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ASSESSMENT OF WATER QUALITY OF OGUN RIVER IN SOUTHWESTERN NIGERIA

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ABSTRACT

The present study assessed the water quality of Ogun river in southwestern Nigeria. Forty water samples were collected from twenty monitoring stations along Ogun River Basin between April 2013 and January 2014. Water samples were analyzed for important physical and chemical parameters such as temperature, pH, turbidity, total suspended solids (TSS), total dissolved solids (TDS), total solids (TS), electrical conductivity EC, dissolved oxygen (DO), silica, anions (F^-, Cl^-, PO_4^{3-}, NO_3^-), hardness, alkalinity and metals (Fe, Pb, Cd, Na, K) using the standard procedures. Data collected were subjected to simple descriptive (mean and standard deviation) and inferential statistics (Duncan Multiple Range Test, DMRT and Principal Component Analysis, PCA) using the Statistical Package for Social Sciences (SPSS, Windows' version 16.0). Results showed higher mean concentrations of turbidity (49.7±13.0 NTU) and total suspended solids (1205.2±4.7 mg/L) than the permissible limits of the World Health Organization (WHO) in drinking water. The values of phosphate (1.14±1.3 mg/L), Cd (0.02±0.01 mg/L) and Pb (0.33±0.05 mg/L) were also observed at higher concentrations than the permissible standards of the WHO. The sources of pollution to Ogun River Basin identified by varimax rotated PCA were industrial effluents, runoff, fertilizer and dissolved salts.

Keyword: assessment, water quality, pollution, multivariate analysis, parameters

INTRODUCTION

Rivers and streams constitute the main inland water resources for domestic, industrial and irrigation purposes. It is therefore necessary to prevent any activities that can pollute them. The periodic monitoring and assessment of water quality are important steps in achieving an effective management and pollution control of surface water. The variances in water quality may be due to natural and anthropogenic activities. Natural sources of water pollution may emanate from bedrock weathering and erosion of materials into water bodies by rain or wind. Urban runoff was identified as one of the natural causes of water pollution (Izonfuo and Bariweni, 2001; Taiwo *et al*., 2011). The study of Taiwo *et al*. (2012) highlighted several anthropogenic activities that had negatively impacted surface water quality. These activities include industrial effluent discharge, oil spills, municipal and agricultural wastes. Recent studies had attributed activities such as food (locust beans) processing, textile making and dyeing, mining, poultry and abattoir wastes as major sources of water pollution (Taiwo *et al*., 2013; Ayantobo *et al*., 2014; Ojekunle *et al*., 2014; Taiwo and Awomeso, 2017). Awomeso *et al*. (2010) reported deterioration of Lagos Lagoon water quality due to dumping of raw sewage.

The water quality of rivers in Nigeria are characterized by high concentrations of total suspended solids (Osibanjo *et al*., 2011), turbidity (Adefemi *et al.,* 2007) and biological oxygen demand, (BOD) (Wakama *et al.,* 2008), nutrients, e.g. phosphate, ammonia and nitrate (Olajire and Imeokparia, 2001), metals (Jaji *et al.,* 2007), microbial contaminants (Taiwo, 2010) and organic chemicals e.g. pesticides (Ogunfowokan *et al*., 2006). The problems of high TSS in surface water include effects on fish growth and survival, nutrient enrichment, reduced sunlight penetration (required for photosynthesis of aquatic plants) and transportation of toxic substances (Schueler, 1997; Taiwo *et al*., 2011). The presence of heavy metals in surface water may pose potential risks to the environment and ecological system. Toxic metals such as Pb, Cd, As, Hg and Cr may bio-accumulate in food chain and therefore initiate severe health problems including cancer, renal dysfunction, kidney and skeletal damage, neurological disorder, encephalopathy, anaemia and disturbance of cardiovascular (Jarup, 2003; Sireli *et al.,* 2006; Olatunde *et al.,* 2014). Nutrient enrichment of water body known as eutrophication may initiate severe problems to surface water in the aspect of destruction of spawning ground for aquatic lives, reduction of dissolved oxygen (DO) and impairment of water quality (Izonfuo and Bariweni, 2001). High BOD concentration in water body is an indicator of high organic loads with consequent effects on dissolved oxygen (Penn et al., 2006). Reduction in surface water DO usually influences water biology and abundance of aquatic organisms (Water Research Center, 2014). Turbid water may increase water temperature (thermal stratification), reduce photosynthetic ability of phytoplankton, decrease fish eggs' survival rate and interference of fish to find food (Alaska Department of Environmental Conservation, 2013). The problems of microbial contaminants are prevalent water-borne and water-related diseases (Awomeso *et al.*, 2010). The main objective of this study is to assess the water quality of Ogun River Basin in southwestern Nigeria.

