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HEAVY METAL GEOCHEMISTRY OF OGUTA LAKE, SOUTH-EASTERN, NIGERIA

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Abstract

The prevalence of natural events like erosion and flooding; and other anthropogenic activities such as oil spills, urbanization, industrial operations and sand mining activities within the Oguta Lake could constitute heavy metals pollution in the lake. In order to evaluate the heavy metal geochemistry of the Oguta Lake, seventy-two (72) samples of water and sediment were collected and analyzed over the periods of dry and rainy seasons. Concentrations of As, Cd, Cr, Fe, Ni, Hg, Pb and Zn were determined using Atomic Absorption Spectrometry AAS. The mean concentrations of water samples (mg/l) were 0.006±0.002, 0.001±0.001, 0.023±0.003, 0.213±0.025, 0.004±0.002, 0.008±0.002, 0.010±0.003, and 1.971, ±0.043 respectively for the rainy season. Result of water analysis during the dry season were 0.007±0.001, 0.002±0.001,0.029±0.010, 0.218±0.031, 0.007±0.001, 0.010±0.002, 0.012±0.002, and 1.981±0.036, respectively. The mean concentration of heavy metal in bottom sediment (mg/kg dry weight) for the rainy season were 1.953±0.143, 0.096±0.007, 20.28±0.804, 3426.4±374.5, 2.693±0.609, 0.141±0.008, 26.33±0.977 and 41.36±1.405, respectively. While the results obtained during the dry season were 1.978±0.120, 0.097±0.008, 20.36±0.881, 3484.8±326.02, 2.793±0.589, 0.146±0.004, 26.61±0.872 and 41.89±1.414, respectively. Apart from Pb, the values of the other heavy metals were in conformity with the WHO and USEPA regulations. Seasonal and spatial variations were observed in the concentration levels of heavy metals. Heavy metal pollution index of 40.71% and 39.08% for the dry and rainy season, respectively, suggest that the Oguta Lake water can be classified as Good. Except for lead Pb, the other analyzed heavy metals showed no sign of enrichment in sediment. The Pearson correlation of multivariate analysis of variance (MANOVA) was used to analyze the inter-relationship between heavy metals in water and bottom sediment for the dry and rainy seasons. Traceability analysis of PCA shows that the origins of heavy metals of component 1, which includes As, Cd and Pb are from a mixture of natural (materials of parent rock) and anthropogenic sources.

Keywords: Atomic Absorption Spectrometry, Pollution Index, Enrichment Factor, Heavy Metals.

INTRODUCTION

Backgrond Problem

Within the vast array of natural water resources available to humans, Lakes are the most paramount freshwater resources. Unfortunately, heavy metals pollution has rapidly become a problem due to their toxic potentials and persistence in many places around the globe. Heavy metals, as common pollutants in the water environment, are toxic, persistent and bio-accumulative (Pekey et al. 2004).

Once contamination occurs beyond its original source, even trace concentrations may pose a risk to aquatic organisms, accumulate in the food web, and subsequently pose serious threat to human health (Salem et al. 2014; Zhang et al. 2016). Heavy metals adversely affect human health and drastically alter the bio-geochemical cycles within freshwater environment (Roquia Rizk et al; 2022). Heavy metals in water diffuse into organisms directly through ingestion. They can also accumulate in organs and cells of aquatic organisms thus spreading into the biosphere through the food web; these could potentially cause health and ecological risks susceptibilities.

Due to their relatively high density, heavy metals, constitute toxicity issues even in minutest quantities (Lenntech, 2004). Heavy metallic elements are inherent, natural constituents of the environment (Aderinola et al., 2009). Also, the existence of bioavailable metals in sediments can influence the condition and location of benthic communities (Kress et al., 2004).

Oguta Lake is the largest freshwater lake within the south-eastern part of Nigeria. It is the main source of water supply, and provides most of the protein needs of the over 50,000 population of the Oguta public within the catchment area (Herschy, R.W. 2012). The lake is rich with bio-diversities and contains 258 species of phytoplankton in 107 genera (Omin, 1983).Apart from serving as the main domestic water supply source to the local communities, it is also used for recreation, fishing, sporting, transportation of both humans, crude and timber; agriculture and sand mining activities. Regrettably, it also serves as a major recipient of both point and non-point sources of pollutants from many natural sources like floods, weathering and riverbed erosion; and anthropogenic activities such as urbanization, intensive/unregulated agricultural practices, fishing practices, effluent discharges and wastes generated by the local manufacturing industries which can adversely modify its physical and bio-chemical parameters.

Significance of This Study

Evaluation of water quality is not only for the suitableness of human consumption only, the relevance also relates to its ability to sustain aquatic life, and its usefulness in the agricultural, industrial, recreational and commercial sectors. Monitoring of water quality is a cardinal tool for the management of freshwater resources. Therefore, the development of appropriate and up-to-date information for assessing the Oguta lake geochemical characteristics, monitoring of heavy metals contamination, pollution prevention and mitigation strategy are necessary as a primary approach in maintaining both the usefulness and resource status of the Oguta Lake. This can be achieved through detailed physical and bio-geochemical assessment of the different Lake environment (lateral variations of the upstream, midstream and downstream; and the vertical variations of surface water areas, mid-water areas and the bottom sediments). An inclusive assessment of the environmental geochemistry and ecotoxicology of perilous heavy metals and metalloids in the Oguta Lake is

paramount towards overcoming the impact of heavy metals on human health and the lake environment at large.

REVIEW OF LITERATURE

Table 1

A comparison of the mean values of investigated heavy metals concentration of the Oguta lake surface water (mg/l) with those of earlier studies.

Heavy Metals (mg/l)	(2014) Umunnakwe & Aharanwa	(2024) Ohaturuonye & Okeke	(2021) Shittu, N. & Ofoegbu	(2016) Chizzy, P. N	(2021) Peace E, Odoemelam S A, Verla Andrew Wirnkor	(2015) Nwoke, C.I.A. et al.	This Study
As	ND	0.002	0.010	-	0.519	ND	0.006
Cd	0.003	ND	0.410	-	0.0175	0.004	0.001
Cr	0.041	0.024	-	-	ND	0.008	0.052
Fe	0.270	-	-	0.179	1.601	0.805	0.434
Ni	0.084	-	0.590	-	0.287	0.003	0.005
Hg	0.001	0.002	ND	-		ND	0.009
Pb	0.001	0.010	0.190	-	0.125	0.230	0.022
Zn	-	-	-	-	0.761	-	1.976

Description of the Study Area

- *Drainage Shape*

The basin shape is mainly influenced by geological structure which gives it a geometrical form of the stream network. The Basin circularity (Re) is the ratio of the basin area (Au) having the same perimeter as the basin. The form factor values vary from 0 (in a highly elongated shape) to 1 (in a perfect circular shape).

