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Ecophysiological and Anthropogenic Determinants of Phytoplankton Community Structure in Streams Receiving Effluents from the Douala-Bassa Industrial Zone

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Authors' contributions

This work was carried out in collaboration among all authors. Authors PTT and FQM conceived the research, and produced the experimental plan. Author DSC implemented the research and collected field data. Authors LH did the laboratory analyses, while author PTT did the statistical analyses. All authors read and approved the final manuscript.

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ABSTRACT

Physicochemical parameters and plankton community structure of streams flowing through the Douala-Bassa Industrial zone were assessed in seven different sites. Anthropogenic activities, water accessibility and the different industries located along the watercourse were considered in selecting the sites. Four sets of water samples were collected from each site and analysed for phytoplankton community structure, nutrient, Chl a and bacteria. Physicochemical parameters were measured insitu using a multi parameter equipment (HANNA 8289). Water temperature ranged from 25.27 - 26.84^0 C. The pH of the water samples ranged from 6.33 – 7.50 while Turbidity ranging from zero - 1000 NTU. The Electrical Conductivity was 495.33 - 261.67 µS/cm and Dissolved

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Oxygen was zero - 1.11 ppm. Chlorophyll a concentration ranged from 1.2 – 48.96µg/l. Total Suspended Solids ranged from 0.15 – 0.88. Phosphate and ammonium concentrations ranged from 1.22 – 12.81µM and 4.29 – 136.48 µM respectively nitrates concentration was 1.15 – 217.09 µM. The number of phytoplankton species varied between the sites with a total of 68 species belonging to 11 Divisions. The Bacillariophytas were the most abundant with 27 species. The Chlorophyta followed with 12 species. The most dominant phytoplankton species were *Microcystis sp*, *Pinnularia gibba* and *Nitzschia palea*. Site 7 was the most diverse site with 70 species. High concentrations of nutrients and the presence of eutrophic species such as the Bacillariophytas and *Microcystis* suggests pollution and a need to monitor activities carried out along the water course with respect to quantity and quality of wastewater discharged into the stream. The ecosystem was in a eutrophic state with variations in the water quality parameters. This could be attributed to possible untreated effluents incorporated in the ecosystem. It can be concluded from the study that phytoplankton dynamics in the Douala-Bassa Industrial Zone are directly related to ecophysiological and anthropogenic drivers.

Keywords: Physicochemicalparameters; wastewater; effluent; phytoplankton; industrial zone.

1. INTRODUCTION

Plant communities are subject to the environment in which they grow, thriving when the environment favours their physiology and growth, and suffering when environmental parameters exceed thresholds for effective functioning [1,2]. This is so, irrespective of whether the plants in question are higher plants or phytoplankton. Phytoplankton, the minuscule lower plants that are responsible for primary production in water bodies, are economically and ecologically important as they form the base of most aquatic food chains [3]. Their dynamics are driven by several factors, among which are nutrient dynamics in water bodies, water temperature, salinity and dissolved oxygen concentrations [1]. These abiotic stressors shape phytoplankton communities either upwards or downwards depending on the magnitude of the stressors. While abiotic stressors in the aquatic milieu could vary naturally, often in urban areas their magnitudes are determined by the extent of anthropogenic interference with the water systems. Uncontrolled releases from manufacturing and refining installations, spillages during transportation, direct discharge from effluent treatment plants and run-off from terrestrial sources such as agriculture could all contribute to altering the physicochemical characteristics of water bodies and if any of these exceed certain thresholds, they become stressors to phytoplankton. Waste management problems coupled with industrialization and urbanization in developing countries have caused trace metal and organic pollution, especially of coastal environments [4], since they are the boundaries between the open ocean and the terrestrial environment. Therefore in areas with high levels of urbanization, ecophysiological studies of phytoplankton communities are inextricably linked to anthropogenic activities, as these influence the abiotic (eco) stressors of phytoplankton.

One such countries in which urban centres are rapidly expanding is Cameroon according to Ngoran [5], with an urbanization rate estimated at about 6% per annum over the past 5 years, especially in cities like Douala the economic capital, which habours a large population and about 80% of Cameroon's industries. A general problem of industrialization in ecosystems is how and where industries discharge their effluents, which is often inevitably in aquatic systems [6]. These industrial discharges have been reported to have adverse consequences on human health and phytoplankton communities [7]. When municipal and industrial wastes are discharged into water bodies, they usually alter the physicochemical quality of water such as acidity (change in pH), electrical conductivity, dissolved oxygen and temperature [8]. These physicochemical parameters become drivers or abiotic stressors to phytoplankton when they exceed certain thresholds. Fonge et al. [9] for example, found that in a logged mangrove forest, anthropogenic activities resulted in the discharge of phosphates into the streams, and in the discharge sites, high phosphate concentrations influenced the diversity and richness of phytoplankton communities. This emphasises the need for regulation and monitoring of levels of physiochemical parameters in effluent meant for discharge into water bodies.

Unfortunately, the industrial sector in Cameroon as with most developing countries is highly unmonitored. The Douala-Bassa Industrial Zone (Douala-Bassa IDZ) in Cameroon is one of those that harbours several industries that discharge effluent into the numerous streams that eventually empty into the Douala lagoon. Studies characterising the effluent discharged, as well as its effects on the phytoplankton communities are rare. This study aimed at characterizing the effluent discharged from different industries in the Douala-Bassa IDZ and determining the effects of potential abiotic stressors on phytoplankton communities in the effluent-receiving streams.

2. MATERIALS AND METHODS

2.1 Description of Study Site

The Douala-Bassa Industrial Zone is situated in Douala, Littoral Region of Cameroon at Latitude 4°2’ N to 5°4’ N and Longitude 9°9’ E to 11°5’ E [10]. It is located 30 km from the sea, with impressive industrial and commercial enterprises. The climate indicates a region of high temperature and rainfall that are almost evenly, spread throughout the year. Mean daily temperatures drop by about 2° C – 3° C. There are 1274 sunshine hours per year and the average temperature ranges between 26.7° C (80° F), the warmest average max/ high temperature is 32° C (90° F) in February, March, April and the coolest average min/low temperature is 22° C (72° F) in July, August, and October [11]. The Douala-Bassa IDZ hosts around forty manufacturing companies; in this area several streams are found, into which some of the industries dump most of their wastewater. The collection of all these streams then make a river called “la Dinde” which flows into the sea.

