Original Article

Water Quality in Relation to Plankton Abundance and Diversity in River Ogun, Abeokuta, Southwestern Nigeria

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Abstract

Aims: Plankton abundance and diversity are governed by certain aquatic environmental factors which collectively determine the health of the aquatic ecosystem. This study was aimed at investigating the water quality of lower Ogun River, Abeokuta, in relation to plankton abundance and diversity. **Materials and Methods:** The dataset consists of physicochemical and plankton data collected for 7 months within the period of December 2011 and June 2012 in four stations. Spatial correlations were determined between physicochemical parameters, plankton abundance, and diversity. Physicochemical parameters that exhibited strong correlation with plankton abundance and diversity were used in the calculation of a water quality index (WQI) for the protection of aquatic life. **Results:** Results showed highly significant correlations ($P \leq 0.05$) between plankton abundance, diversity, and the physicochemical parameters monitored during the study period excluding alkalinity and phosphates. The Canadian Council of Ministers of the Environment WQI showed that the river water quality in all the sampled stations (A, 63; B, 63; C, 56; and D, 64) was marginal in classification. **Conclusion:** It was concluded that River Ogun is polluted beyond doubt. Hence, corrective measures should be put in place so as to prevent total ecological collapse.

Keywords: Correlation, diversity, physicochemical, plankton abundance, river Ogun, water quality index

Introduction

Rivers which are among the oldest water bodies in the world[1] are the zone of earth's highest biological diversity and also of most intense human activity.[2] Water from river sources is usually prone to pollution due to human activities around the resource. Major water quality problems stem from sewage pollution, the intensive agricultural use of fertilizers and pesticides, industrial wastes, saltwater intrusion, and soil erosion.[3] The dependency of plankton on water quality can be likened to the dependency of humans on air quality. Therefore, just as how humans will greatly be affected if the atmosphere is polluted with noxious gases, so also all aquatic life if their environment (which is water) is polluted with effluents. The quality of water is, therefore, germane to the survival and well-being of all aquatic life in the ecosystem. According to Lohdip,[4] water quality is a complex subject which involves physical, chemical, hydrological, and biological characteristics of water and their complex delicate relations. The plankton (phytoplankton and zooplankton) are the primary and secondary producers in an aquatic ecosystem and represent the biological parameters mostly measured when assessing water quality. As they (phytoplankton) are dependent on water quality parameters, especially nitrates and phosphates for optimum growth, reproduction, and survival, so also are all consumer aquatic life (zooplankton, aquatic invertebrates, fish larvae, etc.) dependent on them at least at an early stage for their nutrition. Any unfavorable change in physicochemical parameters could affect plankton yield, i.e. primary productivity and in turn bring about attendant problems (such as depletion of dissolved oxygen levels at night or supersaturation of dissolved oxygen in the day, food shortage, competition for available food, stress and death) to all consumer aquatic life.