- *Land use in the study area*

Human land-use activities may affect all aspects of the channel and drainage basin characteristics that control the rate of water movement and thus flood conditions. The classes of land use adopted in this study are namely: barren land, farmland, forest land, water body, etc. 37.32% of Oguta drainage basin consists of grass land and farmland, 27.51% of forest, 5.28% water and 20.06% bare land.

- *Physical Dimensions*

The surface area varies from 180-300 hectares which is dependent on season. It is largest during rainy season. It has a maximum depth of 8.0m, and an average depth of 5.5m. The water level is Unregulated. The actual range of annual water level fluctuation is 9.3m, while the length of shoreline is 10km (Nfor and Akaegbobi, 2012).

- *G3 Population within the catchment*

Urban: 30,000, Rural: 20,000, total population density: 50,000 (Herschy, R.W. 2012).

Location of Study Area

The Oguta Lake is located at coordinates Longitude $05^{0}42'474"$N, and Latitude$006^{0}47'33"$E, covering approximately 8.05kmof water area and it is the largest fresh-water lake in the South-eastern part of Nigeria.

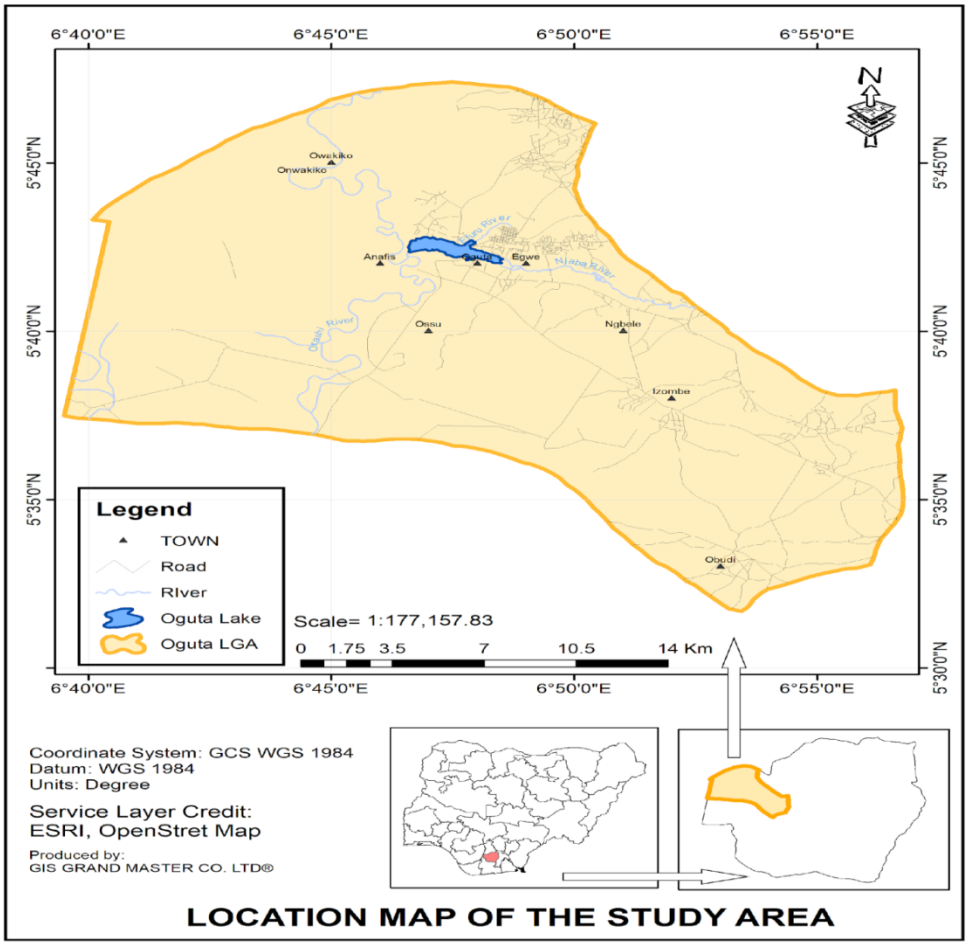

Fig. 1.Location map of the study area.

Geologic Setting

The local geologic setting of the Oguta Lake indicates that it falls under the Benin Formation (Onyeagocha, 1980). It stretches from the west over the Niger Delta and southward past the present coastline. It comprises of some shale intercalations in some areas and consists of over 90 percent of sandstone. Hence, it can be described as partially estuarine, marine, deltaic, fluviolacusterine and lagoonal in origin (Reyment, 1976).

The Benin Formation consists of friable sands with intercalations of shale-clay lenses and it is Pliocene to Miocene in age. The formation also contains some isolated units of gravels, conglomerates, very coarse sands and sandstones (Ananaba et al., 1993). The formation thins out at the contact with the Ogwashi - Asaba and thickens in Owerri area. The average thickness of the Benin Formation around Owerri and environs is 800m (Avbovbo, 1978).