2.2 Site Selection and Observations at the Sites Selected

A reconnaissance survey was done through which seven sampling points were selected based on accessibility, land uses and anthropogenic activities in and around the water course (Table 1). Black bridge water (Site 1) flows through Dakar to Ndopassi III. Human activities like wood transportation in canoes are rampant here. This site is like the meeting point through which the water is discharged into the ocean. Site 2 flows through the Brazzaville and Terminus zones. Companies found along this water course deal with draining and cleaning. There is also a resident human community within the area.

Site 3 flows through the Dakar area and along this stream is a human community with refuse disposal on-going. Site 4 flows through the Oyack discharge pipe. This stream is bounded by companies dealing with iron melting (Industry B). Sites 5 and 6 flow through the Bassa zone and are connected to industries effluents discharge (Industry C which is the paint industry; Industry D dealing with iron transformation; Industry E which deals with wood transformation). Site 7 flows through a disused soap industry (Fig. 1). This stream is bounded by a resident community, and the residents use the water for agricultural purposes. However, Industrial activity is very high due to numerous and larger enterprises. This water is not generally fast-flowing.

2.3 Sample Collection and Handling

At each sampling point, three sets of water samples were collected 5-10 cm below the water surface in 350 ml pre-sterilized bottles in triplicate for physicochemical/nutrient, and phytoplankton analyses respectively. These samples were collected from all the zones between 07:30 AM and 11:00 AM; the sampling points were observed, described and geo-localized using a Garmin GPS. Three to four drops of 10 % Lugol’s iodine were added to each of the samples reserved for phytoplankton analyses to fix the phytoplankton. For nutrient analysis, the water samples were sent to the Nelson Mandela University, South Africa for analyses.

Samples for chlorophyll a, Total suspended Solids determination and phytoplankton assessment were then transported in cooler boxes with ice to the University of Buea Life Sciences Laboratory.

2.4 *In-situ* Determination of Water Quality Parameters

Temperature, Turbidity, Total dissolved solids, Dissolved oxygen, pressure, pH and Electrical conductivity were measured directly on the field for each site with the use of a YSI multi-parameter equipment (HANNA, 9289).

2.5 Chlorophyll a (Chl a) Determination

Samples were filtered on the day of collection. One hundred milliliters of each water sample was passed through a Whatmann 42 filter paper (pore size 0.4 µm). Each filter was then placed in 10 ml 90% ethanol, and placed in a dark cupboard to undergo pigment extraction. After 24 hours the extract was filtered and the absorbance of each sample read at wavelength 665 and 750 nm on a 722s spectrophotometer (UNICO 1200) at the University of Buea chemistry laboratory. The concentration of Chlorophyll a in each sample was then calculated according to Webb et al. [12]:

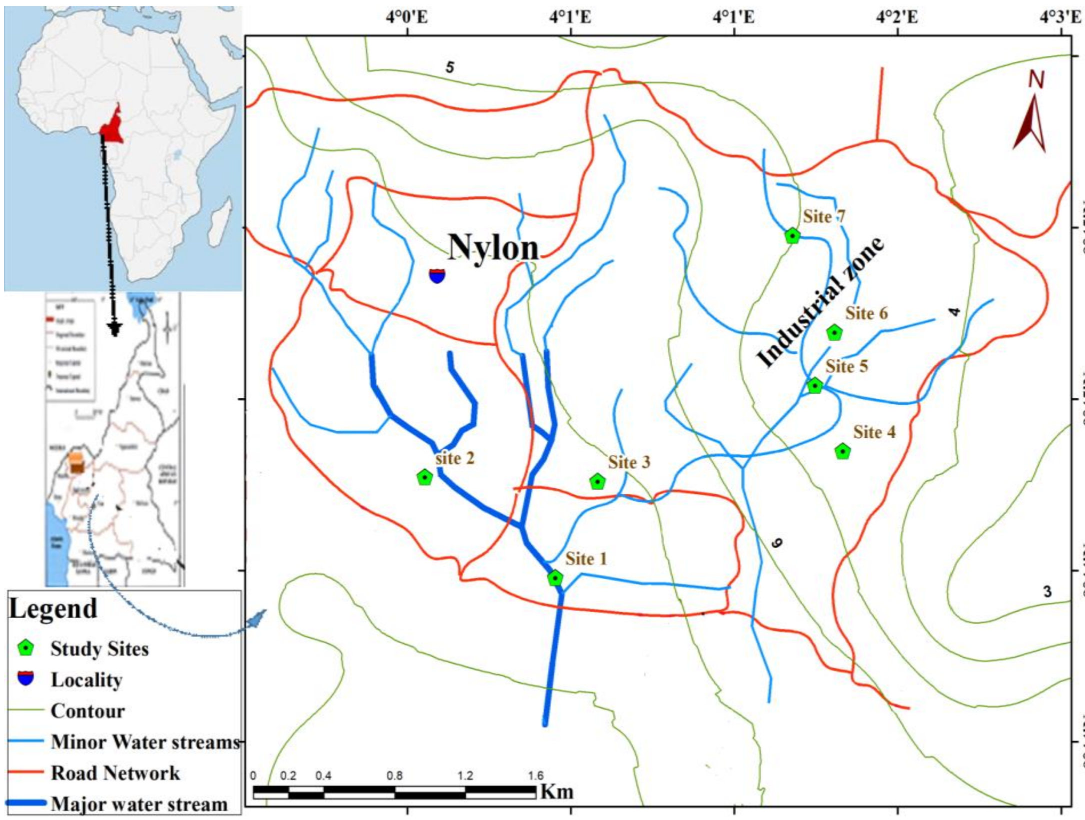


Fig. 1. Map showing study site and sampling points in water courses around the Douala-Bassa industrial zone

Table 1. Site description and dominant plant species within the Douala-Bassa industrial zone

Study site	Coordinates	Resident human community	Industrial activity	Higher pluant community
Site1 (stream)	Lon. 009°44.296''E Lat.N04°00.544''N	Present	Nil	*Commelina benghalensis* and *Solonostemon monostachyus*
Site 2 (stream)	Lon. 009°44.193''E Lat.009°44.193''N	Absent	Draining and cleaning industry	Dominated by *Acmella caulirhiza* and *Cuphea hyssopifolia*
Site 3 (stream)	Lon. 009°43.826''E Lat. N04°01.184''N	Absent	Refuse disposal	*Ludwigia palustris*
Site 4 (effluent)	Lon. 009°44.548''E Lat. N04°01.724''N	Present	Iron melting industry	Nil
Site 5 (effluent)	Lon. 009°44.548''E Lat. N04°01.724''N	Absent	Paint industry	
Site 6 (effluent)	Lon. 009°44.594''E Lat. N04°01.705''N	Absent	wood transformation industry	none
Site 7 (stream)	Lon. 009°44.564''E Lat. N04°02.031''N	Present	Agricultural farms	*Cuphea hyssopifolia* and *Solenostemon monostachyus*

$$\text{chlorophyll a } (\mu g l^{-1}) = \frac{(11.99 \times (A665 - A750) \times s)}{\text{Vp}} \quad (1)$$

Where A665 = absorbance at 665 nm, A750 = absorbance at 750 nm, s= solvent extraction volume (ml), V= Volume of water and p= diameter of the cuvete.