MATERIALS AND METHODS

The study Area

Ogun River Basin (Ogun, Ofiki, Opeki and Oyan) covers a total area of 23,700 km^2 and is located between latitude 6º 33' and 9ºN and longitude 2º40' and 3º 45' E in the Rain Forest zone of Nigeria. The climate of the study area is characterized by two seasons viz: wet (March –October) and dry (November to March) seasons. The annual rainfall ranges between 1250 and 1400 mm (Eruola *et al.,* 2012), while the annual average temperature is 30 ºC. Ogun River Basin is an important water source for domestic, commercial, industrial and agricultural purposes (Ojekunle *et al.,* 2011). The major socio-economic activities in the study areas are farming, fishing, sand dredging and cloth dyeing. There are few industries located around Ogun river axis of Lagos State (Okeyode, 2012). Figure 1 shows the map of Ogun River Basin and the sampling locations.

Water Collection and Analysis

Forty water samples were collected from twenty monitoring stations along Ogun River Basin in Ogun, Ofiki, Opeki and Oyan between April 2013 and January 2014, covering rainy and dry seasons. Water samples were collected in prewashed 1 and 2 L plastic bottles. Samples for determination of metals were acidified at the point of collection with 2 mL nitric acid. Parameters determined were physical {temperature, colour, turbidity, total suspended solids (TSS) and total solids (TS)} and chemical {pH, total dissolved solids (TDS), electrical conductivity (EC), dissolved oxygen (DO), anions (F^-, Cl^-, PO_4^{3-}, NO_3^-), hardness, alkalinity, metals (Pb, Cd, Zn, Na and K) parameters using the standard procedures (APHA, 1999).

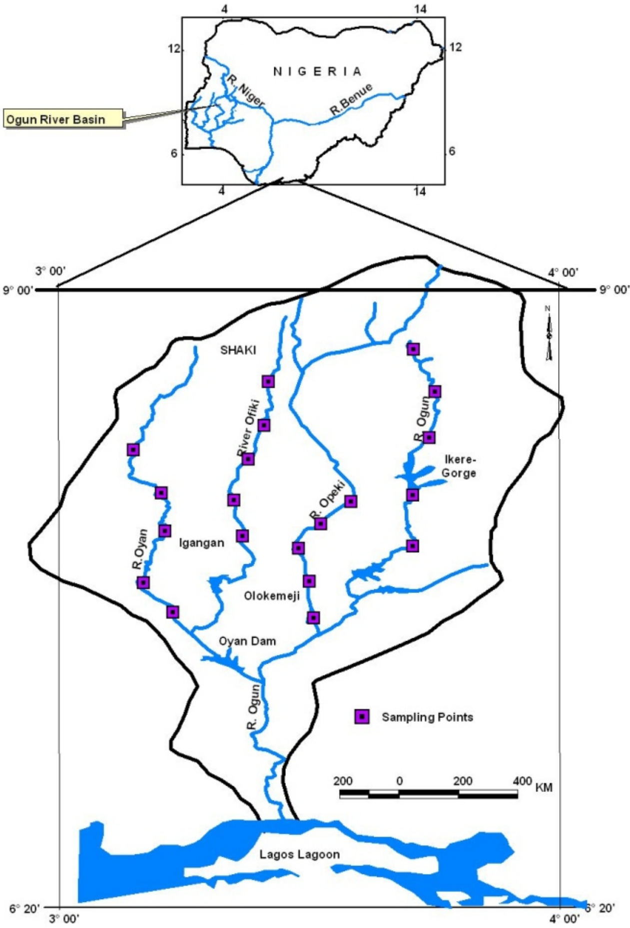

Figure 1: Map of Ogun River Basin showing the sampling points

Water temperature, pH, TDS, EC and DO were determined in-situ. The collected water samples were transported to the Department of Environmental Management and Toxicology Laboratory for analysis of important water parameters using the standard methods (APHA, 1999). Water temperature, pH, TDS and EC were determined electronically using the combined temperature/pH/TDS/EC meter (Combo Hi 98130, Hanna USA). Dissolved oxygen was measured using the DO meter (HachsensION, UK). TSS was determined gravimetrically, while TS was obtained by summing up the values of TDS and TSS. Colour and turbidity were determined using a UV-visible Spectrophotometer (Hach DR/4000, UK).

Chloride was determined by Mohr's silver nitrate method (Korkmaz, 2005). Dissolved silica (SiO_2) was analyzed using the Heteropoly Blue method described in APHA (1999). Nitrate (NO_3^-) was measured using the sodium salicylate method (Ademoroti, 1996; Taiwo, 2010). Sulphate (SO_4^{2-}) and fluoride were determined spectrophotometrically (Ademoroti, 1996). Metals (Fe, Pb, Cd) were determined by Atomic Absorption Spectrophotometry (Buck Scientific 200, USA) and Flame Photometry (Model 970, Jenway, EU) for Na and K. Prior to measurement of metals, water samples were digested with concentrated HNO_3 using the method described by Ayantobo *et al.* (2014).

All reagents used were of Analytical Grade (Sigma-Aldrich Chemie, GmbH, Germany). Blank samples were also analyzed to cancel the background effects of the extracting chemicals (Taiwo *et al.*, 2014). The calibration of AAS instrument follows preparation of series of standards in the concentration range of 0–100 mg L^{-1}, to obtain the calibration curves.