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This possibility necessitates the continuous monitoring of water quality to protect aquatic life. According to Canadian Council of Ministers of the Environment (CCME),[5] the traditional practice of reporting water quality has been to produce reports describing trends and compliance with official guidelines or other objectives on a variable by variable basis. The advantage of this approach is that it provides a wealth of data and information; however, in many cases, managers and the general public have neither the inclination nor the training to study these reports in detail. One possible solution to this problem is to reduce the multivariate nature of water quality data by employing an index that will mathematically combine all water quality measures and provide a general and readily understood description of water. River Ogun is a free-to-all perennial river used without regulation for many domestic and industrial purposes and as a result is liable to pollution. Several studies have been carried out on the water quality of the river including (Diayi and Gbadebo,[6] who carried out pollution assessment of sediment metals from the middle region of the Ogun River; Ojekunle *et al*.,[7] who assessed the effect of commercial activities on the surface water quality of Ogun River; Onyema *et al*.,[8] who determined the composition, abundance, and temporal variation of phytoplankton and zooplankton at the lower part of Ogun river in Lagos in relation to water quality characteristics; Adeosun *et al*.,[9] who assessed the physical and chemical parameters of lower Ogun River, Akomoje, Ogun State, Nigeria; Alani *et al*.,[10] who carried out preliminary investigation of the state of pollution of Ogun River at Kara Abattoir, near Berger, Lagos; Iji and Adeogun,[11] who evaluated the cytotoxic effect of effluents at inducing chromosomal aberrations in Catfish [*Clarias pachynema*] from Ogun river; Taiwo *et al*.,[12] who assessed the impact of Lafenwa abattoir effluents on Ogun river course in Abeokuta, Nigeria; Olayinka *et al*.,[13] who assessed the physicochemical parameters, heavy metals, and bacteriological parameters of water samples of Ogun River near Lafenwa slaughterhouse in Abeokuta; Oketola *et al*.,[14] who assessed the water quality of River Ogun using multivariate statistical techniques; Oke *et al*.,[15] who mapped river water quality using inverse distance weighted interpolation in Ogun-Osun River Basin, Nigeria; Dimowo,[16] who assessed the physicochemical parameters of River Ogun in comparison with national and international standards; Olopade,[17] who assessed the water quality characteristics for aquaculture uses in Abeokuta North Local Government Area; Dimowo,[18] who reported the monthly spatial occurrence of phytoplankton and zooplankton in River Ogun, Abeokuta; Awoyemi,[19] who assessed the physical and chemical parameters of Ogun river [Opeji river], Opeji Village, Abeokuta, Ogun State, Nigeria; Osunkiyesi,[20] who carried out physicochemical analysis of water samples in Ogun River; Ikotun *et al*.,[21] who investigated the influence of human activities on the water quality of Ogun river in Nigeria; Murtala *et al*.,[22] who studied the bioaccumulation of heavy metals in fish [*Hydrocynus forskahlii*, *Hyperopisus bebe occidentalis,* and *Clarias gariepinus*] organs in downstream Ogun coastal water, Nigeria; Adeogun *et al*.,[23] who assessed the impact of abattoir and sawmill industry effluents on the physicochemical properties of upper Ogun River [Abeokuta], Nigeria; Aramide[24] and Owoade,[25] who carried out water and sediment quality assessment of River Ogun around the cattle market, Isheri along Lagos-Ibadan Express Road, Nigeria; Jaji *et al*.,[26] who assessed the water quality of River Ogun; Babalola,[27] who carried out pollution studies of Ogun River at Isheri along Lagos-Ibadan Express Road, Nigeria; Martins,[28] who studied the geochemical characteristics of a small drainage basin in Ogun river; and Adebisi,[29] who studied the physicochemical hydrology of Upper Ogun River, etc.). However, no study has specifically linked water quality to planktonic existence. This study is, therefore, aimed at: (i) investigating the spatial relationship between the physicochemical parameters, plankton abundance, and diversity of River Ogun and (ii) generating a water quality index (WQI) for appropriate communication of river water quality results in a nontechnical way to the public.

Materials and Methods

Geography of the River

River Ogun [Figure 1] is one of the major rivers in Southwestern Nigeria with a total area of 22.4 km^2 and a fairly large flow of about 393 m^3/s during the wet season.[30] It has coordinates of 3°28”E and 8°41”N from its source in Oyo state to 3°25”E and 6°35”N in Lagos where it enters the Lagos lagoon.[31] A dry season from November to March and a wet season between April and October are the two seasons distinguishable in Ogun river basin. Mean annual rainfall ranges from 900 mm in the north to 2000 mm toward the south. The estimates of total annual potential evapotranspiration have been put between 1600 and 1900 mm.[32] The water is used for agriculture, transportation, human consumption, various industrial activities, and domestic purposes.[30,31] 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,

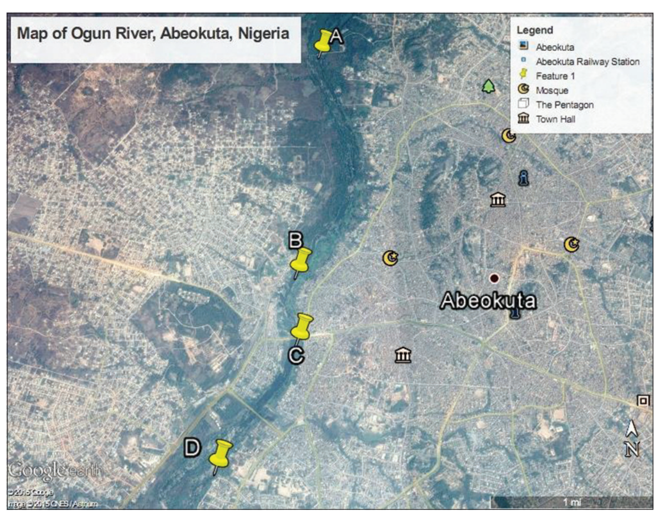

Figure 1: Map of River Ogun showing the Sampling Stations. Source: Google Earth

dyeing industries, tanneries, domestic wastewater,[30,31] and locust bean processors before finally discharging to Lagos lagoon. A 100 km^2 area around River Ogun has an approximate population of 3,637,013 (0.03637 persons/m^2) and an average elevation of 336 m above the sea.[33]