2.6 Total Suspended Solids (TSS)

The dry mass of each filter paper was measured gotten with a balance; they were then placed inlabelled petri dishes and oven dried at 60^{0}C. After 48 hours the mass of the filter papers were recorded again. 100 ml of each water sample was filtered through the oven dried filter papers and each filter paper with the filtrate was re-dried in the oven at 60 ^{0}C. After 24 hours they were removed and the TSS was calculated as follows:

$$\text{TSS= B-A} \quad (2)$$

Where A is dry mass of filter paper only B is dry mass of filter paper and Total Suspended Solids

2.7 Nutrient Analysis

Nitrates were determined by the Cadmium Column Reduction Method, Phosphates by the ammonium molybdate method [13] and Ammonium was determined by the Phenolhypochlorite method [14]. These analyses were done in the Botany Laboratory of the Nelson Mandela University of South Africa.

2.8 Phytoplankton Enumeration and Identification

The wet mount method was used for phytoplankton enumeration. Slides of each sample were prepared in triplicate. A drop of well-mixed sample was placed on a sterilized slide, covered with a coverslip and observed under the Olympus light microscope. Phytoplankton species were identified and counted by the use of a binocular light microscope (Olympus BH2), at a magnification of 100 and 400x. Identification was through comparative morphology and description using relevant text books, manuals and articles like Nguetsop et al. [15], Bellinger and Siegee [16].

2.9 Statistical Analysis

Data obtained from this study (physicochemical parameters and phytoplankton assessment) were analysed using Microsoft Excel 2007 and the Minitab Version 17 statistical package for mean separation. For distribution of phytoplankton species, presence/absence data were used, with presence coded as = 1 and absence of species = 0. Simple Correspondence Analyses were then done, to investigate spatial associations of the species distribution and abundance of phytoplankton within the different sites and nutrient distribution across sites. In addition, Shannon diversity indices, evenness, richness of species, and Sorenson Similarity indices were calculated.

2.9.1 Determination of ecological indices of phytoplankton

2.9.1.1 Abundance

The abundance of each alga per milliliter was obtained from the sum of its occurrences in the three slides (drops) as follows:

$$\text{Abundance (ml)} = \frac{\text{n1+n2+n3}}{0.15} \quad (3)$$

Where; n1 n3 = algal counts in drops; 0.15 = volume of three drops in ml. The relative abundance was the percentage of the abundance of the particular alga over the total abundance of algae for the site.

2.9.2 Euglenophycean index

The saprobic index was used to determine trophic status and calculated according to [16]:

$$\text{Euglenophycean index} = \frac{\text{Number of Euglenophyta}}{\text{Number of cyanophyta+Chlorophyta}} \quad (4)$$

If the saprobic index is < 1 the system is eutrophic, and if > 1 the system is oligotrophic.

2.9.3 Shannon-weaver diversity (H)

Shannon Weaver diversity index of phytoplankton species diversity within the different sites was determined using the following equation:

$$\text{Shannon H}' = \sum_{i}^{i=1} \text{pilnpi} \quad (5)$$

Where, H' = Index of species diversity, Pi = Proportion of total sample belonging to its species, n = number of species, Ln. = natural log.

2.9.4 Evenness of phytoplankton

Evenness of phytoplankton communities was calculated following that of Shannon Index as follows:

$$\text{Evenness} = \frac{\text{Shannon H}'}{\ln S} \quad (6)$$

Where S is the total number of species, ln = natural log

2.9.5 Palmer's pollution index

Palmer's pollution index based on algal genera was used in rating the water samples for organic pollution [17].

2.9.6 Mean separation

Differences of physicochemical parameters, nutrients and heavy metals across sampling stations were tested using ANOVA with Tukey HSD test at α = 0.05.

Patterns of species distribution across sites, as well as the association of different physicochemical parameters with the different sites were analyzed using Simple Correspondence Analyses. Pearson's correlation was used to determine relationships between nutrient and phytoplankton parameters and species abundance across the different sites. Pearson correlations were also conducted for water nutrients, physicochemical parameters and phytoplankton community descriptors, and a general correlation of all variables. All analyses were done at α = 0.05, using the Minitab Version 17 statistical package (Minitab Inc., USA).

3. RESULTS

3.1 Physicochemical Parameters

Table 2 presents the physic-chemical characteristics of the effluent water from the Douala-Bassa IDZ. The Surface water temperatures varied significantly throughout the sites, and ranged from 25.27^0 C at site 4 to 26.84^0 C at Site 6.Water was weakly acidic with pH ranging between 6.33 and 6.92, but at Sites 4 and 6 the water was neutral (7.50 and 7.24 respectively). The Electrical Conductivity was highest at Site 2 (495.33 µS/cm) and lowest at Site 7 (261.67 µS/cm). The Total Dissolved Solute was higher at Site 2 (247.67 ppm) and lowest at Site 7 (131 ppm). Sites 2 and 6 were completely anoxic (0 ppm dissolved oxygen concentration). Turbidity ranged from o to 1000 FNU with the most turbid water from Site 5 and the clearest water at Site 6 Table 2. All the physicochemical parameters varied significantly across sites (Table 2).

The Chlorophyll a and nutrient composition of water samples of different sites are presented in Table 3. Chlorophyll a concentration was lowest at Site 3 (1.2 µg/l) and highest at Site 7 (485.96 µg/l) where it exceeded eutrophic levels.

Total Suspended Solute did not vary across sites and concentrations were low (0.15 to 0.88mg/l). Ammonium concentration was lowest at Site 5 (4.29 µM) and highest at Site 6 (136.48 µM). Total Oxidizable Nitrogen ranged from 1.15µM at Site 2 to 217.09 µM at Site 1 Table 3.

