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Use of Epiphytic Diatom-Based Indices in River Quality Assessment: A Case Study of Lower Ogun River (Abeokuta, Southwestern Nigeria)

Gbadebo AM[1]*, Dimowo BO[1], Taiwo AM[1] and Omoniyi IT[2]

[1]Department of Environmental Management and Toxicology; Federal University of Agriculture, PMB 2240, Abeokuta, Nigeria

[2]Department of Aquaculture and Fisheries Management; Federal University of Agriculture, PMB 2240, Abeokuta, Nigeria

***Corresponding Author:** Gbadebo AM, Department of Environmental Management and Toxicology; Federal University of Agriculture, PMB 2240, Abeokuta, Nigeria

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Abstract

The use of diatom indices for water quality assessment in various parts of the world is extensive. This study which is part of a nine paper series that emanated from a research project pioneered the use of epiphytic diatom-based indices in water quality assessment in Nigeria using a case study of Lower Ogun River. Water and epiphytic diatom samples were collected forthnightly from four sampling stations for a period of four consecutive months (March – June, 2015). Water samples were analysed for pH, temperature, electrical conductivity, total dissolved solids, dissolved oxygen, chemical oxygen demand, nitrite, nitrate, ammonium, phosphate, sulphide, chloride, iron, manganese, silicate, total alkalinity, total hardness, total suspended solids, transparency and total organic carbon using standard methods. Epiphytic-diatom samples were collected from aquatic macrophytes such as Nymphia lotus and Pistia stratiotes and analysed following standard protocols. Data collected were subjected to descriptive (frequency, mean) and inferential statistics (Diatom Indices, Pearson Correlation) using OMNIDIA and SPSS statistical packages. Results showed that the water quality of Lower Ogun River during the study period ranged between bad and high quality. The diatom indices (Trophic diatom index, Biological diatom index, Generic Saprobity index) except the generic salinity index and generic trophic index were correlated with physical and chemical parameters thereby indicating their effectiveness in water quality ranking.

Key words: *Environmental Management; Applied Ecology; Ecosystem Health; Water Quality Assessment; Surface water Bio-indicators*

Introduction

Diatoms are of extreme importance to man and the aquatic ecosystem due to the fact that they account for approximately 105 Pg carbon per year for total net primary production for the globe (Field et al., 1998; Yool and Tyrrell, 2003; Mann, 2010). Organisms such as Zebra mussel, the larvae of echinoderms, mollusks and shrimp and fish have been reported to feed directly on diatoms (Shin, 1999; Olojo et al., 2003; Ipinmoroti and Olasunkanmi, 2004; Ayoade et al., 2008; Doubek, 2009; Uwem et al., 2011 and Akinwunmi, 2014). The ecological importance of diatoms can therefore not be understated. Diatom communities typically range from opportunistic tolerant species in areas of severe pollution, giving way to less tolerant and more competitively dominant species at the most distant location from the pollution source. They are hence widely used in bioassessments, and a substantial number of diatom indices have been developed for estimation of water quality in various geographic areas.

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Some of such indices include: Descy's Index or DES (Descy, 1979); Sládecek's Index or SLA (Sládecek, 1986); Leclercq and Maquet's Index or LMI (Leclercq and Maquet, 1987); the Watanabe Index or WAT (Watanabe, 1990); the Commission of Economical Community Index or CEC (Descy and Coste, 1991); Schiefele and Schreiner's Index or SHE (Schiefele and Schreiner, 1991); Rott's Index or ROT (Rott, 1991); the Generic Diatom Index or GDI (Coste and Ayphassorho, 1991); the Specific Pollution Sensitivity Index or SPI (Coste in CEMAGREF, 1982); the Biological Diatom Index or BDI (Lenoir and Coste, 1996); the Eutrophication/Pollution Index or EPI (Dell'Uomo, 1996); the Artois-Picardie Diatom Index or APDI (Prygiel et al., 1996); the Trophic Diatom Index or TDI (Kelly and Whitton, 2001); Pampean Diatom index or IDP (Gómez and Licursi, 2001); and the South African Diatom Index (Harding and Taylor, 2011). These indices according to Taylor et al. (2005) function in the following manner: In a sample from a body of water with a particular level of determinant (e.g. salinity), diatom taxa with their optimum close to that level will be most abundant. Therefore an estimate of the level of that determinant in the sample can be made from the average of the optima of all the taxa in that sample, each weighted by its abundance. A further refinement is the provision of an indicator value which is included to give greater weight to those taxa which are good indicators of particular environmental conditions. In practice, the first step to be completed when using diatom indices is the compilation of a list of taxa in a sample, together with their absolute abundance. The final index value is expressed as the mean of the optima of the taxa in the sample, weighted by the abundance of each taxon. The indicator value acts to further increase the influence of certain species (Kelly, 1998; Taylor et al., 2005). All these indices are based on the formula of Zelinka and Marvan (1961) except the CEC, SHE, TDI and WAT Index (Taylor et al. 2005). The use of these indices in effectively monitoring organic pollution and eutrophication has been extensively studied worldwide (Acs et al., 2009). These indices are however yet to be applied in water quality assessments in Nigeria. This pioneer study therefore investigated the use of some epiphytic diatom-based indices in the assessment of Ogun River quality.

Materials and Methods

Description of the Study Area

Abeokuta is the capital and the largest city in Ogun State which is situated in the southwestern part of Nigeria (NBS, 2012). Soils in Abeokuta have been characterized as being sandy, formed from sedimentary rocks and can only support savannah vegetation. Vegetation is predominated by guinea and derived savannah (Online Nigeria, 2016).