Dataset

Secondary data were acquired from Dimowo.[18] The dataset consists of physicochemical, plankton abundance and diversity data collected from four stations for a period of 7 months (December 2011–June 2012). The plankton species encountered during the study period have been published elsewhere. The methods of sample collection and identification are in Dimowo.[18]

Statistical analysis

For the purpose of this study, inferential statistics such as correlation analysis were employed. MS EXCEL and SPSS version 17.0 statistical packages were used for the analysis. For the calculation of the WQI, the CCME WQI was employed following CCME.[5] It is given by:

CCME WQI

$$100-\left(\sqrt{\frac{F_1^2+F_2^2+F_3^2}{1.732}}\right)$$

where F_1 represents scope and refers to the percentage of variables that do not meet their objectives at least once during the time period under consideration. It is calculated as follows:

$$F_1=\left(\frac{\text{Number of failed variables}}{\text{Total number of variables}}\right)\times 100 \quad (1)$$

F_2 represents frequency and refers to the percentage of individual tests that do not meet objectives. It is calculated as follows:

$$F_2=\left(\frac{\text{Number of failed variables}}{\text{Total number of variables}}\right)\times 100 \quad (2)$$

F_3 represents amplitude and refers to the amount by which failed test values do not meet their objectives. It is calculated in three steps:

a. Calculation of excursion: Excursion is the number of times by which an individual concentration is greater than (or less than, when the objective is a minimum) the objective. This is calculated as follows:
When the test value must not exceed the objective:

$$\text{Excursion}_i=\left(\frac{\text{Failed test value}_i}{\text{Objective}_j}\right)-1 \quad (3a)$$

For the cases in which the test value must not fall below the objective:

$$\text{Excursion}_i=\left(\frac{\text{Objective}_j}{\text{Failed test value}_i}\right)-1 \quad (3b)$$

b. Summation of normative excursions: Normative sum of excursions (nse) is the collective amount by which individual tests are out of compliance. This is calculated as follows:

$$\text{nse}=\frac{\sum_{i=1}^{n}\text{Excursion}_i}{\text{Total number of tests}} \quad (4)$$

c. Calculation of amplitude: It is calculated by an asymptotic function that scales the normalized sum of the excursions from objectives (nse) to yield a range between 0 and 100. This is calculated as follows:

$$F_3=\left(\frac{\text{nse}}{0.01\times\text{nse}+0.01}\right)$$

The divisor 1.732 normalizes the resultant values to a range between 0 and 100, where 0 represents the "worst" water quality and 100 represents the "best" water quality.[5]

For the purpose of this study, physicochemical parameters such as total alkalinity and phosphates were excluded from the calculation due to the fact that they failed to exhibit strong correlation with plankton abundance and diversity.

Results

Mean values of the physicochemical and biological properties of the river are presented in Table 1. The CCME WQI of the various sampling stations is shown in Figure 2.

Spatial correlation between physicochemical parameters, plankton abundance and diversity

The correlation of the physicochemical parameters with plankton abundance and diversity of River Ogun [Tables 2-5] revealed that:

In Station A, conductivity was negatively correlated with water temperature ($r = -0.876$, $P \leq 0.01$) and positively correlated with total dissolved solids (TDS) ($r = 0.996$, $P \leq 0.01$), zooplankton abundance ($r = 0.842$, $P \leq 0.01$), and zooplankton species diversity ($r = 0.829$, $P \leq 0.05$). TDS was negatively correlated with water temperature ($r = -0.862$, $P \leq 0.01$) and positively correlated with zooplankton abundance

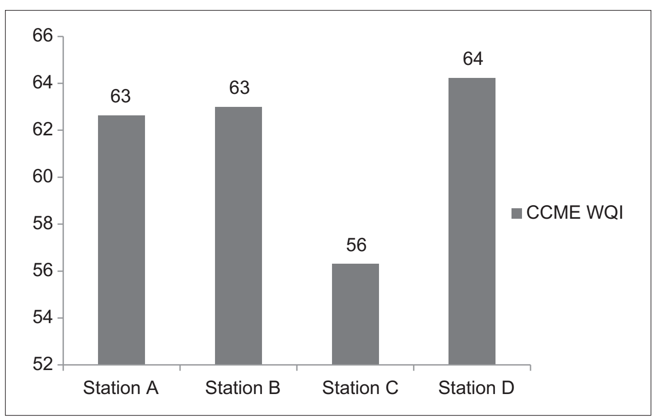

Figure 2: The water quality index of River Ogun at the various sampling stations

Table 1: Mean values of the physicochemical and biological properties of River Ogun, Abeokuta, over the study period (December 2011-June 2012)