3.2 Phytoplankton Community Structure

Sixty eight (68) morphospecies belonging to 10 divisions were identified in the streams at the Douala-Bassa IDZ during the study, namely Bacillariophyta, Chlorophyta, Chrysophyta, Cryptophyta, Cyanophyta, Dinophyta, Euglenophyta, Charophyta, Rhodophyta and Euglenozoa Fig. 2. The most abundant division was the Bacillariophyta (diatoms) which had 27 species, followed by the Chlorophyta with 12 species and the Cyanophyta with 8 species while the least were the Rhodophyta, Euglenozoa and Cryptophyta with one species each (Fig. 2). The Euglenophycean Index was markedly <1, indicating that the waters were eutrophic throughout and for both the effluent and the control water sample. The most abundant species were *Microcystis sp* (35.71% at Site 4 and 21.31 % at Site 6), *Pinnularia gibba* (17.39% at Site 2), *Nitzschia palea* (17.25% at Site 6) and *Peridinium crassipes* (13.88% at Site 4). The least abundant species were *Fragilaria construens* and *Tribonema vulgares* (Site 1), *Navicula rhynchocephala* (Site 7), *Phacus acuminatus* (Site 5) *and Selenastrum sp* (Site 7) which were each represented by one individual each. Plate 1 shows some of the interesting species identified during the study.

3.3 Phytoplankton Diversity, Evenness, Abundance and Species Richness

Phytoplankton community structure parameters are presented in Table 4. Site 7 was the most diverse site (H' = 3.176) and Site 4 was the least diverse (H' = 2.304). Site 7 was also the richest with 37 species while there were 17 species for Site 2 which was the least species-rich site. With respect to abundance of phytoplankton species, Site 3 had the least mean abundance (248) while Site 7 had the highest (618) Table 4. Phytoplankton species were more evenly distributed at Site 5 (Evenness = 0.823) while the phytoplankton community in Site 4 was the least uniform (evenness = 0.756). Euglenophycean index showed that the water was eutrophic all through, with a saprobic index ranging from 0.01 to 0.66.

Table 2. Physicochemical characteristics of water from sites within the Douala-Bassa industrial zone

Sites	T (°C)	PH	EC[µS/cm]	TDS [mg/l]	D.O.[mg/l]	Turbidity.NTU
Site1	26.24± 0.04^{d}	6.73 ±0.01^{cd}	488.67± 21.36^{b}	244.00± 10.3^{b}	0.40±0.69^{b}	32.80± 0.82^{e}
Site2	26.70± 0.07^{b}	6.33 ±0.08^{d}	495.33±23.12^{a}	247.67± 11.55^{a}	0^{d}	75.97± 3.48^{b}
Site3	26.36 ±0.02^{c}	6.73 ±0.02^{cd}	465.67±3.51^{c}	232.67± 1.53^{c}	0.25± 0.44^{c}	54.27± 19.08^{c}
Site4	25.27± 0.00^{f}	7.50 ±0.37^{a}	277.67± 23.67^{e}	138.67± 11.55^{e}	1.11± 0.06^{d}	53.03± 1.10^{d}
Site5	26.06± 0.12^{e}	6.92 ±0.04^{bc}	356.67± 4.93^{g}	178.33± 2.08^{g}	0.04± 0.08^{d}	100.00± 0.29^{a}
Site6	26.84 ±0.05^{a}	7.24± 0.05^{ab}	463.00 ±9.00^{d}	231.67± 4.51^{d}	0^{a}	0^{g}
Site7	26.65± 0.14^{b}	6.65 ±0.53^{cd}	261.67±31.34^{f}	131.00± 15.39^{f}	1.10± 1.91^{a}	24.47± 1.24^{f}

Values represent means ±standard error. Means separated through One Way ANOVA with Tukey HSD test at α = 0.05. Means with the same letter within the column are not statistically different. T=temperature, EC = electrical conductivity, TDS = total dissolved solutes, DO = dissolved oxygen

Table 3. Chlorophyll a and nutrient composition of water samples from sites within the Douala-Bassa IDZ

Sites	Chl a(µg/L)	TSS (mg/L)	NH_4^+	PO_4^{2-}	TOxN
Site1	8.99±4.20^{c}	0.47±0.26^{a}	82.65±10.01^{e}	4.62±0.02^{d}	217.09±108.45^{a}
Site2	2.40±1.70^{e}	0.57±0.02^{a}	126.16±4.11^{c}	5.44±3.15^{c}	1.15±0.26^{g}
Site3	1.20±1.70^{f}	0.88±0.75^{a}	120.09±22.88^{d}	4.64±1.17^{d}	98.21±97.35^{c}
Site4	2.40±1.70^{e}	0.43±0.10^{a}	18.69±18.12^{f}	1.58±0.93^{e}	7.40±5.90^{e}
Site5	14.99±12.70^{b}	0.48±0.00^{a}	4.29±4.57^{g}	1.22±0.85^{f}	3.51±3.27^{f}
Site6	4.20±9.30^{d}	0.76±0.67^{a}	136.48±7.32^{a}	12.81±0.34^{a}	32.38±19.86^{d}
Site7	485.96±76.40^{a}	0.15±0.00^{a}	126.49±6.37^{b}	10.87±0.90^{b}	199.52±3.65^{b}
P-value	0.000	0.000	0.000	0.000	0.000

Values represent means ±standard error. Means separated through One Way ANOVA with Tukey HSD test at α = 0.05. Means with the same letter within the column are not statistically different. Chla = chlorophyll a, TSS= total suspended solutes, TOxN = total oxidizable nitrogen