Statistical Analysis

Data collected were subjected to simple descriptive (mean and standard deviation) and inferential (Duncan Multiple Range Test, DMRT, t-test and Principal Component Analysis, PCA) statistics using the Statistical Package for Social Science (SPSS) Windows version 16.0. PCA is a multivariate statistical tool that explains the statistical variance of chemical species measured at the receptor site in a number of original variances by a minimum number of significant components (Taiwo, 2013).

RESULTS AND DISCUSSION

The seasonal variations of Ogun River Basin water quality physical parameters at different Ogun River Basin are presented in Table S1 (in the supplementary information). The water temperature at the two seasons was generally lower than 29°C. During the wet season, Oyan river showed higher concentrations of turbidity (166.3±2.4 NTU), TSS (1205.2±4.7 mg/L) and TS (1217.1±5.0 mg/L). The values of turbidity and TSS were higher than the permissible levels in unpolluted water (Taiwo *et al.*, 2013). Except in Ogun river, where the turbidity value (5.77±5.83 NTU) was slightly higher than the WHO standard of 5.0 NTU (WHO, 2011; Taiwo *et al.*, 2013). Other rivers showed lower turbidity values during the dry season. The dry season values of TSS at the sampling sites were also higher than the normal TSS value often found in natural surface water indicating pollution of the Basin at all the sampling sites.

Table S2 (in the supplementary information) presents the site-based seasonal variations of chemical parameters of Ogun River Basin. The pH of water samples at all the sampling sites was neutral showing values ranging from 7.01±0.01 (wet season) to 7.12±0.21 (dry season). The DO concentrations were higher during the dry season than the wet season. At the two seasons, the mean DO values were generally greater than the minimum value of 5.0 mg/L that will support aquatic lives in natural water (Water Research Center, 2014). During the two seasons, the mean concentrations of EC (<80 µS/cm), TDS (<60 mg/L), total hardness (<75 mg/L), chloride (<40 mg/L), nitrate (<2.0 mg/L), sulphate (<20.0 mg/L) and silica (<5.0 mg/L) were within the permissible limits in natural water (Taiwo, 2010). At wet season, the highest fluoride value of 2.07±1.74 mg/L was observed in Ofiki river; while at dry season, the highest fluoride concentration (1.68±0.08 mg/L) was measured in Ogun river. The measured phosphate values from the monitored rivers were generally high at both wet and dry seasons. The data of metal concentrations of the River Basin is presented in Table S3 (in the supplementary information). At wet season, Oyan river had the highest concentrations of Na (13.47±0.29 mg/L), Fe (0.54±0.44 mg/L), Cd (0.03±0.01 mg/l) and Pb (0.31±0.06 mg/L). The dry season data showed the highest values of K, Fe and Pb for the same river. Fe, Pb and Cd concentrations at each monitoring site were generally higher than the World Health Organization permissible standards in drinking water (WHO, 2011).

The summary of Ogun River Basin water quality data is presented in Figures 2-5. The mean value of turbidity (49.69±13.0 NTU) was higher than the WHO limit of 5.0 NTU (WHO, 2011). The mean concentrations of pH, EC, DO, total hardness, calcium hardness, magnesium hardness, nitrate and silica were within the normal values often found in surface water. However, the mean phosphate concentration observed in Ogun River Basin was extremely high. The combined average value of phosphate (1.14±1.28 mg/L) was about 40 times higher than the normal phosphate concentration in unpolluted surface water. The average concentration of fluoride in the River Basin was 1.45±0.92 mg/L. The pooled mean value of Cd and Pb were found to be 19 and 7 times higher than the maximum permissible limits of 0.001 and 0.05 mg/L, respectively (WHO, 2011). The mean concentration of Fe was within the WHO standard of 0.03 mg/L (WHO, 2011). Na and K values in the River Basin were generally less than 15 mg/L.

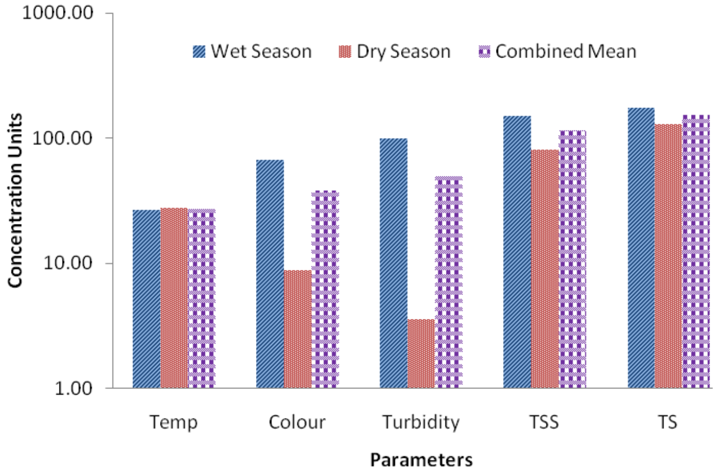

Figure 2: The average seasonal concentrations of physical water quality parameters of Ogun River Basin.Temp-temperature (°C), colour (TCU), turbidity (NTU), TSS-total suspended solids (mg/L), TS-total solids (mg/L).