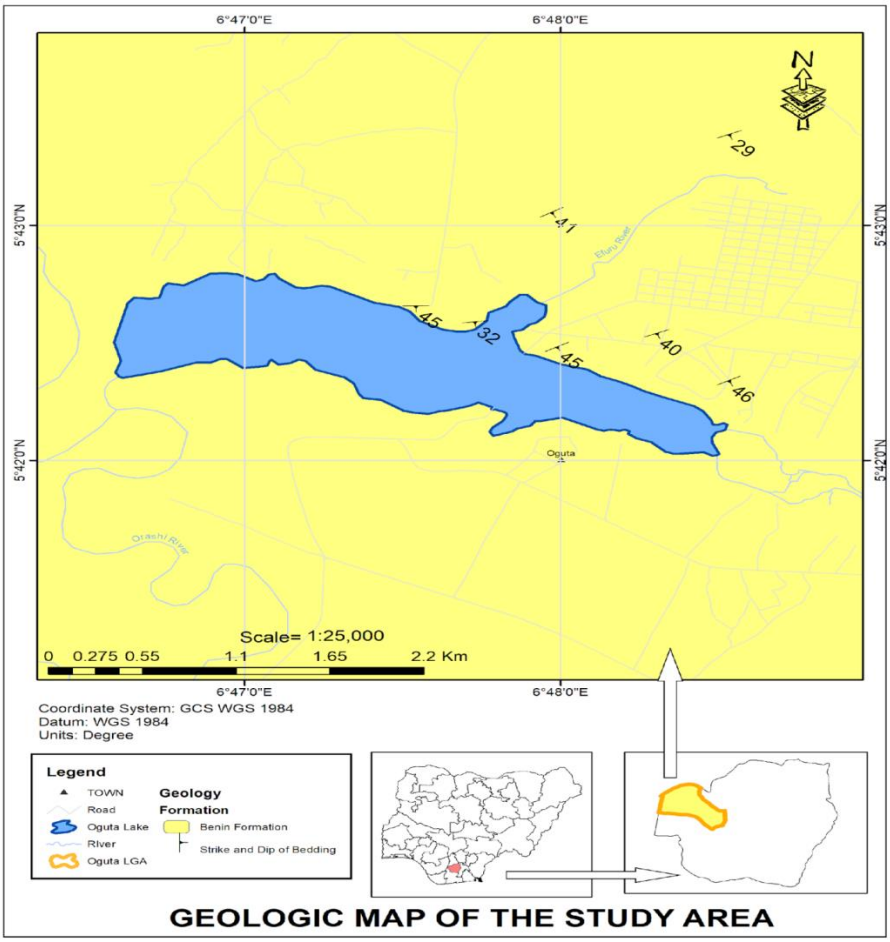

Fig. 2. Geologic map of the study area.

Hydrology

The Oguta Lake is fed by two rivers: River Njaba and Awbana. Third River, Utu River flows into the lake only during the rains. A fourth associated river, is Orashi River, which flows past the lake at its southwestern end. Orashi River is a major river of the lower Niger Basin. Apart from the rivers that feed the lake, there is also input from precipitation during the rainy season. The volume of water that flows into the lake as well as the precipitation during the rains are main sources of recharge of the Oguta

Lake. Although, the water level of the lake is unregulated, it is relatively higher during the rains than during the dry season.

MATERIALS AND METHOD

Sample Procedure

Seventy-two (72) samples of surface water and bottom sediment were collected from the Oguta Lake for the purpose of this study. The sampling was carried out simultaneously both laterally and vertically. The upstream, midstream and downstream, together with their downward vertical columns, which includes the Limnetic zone (the surface water areas of the lake), profundal zone (the middle column of the lake) and also, the benthic zone (the bottom part of the lake) where the bottom sediments were sampled. The profundal zone was sampled at 13ft epi-distance from the limnetic zone and the benthic zone. Sampling was carried out at an average of 2.6km equidistance from the upstream, midstream and downstream parts of the lake. Four samples apiece at the limnetic, profundal and benthic zones were collected. Majority of the surface water samples were collected in the riparian parts of the lake, where the processes of suspended sedimentation and concentration of heavy metals take place. Forty-eight (48) water samples were collected at the limnetic and profundal zones; and a total of 24 bottom sediment were collected. Sampling of the Oguta Lake was carried out within the periods of July, 2024 (about the peak of Rainy season) and December, 2023 (during the dry season).

Sampling Equipment

In generally, two types of samplers are commonly used for collecting bottom sediments: (1) grab samplers for collecting surface sediments, thereby providing material for the determination of horizontal distribution of variables; and (2) core samplers for collecting a depth profile of sediments, thereby providing material for determination of vertical distribution of variables N. (Cavanagh, 2015). For the purpose of this study, Core sampler was employed due to its ability to penetrate the sediment more deeply than grab samplers. Consequently, they provide a cross-sectional slice of sediment layers and thus, information about the sediment deposition.

Pre-treatment and Digestion

Samples collected from each of the sampling points were thoroughly mixed to ensure homogeneity and filtered through a standard sieve of 1mm mesh size. This sieve fraction was selected because it has been reported that dust particles in this size contains high levels of heavy metal (Ward et al., 2004).

The water and sediment core samples were transferred into sterilized pre-labelled containers and subsequently, transported to Analytical Laboratory for further processing and analysis. The entire equipment and materials utilized for sieving,

holding and homogenization of samples were pre-treated to reduce the likelihood of cross contamination. The reported EPA digestion method 3050B for inductively Coupled Pasma-Optical Emission (ICP-OES) analysis was adopted in the digestion of samples.

A known amount (1.00g) of each sample was turned-over into a digestion vessel and 10mL of 1:1 nitric acid (HNO_3) was added, vigorously mixed and placed over with a watch glass.

The samples were eventually heated to a temperature of 90^{o}C and refluxed at this temperature for 10 minutes before letting them to cool for at least 5minutes under room temperature. Subsequently, 5ml of concentrated HNO_3 was added to each of them, covered and refluxed again at 90^{o}C for about 30 minutes. After, the solution was allowed to go through evaporation without actually boiling to approximately 5ml each and cooled again for 5 minutes. Then addition of 2mL of deionised water plus 3mL of 30% hydrogen peroxide (H_2O_2) followed. At this point, the vessels were again covered and heated just enough to warm the solutions for the peroxide reaction to start (EPA, 1996). This process continued until effervescence subsided and the solutions were cooled. The acid-peroxide digestates were covered with watch glasses and heated until the volume reduced to approximately 5mL again. Thereafter, 10mL of concentrated hydrochloric acid (HCl) was added to each, covered and heated on a heating mantle, then refluxed at 90^{o}C for 15 minutes. After cooling, each digestate was filtered through Whatman No.41 filter paper into a 100 mL volumetric flask and the volume made to the mark with deionised water (FEPA, 1996).

Acid-washed (dilute hydrochloric acid) water containers (2 liters), rinsed thoroughly with distilled water were used in the collection of water samples. Each sample was carefully corked under the water in order to avoid contact with the atmospheric air.

The samples were preserved in a dark cooler of ice at a temperature of 4°C and later sent to the laboratory for analysis.

Analysis of sample

The atomic absorption instrument was set up, and fame condition and absorbance were optimized. Then blanks (deionized water), standards, sample blank and samples were aspirated into the fame in AAS (model iCE 3300). The calibration curves were obtained for concentration versus absorbance. Data were statistically analysed using fitting of straight line by least square method. A blank reading was also taken, and necessary corrections were made during the calculation of concentration of various elements.The pH of the water samples was determined using a digital pH meter (model KN0214) at the field.