Ogun River (Figure 1) is one of the main rivers in the southwestern part of Nigeria with a total area of 22.4 km^2 and a fairly large flow of about 393 m^{3}sec^{-1} during the wet season (Oketola et al., 2006). It has coordinates of 3^{0}28''E and 8^{0}41''N from its source in Oyo State to 3^{0}25''E and 6^{0}35''N in Lagos where it enters the Lagos lagoon (Ayoade et al., 2004). Mean annual rainfall ranges from 900 mm in the north to 2000 mm towards the south. The estimates of total annual potential evapo-transpiration have been put between 1600mm and 1900mm (Bhattacharya and Bolaji, 2010). Ogun River water is used for agriculture, transportation, human consumption, various industrial activities and domestic purposes (Ayoade et al., 2004; Oketola et al., 2006). It also serves as a raw material to the Ogun State Water Corporation which treats it before dispensing it to the public. Along its course, it constantly receives effluents from breweries, slaughterhouses, dyeing industries, tanneries and domestic wastewater before finally discharging to Lagos lagoon (Ayoade et al., 2004; Oketola et al., 2006).

Water Quality History of Lower Ogun River at Abeokuta

The water quality history of Ogun River spans over 30 years (Adebisi, 1981; Martin, 1987). The water quality of Lower Ogun River at Abeokuta has been studied by various scientists. Among such studies (Table 1) include: Ojekunle *et al*. (2014), Adeosun *et al*. (2014), Taiwo *et al*. (2014), Olayinka *et al*. (2013), Ikotun *et al*. (2012), Awoyemi (2012), Dimowo (2012), Osunkiyesi (2012) and Adeogun *et al*. (2011). A summary of the range of values of physical and chemical parameters reported by these scientists is presented in Table 1.

Water Sampling and Analysis Procedure

Water samples were collected into well labeled sample bottles forthnightly for the period of four months (March - June, 2015) from four sampling stations along the river. Station A was located close to the Ogun State Water Works Corporation, Arakanga, Ibẹrẹkodo; Station B was located close to the FADAMA III supported ferry at Agọ-ika; Station C was located just below the bridge connecting to Lafenwa at Ẹnu gada; and Station D was located just down the road off Pepsi bus stop, Quarry road. The physical and chemical parameters determined included pH, water temperature, electrical conductivity and total dissolved solids which were determined in-situ with the use of HANNA Hi 98129 multi meter while dissolved oxygen, chemical oxygen demand, nitrite, nitrate, ammonium, phosphate, sulphide,