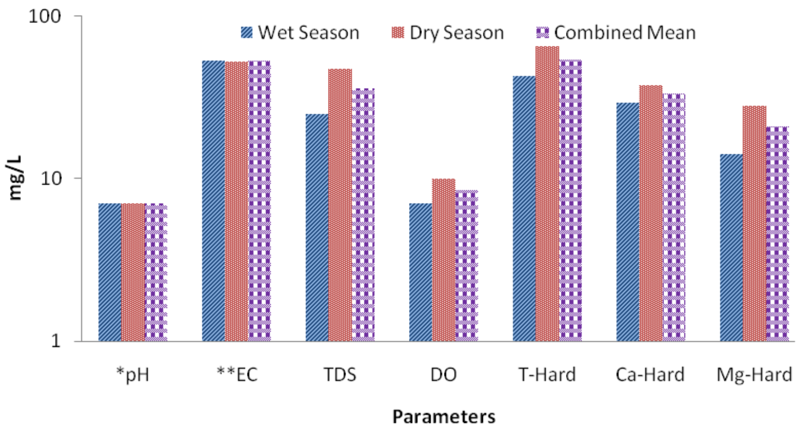

Figure 3: The average seasonal concentrations of important chemical water quality parameters of Ogun River Basin.*pH has no unit, **EC-electrical conductivity (μS/cm), TDS- total dissolved solids, T-Hard-total hardness, Ca-Hard-calcium hardness, Mg-Hard-magnesium hardness.

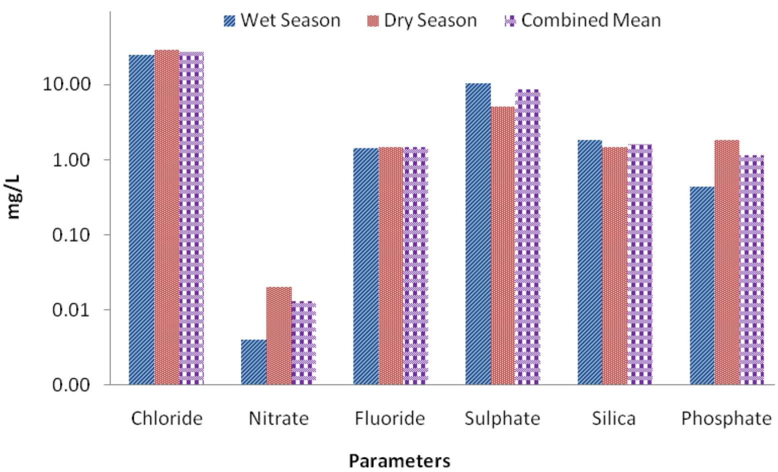

Figure 4: The mean seasonal variations of water anions of Ogun River Basin

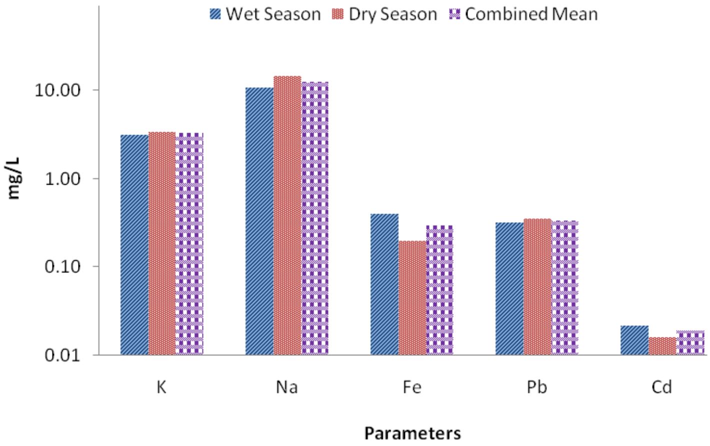

Figure 5: The mean seasonal concentrations of metals of Ogun River Basin

The principal component analysis data of Ogun River Basin is presented in Table 1. Four factors were identified by the model explaining 80% of the total variance. Factor 1 has high loading for pH, TDS, calcium, magnesium, total hardness, K, Na and Pb. This factor may suggest an industrial source. Even though, the concentrations of most of the parameters explained by Factor 1 were found to be within the permissible limits; but the high value of Pb indicates anthropogenic emission. Emission sources of Pb in the environment are mainly from industries such as iron and steel, paints, batteries, petrochemicals, electroplating and smelting (Taiwo, 2013). Industrial effluents had been observed as an important source of pollution to surface water in Nigeria (Taiwo, 2012).

Factor 2 is characterized by significance for colour, turbidity, TS, TSS and dissolved silica. This factor may be linked to runoff of materials from point and non-point sources. During the rainfall, different materials including soil, leaves, solid and liquid wastes, pesticides and chemicals are washed into the surface water bodies (Izonfuo and Bariweni, 2001; Taiwo *et al.*, 2011). Anthropogenic sources of water pollution from runoff had been reported in many studies (Jaji *et al.*, 2007; Mustapha, 2008; Taiwo, 2010; Kelly *et al.*, 2012, Taiwo, 2012).