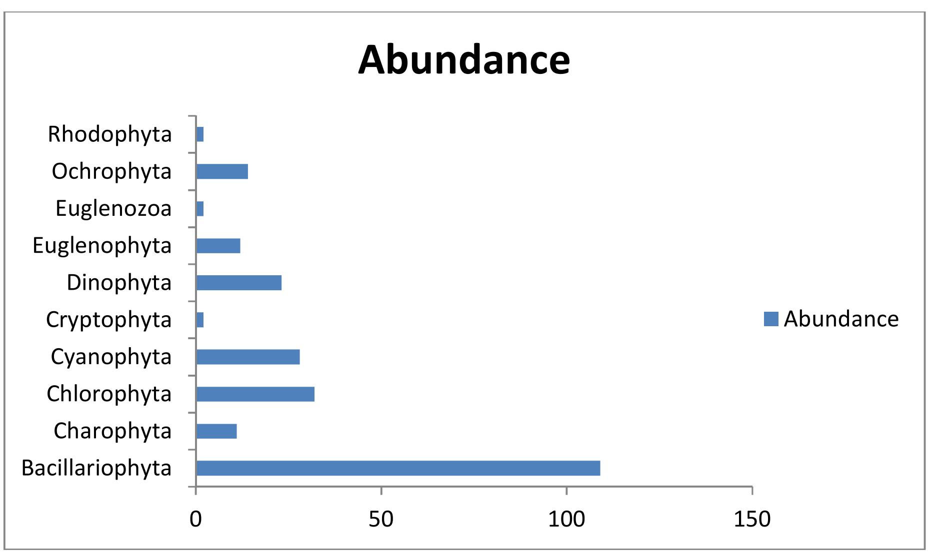
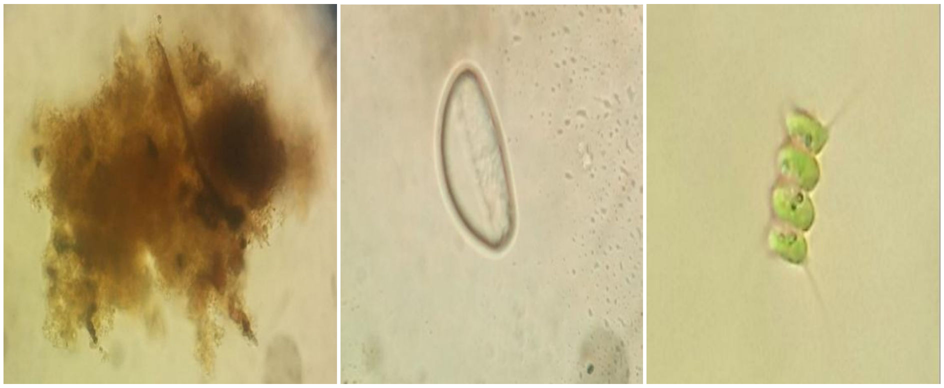
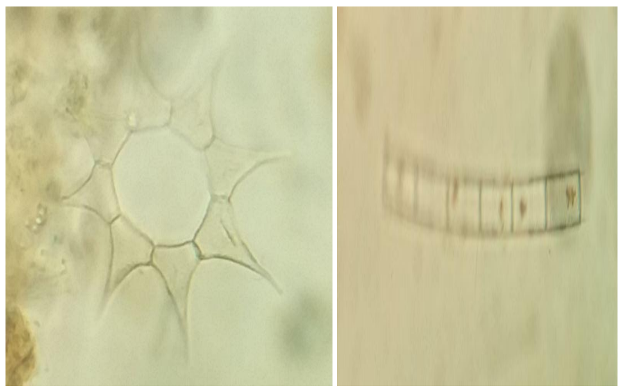


Fig. 2. Different Division abundance across sites in streams of the Douala-Bassa industrial zone



A. *Microcystis flos aquae* B. *Cymbella cistula* C. *Scenedesmus sp*



D. *Pediastrum simplex* E. *Aulacoseira granulata*

Plate 1. Some phytoplankton species identified at the Douala-Bassa IDZ

3.4 Correlation of Water Physicochemical Parameters with Phytoplankton Species

The results of Pearson Correlation analyses between water physicochemical parameters and phytoplankton descriptors are presented in Table 5. There was a strong positive correlation between phytoplankton abundance and Chlorophyll a concentration ($r = 0.844$, $P < 0.017$), richness and chlorophyll a concentration ($r = 0.85$, $P < 0.015$).

3.5 Ordinations

Fig. 3 shows the ordination of species across sites. The observed species distribution can be partially explained by two main components, which contributed 27.66% and 23.35% respectively of the total inertia. Site 4 was highly associated with *Aulacoseira islandica, Pandorina sp*, *Cymatopleura solea, Melosira varians, Closterium acutum, Microcystis flos-aquae* and *Pseudoanabaena catenata* which were not found in the other sites. *Stephanodiscus sp*, *Vaucheria sp*, *Fragilaria construens*, *Spyrogyra sp*, *Navicula rhynchocephala*, *Pleurosigma angulatum*, *Tribonema vulgare*, *Cyclotella meneghiniana* and *Ceratium hirundinella* were found solely at Site 5. *Synedra ulna*, *Cylindrospermopsis sp*, *Amphipleura sp*, *Oedogonium sp*, *Pediastrum simplex*, *Ceratium sp*, *pleurotaenium trabecular*, *pleurotaenium trabecular*, *Chlorella vulgaris, Cryptomonas s, Pseudoanabaena sp* and others were only found in Sites 7 and 2, distinguishing them from other sites where no species existed exclusively; the rest of species observed were cosmopolitan Fig. 3.

Constraining the species observed with ecophysiological determinants of community structure resulted in a spatial pattern which can be explained by two main components that contributed 64.57% of the total inertia. Fig. 4 shows that Site 5 was associated with turbidity which drives the presence of *Stephanodiscus sp, Spyrogyra sp, Vaucheria sp, Pleurosigma* *angulatum, Navicula rhynchocephala, Fragilaria construens, Ceratium hirundinella, Cyclotella meneghiniana, Cyclotella meneghiniana, Cocconeis pediculus, Tribonema vulgare, Euglena viridis, Gymnodinium hetorostriastrum, Tabellaria flocculosa* and *Microcystis aeruginosa*. Site 7 could only be associated with chlorophyll a concentration which influences the presence of *Pseudoanabaena catenata, Synedra ulna, Anabaena circinalis, Stephanodiscus binderanus, Ceratium sp, Pseudoanabaena sp, Chlamydomonas sp, Surirella ovalis, Oedogonium sp, Closterium moniliferum, Coscinodiscus lacustris, pleurotaenium trabecular, Ankistrodesmus gracilis, Sphaerodinium polinicum* and *Selenastrum sp*. Site 3 was highly associated with Total Oxidizing Nitrogen and not a high number of phytoplankton species is strongly associated with this site (Fig. 4).

