond of centric and pennate groups of diatom during dry season with silicate level, salinity range, conductivity level and TDS reveals the effect of these variables on their distributional pattern. During wet period, centric diatom responded significantly with conductivity and salinity indicating the effect of freshwater discharge on their distribution in the coastal water. Freshwater discharge affects salinity and conductivity level of any coastal water. Rainfall itself can have a higher conductivity than pure water due to the incorporation of gases and dust particles. However, heavy rainfall can decrease the conductivity of a body of water as it dilutes the current salinity concentration as observed in S1, 2, 3 & 8. In the tropics, conductivity usually drops during the wet season due to the dilution of the water source. Though the overall conductivity is lower for the season, there are often conductivity spikes as water initially enters a nutrient rich zone. These nutrient-rich or mineralized soils dissolve in the water to raise the conductivity level.

Shannon-wiener index of diversity for both seasons revealed that the coastal water of Eastern Obolo is moderately polluted by organic materials. The Shannon-Wiener index of diversity value of 1–3 according to Hynes, [32] signifies moderately polluted water and above 3 signify clean water situation. With this index, station 2 has a high level of organic pollution due to direct discharge of domestic waste and other associated human waste into the water. The strong significant correlation of species diversity index with conductivity and TDS during dry period indicated that the diversity of diatom species is being controlled by this important physiochemical variable. [22], observed the importance of these variables on the phytoplankton composition and abundance at Epe lagoon tributary. The observed correlation between species evenness index, salinity and conductivity during raining season revealed the dilution effect of rain on these parameters which in turn affect the even distribution of diatom cells in the area.

5. CONCLUSION

The surface water of Eastern Obolo is rich in diatom cells both in density and in species diversity. It is inevitable that diatom play an important role in primary productivity of the area thereby supporting other trophic level. The observed moderate pollution of the coastal areas in the state has called for the need for Government to develop coastal communities, as this will discourage direct disposal of waste into the water body and other human activities facing this region especially deforestation of mangrove plants. The ratio of centric to pennate diatoms as used in this work to quantify respond of different group of diatoms to environmental variables should be standardized as one of the biological index. The low ratio at S1 & 2 for both seasons was a clear respond of diatoms group to salinity variation in coastal water. However, in respect to high TSS and sediment disturbance caused by the rainfall, the centric group adapted more to sites with high values in salinity, TDS and conductivity than pennate group. In other word, salinity, TDS and conductivity play a critical role in the coastal water by affecting the distribution, composition and abundance of estuarine organisms. The concentration of silicate in the surface water indicated seasonal fluctuation, as it was very high during hamarthan period due to deposition of silicate rich dust in the water. This and other nutrients as indicated in the study boast the growth and development of diatom cells.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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