Factor 3 is loaded for colour, sulphate, fluoride and Fe. This factor may be best described as fertilizer source. The fertilizer factor identified in component 3 might suggest the use of iron sulphate ($FeSO_4$) fertilizer (http://passel.unl.edu/pages/informationmodule.php?idinformationmodule=1130447045&topicorder=7&maxto=7). Wastes from poultry farm activities and the use animal manures for soil amendment might also be responsible for high Fe and SO_4^{2-} concentrations in water (Fairchild et al., 2006). Factor 4 has high loadings for EC and chloride indicating a dissolved salt or a saline source. Dissolved salts in water bodies could be due to deposition of sea spray, urbanization and agriculture (Podmore, 2009). Cole and Ryan (2003) suggested that high EC in water might be attributed to sewage contamination.

Table 1: PCA of Ogun River Basin

Rotated Component Matrix[a]

	Component				
	1	2	3	4	Communalities
Temperature	.280	-.555	.252	-.167	.478
pH	.940	-.256	-.067	.018	.953
DO	.048	-.951	-.079	-.026	.914
EC	.067	.384	.103	.776	.765
Colour	-.269	.681	.617	.179	.949
Turbidity	-.133	.960	.189	-.016	.976
TS	.168	.901	.274	.191	.952
TDS	.733	-.549	.040	.322	.945
TSS	.044	.939	.253	.130	.965
Total Hardness	.962	.005	.099	.032	.936
Ca Hardness	.758	.078	.025	-.139	.601
Mg Hardness	.806	-.068	.131	.352	.795
Chloride	.088	-.039	.040	.592	.361
Nitrate	-.706	-.524	-.051	.093	.784
Fluoride	-.050	-.009	.824	.216	.728
Sulphate	-.093	.227	.856	.092	.802
Silica	-.051	.686	.007	-.602	.836
K	.966	-.111	.011	.161	.971
Phosphate	.448	-.855	-.071	.210	.981
Na	.859	-.400	-.071	.143	.924
Fe	.175	.207	.724	-.195	.636
Pb	.688	-.249	-.123	-.284	.632
Cd	-.593	-.172	.296	-.238	.526
% Variance	31	28	12	9	(80%)
Sources	Industry	Run-off	Fertilizer	Dissolved Salt	

DO- Dissolved Oxygen, EC-Electrical Conductivity, TS-Total Solids, TDS-Total Dissolved Solids, TSS-Total Suspended Solids

It was generally observed that during the wet season, there were higher significant ($p<0.05$) concentrations of colour, turbidity, TSS, TS, Fe and Na. This might be attributed to runoff of pollutants from diverse point and non-point sources (Taiwo, 2012; Li *et al.,* 2015; Mezgebe *et al.,* 2015). Water quality parameters including temperature, DO, TDS, total hardness, Ca hardness, Mg hardness, PO_4^{3-} were significantly higher ($p<0.05$) during the dry season. Apart from temperature, other water parameters were expected to show higher concentrations during the wet season (Athuman, 2012). But these parameters were measured at higher values during the dry season. This may therefore suggest anthropogenic influence from industry, agriculture, abattoir activities, textile dyeing, washing and bush burning (Dike et al., 2010; Ubwa *et al.,* 2013; Ojekunle *et al.,* 2014). In the South-east Asia, biomass burning had been found to be the greatest contributor to atmospheric fluxes of nutrients with subsequent effects on water quality (Balasubra-manian and Qian, 2004; Sundarambal *et al.,* 2010). There were no significant ($p>0.05$) seasonal variations in the concentrations of pH, EC, Cl^-, NO_3^-, SO_4^{2-}, SiO_2, K, Pb and Cd in water samples.

The high mean values of TSS indicated that the River Basin is polluted. The past studies from Ogun river had reported similar high values of colour, turbidity and TSS (Jaji *et al*., 2007; Etim and Adie, 2012). A study had shown that turbidity values above 1,000 NTU (for months) in water bodies can cause fish death (Denby *et al.,* 1987). TSS value above 80 mg/L is also dangerous to aquatic organisms (Taiwo, 2013). Colour, turbidity and TSS could impact water quality in many ways among which are: (1) reduction of water clarity, which is very dangerous to divers. (2) reduction in aesthetic quality of water bodies with impacts on recreation and tourism. (3) contribution to outbreak of water-borne diseases by shielding the microbes associated with organic portion (Wilson, 2010).

Phosphate values obtained in this study was higher than the value that is normally found in natural surface water. In uncontaminated lake, phosphate value is measured usually between the range of 0.01 and 0.03 mg/L (Water Research Center, 2014). Phosphate value above 0.10 mg/L could accelerate plant's growth or algae bloom with subsequent ecological and environmental problems (Water Research Center, 2014). Phosphate value greater than 100 μg/L may interfere with coagulation process (Fadiran *et al.*, 2008). The high concentration of phosphate obtained in this River Basin may have negative impacts on water treatment processes and thereby affects water supply.