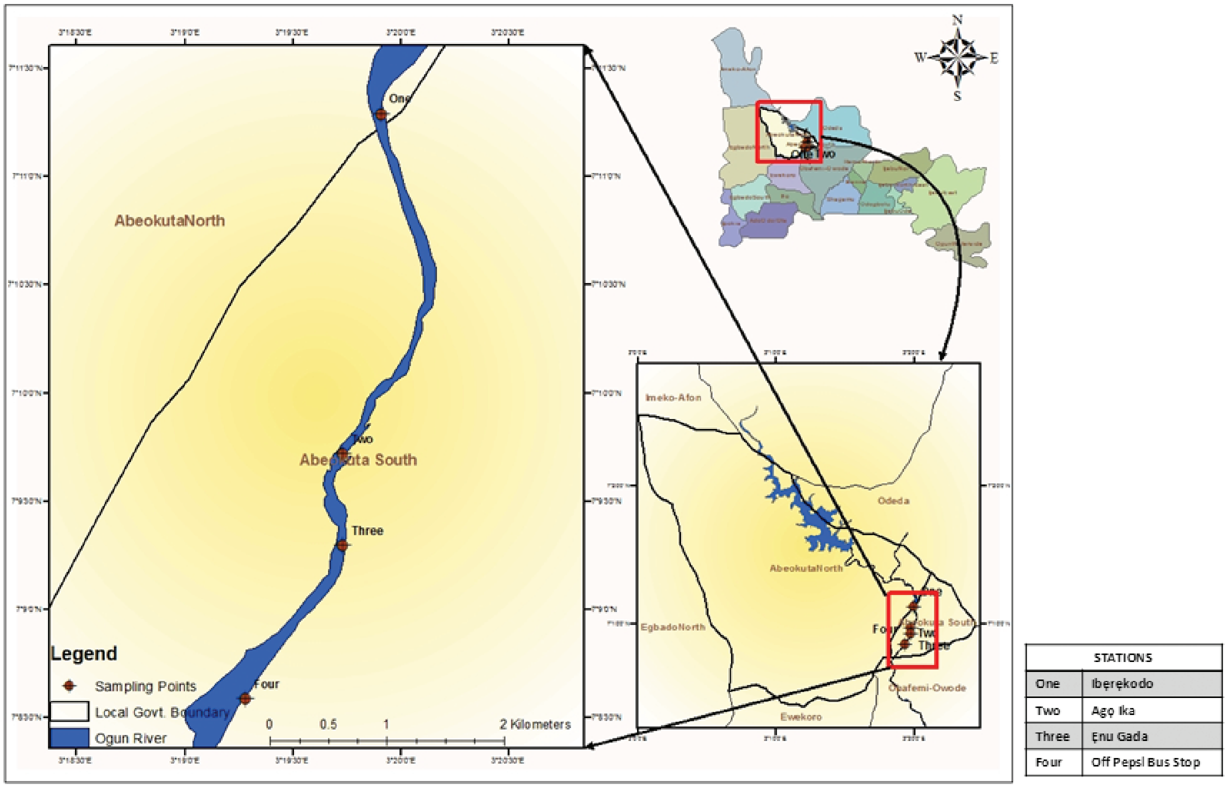

Figure 1: *Map of Lower Ogun River, Abeokuta showing the sampling stations*

Parameters	Ojekunle et al. 2014	Adeosun et al. 2014	Taiwo et al. 2014	Olayinka et al. 2013	Ikotun et al. 2012	Awoyemi, 2012	Dimowo, 2012	Osunkiyesi, 2012	Adeogun et al. 2011
W-T (^{0}C)	24.3 – 27.5	24 – 30.7	26.8 - 27	27.87 – 29.5	23.7 – 31.7	29 – 31	26.9 – 32.1	27 – 32	24.5 – 32
TRANS (cm)	NA	53 - 100	NA	NA	NA	98 – 173	20 – 70	NA	NA
COND (µS/cm)	NA	140 - 190	103.7 - 105	412.67 – 514.67	NA	150 – 388	99 – 180.5	NA	725.19 – 3400
TDS (mg/L)	690 - 7000	70 - 95	46 - 48	93.33 – 95	NA	75 – 194	48.8 – 90.8	438 - 448	346.05 – 757.03
NO_3- (mg/L)	35 – 205	0.235 - 5.445	0.4 – 0.9	1.85 – 2.13	0.66 – 3.91	20.49 – 63.42	0.6 – 113.4	NA	12.28 – 89.43
NO_2- (mg/L)	NA	NA	NA	NA	NA	NA	NA	0.65 – 0.69	NA
PO_4- (mg/L)	52 - 250	0.02 - 0.75	NA	2.68 – 3.26	0.19 – 2.0	0.035 – 0.583	0 – 0.1	NA	1.85 – 18.62
DO (mg/L)	0.1 – 8.82	4.12 - 5.32	5.5 – 6.0	3.7 – 4.75	3.9 – 7.7	1.88 – 5.52	2.8 – 7.7	NA	0 – 11.27
COD (mg/L)	350 - 2500	NA	NA	88.33 - 111.67	NA	NA	NA	NA	181.5 – 1374.91
pH	6.14 – 7.3	7.45 – 9.73	7.92 – 7.96	6.37 – 7.1	6.5 – 7.7	6.5 – 7.95	7.7 – 9.1	7.6 – 7.72	5.5 – 8.8
TSS (mg/L)	NA	NA	79 - 95	2.79 – 5.32	52.9 – 107.5	NA	NA	446.00 – 448.09	822.93 – 1495.47

TA (mg/L)	NA	4.5 – 14.5	0.1 – 0.1	NA	NA	NA	4.4 – 17.8	42.9 – 43.6	NA
TH (mg/L)	NA	NA	41 - 50	NA	NA	NA	45.5 – 105	36.1 – 38.1	NA
Cl^- (mg/L)	380 – 1990	NA	NA	NA	29.3 – 104.5	NA	NA	8.98 – 9.86	15.33 – 183.58
Fe^+ (mg/L)	NA	NA	0.3 – 0.4	1.37 – 1.73	0.12 – 2.3	NA	NA	13800 – 16100	NA
Mn^+ (mg/L)	NA	NA	NA	NA	0 – 1.0	NA	NA	289 – 466	NA

Where: W-T = Water temperature; pH = Hydrogen ion concentration; COND = Electrical Conductivity; TDS = Total Dissolved Solids; TRANS = Water Transparency; Fe^+ = Iron; NO_2- = Nitrite; NO_3- = Nitrate; Mn+ = Manganese; SiO_3- = Silicate; PO_4 = Phosphates; Cl- = Chloride; TA = Total Alkalinity; TH = Total Hardness; COD = Chemical Oxygen Demand; TSS = Total Suspended Solids; DO = Dissolved Oxygen

Table 1: *Water Quality History of Lower Ogun River at Abeokuta.*

chloride, iron, manganese, silicate, total alkalinity, hardness, total suspended solids and total organic carbon were determined in the laboratory using standard methods (Merck, 2014). Water transparency was also measured insitu using Secchi disc. The specific procedures followed and results are presented in Article 5.

Epiphytic Diatom Sampling and Analysis Procedure

Diatom samples were collected forthnightly from four sampling stations along the river for the period of four months (March - June, 2015). Diatoms were sampled from available aquatic macrophytes found at the sampling stations. The aquatic macrophytes included Nymphia lotus and Pistia stratiotes. The algae growing on plants were collected by gathering leaves that were alive and stem sections, discarding either those parts that had been recently out of the water or those that were near the bottom and covered by sediment. The stems and leaves were gently swished, while softly washing with water. The obtained brown or greenish suspension containing the diatoms was collected and preserved with neutral formaldehyde (4%) to prevent the silica cell walls from cracking. This method was adapted from the recommendations of Martin and Fernandez (2012). Thereafter, in the laboratory, the samples were mounted on microscope slides by first shaking the samples vigorously and then pipetting a drop onto the slides with the use of a dropper. The identification of the diatoms was done to the lowest taxonomic category possible under the microscope using keys of identification (such as Edmondson, 1959; Gell et al., 1999; Biggs and Kilroy, 2000; Janse et al., 2006). Then enumeration was carried out using the drop count method adapted from Dhargalkar and Ingole (2004). The abundance of organisms in each sample was extrapolated from the number of organisms per drop to the number of organisms per ml by multiplying the number of organisms per drop by 20 based on the tested premise that 20 drops of the sample make 1 ml.