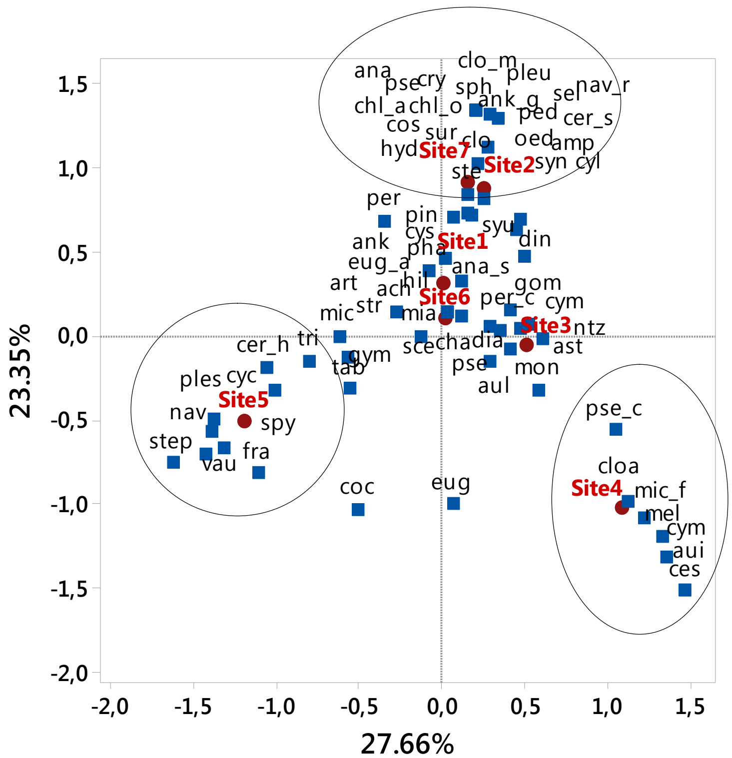


Fig. 3. Species association of phytoplankton abundance with sites of the Douala-Bassa industrial zone Red dots = the sites; blue dots = phytoplankton species

Achnanthidium sp = ach; Amphipleura sp = amp; Anabaena circinalis = ana; Anabaena spiroides = ana_s; Ankistrodesmus sp = ank; Ankistrodesmus gracilis = ank_g; Aulacoseira islandica = aui; Aulacoseira granulate = aul; Arthrospira sp = art; Asterionella Formosa = ast; Ceratium hirundinella = cer_h; Pandorina sp = ces; Ceratium sp = cer_s; Chaetophora sp = cha; Chlamydomonas sp = chl_a; Chlorella vulgaris = chl_o; Closterium acutum = cloa; Closterium gracile = clo; = clo_m; Cocconeis pediculus = coc; Coscinodiscus lacustris = cos; Cryptomonas sp = cry; Cyclotella meneghiniana = cyc; Closterium moniliferum = clo_m; Cylindrospermopsis sp = cyl; Cymbella afinis = cym_a; Cymatopleura solea = cym; Cystodinum bataviense = cys; Diatoma vulgaris = dia; Dinobryon sertularia = din; Euglena viridis = eug; Euglena acus = eug_a; Fragilaria construens = fra; Gomphonema parvulum = gom; Gymnodinium hetorostriastrum = gym; Hildenbrandia prototypus = hil; Hydrodictyon sp = hyd; Melosira varians = mel; Micrasterias furcata = mia; Microcystis aeruginosa = mic; Microcystis flos-aquae = mic_f; Monoraphidium griffithii = mon; Navicula rhynchocephala = nav; Navicula rhyncho cephala = nav_r; Nitzschia palea = ntz; Oedogonium sp = oed; Phacus acuminatus = pha; Pediastrum simplex = ped; Peridinium cinctum = per; Peridinium crassipes = per_c; Pinnularia gibba = pin; pleurotaenium trabecular = pleu; Pleurosigma angulatum = ples; Pseudoanabaena sp = pse; Pseudoanabaena catenata = pse_c; Pseudo-nitzchia serata = pse_n; Scenedesmus sp = sce; Selenastrum sp = sel; Sphaerodinium polinicum = sph; Spyrogyra sp = spy; Stephanodiscus binderanus = ste; stephanodiscus sp = step; Strombomonas verrucosa = str; Surirella ovalis = sur; Synedra ulna = syn; synura peternii = syu; Tabellaria flocculosa = tab; Tribonema vulgares = tri; Vaucheria sp = vau

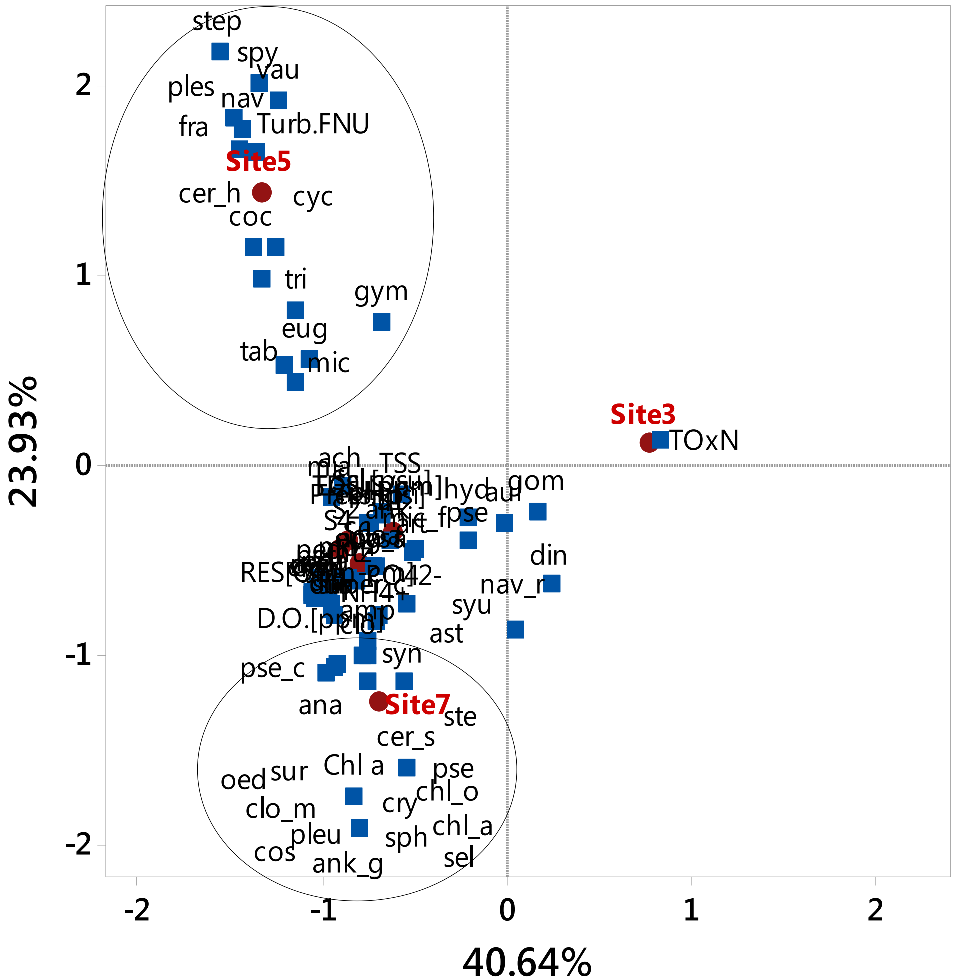


Fig. 4. Species association of physico-chemical parameters and phytoplankton abundance with sites across the Douala-Bassa Industrial zone