At the lower course, Ogun River Basin was abstracted for public water supply in Abeokuta. The Waterworks is a source of potable water to at least one hundred and eighty thousand residents (Ufoegbune et al., 2010). The mean value of phosphate concentration observed in this study was higher than the value of 0.17±0.01 mg/L measured in New Calabar river (Abu and Egenonu, 2008). However, studies from northern parts of Nigeria had measured higher phosphate values ranging from 3.8 to 16 mg/L (Dike *et al.*, 2010; Ubwa *et al.*, 2013). Comparing this study with the previous study of Ogun river by Jaji *et al.* (2007) showed that the value of phosphate had increased by a factor of 25. This shows that human activities leading to phosphate pollution around the River Basin had also increased. The major activities that could increase phosphate concentration in surface water are industrial effluent discharge wastes and disposal of municipal, agricultural and abattoir wastes (Taiwo *et al.*, 2011). The high values of phosphate concentrations observed in Jakara river (Kano) and Gboko Stream (Benue) had been attributed to abattoir wastes discharge into the surface water bodies (Dike *et al.*, 2010; Ubwa *et al.*, 2013).

The average fluoride value of Ogun River Basin was higher than the range value of 0.90-1.2 mg/L that could result into mild fluorosis, a condition characterized by staining and pitting of the teeth (WHO, 2004; 2015). The presence of Cd and Pb at concentrations higher than the permissible standards may pose health risk on humans and animals. The concentrations of Cd and Pb in water and/or food are of major health concerns due to the fact that these metals have no known physiological functions in human body (Hou *et al.*, 2013). The health effects of Cd and Pb had been described explicitly by Jarup (2003).

CONCLUSION

This study had examined the water quality of Ogun River Basin. The study revealed high concentrations of colour, turbidity, total suspended solids, phosphates, Cd and Pb. These parameters had values greater than the permissible limits allowed by the World Health Organization (WHO). The pooled mean concentration of Fe was found to be within the value of 0.30 mg/L permitted by the WHO. The study also revealed higher significant concentrations of parameters such as turbidity, TSS, TS, Fe and Na during the wet season, while temperature, DO, TDS, hardness (total, Ca and Mg), PO_4^{3-} were higher during the dry season. There were no seasonal variations in concentrations of pH, EC, Cl^-, NO_3^-, SO_4^{2-}, SiO_2, K, Pb and Cd. The principal component analysis revealed four major sources of pollutants, which include industry, runoff, fertilizer and dissolved salts. The study had shown that Ogun River Basin water quality had been deteriorated as a result of human activities.

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COMPETING INTERESTS

The authors declare no competing interests.

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Table S1: Seasonal variations of Ogun River Basin water quality physical parameters

Parameters		Descriptive Statistics							
		Wet season				Dry season			
		Ogun	Ofiki	Opeki	Oyan	Ogun	Ofiki	Opeki	Oyan
Temperature (°C)	Mean	26.78[a]	26.58[a]	26.08[a]	26.08[a]	26.90[a]	27.67[a]	27.53[a]	27.56[a]
	SD	0.19	0.40	0.65	0.48	1.23	0.19	0.09	0.09
	Range	26.05-27.00	26.00-27.10	25.60-27.20	25.70-26.90	24.90-27.80	27.38-27.80	27.38-27.58	27.40-27.60
	WHO	Ambient	Ambient	Ambient	Ambient	Ambient	Ambient	Ambient	Ambient
Turbidity (NTU)	Mean	41.43[b]	40.98[b]	29.73[b]	166.28[c]	5.77[a]	3.50[a]	1.46[a]	3.64[a]
	SD	0.40	0.87	0.23	2.40	5.83	4.75	0.43	4.69
	Range	41.10-42.10	40.10-42.30	29.50-30.10	56.90-596.0	1.16-12.20	1.10-11.96	1.12-1.99	1.14-12.00
	WHO	5	5	5	5	5	5	5	5
TSS (mg/L)	Mean	151.22[b]	179.25[c]	133.24[b]	1205.2[d]	79.58[a]	78.32[a]	79.28[a]	84.64[a]
	SD	0.98	0.46	0.81	4.70	17.36	31.32	16.95	18.19
	Range	150.30-152.8	178.70-179.8	132.40-134.3	1200-12101	70.30-110.5	34.20-108.7	68.90-109.3	69.90-108.6
	WHO	20-80	20-80	20-80	20-80	20-80	20-80	20-80	20-80
TS (mg/L)	Mean	174.75[c]	214.03[d]	163.1[bc]	1217.1[e]	122.04[a]	137.8[b]	122.32[a]	129.94[ab]
	SD	1.48	1.43	1.18	5.02	35.60	41.61	34.15	33.84
	Range	173.0-177.0	212.4-216.2	162.3-165.2	1212-1223	100.2-184.8	99.0-182.9	98.0-182.5	100.0-182.7
	WHO	2000	2000	2000	2000.00	2000	2000	2000	2000

TSS-Total Dissolved Solids; TS-Total Solids; Means of the same alphabets along the rows are not significantly different ($p>0.05$).