Parameters	Station A	Station B	Station C	Station D	Water quality standards for aquatic life
WT (°C)	28.53±0.63^{a}	29.47±0.75^{a}	31.09±1.57^{a}	29.77±0.74^{a}	20-33[1]
DO (mg/L)	6.01±0.83^{a}	3.59±0.74^{a}	4.42±0.94^{a}	5.46±0.90^{a}	≥5.0[2]
COND	105.86±12.00^{a}	159.57±21.40^{a,b}	131.00±10.63^{a,b}	140.01±12.08^{b}	≤500[3,4]
TDS	53.14±5.96^{a}	80.14±10.83^{a,b}	64.71±5.42^{a,b}	69.85±6.11^{b}	≤1000[2]
TRANS (cm)	73.86±10.21^{a}	52.50±9.01^{a,b}	54.50±5.91^{a,b}	47.96±6.45^{b}	30-45[5]
ALK	5.64±2.15^{a}	7.43±1.80^{a}	6.86±1.91^{a}	7.29±1.66^{a}	≥20[2,5]
HARD	68.57±29.37^{a}	66.57±7.22^{a}	51.71±2.24^{a}	74.86±20.10^{a}	≥20[5]
pH	8.65±0.19^{a}	7.88±0.26^{a,b}	8.05±0.23^{a,b}	8.36±0.19^{b}	6.5-8.5[2]
NITR	35.50±18.13^{a}	33.51±13.11^{a}	34.08±15.42^{a}	37.68±16.84^{a}	0.2-10[5]
PHO	0.21±0.06^{a}	0.24±0.09^{a}	0.20±0.08^{a}	0.24±0.11^{a}	0.02-0.20[2]
AIRTEMP	30.71±0.75^{a}	30.57±1.46^{a}	31.14±1.50^{a}	31,29±1.19^{a}	
NZOO	194.29±46.13^{a}	205.71±23.79^{a}	240±62.03^{a}	225.71±35.65^{a}	
NPHYTO	300±99.24^{a}	325.71±47.15^{a}	348.57±50.49^{a}	371.43±64.27^{a}	
SZOO	3.71±0.84^{a}	4±0.31^{a}	4.29±0.64^{a}	4.43±0.65^{a}	
SPHYTO	5.86±1.50^{a}	7.14±1.22^{a}	7.57±0.95^{a}	7.14±1.01^{a}	
CCME WQI	63	63	56	64	

Means (mean±SE) with the same superscript along the row are not statistically significant ($P \leq 0.05$). CCME: Canadian Council of Ministers of the Environment, WQI: Water Quality Index, SE: Standard error, WT: Water temperature, DO: Dissolved oxygen, COND: Conductivity, TDS: Total dissolved solids, TRANS: Transparency, ALK: Alkalinity, HARD: Hardness, pH: Hydrogen ion concentration, NITR: Nitrates, PHO: Phosphates, AIRTEMP: Air temperature, NZOO: Zooplankton abundance, NPHYTO: Phytoplankton abundance, SZOO: Zooplankton species diversity, SPHYTO: Phytoplankton species diversity

Table 2: Pearson correlation coefficient of physicochemical parameters, plankton abundance, and diversity at Station A in River Ogun (December 2011-June 2012)

	WT	DO	COND	TDS	TRANS	ALK	HARD	pH	NITR	PHO	AIRTEMP	NZOO	NPHYTO	SZOO	SPHYTO
WT	1														
DO	0.301	1													
COND	−0.876**	−0.114	1												
TDS	−0.862**	−0.117	0.996**	1											
TRANS	0.555	−0.544	−0.541	−0.517	1										
ALK	0.648	0.385	−0.307	−0.303	0.125	1									
HARD	0.478	0.305	−0.073	−0.081	0.095	0.940**	1								
pH	−0.393	−0.249	0.598	0.576	−0.131	0.028	0.333	1							
NITR	−0.290	0.577	0.240	0.252	−0.823*	−0.003	−0.155	−0.337	1						
PHO	−0.101	0.091	0.061	0.108	−0.252	0.142	−0.088	−0.522	0.704*	1					
AIRTEMP	0.485	−0.177	−0.495	−0.539	0.441	0.502	0.457	−0.176	−0.430	−0.163	1				
NZOO	−0.826*	−0.147	0.842**	0.844**	−0.654	−0.263	−0.123	0.572	0.446	0.257	−0.561	1			
NPHYTO	−0.412	0.624	0.354	0.321	−0.891**	−0.107	−0.137	−0.208	0.799*	0.290	−0.186	0.329	1		
SZOO	−0.740*	−0.367	0.829*	0.836**	−0.313	−0.301	−0.065	0.814*	0.010	−0.080	−0.555	0.881**	−0.063	1	
SPHYTO	−0.426	0.656	0.398	0.372	−0.873**	−0.154	−0.169	−0.207	0.782*	0.266	−0.282	0.314	0.987**	−0.043	1