RESULTS

The assessment and interpretation of the heavy metal contamination status obtained from Atomic Absorption Spectrophotometry AAS analysis of the samples were carried out using appropriate descriptive and inferential statistical techniques. Enrichment factor (EF), Heavy Metal pollution Index HPI, Pearson Correlation Matrix and Multi-variate Principal Component factor Analysis (PCA) were all successfully applied. The results obtained from the AAS analysis of the water samples are presented in Tables 2 and 3 for the two nominal seasons. Heavy Metal Concentration in sediment samples (mg/kg of dry weight) during the dry season and rainy seasons are presented in tables 4 and 5. The following parameters were calculated for all analyzed heavy metals, both for surface water and bottom sediment samples: minimum, maximum, arithmetic mean, and standard deviation. Eight heavy metals (As, Cd, Cr, Fe, Ni, Hg, Pb and Zn) were detected and their concentrations determined.

Table 2

Result of Heavy Metal Concentrations in Water Sample (mg/l) for the Dry Season (December, 2023). pH @ 6.00. Lim: Limnetic Zone, Pro: Profundal Zone.

S. Points (mg/l)	As	Cd	Cr	Fe	Ni	Hg	Pb	Zn
1 Lim. Upstream	0.004	BDL	0.010	0.160	0.003	0.004	0.005	1.899
2	0.005	BDL	0.017	0.170	0.002	0.007	0.007	1.903
3	0.005	BDL	0.019	0.179	0.004	0.007	0.008	1.907
4	0.006	BDL	0.020	0.191	0.004	0.008	0.010	1.982
1 Pro.	0.006	0.001	0.022	0.201	0.005	0.006	0.011	2.013
2	0.007	0.001	0.023	0.203	0.007	0.007	0.012	1.910
3	0.008	0.001	0.026	0.209	0.007	0.009	0.012	1.981
4	0.010	0.001	0.024	0.199	0.008	0.009	0.014	2.012
1 Lim. Midstream	0.005	BDL	0.019	0.208	0.003	0.008	0.006	1.971
2	0.005	BDL	0.016	0.210	0.003	0.008	0.007	1.990
3	0.005	BDL	0.023	0.213	0.004	0.007	0.008	1.990
4	0.006	BDL	0.020	0.217	0.004	0.008	0.011	2.011
1 Pro.	0.006	0.001	0.025	0.198	0.006	0.010	0.012	1.981
2	0.007	0.001	0.024	0.210	0.006	0.010	0.013	2.014
3	0.008	0.001	0.021	0.212	0.007	0.008	0.015	1.903
4	0.009	0.001	0.023	0.219	0.007	0.011	0.015	1.952
1 Lim. Downstream	0.003	BDL	0.021	0.224	0.003	0.009	0.005	2.013
2	0.003	BDL	0.023,	0.223	0.003	0.009	0.016	2.015
3	0.004	BDL	0.024	0.227	0.003	0.007	0.008	1.979
4	0.005	BDL	0.025	0.231	0.004	0.009	0.008	1.982
1 Pro.	0.005	0.001	0.022	0.229	0.006	0.010	0.010	1.896
2	0.006	0.001	0.023	0.264	0.007	0.011	0.011	1.970
3	0.007	0.001	0.026	0.258	0.007	0.010	0.011	2.020
4	0.007	0.001	0.030	0.261	0.007	0.012	0.013	2.019
Maximum	0.010	0.001	0.030	0.264	0.008	0.010	0.015	2.020
Minimum	0.003	0.001	0.010	0.160	0.002	0.003	0.005	1.896
Mean	0.006	0.001	0.023	0.213	0.004	0.008	0.010	1.971
SD	0.002	0.001	0.003	0.025	0.002	0.002	0.003	0.043
WHO	0.05	0.05	0.05	0.30	0.01	0.01	0.01	5.0
USEPA	0.01	0.05	0.05	0.30	NIL	0.02	0.01	5.0
NESREA	0.01	0.03	0.05	0.30	0.02	0.01	0.01	3.0

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Table 3

Result of Heavy Metal Concentration in Water Samples (mg/l) for the Rainy Season (July, 2024). pH @ 6.01.BDL: Below Detectable Limit

S. POINTS (MG/L)	AS	CD	CR	FE	NI	HG	PB	ZN
1 LIM. (UPSTREAM.)	0.006	0.001	0.012	0.164	0.006	0.006	0.010	1.998
2	0.006	0.001	0.010	0.169	0.006	0.007	0.009	1.910
3	0.007	0.001	0.019	0.175	0.007	0.009	0.011	1.910
4	0.007	0.002	0.026	0.179	0.009	0.009	0.013	1.980
1 PRO.	0.009	0.003	0.034	0.184	0.008	0.010	0.015	1.973
2	0.008	0.003	0.038	0.211	0.009	0.010	0.017	1.980
3	0.008	0.002	0.037	0.219	0.010	0.011	0.018	1.984
4	0.010	0.004	0.035	0.190	0.009	0.010	0.017	1.986
1 LIM. (MIDSTREAM)	0.008	0.001	0.020	0.205	0.010	0.012	0.010	1.998
2	0.006	0.001	0.035	0.199	0.009	0.008	0.010	1.910
3	0.007	0.001	0.030	0.198	0.006	0.007	0.011	1.910
4	0.008	0.001	0.029	0.219	0.005	0.013	0.012	1.980
1 PRO.	0.009	0.001	0.041	0.223	0.006	0.011	0.013	1.989
2	0.008	0.001	0.021	0.226	0.008	0.009	0.011	1.983
3	0.007	0.001	0.039	0.224	0.007	0.010	0.015	1.985
4	0.010	0.002	0.038	0.239	0.007	0.009	0.014	1.988
1 LIM. (DOWNSTREAM)	0.006	0.001	0.027	0.240	0.004	0.008	0.010	1.981
2	0.007	0.001	0.019	0.252	0.005	0.012	0.011	2.018
3	0.009	0.001	0.021	0.261	0.006	0.009	0.011	2.020
4	0.008	0.002	0.021	0.253	0.007	0.009	0.012	2.026
1 PRO.	0.008	0.003	0.029	0.265	0.007	0.010	0.012	1.981
2	0.009	0.003	0.035	0.241	0.008	0.008	0.013	2.018
3	0.009	0.002	0.040	0.259	0.008	0.008	0.013	2.020
4	0.010	0.004	0.048	0.257	0.009	0.012	0.014	2.026
MAXIMUM	0.010	0.004	0.048	0.265	0.010	0.013	0.018	2.026
MINIMUM	0.006	0.001	0.010	0.164	0.004	0.006	0.009	1.910
MEAN	0.007	0.002	0.029	0.218	0.007	0.010	0.012	1.981
SD	0.001	0.001	0.010	0.031	0.001	0.002	0.002	0.036
WHO	0.05	0.05	0.05	0.30	0.01	0.01	0.01	5.0
USEPA	0.01	0.05	0.05	0.30	NIL	0.02	0.01	5.0
NESREA	0.01	0.03	0.05	0.30	0.02	0.01	0.01	3.0