Table S2: Seasonal variations of Ogun River Basinwater quality chemical parameters

Parameters	Statistics	Sampling locations							
		Wet season				Dry season			
		Ogun	Ofiki	Opeki	Oyan	Ogun	Ofiki	Opeki	Oyan
pH	Mean	7.01^{a}	7.07^{a}	7.08^{a}	7.08^{a}	7.06^{a}	7.08^{a}	7.02^{a}	7.12^{a}
	SD	0.01	0.04	0.04	0.02	0.19	0.18	0.19	0.21
	Range	7.00-7.04	7.02-7.11	7.03-7.13	7.05-7.09	6.93-7.37	6.91-7.36	6.89-7.34	6.91-7.35
	WHO	6.5-8.5	6.5-8.5	6.5-8.5	6.5-8.5	6.5-8.5	6.5-8.5	6.5-8.5	6.5-8.5
DO (mg/L)	Mean	6.97^{a}	7.41^{a}	7.07^{a}	7.02^{a}	10.18^{b}	10.10^{b}	10.01^{b}	10.12^{b}
	SD	0.01	0.05	0.53	0.51	0.26	0.36	0.20	0.23
	Range	6.98-6.99	7.32-7.45	6.16-7.42	6.20-7.46	9.73-10.40	9.70-10.50	9.71-10.25	9.72-10.30
	WHO	5	5	5	5	5	5	5	5
EC(µS/cm)	Mean	50.33^{c}	73.07^{f}	63.48^{b}	26.80^{a}	38.89^{b}	57.25^{d}	64.63^{e}	50.49^{c}
	SD	0.22	2.92	0.36	1.76	5.77	4.99	3.77	0.25
	Range	50.0-50.60	68.43-76.20	63.00-64.0	25.00-29.50	32.53-46.40	53.40-64.05	60.20-70.60	50.20-50.80
	WHO	1000	1000	1000	1000	1000	1000	1000	1000
TDS (mg/L)	Mean	23.53^{a}	34.78^{bc}	29.9^{bc}	11.92^{a}	42.46^{cd}	59.26^{d}	43.04^{cd}	45.30^{cd}
	SD	0.54	1.32	0.69	0.42	18.86	21.27	17.72	17.37
	Range	22.70-24.20	32.80-36.40	28.95-30.90	11.56-12.60	29.30-74.30	29.00-74.60	29.10-73.20	29.20-74.10
	WHO	500	500	500	500	500	500	500	500
T-Hard.(mg/L)	Mean	48.00^{ab}	56.00^{ab}	46.25^{ab}	22.75^{a}	60.40^{b}	73.80^{b}	61.80^{b}	65.00^{b}
	SD	3.54	0.71	0.83	3.11	29.01	31.92	26.36	25.89
	Range	45.0-54.0	55.0-57.0	45.0-47.0	20.0-28.0	36.0-107.0	33.0-108.0	34.0-105.0	35.0-106.0
	WHO	150	150	150	150	150	150	150	150
Ca (mg/L)	Mean	36.75^{b}	38.00^{b}	26.75^{ab}	16.25^{a}	35.20^{b}	40.20^{b}	38.20^{b}	36.40^{b}
	SD	0.15	0.71	3.11	2.28	15.51	17.34	22.02	14.22
	Range	35.0-39.0	37.0-39.0	24.0-32.0	14.0-20.0	24.0-60.0	21.0-59.0	22.0-67.0	23.0-58.0
	WHO								
Mg (mg/L)	Mean	12.25^{ab}	22.25^{bc}	22.00^{bc}	0.75^{a}	23.20^{bc}	32.80^{c}	28.20^{c}	28.40^{c}
	SD	1.48	4.71	0.71	0.15	11.69	15.74	12.95	13.01
	Range	10.00-14.00	18.00-30.00	21.00-23.00	0.60-1.00	10.00-38.00	10.00-49.00	11.00-47.00	12.00-48.00
	WHO	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Cl^{-} (mg/L)	Mean	21.75^{a}	25.08^{a}	28.50^{a}	24.25^{a}	27.80^{a}	33.80^{a}	25.00^{a}	28.20^{a}
	SD	1.09	12.62	4.92	0.83	15.01	10.13	9.08	7.95
	Range	20.00-23.00	3.30-34.00	25.00-37.00	23.00-25.00	14.00-50.00	24.00-49.00	16.00-38.00	18.00-40.00
	WHO	250	250	250	250	250	250	250	250
F^{-} (mg/L)	Mean	1.42^{a}	2.07^{b}	1.38^{b}	0.84^{a}	1.68^{b}	1.46^{b}	1.30^{ab}	1.42^{b}
	SD	0.08	1.74	0.01	0.10	0.08	0.17	0.10	0.08
	Range	1.30-1.50	0.42-5.00	1.37-1.39	0.70-0.95	1.60-1.80	1.30-1.70	1.20-1.40	1.30-1.50
	WHO	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Nitrate (mg/L)	Mean	0.90^{a}	0.6^{a}	1.088^{a}	0.22^{a}	1.05^{a}	0.89^{a}	0.94^{a}	0.94^{a}
	SD	0.05	0.05	0.39	0.01	0.32	0.30	0.26	0.27
	Range	0.86-0.99	0.42-0.54	0.42-1.32	0.21-0.23	0.64-1.38	0.61-1.35	0.60-1.84	0.62-1.36
	WHO	50	50	50	50	50	50	50	50
Phosphate (mg/L)	Mean	0.21^{a}	0.48^{ab}	0.57^{ab}	0.48^{ab}	1.95^{b}	1.94^{b}	1.72^{ab}	1.76^{ab}
	SD	0.01	0.04	0.01	0.01	2.27	1.75	0.89	1.32
	Range	0.20-0.23	0.44-0.54	0.56-0.58	0.46-0.50	0.71-6.00	0.67-5.00	0.68-3.00	0.69-4.00
	WHO	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Sulphate (mg/L)	Mean	11.13^{a}	14.25^{a}	15.00^{a}	1.01^{a}	7.00^{a}	5.00^{a}	3.50^{a}	4.00^{a}
	SD	0.74	17.77	19.07	0.07	2.65	0.00	3.54	2.65
	Range	10.00-12.00	3.00-45.00	3.00-48.00	0.90-1,10	4.00-9.00	5.00-5.00	1.00-6.00	2.00-7.00
	WHO	250	250	250	250	250	250	250	250
Silica(mg/L)	Mean	3.25^{c}	1.44^{b}	1.71^{b}	0.76^{a}	1.42^{b}	1.38^{ab}	1.56^{b}	1.38^{ab}
	SD	0.11	0.01	0.02	0.38	0.66	0.63	0.64	0.57
	Range	3.10-3.40	1.43-1.45	1.69-1.74	0.10-1.00	1.08-2.60	1.05-2.50	1.04-2.30	1.06-2.40
	WHO								