Red dots = the sites; blue dots = phytoplanktons and physicochemical parameters. *Achnanthidium sp* = ach; *Amphipleura sp* = amp; *Anabaena circinalis* = ana; *Anabaena spiroides* = ana_s; *Ankistrodesmus sp* = ank; *Ankistrodesmus gracilis* = ank_g; *Aulacoseira islandica* = aui; *Aulacoseira granulate* = aul; *Arthrospira sp* = art; *Asterionella Formosa* = ast; Chlorophyll a = chl a; *Ceratium hirundinella* = cer_h; D.O = Dissolved Oxygen; *Pandorina sp* = ces; *Ceratium sp* = cer_s; *Chaetophora sp* = cha; *Chlamydomonas sp* = chl_a; *Chlorella vulgaris* = chl_o; *Closterium acutum* = cloa; *Closterium gracile* = clo; = clo_m; *Cocconeis pediculus* = coc; *Coscinodiscus lacustris* = cos; *Cryptomonas sp* = cry; *Cyclotella meneghiniana* = cyc; *Closterium moniliferum* = clo_m; *Cylindrospermopsis sp* = cyl; *Cymbella afinis* = cym_a; *Cymatopleura solea* = cym; *Cystodinum bataviense* = cys; *Diatoma vulgaris* = dia; *Dinobryon sertularia* = din; *Euglena viridis* = eug; *Euglena acus* = eug_a; *Fragilaria construens* = fra; *Gomphonema parvulum* = gom; *Gymnodinium hetorostriastrum* = gym; *Hildenbrandia prototypus* = hil; *Hydrodictyon sp* = hyd; *Melosira varians* = mel; *Micrasterias furcata* = mia; *Microcystis aeruginosa* = mic; *Microcystis flos-aquae* = mic_f; *Monoraphidium griffithii* = mon; *Navicula rhynchocephala* = nav; *Navicula rhyncho cephala* = nav_r; *Nitzschia palea* = ntz; *Oedogonium sp* = oed; *Phacus acuminatus* = pha; *Pediastrum simplex* = ped; *Peridinium cinctum* = per; *Peridinium crassipes* = per_c; *Pinnularia gibba* = pin; *pleurotaenium trabecular* = pleu; *Pleurosigma angulatum* = ples; *Pseudoanabaena sp* = pse; *Pseudoanabaena catenata* = pse_c; *Pseudo-nitzchia serata* = pse_n; Ressitivity = Res; *Scenedesmus sp* = sce; *Selenastrum sp* = sel; *Sphaerodinium polinicum* = sph; *Spyrogyra sp* = spy; *Stephanodiscus binderanus* = ste; *stephanodiscus sp* = step; *Strombomonas verrucosa* = str; *Surirella ovalis* = sur; *Synedra ulna* = syn; *Synura peternii* = syu; *Tabellaria flocculosa* = tab; ToxN = Total oxidising Nitrogen; *Tribonema vulgares* = tri; TSS = Total Suspended Solid; Turb = Turbidity; *Vaucheria sp* = vau

3.6 Palmer's Pollution Status

Site7 had the highest Total Index Score above 20 making it the most polluted site, while Site 2 with the least Total Index Score (13) was the least polluted site Table 6.

4. DISCUSSION

4.1 Variation in Abiotic (Physicochemical Parameters) in Relation to Anthropogenic Activities

The average temperature of industrial effluents varied between 25.27° C for the effluent of Oyack (Site 4) and 26.84° C for the effluents from the paint and iron transformation industries (Site 6). This is low compared to the findings of Ram et al. [18] who recorded a range from 29.3 to 30.2° C for the physicochemical parameters of wastewater effluents from industrial area of Mumbai, India. The temperature profile of the effluent receiving stream varies significantly. The temperature range was consistent with [19] in which the recommended limit is 30° C for water of streams receiving effluent. Water samples from Site 2 and Site 7 showed low acidic pH (pH 6.33 to 6.65), probably due to the presence of runoff from agricultural farmland and dumping from resident communities.

The total dissolved solids (TDS) values were proportional to conductivity values all through the study, consistent with findings of Siyanbola [20] who reported that as the total dissolved solids (TDS) values increase the conductivity values also increase. Samples at Site 7 had the lowest TDS values probably due to fact that there are no industries located at this Site, while that of the stream water (Site 1, Site 2 and Site 3) was highest, probably due to the presence of the draining and cleaning industries and agricultural farmlands around this area. Onyema [21] also reported that sources of TDS in Lagos Lagoon included untreated sewage, sawdust, petrochemical material, detergent, industrial effluent and at the time of study, the lagoon was under intense pollution pressure from the sources listed, much similar to the situation of the Douala-Bassa IDZ. Total suspended solids (150 to 880 mg/L) were higher than the maximum permissible limit for Effluent discharge Standards (35g/ml) [22]. The effluents obtained from Sites 3 and 6, with refuse disposal and a wood transformation industry respectively showed high TSS values. The values obtained here are equally similar to those of Kanu and Nwakanma [23] when Assessing Saclux Paint Industrial Effluents on Nkoho River in Abia State, Nigeria. Once again, we see a strong anthropogenic effect on the expression of abiotic factors in effluent-receiving waterways. The overall dissolved oxygen across the sites was very low. Low D.O concentration may be due to higher water temperature and increased activity of microorganisms in the water, which consumes a lot of oxygen due to metabolic processes and the decomposition of organic material. This is similar to the findings of Nivruti et al [24] who reported that the Dissolved Oxygen in some industrial effluents from Vapi Industrial Area in India ranged from 0.0-2.34 mg/L. In the present study, all samples (Site 1 to Site 7) show EC within limits prescribed by WHO (2700 µS/cm) and all samples exceed limits of FAO (> 3.0 µS/cm), and hence they are not fit for irrigation.