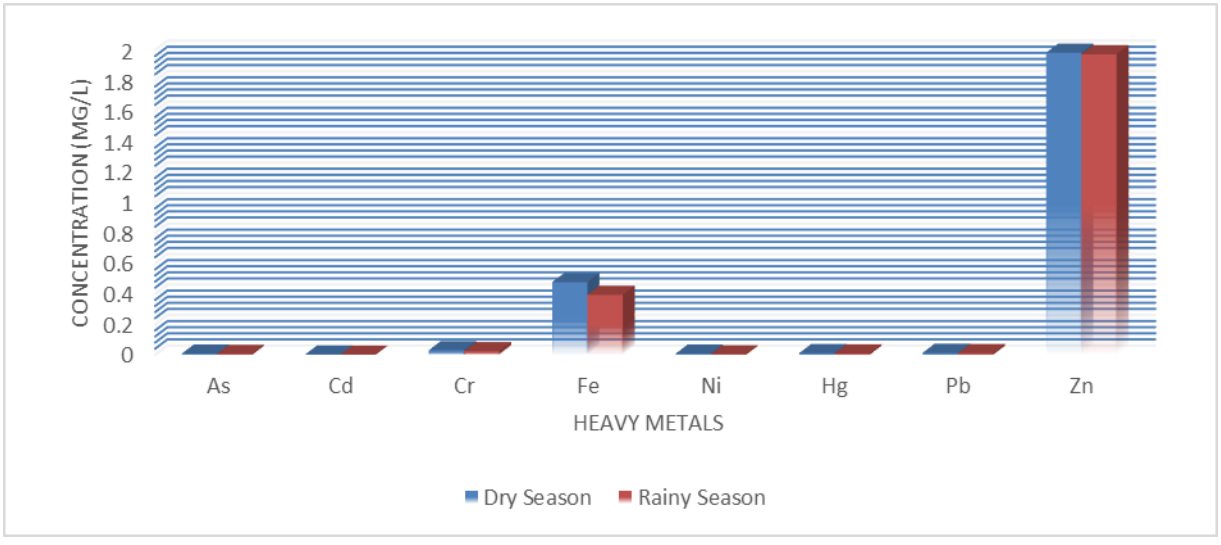

Fig. 3. Graphical Description of the combined Mean Concentrartions of heavy metals in Water (mg/l), between December, 2023 and July, 2024.

There were slight seasonal variations recorded in the mean values of heavy metals between the dry season and the rainy season, both in water and sediment concentrations. The results obtained during the dry season of December, 2023 are as follows: Arsenic As, concentration in water ranges from 0.006-0.010, with a mean value of 0.007±0.001, Cadmium Cd ranges from 0.001-0.004 with a mean of 0.002±0.001, Chromium Cr has a range of 0.010-0.048 and a mean value of 0.029±0.010, Iron Fe has a mean and standard deviation of 0.218±0.031 and its range is from 0.164-0.265, Nickel Ni ranges from 0.004-0.010 and a mean of 0.007±0.001, Mercury Hg has a mean value of 0.010±0.002 and ranges from 0.006-0.013, Lead Pb value is from 0.009-0.018 and a mean of 0.012±0.002, Zinc Zn has a mean value of 1.981±0.036 and it is from 1.910-1.981.

The results obtained during the rainy season of July, 2024 are represented in table 3. Arsenic As values were from 0.003-0.010 with mean of 0.006±0.002, Cadmium Cd recorded a minimum and maximum value of 0.001 and an average of 0.001±0.001, Chromium Cr ranges from 0.010-0.048 and a mean value of 0.029±0.010, Iron Fe ranges from 0.164-0.265 and mean of 0.218±0.031, the mean value of Nickel Ni is 0.007±0.001 and its range is from 0.004-0.010, Mercury Hg ranges from 0.006-0.013 and 0.010 in average, Lead Pb ranges from 0.009-0.018 and an average value of 0.012±0.002, Zinc Zn recorded concentration values between 1.910-2.026 with a mean value of 1.981±0.036.

Table 4

Conc. of Heavy Metals in sediment (mg/kg Of Dry Weight) for dry season

(Mg/Kg)	As	Cd	Cr	Fe	Ni	Hg	Pb	Zn
1 UPSTREAM	1.841	0.099	19.99	3026.5	2.862	0.140	25.22	40.22
2	1.820	0.087	20.01	3486.1	1.970	0.145	26.97	42.87
3	2.109	0.091	18.98	3678.4	2.009	0.147	27.01	40.21
4	1.899	0.103	18.95	2992.9	1.898	0.144	27.46	44.34
1 MIDSTREAM	1.896	0.105	20.06	3166.3	3.010	0.148	26.89	41.30
2	1.852	0.079	19.89	2989.6	2.907	0.146	28.03	43.29
3	2.114	0.102	21.82	3841.0	3.112	0.139	26.97	39.95
4	1.967	0.094	20.81	3746.5	4.102	0.150	25.90	42.26
1 DOWNSTREAM	1.893	0.093	21.63	3629.7	3.145	0.149	24.99	40.71
2	2.125	0.106	20.37	3810.2	2.993	0.153	27.21	41.33
3	2.107	0.098	21.31	3698.1	2.874	0.146	26.76	42.69
4	2.119	0.097	20.47	3752.4	2.634	0.151	25.94	43.58
MAXIMUM	2.125	0.106	21.82	3410.0	4.102	0.153	28.50	44.34
MINIMUM	1.820	0.079	18.95	2989.6	1.898	0.140	24.99	39.95
MEAN	1.978	0.097	20.36	3484.8	2.793	0.146	26.61	41.89
SD	0.120	0.008	0.881	326.02	0.589	0.004	0.872	1.414

Table 5

Conc. of Heavy Metals in sediment samples (mg/kg Of Dry Weight) for rainy season.