Statistical Analysis

Descriptive statistics in the form of frequency tables and range were used in the presentation of the data. Inferential statistics such as Diatom Indices viz. Biological Diatom Index (IBD), Trophic Diatom Index (TDI) and Generic Diatom Indices (GDI) - (saprobity index, trophic index and salinity index) were utilized in determining the water quality status of Ogun River. IBD was calculated using Omnidia free version software (Lecointe et al., 1993) while TDI and GDI were calculated using Ms Excel spreadsheets following the method adapted from Kelly et al. (2001) and Van dam et al. (1994) respectively.

Correlation Analysis

Bivariate Correlation Analysis was carried out using Pearson's Product-Moment Coefficient of Correlation in SPSS to check for the relationship between the physical, chemical parameters and diatom indices. The physical and chemical parameters (except pH) and diatom abundance data were log transformed before analysis in order to achieve normal distribution. Pearson's Product Moment Coefficient of Correlation formula is given as:

$$r = \frac{\sum_{i=1}^{n}(X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum_{i=1}^{n}(X_i - \bar{X})^2}\sqrt{\sum_{i=1}^{n}(Y_i - \bar{Y})^2}}$$

Ranking of water quality using diatom based indicators

According to Taylor et al. (2005), in all cases except in the Commission of Economical Community Index (CEC), Schiefele and Schreiner's Index (SHE), Trophic Diatom Index (TDI) and Watanabe Index (WAT Index), the diatom-based indicators are calculated using the formula of Zelinka and Marvan (1961) and have the basic form (Harding et al., 2005) given below:

$$index = \frac{\sum_j^a = 1^{a_j s_j v_j}}{\sum_j^a = 1^{a_j v_j}}$$

Where:

a_j = abundance (proportion) of species j in sample

s_j = pollution sensitivity of species j

v_j = indicator value

The performance of the indices depends on the values given to the constants s and v for each taxon and the values of the index ranges from 1 to an upper limit equal to the highest value of s. Diatom indices differ in the number of species used and in the values of s and v which have been attributed after compiling the data from literature and from ordinations (Prygiel and Coste, 1993; Harding et al., 2005). For all of the above indices, except TDI (maximum value of 100), the maximum value of 5 (converted to 20 by the software package OMNIDIA) indicates a high quality or pristine water resource (Taylor et al., 2005).

Interpretation of diatom based indicators

The diatom biotic indices viz. IBD, TDI and GDI were interpreted following the classifications in Tables 2, 3 and 4.

Index score	Water Quality Rank	Trophic status
>17	High quality	Oligotrophy
15 to 17	Good quality	Oligo-mesotrophy
12 to 15	Moderate quality	Mesotrophy
9 to 12	Poor quality	Mesoeutrophy
<9	Bad quality	Eutrophy

Source: Adapted from Eloranta and Soininen (2002)

Table 2: *Water quality ranking with the use of IBD.*

		Percentage of motile valves				Interpretation	Remarks
		<20%	21 – 40%	41 – 60%	>60%		
TDI Range	0 – 9 10 – 19					A vertical movement on the chart indicates a change in water quality due to nutrients while a horizontal movement indicates change due to other factors.	Oligotrophic Fairly oligotrophic
	20 – 29 30 – 39						Oligo-mesotrophic Highly oligo-mesotrophic
	40 – 49 50 – 59						Fairly mesotrophic Mesotrophic
	60 – 69 70 – 79						Meso-eutrophic Fairly eutrophic
	80 – 89 ≥90						Eutrophic Highly eutrophic

Source: Adapted from Kelly et al. (2001)

Table 3: *TDI water quality look-up chart.*

Generic Salinity Index	Generic Trophic Index	Generic Saprobity Index	Water quality classes	Index core
Very Clean	Oligotrophic	Oligosaprobous	I	>1
Clean	Oligo/mesotrophic	β-mesosaprobous	II	1 - 0.96
Moderate	Mesotrophic	α-mesosaprobous	III	0.95 - 0.76
Polluted	Eutrophic	Meso-polysaprobous	IV	0.75 - 0.56
Very polluted	Hypereutrophic	Polysaprobous	V	<0.56

Source: Based on Delta Environmental (2007) and Van dam et al. (1994)

Table 4: *Interpretation of Generic Diatom Indices*

Results

The weekly and monthly spatial variation in the physical, chemical parameters, the weekly variation in the epiphytic diatom abundance and epiphytic diatom indices of Ogun River at Abeokuta are available as supplementary files.