*Correlation is significant at the 0.05 level (one-tailed), **Correlation is significant at the 0.01 level (one-tailed). WT: Water temperature, DO: Dissolved oxygen, COND: Conductivity, TDS: Total dissolved solids, TRANS: Transparency, ALK: Alkalinity, HARD: Hardness, pH: Hydrogen ion concentration, NITR: Nitrates, PHO: Phosphates, AIRTEMP: Air temperature, NZOO: Zooplankton abundance, NPHYTO: Phytoplankton abundance, SZOO: Zooplankton species diversity, SPHYTO: Phytoplankton species diversity

($r = 0.844$, $P \leq 0.01$) and zooplankton species diversity ($r = 0.836$, $P \leq 0.01$). Hardness was positively correlated with alkalinity ($r = 0.94$, $P \leq 0.01$). Nitrates were negatively correlated with transparency ($r = -0.823$, $P \leq 0.05$) and positively correlated with phosphates ($r = 0.704$, $P \leq 0.05$), phytoplankton abundance ($r = 0.814$, $P \leq 0.05$), and phytoplankton species diversity ($r = 0.782$, $P \leq 0.05$). Zooplankton abundance was negatively correlated with water temperature ($r = -0.826$, $P \leq 0.05$) and positively correlated with zooplankton species diversity. Phytoplankton abundance was negatively correlated to transparency ($r = -0.891$, $P \leq 0.01$) and positively correlated to phytoplankton species diversity ($r = 0.987$, $P \leq 0.01$). Zooplankton species diversity was negatively correlated with water temperature ($r = -0.74$, $P \leq 0.05$) and positively correlated with hydrogen ion concentration ($r = 0.814$, $P \leq 0.05$). Phytoplankton species diversity was negatively correlated with transparency ($r = -0.873$, $P \leq 0.01$).

Table 3: Pearson correlation coefficient of physicochemical parameters, plankton abundance, and diversity at Station B in River Ogun (December 2011-June 2012)

	WT	DO	COND	TDS	TRANS	ALK	HARD	pH	NITR	PHO	AIRTEMP	NZOO	NPHYTO	SZOO	SPHYTO
WT	1														
DO	0.282	1													
COND	−0.725*	−0.123	1												
TDS	−0.733*	−0.089	0.998**	1											
TRANS	0.091	−0.472	−0.259	−0.264	1										
ALK	0.624	0.615	−0.145	−0.148	0.021	1									
HARD	−0.234	0.158	0.726*	0.704*	−0.423	0.283	1								
pH	−0.798*	0.058	0.723*	0.732*	0.051	−0.050	0.381	1							
NITR	−0.186	0.187	0.554	0.540	−0.837**	0.079	0.618	0.147	1						
PHO	0.153	−0.079	−0.018	−0.045	−0.538	0.021	0.028	−0.239	0.715*	1					
AIRTEMP	0.876**	0.200	−0.592	−0.587	−0.040	0.338	−0.240	−0.900**	−0.135	0.063	1				
NZOO	−0.262	−0.466	1.588	0.587	0.446	−0.043	0.252	0.294	−0.062	−0.302	−0.098	1			
NPHYTO	−0.436	−0.275	0.681*	0.664	−0.295	−0.319	0.759*	0.191	0.378	−0.162	−0.194	0.377	1		
SZOO	0.411	−0.230	0.050	0.028	0.599	0.515	0.256	−0.116	−0.289	−0.319	0.317	0.649	0.131	1	
SPHYTO	0.141	−0.050	0.210	0.185	−0.357	0.006	0.672*	−0.306	0.303	−0.062	0.299	0.044	0.807*	0.252	1

*Correlation is significant at the 0.05 level (one-tailed), **Correlation is significant at the 0.01 level (one-tailed). WT: Water temperature, DO: Dissolved oxygen, COND: Conductivity, TDS: Total dissolved solids, TRANS: Transparency, ALK: Alkalinity, HARD: Hardness, pH: Hydrogen ion concentration, NITR: Nitrates, PHO: Phosphates, AIRTEMP: Air temperature, NZOO: Zooplankton abundance, NPHYTO: Phytoplankton abundance, SZOO: Zooplankton species diversity, SPHYTO: Phytoplankton species diversity

Table 4: Pearson correlation coefficient of physicochemical parameters, plankton abundance, and diversity at Station C in River Ogun (December 2011-June 2012)