(MG/KG)	AS	CD	CR	FE	NI	HG	PB	ZN
1 UPSTREAM	1.798	0.105	21.29	2991.7	1.981	0.135	26.21	41.34
2	1.810	0.100	19.89	3166.3	2.019	0.140	24.93	40.23
3	1.996	0.101	21.60	3468.9	1.949	0.149	26.88	41.21
4	2.116	0.086	19.90	3751.1	1.890	0.150	25.87	42.19
1 MIDSTREAM	1.786	0.097	20.24	3812.3	3.002	0.138	27.56	40.70
2	2.093	0.080	18.96	3710.9	3.128	0.120	24.43	41.22
3	1.794	0.094	18.99	3621.2	2.890	0.147	26.69	43.19
4	1.842	0.093	20.31	3840.1	3.997	0.148	25.87	39.89
1 DOWNSTREAM	1.865	0.105	20.95	3483.8	3.146	0.142	26.98	44.10
2	2.148	0.102	21.02	3692.0	2.897	0.141	27.55	42.54
3	2.087	0.094	19.77	2741.6	2.799	0.138	25.66	38.77
4	2.107	0.095	20.48	2837.5	2.621	0.145	27.40	40.99
MAXIMUM	2.148	0.105	21.60	3840.1	3.997	0.150	24.93	44.10
MINIMUM	1.786	0.080	18.96	2741.6	1.890	0.120	24.43	38.77
MEAN	1.953	0.096	20.28	3426.4	2.693	0.141	26.33	41.36
SD	0.143	0.007	0.804	374.5	0.609	0.008	0.977	1.405

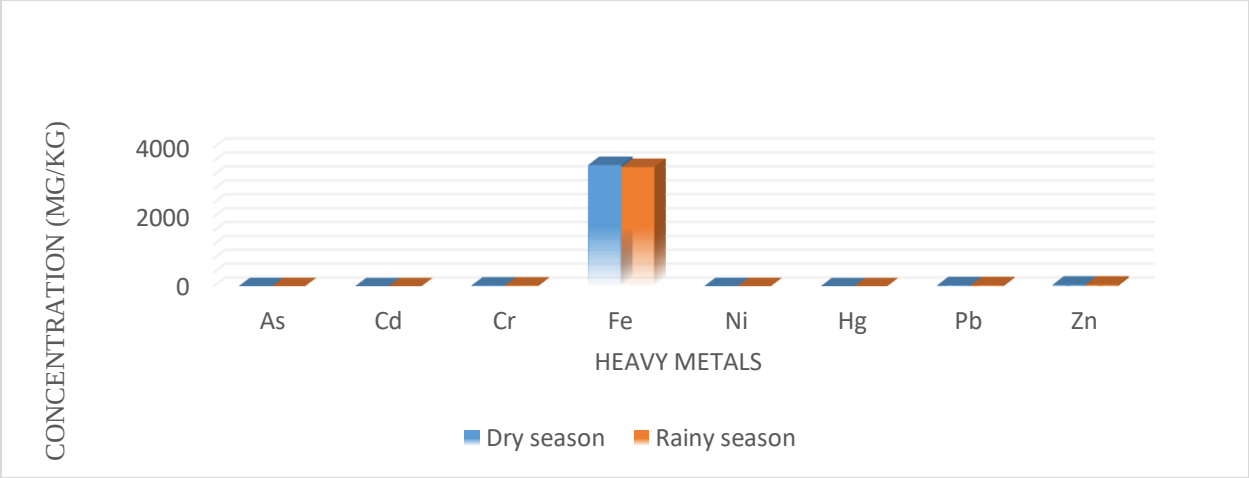

Fig. 4.Graphical Description of the combined Mean Concentrations of heavy metals in bottom sediments (mg/kg), between December, 2023 and July, 2024.

The determined concentrations in mg/kg of dry weight from the geochemical analysis of bottom sediments of the Oguta Lake during the dry season are presented in table 4. The heavy metals of concern are the same with those analyzed for the water samples (As, Cd, Cr, Fe, Hg, Ni, Hg, Pb and Zn).

The mean concentration of Arsenic As in sediment is 1.978±0.120, it ranges from 1.820-2.125, Cadmium Cd in sediment is from 0.079-0.106 with a mean value of 0.097±0.008, Chromium recorded a mean value of 20.36±0.881 and varies from 18.95-21.82. Iron Fe varies from 2989.6-3410.0 and recorded a mean value of

3484.8±326.02, Nickel Ni ranges from 1.898-4.102 and an average concentration of 2.793±0.589, Mercury Hg ranges from 0.140-0.153 and a mean of 0.146±0.004, Lead Pb has an average concentration of 26.61±0.872, it varies from 24.99-28.50, Zinc Zn has a minimum value of 39.95 and maximum value of 44.34, with an average of 41.89±1.414.

The results determined from the analysis of bottom sediments during the rainy season of December, 2023 are presented in table 3.

Arsenic As in sediment has a mean value of 1.953±0.143, it ranges from 1.786-2.148, Cadmium Cd in sediment is from 0.080-0.105 with a mean value of 0.096±0.007, Chromium recorded a mean value of 20.28±0.804 and varies from 18.96-21.60. Iron Fe varies from 2741.6-3840.0 and recorded a mean value of 3426.8±374.5, Nickel Ni ranges from 1.890-3.997 and an average concentration of 2.693±0.609, Mercury Hg ranges from 0.120-0.150 and a mean of 0.141±0.008, Lead Pb has an average concentration of 26.33±0.977, it varies from 24.43-24.93, Zinc Zn has a minimum value of 38.77 and maximum value of 44.10, with an average of 41.36±1.405.

Table 6

Descriptive Statistics of Water and Sediments in the Oguta Lake from 2023 – 2024.