Species Composition and Count of Epiphytic Diatoms of Ogun River at Abeokuta

A total of 66 epiphytic diatoms (Table 5) belonging to 12 orders and 3 classes were identified in the study sites. The diatoms identified in this study included: *Melosira varians, Aulacoseira granulata, Cyclotella meneghiniana, Cyclotella stelligera, Coscinodiscus rothii, Stephanodiscus margarae, Stephanodiscus agassizensis, Stephanodiscus spp, Cyclostephanos dubius, Fragilaria capucina, Fragilaria crotonensis, Synedra acus, Synedra nana, Synedra ulna, Diatoma vulgaris, Diatoma hiemale, Diatoma tenuis, Staurosira cf. elliptica, Meridion circulare, Tabellaria flocculosa, Tetracyclus lacustris, Cymbella tumida, Gomphonema cf. affine, Gomphonema parvulum, Gomphonema truncatum, Gomphoneis minuta var. cassieae, Rhoicosphenia abbreviate, Asterionella Formosa, Amphicampa erura, Eunotia serpentina, Eunotia bilunaris, Gyrosigma cf. scalproides, Gyrosigma attenuatum, Navicula viridula, Navicula capitoradiata, Navicula cryptocephala, Navicula spp, Pinnularia viridis, Pinnularia cf. interrupta, Frustulia vulgaris, Frustulia rhomboides, Sellaphora seminulum, Sellaphora bacillum, Stauroneis cf. kriegerii, Stauroneis phoenicenicron, Amphipleura pellucida, Craticula cuspidata, Diadesmis confervacea, Amphiprora alata, Achnanthes lanceolata, Planothidium lanceolatum, Cocconeis placentula, Achnanthidium minutissimum, Nitzchia cf. acicularis, Nitzschia frustulum, Nitzschia cf. dissipata, Nitzschia palea, Nitzschia intermedia, Bacillaria paradoxa, Cylindrotheca gracilis, Cymatopleura solea, Campylodiscus clypeus, Rhopalodia gibba, Epithemia adnata, Denticula subtilis and Amphora veneta. Synedra ulna* (18.71%) had the highest relative abundance followed by Coscinodiscus rothii (8.74%) and Nitzschia palea (5.9%) etc.

Variation in the epiphytic diatom indices of Ogun River at Abeokuta

The monthly spatial variation in epiphytic diatom indices (Table 6) was in the following order: Trophic diatom index was highest in Station D (June) and lowest in Station C (April). %motile taxa was highest in Station D (March) and lowest in Station C (May). Biological diatom index was highest in Station D (June) and lowest in Station D (March). Generic salinity index was highest in Station A (April) and lowest in Stations B, C, D (May) and D (June). Generic trophic index was highest in Station A (April) and lowest in Station D (March). Generic saprobity index was highest in Station A (April) and lowest in Station D (March).

All the epiphytic diatom indices also differed in their ranking of the water quality of Ogun River. However, the epiphytic generic diatom indices were quite similar in their water quality ranking.

Relationship between physical, chemical parameters and epiphytic diatom indices of Ogun River at Abeokuta

Table 7 shows the Pearson correlation coefficients of physical, chemical parameters and epiphytic diatom indices of Ogun River at Abeokuta. Physical, chemical parameters and epiphytic diatom indices exhibited the following relationship pattern: Trophic diatom index was negatively correlated with water temperature ($p < 0.05$), hydrogen ion concentration ($p < 0.05$), water transparency ($p < 0.05$), iron ($p < 0.05$), ammonium ($p < 0.05$), phosphate ($p < 0.01$), generic trophic index ($p < 0.05$) and generic saprobity index ($p < 0.05$). % motile taxa was positively correlated with silicate ($p < 0.01$), and negatively correlated with total alkalinity ($p < 0.05$). Biological diatom index was negatively correlated with nitrite ($p < 0.05$). Generic salinity index was positively correlated with generic saprobity index ($p < 0.05$). Generic trophic index was negatively correlated with trophic diatom index ($p < 0.05$) and positively correlated with generic saprobity index ($p < 0.01$). Generic saprobity index was positively correlated with hydrogen ion concentration ($p < 0.05$), generic salinity index ($p < 0.05$), generic trophic index ($p < 0.01$) and negatively correlated with trophic diatom index.

Discussion

A total of 66 diatom species were identified in this study. Synedra ulna emerged with the highest relative abundance followed by Coscinodiscus rothii and Nitzschia palea.

The dominance of Synedra ulna has also been reported by Edward and Ugwumba (2010) who reported Synedra ulna as having the highest percentage abundance of diatoms in Egbe Reservoir.

Epilithic Diatom Species	March, 2015				April, 2015				May, 2015				June, 2015				Total Count
	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	
Melosira varians	320	320	240	0	40	40	0	20	0	0	60	0	180	60	200	140	1620
Aulacoseira granulata	40	40	0	0	560	20	20	0	20	140	120	40	300	0	160	80	1540
Cyclotella meneghiniana	40	0	0	0	100	0	40	0	200	60	0	0	1020	100	120	0	1680
Cyclotella stelligera	0	0	0	0	0	0	0	0	160	0	0	20	0	0	0	0	180
Coscinodiscus rothii	0	0	100	200	120	100	120	160	260	1040	920	0	0	0	240	0	3260
Stephanodiscus margarae	0	0	0	0	0	0	0	0	60	240	0	0	0	0	0	0	300
Stephanodiscus agassizensis	0	0	0	0	680	120	220	40	0	0	0	0	0	0	0	0	1060
Stephanodiscus spp	40	0	0	0	0	0	20	0	0	0	0	0	0	0	0	0	60
Cyclostephanos dubius	0	0	0	0	0	0	0	0	0	0	20	0	0	0	0	0	20
Fragilaria capucina	20	0	0	80	0	0	0	0	20	0	0	0	0	40	80	0	240
Fragilaria crotonensis	0	0	0	0	0	0	0	0	0	0	20	0	20	0	0	40	80
Synedra acus	0	0	0	0	80	0	0	0	20	0	0	0	0	60	80	80	320
Synedra nana	0	0	0	0	0	0	0	0	0	0	0	0	200	200	60	520	980
Synedra ulna	160	140	20	320	580	40	40	40	460	240	700	1280	2200	240	500	20	6980
Diatoma vulgaris	0	0	0	0	0	0	0	0	40	20	0	0	0	140	0	60	260
Diatoma hiemale	0	0	0	0	0	0	0	0	180	0	0	20	0	0	0	0	200
Diatoma tenuis	0	100	140	0	20	0	0	80	80	0	0	60	0	0	0	0	480
Staurosira cf. elliptica	0	0	0	0	0	0	0	0	0	0	0	20	0	0	0	0	20
Meridion circulare	0	0	0	20	60	0	0	0	60	0	0	0	0	0	0	0	140
Tabellaria flocculosa	0	0	0	0	0	0	0	0	60	0	0	0	0	0	0	0	60
Tetracyclus lacustris	0	0	0	0	0	0	20	0	0	0	0	0	0	0	0	0	20
Cymbella tumida	40	0	0	0	20	20	40	0	0	20	0	80	0	0	0	0	220
Gomphonema cf. affine	0	0	0	0	0	0	0	0	0	0	0	0	0	100	0	40	140
Gomphonema parvulum	20	0	0	60	0	0	0	0	0	0	0	0	0	40	0	40	160
Gomphonema truncatum	20	0	0	0	60	0	0	0	100	40	80	0	0	0	0	0	300
Gomphoneis minuta var. cassieae	0	0	0	0	0	0	0	0	0	0	20	0	0	0	0	0	20