	WT	DO	COND	TDS	TRANS	ALK	HARD	pH	NITR	PHO	AIRTEMP	NZOO	NPHYTO	SZOO	SPHYTO
WT	1														
DO	0.367	1													
COND	−0.268	0.075	1												
TDS	−0.278	0.091	0.999**	1											
TRANS	0.121	−0.757*	−0.500	−0.511	1										
ALK	0.024	0.327	−0.029	−0.012	−0.217	1									
HARD	0.494	0.773*	0.206	0.218	−0.513	−0.091	1								
pH	−0.417	0.466	0.730*	0.745*	−0.706*	0.023	0.377	1							
NITR	−0.200	0.663	−0.172	−0.155	−0.660	−0.034	0.449	0.396	1						
PHO	−0.153	0.308	−0.403	−0.380	−0.148	−0.087	0.424	0.021	0.723*	1					
AIRTEMP	0.395	−0.128	−0.591	−0.607	0.219	0.250	−0.351	−0.807*	−0.139	−0.149	1				
NZOO	−0.521	0.015	0.907**	0.917**	−0.394	0.004	0.130	0.833**	−0.074	−0.191	−0.817*	1			
NPHYTO	−0.005	0.387	0.803*	0.800*	−0.577	−0.314	0.508	0.812*	0.124	−0.265	−0.680*	0.708*	1		
SZOO	−0.279	0.336	0.841**	0.850**	−0.580	−0.208	0.471	0.932**	0.204	−0.058	−0.868**	0.882**	0.924**	1	
SPHYTO	0.401	0.350	0.319	0.297	−0.477	−0.414	0.349	0.196	0.147	−0.362	0.107	−0.016	0.620	0.306	1

*Correlation is significant at the 0.05 level (one-tailed), **Correlation is significant at the 0.01 level (one-tailed). WT: Water temperature, DO: Dissolved oxygen, COND: Conductivity, TDS: Total dissolved solids, TRANS: Transparency, ALK: Alkalinity, HARD: Hardness, pH: Hydrogen ion concentration, NITR: Nitrates, PHO: Phosphates, AIRTEMP: Air temperature, NZOO: Zooplankton abundance, NPHYTO: Phytoplankton abundance, SZOO: Zooplankton species diversity, SPHYTO: Phytoplankton species diversity

In Station B, conductivity was negatively correlated with water temperature ($r = -0.725$, $P \leq 0.05$) and positively correlated with TDS ($r = 0.998$, $P \leq 0.01$), hardness ($r = 0.726$, $P \leq 0.05$), hydrogen ion concentration ($r = 0.723$, $P \leq 0.05$), and phytoplankton abundance ($r = 0.681$, $P \leq 0.05$). TDS was negatively correlated with water temperature ($r = -0.733$, $P \leq 0.05$) and positively correlated with hardness ($r = 0.704$, $P \leq 0.05$) and hydrogen ion concentration ($r = 0.732$, $P \leq 0.05$). Hydrogen ion concentration was negatively correlated with water temperature ($r = -0.798$, $P \leq 0.05$) and air temperature ($r = -0.9$, $P \leq 0.01$). Nitrates were negatively correlated with transparency ($r = -0.837$, $P \leq 0.01$) and positively correlated with phosphates ($r = 0.715$, $P \leq 0.05$). Air temperature was positively correlated with water temperature ($r = 0.876$, $P \leq 0.01$). Phytoplankton abundance was positively correlated with hardness ($r = 0.754$, $P \leq 0.05$) and phytoplankton species diversity ($r = 0.807$, $P \leq 0.05$). Phytoplankton species diversity was positively correlated with hardness ($r = 0.672$, $P \leq 0.05$).

In Station C, TDS was positively correlated with conductivity ($r = 0.999$, $P \leq 0.01$), hydrogen ion concentration

Table 5: Pearson correlation coefficient of physicochemical parameters, plankton abundance, and diversity at Station D in River Ogun (December 2011-June 2012)