4.2 Impact of Abiotic Factors on Chlorophyll a Concentration as a Measure of Phytoplankton Biomass

The nitrate/nitrite content and ammonium concentration of the polluted water was found to be higher than the 1mg/L levels permitted by [25] for industrial area water. Both the upstream and

Table 4. Phytoplankton community structure characteristics in the different sites of the Douala-Bassa IDZ

Sites	Diversity H'	Evenness	Abundance	Richness	Euglenophycean index
Site 1	2.775	0.862	424	25	0.20
Site 2	2.424	0.856	278	17	0.20
Site 3	2.716	0.866	248	23	0.40
Site 4	2.304	0.756	336	21	0.25
Site 5	2.808	0.923	516	21	0.66
Site 6	2.750	0.844	438	26	0.42
Site 7	3.176	0.886	618	37	0.01

H' = Shannon-Weaver diversity index

Table 5. Correlation analysis of water physicochemical parameters and phytoplankton species

	Temp	pH	Chl a	PO42-	TOxN	Diversity
Diversity	0,508	-0,291	0,817	0,525	0,673	
	0,244	0,527	0,025	0,226	0,098	
Richness	0,318	-0,008	0,85	0,652	0,725	0,85
	0,487	0,986	0,015	0,112	0,065	0,015
Evenness	0,563	-0,612	0,429	0,126	0,257	0,707
	0,188	0,144	0,337	0,788	0,578	0,076
Abundance	0,174	0,046	0,844	0,367	0,426	0,79
	0,709	0,922	0,017	0,419	0,34	0,035

Table 6. Palmer's algal pollution index value of different water sites

Division	Genus	PPI	Site1	Site2	Site3	Sie4	Site5	Site6	Site7
Bacillariophyceae	*Navicula*	3	3	-	3	-	3	-	3
	Synedra	2	2	2	2	-	-	2	2
	Pseudo-nitzschia	3	-	-	-	-	-	-	3
	Nitzschia	3	3	3	3	3	3	3	3
	Gomphonema	1	1	-	1	-	-	1	1
Chlorophyceae	*Ankistrodesmus*	2	2	-	2	2	2	2	2
	Scenedesmus	4	-	-	-	-	-	4	-
	Chlamydomonas	4	-	-	-	-	-	-	4
	Chlorella	3	-	-	-	-	-	-	3
Conjugatophyceae	*Closterium*	1	1	-	1	1	-	-	-
Cosinodiscophyceae	*Melosira*	1	-	1	-	1	-	-	-
Cyanophyceae	*Anabaena*	1	1	-	-	-	-	-	-
	Microcystis	1	-	-	1	1	-	1	-
Euglenophyceae	*Euglena*	5	-	5	5	5	5	5	-
	Phacus	2	-	2	-	-	2	2	2
Mediophyceae	*Cyclotella*	1	1	-	-	-	1	1	-
		TIS	14	13	18	13	16	21	23

PPI: Palmer's Pollution Index; TIS: Total Index Score. According to Palmer's Algal Pollution Index values 0-10 indicates lack of organic pollution, 10-15 moderate pollution, 15-20 probable high organic pollution and 20 and above as confirmed high organic pollution

the point of effluent discharge were found to have nitrate levels above the permissible levels, which shows that there are other sources of contamination apart from the industrial effluents such as agricultural farm land and wastes disposal (anthropogenic impacts). Dissolved oxygen concentration observed correlates negatively with high ammonium concentration, which is characteristic of nutrient-enriched waters, consistent with findings of Walakira [6] who reported the major routes of entry of nutrient into bodies of water are municipal and industrial wastewater and private sewage disposal systems. The significantly high chlorophyll a concentrations at Site 7 (485.96 µg l^{-1}), which exceed bloom concentrations, are probably a result of high nutrient input [26], as this site was characterised by a resident human population, and agricultural farms adjacent to the streams, both of which discharge into the water. In this, we once again identify anthropogenic drivers of abiotic stressors in aquatic systems.

4.3 Phytoplankton Community Structure in Relation to Abiotic Stressors in Water Receiving Effluents from the Douala-Bassa IDZ

Many factors have influenced the growth of phytoplankton, generally represented by the concentration of chlorophyll-a; amongst these, abiotic factors such as nutrients, organic substances, and metal ions are dominant [27,28]. The 68 species of phytoplankton found in streams at the Douala-Bassa Industrial zone represent a low number as would be expected in a eutrophic body of water. This is indeed a small number when compared to other records of the same fields. Hans et al. [29] observed that phytoplankton biomass increases with increase in nutrients. For the effluent samples (Site 4, 5 and 6), Site 6 had higher abundance of species. The diversity of species across sites increased with increase in the level of nitrates and Phosphates. For the stream samples (Site 1, 2, 3 and 7), Site 7 had the most abundant species while Site 2 had the least abundant. Here, the diversity of species across sites increased with an increase in the level of the total oxidizable nitrogen, phosphate and ammonium. Hence, nutrient enrichment of the system, influenced by anthropogenic activities within and adjacent to these streams, drives the resulting phytoplankton community structure [9].

The Bacillariophyta, indicators of pollution was the greatest division in number in this study. Similar finding were reported by Onyema [21,30,31]. The presence of *Microcystis sp* at the entire Site is an indication of pollution, as had been reported previously by Fonge et al. [31] for the Douala lagoon. *Nitzschia sp* was present at all the seven Sites and most abundant at site 6 which shows their ability to adapt to a wide range of physicochemical parameters and anthropogenic influences [32]. Their presence here also indicates anthropogenic contamination as has been reported previously [33].

The overall mean Palmer's index value for the different Sites (Site 1, 2, 3, 4, 5, 6 and 7) indicates that the water sources generally experienced organic pollution [17], with Site 7 having the highest degree of the pollution. This could be as a result of anthropogenic activities along this water course. There was a complete consistency between species richness and Palmer's pollution indices of various water Sites. Although Palmer's pollution tolerant genera list recorded only *Anabaena* and *Microcystis* as the only cyanobacteria, Anyinkeng et al [34] reported that the occurrence of this group of algae in water is of great concern.

4.4 Significance of the Study

These results are significant in how they explain the interrelationship between anthropogenic activities, abiotic stressors and phytoplankton community structure. The study shows that there is potential, with each effluent discharge, to alter not just the abiotic environment, but the biotic community of the receiving streams, and this has implications for management of both the effluent, and the streams in which they discharge.

5. CONCLUSION

The results show a clear and functional relationship between anthropogenic activities, the abiotic conditions and resultant phytoplankton community structure in the Douala-Bassa IDZ. Human activities through leaching and discharge of poorly treated effluent into streams, alter the abiotic factors' thresholds such that these become stressors, altering phytoplankton community structure, and sometimes resulting in blooms. Therefore there is need for more intensive monitoring of water bodies in urban and peri-urban areas, as well as the industries that discharge effluent into them, for better ecology, human health and aesthetics.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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