Table 5: *Monthly spatial variation in the Count of epiphytic diatoms of Ogun River in Abeokuta.*

Epilithic Diatom Species	March, 2015				April, 2015				May, 2015				June, 2015				Total Count
	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	
Rhoicosphenia abbreviata	0	0	0	0	0	0	0	0	0	0	0	0	20	20	0	60	100
Asterionella formosa	0	0	0	0	0	0	0	0	40	0	0	0	0	980	0	0	1020
Amphicampa erura	60	0	0	0	120	140	40	80	0	0	0	120	0	0	0	0	560
Eunotia serpentine	0	20	0	60	40	0	0	60	60	140	0	20	0	0	0	20	420
Eunotia bilunaris	60	0	40	0	60	80	220	100	60	0	0	0	0	0	0	0	620
Gyrosigma cf. scalproides	0	0	0	0	0	0	0	0	20	0	0	0	320	340	340	0	1020
Gyrosigma attenuatum	0	0	0	0	0	0	0	0	140	0	0	60	60	0	0	540	800
Navicula viridula	0	0	0	0	0	0	0	0	0	40	0	0	80	100	120	20	360
Navicula capitoradiata	0	160	20	0	0	0	0	0	0	0	0	0	0	0	0	0	180
Navicula cryptocephala	0	200	0	80	0	0	0	0	0	20	0	0	0	0	0	0	300
Navicula spp	20	0	0	0	140	0	0	0	0	0	0	0	0	0	0	0	160
Pinnularia viridis	0	100	20	100	240	120	0	0	200	0	20	0	0	40	140	0	980
Pinnularia cf. interrupta	80	0	0	0	60	0	0	0	0	0	0	0	0	0	0	0	140
Frustulia vulgaris	0	0	0	20	60	0	20	20	20	40	0	0	340	0	380	20	920
Frustulia rhomboides	0	200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	200
Sellaphora seminulum	0	240	0	0	0	0	0	0	0	0	0	0	0	0	0	0	240
Sellaphora bacillum	0	100	0	0	0	0	0	0	0	0	20	0	0	0	0	0	120
Stauroneis cf. kriegerii	0	0	20	0	0	0	0	0	0	0	0	20	0	0	0	0	40
Stauroneis phoeniceni-cron	0	0	0	0	0	0	0	0	0	0	0	0	140	40	0	0	180
Amphipleura pellucida	0	0	0	0	0	0	0	0	0	0	0	0	40	40	0	0	80
Craticula cuspidata	0	0	140	20	0	0	0	0	0	0	0	0	0	0	0	0	160
Diadesmis confervacea	0	0	0	0	0	0	0	0	20	20	0	0	0	0	0	0	40
Amphiprora alata	0	40	0	0	0	0	0	0	0	0	20	20	0	0	0	0	80
Achnanthes lanceolata	20	0	0	0	240	0	0	20	60	0	40	0	160	60	0	0	600
Planothidium lanceolatum	0	0	0	0	0	0	0	20	0	0	0	0	0	40	0	140	200
Cocconeis placentula	0	0	0	0	0	0	0	0	100	0	0	0	100	120	200	0	520
Achnanthidium minutis-simum	20	80	0	0	0	0	0	0	0	160	0	0	0	0	0	0	260

Table 5: *Monthly spatial variation in the Count of epiphytic diatoms of Ogun River in Abeokuta Continued.*

Synedra ulna has been reported of being tolerant of water pollution (Singh et al., 2013). Coscinodiscus rothii is found in marine environments (Guiry, 2017a). Following the ecological indicator values reported by Van dam et al. (1994), Nitzschia palea occurs mainly in water bodies but is sometimes found in wet environments. It is an obligate nitrogen-heterotrophic taxa, needing consistently large amounts of organically bound Nitrogen with low oxygen requirements (30% saturation). It is circumneutral mainly occurring in fresh brackish waters with pH about 7, chloride levels <500 mg/L and salinity less than 0.9‰. Nitzschia palea is hypereutraphentic and polysaprobous thereby falling under water quality class IV.

All the diatom indices (TDI, IBD, GSI1, GSI2, GTI) differed in their ranking of the water quality of Lower Ogun River at Abeokuta. However, the generic diatom indices (GSI1, GSI2, GTI) were quite similar in their water quality ranking.