	WT	DO	COND	TDS	TRANS	ALK	HARD	pH	NITR	PHO	AIRTEMP	NZOO	NPHYTO	SZOO	SPHYTO
WT	1														
DO	−0.141	1													
COND	−0.575	−0.043	1												
TDS	−0.580	−0.047	1.000**	1											
TRANS	0.319	−0.778*	0.310	0.315	1										
ALK	0.569	0.265	−0.095	−0.086	0.263	1									
HARD	−0.069	−0.032	−0.389	−0.393	−0.141	−0.357	1								
pH	−0.698*	−0.003	0.969**	0.972**	0.250	−0.112	−0.242	1							
NITR	−0.584	0.770*	−0.051	−0.049	−0.833*	−0.175	0.347	0.112	1						
PHO	−0.172	0.160	−0.334	−0.340	−0.289	−0.306	0.954**	−0.171	0.529	1					
AIRTEMP	0.710*	−0.297	−0.534	−0.550	0.084	−0.116	−0.024	−0.708*	−0.558	−0.129	1				
NZOO	−0.606	0.403	0.583	0.597	−0.075	0.253	−0.085	0.723*	0.517	0.019	−0.972**	1			
NPHYTO	−0.777*	0.460	0.538	0.539	−0.415	−0.126	−0.237	0.622	0.630	0.015	−0.661	0.619	1		
SZOO	−0.347	0.098	0.324	0.339	0.227	0.379	0.214	0.507	0.321	0.318	−0.828*	0.785*	0.425	1	
SPHYTO	−0.408	0.794*	0.252	0.259	−0.512	0.394	−0.252	0.352	0.720*	−0.014	−0.699*	0.750*	0.773*	0.529	1

*Correlation is significant at the 0.05 level (one-tailed), **Correlation is significant at the 0.01 level (one-tailed). WT: Water temperature, DO: Dissolved oxygen, COND: Conductivity, TDS: Total dissolved solids, TRANS: Transparency, ALK: Alkalinity, HARD: Hardness, pH: Hydrogen ion concentration, NITR: Nitrates, PHO: Phosphates, AIRTEMP: Air temperature, NZOO: Zooplankton abundance, NPHYTO: Phytoplankton abundance, SZOO: Zooplankton species diversity, SPHYTO: Phytoplankton species diversity

(r = 0.745, $P \leq 0.05$), zooplankton abundance (r = 0.917, $P \leq 0.01$), phytoplankton abundance (r = 0.8, $P \leq 0.05$), and zooplankton species diversity (r = 0.85, $P \leq 0.01$). Transparency was negatively correlated with dissolved oxygen (r = −0.757, $P \leq 0.05$) and hydrogen ion concentration (r = −0.706, $P \leq 0.05$). Hardness was positively correlated with dissolved oxygen (r = 0.773, $P \leq 0.05$). Hydrogen ion concentration was positively correlated with conductivity (r = 0.73, $P \leq 0.05$), zooplankton abundance (r = 0.833, $P \leq 0.01$), phytoplankton abundance (r = 0.812, $P \leq 0.05$), and zooplankton species diversity (r = 0.932, $P \leq 0.01$) and negatively correlated with air temperature (r = −0.807, $P \leq 0.05$). Phosphates were positively correlated with nitrates (r = 0.723, $P \leq 0.05$). Zooplankton abundance was positively correlated with conductivity (r = 0.907, $P \leq 0.01$), phytoplankton abundance (r = 0.708, $P \leq 0.05$), and zooplankton species diversity (r = 0.882, $P \leq 0.01$) and negatively correlated with air temperature (r = −0.817, $P \leq 0.05$). Phytoplankton abundance was positively correlated with conductivity (r = 0.803, $P \leq 0.05$) and zooplankton species diversity (r = 0.924, $P \leq 0.01$) and negatively correlated with air temperature (r = −0.68, $P \leq 0.05$). Zooplankton species diversity was positively correlated with conductivity (r = 0.841, $P \leq 0.01$) and negatively correlated with air temperature (r = −0.868, $P \leq 0.01$).

In Station D, TDS was positively correlated with conductivity (r = 1, $P \leq 0.01$) and hydrogen ion concentration (r = 0.972, $P \leq 0.01$). Transparency was negatively correlated with dissolved oxygen (r = −0.778, $P \leq 0.05$) and nitrates (r = −0.833, $P \leq 0.05$). Hydrogen ion concentration was negatively correlated with water temperature (r = −0.698, $P \leq 0.05$) and air temperature (r = −0.708, $P \leq 0.05$) and positively correlated with conductivity (r = 0.969, $P \leq 0.01$) and zooplankton abundance (r = 0.723, $P \leq 0.05$). Nitrates were positively correlated with dissolved oxygen (r = 0.77, $P \leq 0.05$) and phytoplankton species diversity (r = 0.72, $P \leq 0.05$). Phosphates were positively correlated with hardness (r = 0.954, $P \leq 0.05$). Air temperature was positively correlated with water temperature (r = 0.71, $P \leq 0.05$) and negatively correlated with zooplankton abundance (r = −0.972, $P \leq 0.01$), zooplankton species diversity (r = −0.828, $P \leq 0.05$), and phytoplankton species diversity (r = −0.699, $P \leq 0.05$). Phytoplankton abundance was negatively correlated with water temperature (r = −0.777, $P \leq 0.05$) and positively correlated with phytoplankton species diversity (r = 0.773, $P \leq 0.05$). Zooplankton species diversity was positively correlated with zooplankton abundance (r = 0.785, $P \leq 0.05$). Phytoplankton species diversity was positively correlated with dissolved oxygen (r = 0.794, $P \leq 0.05$) and zooplankton abundance (r = 0.75, $P \leq 0.05$).