DO-Dissolved Oxygen; EC, Electrical Conductivity; TDS, Total Dissolved Solids; T-Hard, Total Hardness; Means of the same alphabets along the rows are not significantly different ($p>0.05$).

Table S3: Seasonal variations of metal concentrations of Ogun River Basin

Parameters	Statistics	Sampling locations							
		Wet season				Dry season			
		Ogun	Ofiki	Opeki	Oyan	Ogun	Ofiki	Opeki	Oyan
K(mg/L)	Mean	3.25^{b}	4.46^{b}	4.60^{b}	0.11^{a}	2.96^{b}	3.04^{b}	3.36^{b}	4.18^{b}
	SD	0.12	0.12	0.16	0.01	2.69	2.56	2.32	2.77
	Range	3.10-3.41	4.30-4.62	4.40-4.81	0.09-0.13	1.10-7.30	1.10-7.20	1.00-6.99	1.20-7.10
	WHO								
Na(mg/L)	Mean	8.44^{a}	9.82^{ab}	11.43^{ab}	13.47^{ab}	13.25^{ab}	16.28^{b}	13.36^{ab}	14.43^{ab}
	SD	0.31	0.19	0.25	0.29	6.87	7.76	6.65	6.34
	Range	7.92-8.71	9.57-10.01	10.99-11.61	12.97-13.67	8.03-24.28	8.03-24.28	8.03-24.28	8.03-24.28
	WHO	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00
Pb(mg/L)	Mean	0.33^{a}	0.32^{a}	0.32^{a}	0.31^{a}	0.34^{a}	0.33^{a}	0.34^{a}	0.35^{a}
	SD	0.05	0.06	0.05	0.06	0.04	0.05	0.04	0.05
	Range	0.25-0.38	0.25-0.39	0.24-0.36	0.22-0.40	0.29-0.40	0.29-0.40	0.29-0.40	0.29-0.40
	WHO	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Cd(mg/L)	Mean	0.02^{a}	0.02^{a}	0.02^{a}	0.03^{b}	0.02^{a}	0.01^{a}	0.01^{a}	0.01^{a}
	SD	0.01	0.01	0.13	0.01	0.02	0.01	0.01	0.01
	Range	0.00-0.04	0.00-0.03	0.00-0.03	0.03-0.05	0.00-0.07	0.00-0.03	0.00-0.03	0.00-0.03
	WHO	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Fe(mg/L)	Mean	0.35^{a}	0.35^{a}	0.35^{a}	0.54^{ab}	0.28^{b}	0.19^{ab}	0.13^{a}	0.60^{c}
	SD	0.11	0.11	0.11	0.44	0.15	0.14	0.08	0.01
	Range	0.20-0.50	0.20-0.50	0.20-0.50	0.10-0.99	0.08-0.50	0.04-0.40	0.06-0.26	0.00-0.06
	WHO	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30

Means of the same alphabets along the rows are not significantly different ($p>0.05$).