Epilithic Diatom Species	March, 2015				April, 2015				May, 2015				June, 2015				Total Count
	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	
Achnanthidium minutissimum	20	80	0	0	0	0	0	0	0	160	0	0	0	0	0	0	260
Nitzchia cf. acicularis	40	0	0	80	0	0	0	0	0	0	0	0	400	0	140	20	680
Nitzschia frustulum	0	0	0	0	60	0	0	0	0	0	0	0	0	0	0	0	60
Nitzschia cf. dissipata	0	0	0	0	0	40	0	0	0	0	0	0	0	0	0	0	40
Nitzschia palea	80	60	220	1840	0	0	0	0	0	0	0	0	0	0	0	0	2200
Nitzschia intermedia	300	0	100	1300	0	0	0	0	0	0	0	0	0	0	0	0	1700
Bacillaria paradoxa	0	0	0	0	0	0	0	0	0	0	20	0	20	0	0	20	60
Cylindrotheca gracilis	60	0	0	0	0	0	0	0	60	0	0	0	0	0	0	0	120
Cymatopleura solea	20	20	0	0	0	0	0	0	20	0	0	0	0	0	80	100	240
Campylodiscus clypeus	0	140	0	0	140	0	0	0	260	160	0	0	0	300	60	80	1140
Rhopalodia gibba	40	0	0	0	60	0	0	20	0	0	0	0	0	0	0	0	120
Epithemia adnata	0	0	0	0	40	0	0	0	0	0	0	0	0	0	0	20	60
Denticula subtilis	0	0	0	0	0	20	0	20	0	0	0	0	0	0	0	0	40
Amphora veneta	40	0	20	0	0	0	40	20	80	0	0	0	0	0	0	0	200

Table 5: *Monthly spatial variation in the Count of epiphytic diatoms of Ogun River in Abeokuta Continued.*

Epiphytic Diatom Indices	March, 2015				April, 2015				May, 2015				June, 2015			
	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D
TDI	55.25	48.06	62.83	73.46	35.53	20.35	8.33	21.74	39.22	27.78	55.00	50.00	59.84	75.52	48.16	85.47
%Motile taxa	7.79	8.67	9.74	19.15	5.45	10.26	1.79	1.16	4.62	3.76	0.57	1.53	7.21	4.80	10.07	4.59
Interpretation	M	M	P	P	G	G	H	G	G	G	M	M	P	P	M	B
IBD	11.77	13.29	9.72	7.47	10.76	12.68	13.18	11.81	12.76	8.18	8.14	11.02	10.51	11.63	10.41	13.32
Interpretation	P	M	P	B	P	M	M	P	M	B	B	P	P	P	P	M
GSI1	0.61	2.67	0.24	0.07	21.33	6.00	7.00	10.00	6.25	0.00	0.00	0.00	1.50	0.00	2.14	16.00
Interpretation	P	H	B	B	H	H	H	H	H	B	B	B	H	B	H	H
GTI	0.52	1.00	0.17	0.05	15.25	6.00	7.00	2.00	0.83	15.00	0.00	2.00	1.20	0.69	0.88	3.00
Interpretation	B	H	B	B	H	H	H	H	M	H	B	H	H	P	M	H
GSI2	0.60	0.38	0.20	0.00	7.63	6.00	3.50	1.67	0.68	3.75	3.00	1.60	0.58	1.00	1.56	1.20
Interpretation	P	B	B	B	H	H	H	H	P	H	H	H	P	H	H	H

Where: TDI = Trophic Diatom Index; %MT = % Motile taxa; IBD = Biological Diatom Index; GSI1 = Generic Salinity Index; GTI = Generic Trophic Index; GSI2 = Generic Saprobity Index; H = High quality; G = Good quality; M = Moderate quality; P = Poor quality; B = Bad quality

Table 6: *Monthly spatial variation in the epiphytic diatom indices of Ogun River, Abeokuta.*

Parameters	TDI	%Motile taxa	IBD	GSI1	GTI	GSI2
LogWT	-.586*	0.011	-0.131	-0.059	0.131	0.257
pH	-.542*	-0.261	-0.216	0.086	0.451	.617*
LogCOND	0.239	-0.128	-0.131	-0.004	-0.291	-0.269
LogTDS	0.253	-0.143	-0.11	0.024	-0.279	-0.266
LogTRANS	-.568*	0.237	-0.087	-0.101	0.279	0.302
LogFe	-.557*	-0.224	0.491	0.012	0.089	0.155
LogNO2	0.073	0.374	-.593*	-0.332	0.035	-0.178
LogNO3	-0.415	0.238	0.261	0.409	0.203	0.385
LogMn	-0.238	-0.073	0.26	0.036	0.011	0.077
LogNH4	-.571*	0.132	0.227	0.116	0.071	0.283
LogSO3	-0.442	-0.187	0.194	0.236	-0.021	0.143
LogSiO3	0.275	.629**	-0.1	-0.301	-0.321	-0.409
LogPO4	-.700**	-0.044	0.149	0.214	0.351	0.419
LogCl	.a	.a	.a	.a	.a	.a
LogTA	-0.158	-.570*	0.231	0.393	0.324	0.452
LogTOC	0.227	-0.325	-0.166	0.198	0.107	0.127
LogTH	0.214	0.121	-0.241	-0.333	-0.297	-0.422
LogCOD	0.007	-0.132	0.034	0.19	0.133	0.047
LogTSS	-0.179	-0.348	-0.035	-0.268	0.232	0.081
LogDO	0.224	-0.167	-0.146	0.01	-0.306	-0.245
TDI	1	0.346	-0.22	-0.191	-.520*	-.583*
%Motile taxa	0.346	1	-0.28	-0.219	-0.224	-0.246
IBD	-0.22	-0.28	1	0.428	-0.079	0.02
GSI1	-0.191	-0.219	0.428	1	0.492	.552*
GTI	-.520*	-0.224	-0.079	0.492	1	.806**
GSI2	-.583*	-0.246	0.02	.552*	.806**	1