Water quality of River Ogun in relation to Plankton

The WQI [Figure 2] for the various stations ranged from 56 in Station C and 64 in Station D. Following the water quality ranking of CCME [Table 6],[5] all the stations of River Ogun were marginal in classification.

Discussion

Shinde *et al*.[34] inferred from their research that positive correlation means that one parameter increases as other parameters also increase while a negative correlation means that as one parameter increases, the other parameters decrease. In this study, transparency was negatively correlated with dissolved oxygen at Stations C and D. This shows that as the transparency values got higher, the dissolved oxygen

Table 6: Canadian Council of Ministers of the Environment Water Quality Ranking

Rank	CCME WQI value	Remark
Excellent	95-100	Water quality is protected with a virtual absence of threat or impairment; conditions very close to natural or pristine levels
Good	80-94	Water quality is protected with only a minor degree of threat or impairment; conditions rarely depart from natural or desirable levels
Fair	65-79	Water quality is usually protected but occasionally threatened or impaired; conditions sometimes depart from natural or desirable levels
Marginal	45-64	Water quality is frequently threatened or impaired; conditions often depart from natural or desirable levels
Poor	0-44	Water quality is almost always threatened or impaired; conditions usually depart from natural or desirable levels

concentration of the water got lower. Nitrates were negatively correlated with transparency at Stations A, B, and D. This shows that higher concentration of nitrates was associated with lower transparency values. This result was also reported by Shinde *et al*.[34] Nitrates were also positively correlated with phosphates at Stations A, B, and C. This could be attributed to runoff from fertilizer and pesticide laden farms along the river. This result was also reported by Shinde *et al*.[34] Water temperature was negatively correlated with conductivity and TDS in Stations A and B. This shows that as the temperature of water got higher, the conductivity and TDS values got lower. This result was also reported by Shinde *et al*.[34] Water temperature was also positively correlated with air temperature and negatively correlated with hydrogen ion concentration (pH) at Stations B and D. This shows that water temperature increased as air temperature increased while water temperature increased as pH decreased. This result of positive correlation between air temperature and water temperature was also reported by Kareem *et al*.[35] pH was positively correlated with conductivity and TDS in Stations B, C, and D. This shows that as the pH got higher, the conductivity and TDS values also got higher. This statement is further reinforced by Waterose Environmental,[36] who suggested that the higher the pH measurement, then the higher the conductivity measurement which concurs with the principle that increased concentrations of ions would increase conductivity. Phytoplankton abundance was positively correlated with conductivity at Stations B and C. This result was also observed by Abowei *et al*.[37] Phytoplankton abundance was also positively correlated with phytoplankton species diversity at Stations A, B, and D. This shows that as the species diversity of phytoplankton got higher, the abundance also got higher. Phytoplankton species diversity was positively correlated with nitrates. This shows that as nitrates concentration increased, the diversity of phytoplankton species also increased. Zooplankton abundance was positively correlated with conductivity and TDS at Stations A and C, positively correlated with hydrogen ion concentration (pH), and negatively correlated with air temperature at Stations C and D. The result of positive correlation between zooplankton abundance and conductivity was also reported by Abowei *et al*.,[37] in Sombreiro River. Zooplankton abundance was also positively correlated with zooplankton species diversity at Stations A, C, and D. This shows that as the species diversity of zooplankton got higher, the abundance also got higher. Zooplankton species diversity was positively correlated with conductivity, TDS, and pH at Stations A and C and negatively correlated with air temperature at Stations C and D. More so, TDS was positively correlated with conductivity at all the sampling stations. This shows that conductivity and TDS are much related and complement each other. This statement can be further reinforced by Kareem *et al*.,[35] who observed the same result.

Conclusion

This study showed that River Ogun is polluted beyond doubt. Hence, corrective measures should be put in place so as to prevent total ecological collapse. It is, therefore, recommended that public enlightenment programs and campaigns should be organized to educate the populace on the ills of dumping untreated wastes and effluents into the waterbody so as to change their personal behaviors and attitudes.

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Conflicts of interest

There are no conflicts of interest.

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