Metals w (mg/l) s (mg/kg)	**Dry Season (July, 2024)**		**Rainy Season (December, 2023)**		***Summary***
	Mean ± SD	Range	Mean ± SD	Range	Mean
As w	0.007 ± 0.001	0.006 – 0.010	0.006 ± 0.002	0.003 – 0.010	0.006
Cd w	0.002 ± 0.001	0.001 – 0.004	0.001 ± 0.001	0.001 – 0.001	0.001
Cr w	0.029 ± 0.010	0.010 – 0.048	0.023 ± 0.020	0.010 – 0.030	0.052
Fe w	0.476 ± 0.090	0.410 – 0.542	0.393 ± 0.018	0.360 – 0.420	0.434
Ni w	0.007 ± 0.001	0.004 – 0.010	0.004 ± 0.002	0.002 – 0.008	0.005
Hg w	0.010 ± 0.002	0.006 – 0.013	0.008 ± 0.002	0.003 – 0.010	0.009
Pb w	0.012 ± 0.002	0.002 – 0.012	0.010 ± 0.003	0.005 – 0.015	0.022
Zn w	1.981 ± 0.036	1.910 – 2.026	1.971 ± 0.043	1.896 – 2.020	1.976
As s	1.978 ± 0.120	1.820 – 2.125	1.953 ± 0.143	1.786 – 2.148	1.965
Cd s	0.097 ± 0.008	0.079 – 1.060	0.096 ± 0.007	0.080 – 0.105	0.096
Cr s	20.36 ± 0.881	18.95 – 21.82	20.28 ± 0.804	18.96 – 21.60	20.32
Fe s	3484.8±326.0	2989.6–3841.0	3426.4 ± 374.5	2741.6 – 3840.1	3455.6
Ni s	2.793 ± 0.589	1.898 – 4.102	2.693 ± 0.609	1.890 – 3.997	2.743
Hg s	0.146 ± 0.004	0.140 – 0.153	0.141 ± 0.008	0.120 – 0.150	0.143
Pb s	26.61 ± 0.872	24.99 – 28.50	26.33 ± 0.977	24.43 – 24.93	26.47
Zn s	41.89 ± 1.414	39.95 – 44.34	41.36 ± 1.405	38.77 – 44.10	41.625

Heavy Metal Pollution Index (HPI)

Heavy metal pollution index HPI assesses heavy metal pollution in surface water by comparing concentration data from water samples to quality standards (Marzouk et al., 2017). The HPI categories of pollution levels are: HPI <100 (low), HPI = 100 (near the threshold), or high HPI >100 (critical pollution index) (Sobhanardakani. et al., 2016).

$$HPI=\sum i=1nWiQi\sum i=1nWi$$

$$Qi=\sum i=1n \{Mi (-) li\} (Si-li) \times 100$$

Where HPI represents the Heavy Metal Pollution Index, Qi signifies the quality standard value for a particular heavy metal parameter, Wi denotes the relative weight assigned to a specific heavy metal within each parameter, and n signifies the total number of parameters under consideration. The second formula calculates Qi using the monitored value, ideal value, and standard value for each parameter.

Table 7

Pollution Status derived from Metal Pollution Index Assessment of the Oguta Lake for the Dry Season and the Rainy season

	HPI Values	
Heavy Metals	**Dry Season**	**Rainy Season**
As	0.815276	0.729161
Cd	2.840776	2.459143
Cr	1.702	0.985293
Fe	2.872455	2.832
Ni	12.99	12.9021
Hg	1.3441	1.09815
Pb	18.19	17.98311
Zn	0.013001	0.09624
Overall HPI values	**40.767608**	**39.085197**

The heavy metal pollution index of As, Cd, Cr, Fe, Ni, Hg, Pb and Zn for the two different seasons were calculated using Microsoft Excel spread sheet. The WHO, 2006 regulation was used as the standard value of the i^{th}parameters. The overall HPI values determined for both the dry and rainy seasons are 40.77% and 39.08%, respectively. These results are represented with a mean value of 39.93%. Applying the water quality categorization and pollution assessment based on Pollution Index, it implies that the water quality is good.

Evaluation Based on Enrichment Factor (E.F)

The Enrichment Factor method was used to quantitatively assess the extent of anthropogenic heavy metal pollution within the Oguta Lake. Elemental concentrations of heavy metals in the analysed sample, together with their concentrations of crustal abundance with respect to the reference element as adopted in this research work are the main basis of E.F method. For the purpose of this study, Iron (Fe) was selected as the main reference element because of its geochemical variability with massively substantial rate of occurrence in the environment, and purely of geologic origin. The values of metal concentration in the Earth's crust as used in this work was extracted from the published handbook by William (2017).

The following equation was used to obtain the EF of the heavy metals:

EFi= (Mi/ Fe s) / (Mi /Fe acv),

Where M_i is the examined concentration of the metal in the sediment sample, Fe s: is the concentration of the reference metal in the examined sediment. M_i acv is the average shale value of the metal concentration in the examined sediment sample, and Fe acv is the concentration of the reference metal in the average shale (Çevik et al., 2009). The EF method was used to assess the contribution of anthropogenic and crustal activities to heavy metal pollution in the Oguta Lake due to its degree of perturbation that gives a distinction between anthropogenic and natural sources. The categories of pollution that are generally recognized for the identification of source of pollution include, EF ≤ 1, no enrichment; 1< EF ≤ 3, minor enrichment; 3 < EF ≤ 5, moderate enrichment; 5 < EF ≤ 10, moderately severe enrichment; 10 < EF ≤ 25, severe enrichment; 25 <EF ≤ 50, very severe enrichment; EF > 50, extremely severe enrichment (Zhang et al., 2019).

Table 8

E.F values for the upstream, midstream and downstream part of the lake obtained for each of dry season and rainy season

	DRY SEASON			RAINY SEASON		
Metals	Ups.	Mid.	Downs.	Ups.	Mid.	Downs.
As	0.04	0.02	0.03	0.05	0.02	0.004
Cd	0.02	0.01	0.02	0.03	0.01	0.03
Cr	0.02	0.02	0.03	0.01	0.02	0.002
Ni	0.03	0.02	0.02	0.03	0.03	0.03
Hg	0.93	0.89	0.88	0.91	0.87	0.87
Pb	2.23	2.22	2.20	2.22	2.21	2.00
Zn	0.09	0.07	0.08	0.08	0.06	0.07

The Enrichment values as represented in Table 8, shows the variation occurrence in the E.F values of the heavy metals bottom sediments. Apart from the mean value of Pb which showed some enrichment, the mean values of As, Cd, Cr, Ni, Hg and Zn have shown no indication of enrichment.