*.Correlation is significant at the 0.05 level (2-tailed). **. Correlation is significant at the 0.01 level (2-tailed).
Where LogWT = Log Water temperature; pH = Hydrogen ion concentration; LogCOND = Log Electrical conductivity; LogTDS = Log Total dissolved solids; LogTRANS = Log Water transparency; LogFe = Log Iron; LogNO2 = Log Nitrite; LogNO3 = Log Nitrate; LogMn = Log Manganese; Log NH4 = Log Ammonium; LogSO3 = Log Sulphide; LogSiO3 = Log Silicate; LogPO4 = Log Phosphate; LogTA = Log Total alkalinity; LogTOC = Log Total organic carbon; LogTH = Log Total hardness; LogCOD = Log Chemical oxygen demand; LogTSS = Log Total suspended solids; LogDO = Log Dissolved oxygen; TDI = Trophic diatom index; IBD = Biological diatom index; GSI1 = Generic salinity index; GTI = Generic trophic index; GSI2 = Generic saprobity index.

Table 7: *Pearson correlation coefficients of physical, chemical parameters and epiphytic diatom indices of Ogun River at Abeokuta.*

The trophic diatom index (TDI) showed that during the study period, the river water was in most cases moderate and good (there was a tie in frequency of occurrence) in terms of quality. However, the biological diatom index (IBD) showed that the river water was most times poor in terms of quality.

The generic salinity index (GSI1) showed that the river water was in most cases high in terms of quality during the study period. The salinity classification was calculated based on the tolerance of diatoms to salinity.

The generic trophic index (GTI) showed that during the study period, the river water was in most cases high in terms of quality. The trophic classification was calculated based on the tolerance of diatoms to the trophic state of the aquatic ecosystem. According to Naumann (1921) as cited by Van dam et al. (1994), variations in trophic state are usually as a result of variations in concentration of inorganic nitrogen and phosphorus compounds. There are however various concepts regarding trophic state. For this reason, water quality assessment based on trophic state was rather qualitative.

The generic saprobity index (GSI2) showed that the river water was in most cases high in terms of quality during the study period. The saprobity classification was calculated based on the indicator properties of diatoms to the presence of biodegradable organic matter and oxygen concentrations in the aquatic ecosystem (Van dam et al., 1994).

The following deductions were made from the relationship between physical, chemical parameters and epiphytic diatom indices: As trophic diatom index (TDI) scores increased, water temperature, hydrogen ion concentration (pH), water transparency, and the concentrations of iron and phosphates decreased. This shows that lower values of water temperature, pH, water transparency, iron and phosphates supported increase in TDI scores. It was also observed in the relationship among the diatom indices that as TDI scores increased, generic trophic index (GTI) and generic salinity index (GSI1) scores reduced.

The relative abundance of motile diatom taxa in this study increased with increasing concentration of silicates and reduced with increasing concentration of total alkalinity. This shows that increased concentrations of silicates and reduced concentration of total alkalinity supported higher relative abundance of motile diatom taxa. This result corroborated Reynolds (1984) as cited by Gbadebo et al. (2013) who observed that silica plays an important role in the ecology of aquatic systems as it is an essential element for diatom existence comprising 26 – 69% of its cellular dry weight.

It was observed that biological diatom index (IBD) increased as the concentration of nitrites increased. This shows that nitrite influenced the diatoms of the aquatic ecosystem which was evidenced in the IBD scores. This result corroborated Kalyonku and Serbetci (2013) who reported significant correlations between IBD and Nitrite Nitrogen.

The lack of correlationship between IBD and Dissolved Oxygen, Temperature, Conductivity, Ammoniacal Nitrogen and Phosphate Phosphorus in this study however contrasted the observations of Kalyonku and Serbetci (2013) who reported significant correlations among these parameters.

The lack of significant relationship between diatom indices (such as TDI, IBD) and physical/chemical parameters (such as electrical conductivity and total dissolved solids) however did not corroborate Solak et al. (2009) who reported negative correlations between TDI, electrical conductivity and total dissolved solids.

It was observed that generic salinity index (GSI1) scores and generic trophic index had no significant relationship with physical and chemical parameters. GSI1 and GTI however increased with increasing generic saprobity index (GSI2) scores.

The relationship between the generic saprobity index (GSI2) scores and pH in the river water signified that increases in pH contributed to increases in GSI2 scores. Also, GSI2 scores increased with decreasing TDI scores and increased with increasing GSI1 and GTI scores.

These results show that there was a close relationship between physical, chemical parameters and diatom-based indices. This agreed with Bere et al. (2014) who applied the indices to urban streams in Zimbabwe. The lack of significant correlation observed between electrical conductivity and the diatom indices in this study was not in agreement with the work of Stancheva et al. (2009) who reported a high negative correlation.

Conclusion

The diatom indices except for the generic salinity index and generic trophic index were correlated with physical and chemical parameters indicating their effectiveness in water quality ranking. The water quality of the Lower Ogun River during the study period ranged between bad and high quality. Limitations on the use of diatom indices include insufficient information on the autecology of diatom species in Nigeria. It is therefore recommended that the ecology of diatoms in Nigeria should be studied in detail to provide information on taxonomy, nomenclature, autecology, sensitivities and tolerance levels of diatoms to pollution in Nigerian waters. Also, diatom keys, identification guides and diatom-based indices specific to water bodies in Nigeria should be developed just as is done in other regions of the world.

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