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Source Analysis for Seasonal Heavy Metal Pollution in the Water and Sediments of the Oguta Lake using Multivariate Statistical Analysis

Table 9
Correlations between water and sediment samples in the rainy and dry seasons. Subscripts wd = water sample for dry season, sr = sediment sample for rainy season

	As_{wd}	Cd_{wd}	Cr_{wd}	Fe_{wd}	Ni_{wd}	Hg_{wd}	Pb_{wd}	Zn_{wd}	As_{sr}	Cd_{sr}	Cr_{sr}	Fe_{sr}	Ni_{sr}	Hg_{sr}	Pb_{sr}	Zn_{sr}
AS_{wd}	1															
Cd_{wd}	0.381	1														
Cr_{wd}	0.272	0.131	1													
Fe_{wd}	0.768**	0.165	0.574	1												
Ni_{wd}		0.103	0.650*	0.294	1											
Hg_{wd}	0.275	0.014	-0.013	0.378	0.231	1										
Pb_{wd}	0.099	-0.139	-0.422	-0.217	-0.387	-0.051	1									
Zn_{wd}	-0.184	-0.222	-0.305	-0.288	-0.263	0.256	0.372	1								
AS_{sr}	0.423	-0.018	-0.294	0.032	-0.291	0.437	0.447	0.565	1							
Cd_{sr}	0.096	0.306	0.197	0.373	0.011	0.102	-0.657*	-0.672*	-0.422	1						
Cr_{sr}	0.116	0.221	-0.278	0.151	-0.092	0.354	-0.542	-0.425	-0.025	0.765**	1					
Fe_{sr}	-0.188	0.076	-0.172	-0.169	0.260	0.134	0.369	-0.097	-0.121	-0.301	-0.157	1				
Ni_{sr}	0.111	-0.058	0.607*	0.341	.909**	0.435	-0.146	-0.034	-0.115	-0.203	-0.264	0.388	1			
Hg_{sr}	0.444	0.505	0.005	0.512	-0.115	0.078	-0.235	-0.119	-0.086	0.301	0.326	0.08	-0.142	1		
Pb_{sr}	0.515	0.706*	0.153	0.413	0.135	0.374	-0.347	-0.462	-0.032	0.553	0.551	0.067	0.057	0.482	1	
Zn_{sr}	-0.006	0.196	0.182	0.045	-0.015	-0.089	-0.155	-0.389	-0.066	0.214	0.123	0.392	-0.036	0.167	0.393	1

**p < 0.01, * p < 0.05 (2tailed)

Pearson's Correlation Matrix analysis was employed to ascertain the interrelationship between heavy metals in water and sediment samples from the Oguta Lake and to determine sources of heavy metals. The results obtained show strong and positive correlations for sediment samples in the dry and rainy seasons at **p < 0.01, * p < 0.05. The analysis showed positive correlations between $Cd_{rw}$and Pb_{ds}(r = 0.706*), $Cr_{rw}$and Ni_{ds}(r = 0.607*),$Ni_{wd}$and Ni_{sr}(r = 0.909*), indicating that they are most likely to come from a single pollution source. The analysis showed a negative correlation between $Pb_{wd}$and Cd_{sr}(r = -0.657*). Also, $Zn_{sr}$and Cd_{wd}(r = -0.672*) were negatively correlated.

The negative correlations indicate they may not be of the same origin as the other heavy metals, their origin may also be controlled by multiple factors.

Principal Component Analysis (PCA)

To conduct the factor analysis, the principal component for extraction was employed and the number of factors was fixed to eigenvalues greater than 1.

Table 10

Rotated Component Matrix for the season

Rotated Component Matrix:

	Components (Rainy Season)		
	1	2	3
As	.654	.246	.174
Cd	.848	.257	-.105
Cr	.721	.272	.195
Fe	-.005	.906	.128
Ni	.763	-.253	.117
Hg	.189	.235	.937
Pb	.845	.078	.241
Zn	.174	.832	.144
As	.654	.246	.174
Cd	.848	.257	-.105

Extraction Method: (Principal Component Analysis). Rotation Method: (Varimax with Kaiser Normalization).
a. Rotation converged in 4 iterations.

KMO is calculated based on the correlation between the variables. Its range is between 0 and 1. Values closer to 1 suggest the variables are correlated and the data is well-suited for factor analysis, otherwise the variables are uncorrelated and there may not be a common factor influencing them. Also, the Varimax Orthogonal rotation was selected for factor extraction. Lastly, items with factor loading > 0.30 were considered and items with factor loadings < 0.30 were dropped (Tabachnick & Fidell, 2007).

The factor analysis contains the following variables: AS, Cd, Cr, Fe, Ni, Hg, Pb, and Zn during the dry season. The results of the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy was 0.719 and the Bartlett test of sphericity was statistically significant ($x2 = 78.749$, $df = 28$, $p < 0.001$), indicating a moderate adequacy of the sample size for the PCA.

From the analysis, three factors were extracted to explain the total variance, i.e., 77.116%, which can better explain the information on the heavy metals in the dry season.

Factor 1 is the most important factor with a contribution rate of 47.218%, among which AS, Cd, Cr, Ni and Pb have large loads. Factor 2 contributed 20.288%, including Fe and Zn loaded, while Factor 3 contributed less with 9.609% where Hg loaded.

The results of PCA include AS, Cd, Cr, Fe, Ni, Hg, Pb, and Zn during the rainy season. results of the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy was

0.752 and the Bartlett test of sphericity was statistically significant (x2 = 140.768, df = 28, p < 0.001), indicating a moderate adequacy of the sample size for the PCA.

Factor 1 is the most important factor with a contribution rate of 57.132%, among which As, Cd, Ni and Pb have large loads. Factor 2 contributed 21.244%, including Cr, Fe and Hg loaded, while Factor 3 contributed less with 8.108% where Zn loaded.

Table 11

Rotated Component Matrix

	Component in Dry Season		
	1	**2**	**3**
As	**.929**	-.002	.061
Cd	**.859**	.248	-.129
Cr	.241	**.689**	.184
Fe	.064	**.929**	.197
Ni	**.898**	.366	-.070
Hg	.256	**.820**	.155
Pb	**.793**	.216	.238
Zn	-.012	.205	**.927**

Extraction Method: (Principal Component Analysis). Rotation Method: (Varimax with Kaiser Normalization). a. Rotation converged in 5 iterations.

CONCLUSION

The dry season recorded higher concentration values in relative to the rainy season, and this could be as a result of reduced water volume and relatively very little or non-mobility of heavy metals. Just like most tropical lakes, Oguta lake recorded a low pH of 6.00 to 6.01 which is not in conformity with the regulations used in this study. The presence of a nearby flow station at Ezi-orsu may be linked to the acidification of this lake. The gaseous emissions (specifically No2 and So2) react with water forming nitric and sulphuric acids respectively. Continuous decrease in pH of this lake may increase its susceptibility to heavy metal pollution and toxicity by increasing their solubility and mobility.

Relative comparisons were made with WHO, 2006, USEPA, 2016 and NESREA, 2011 regulations. Mercury Hg recorded mean value slightly higher than these 3 regulations for surface water during the dry season, and mean values close to the standard limit during the rainy season. Same trend was also observed in the mean concentrations of lead (Pb). Its mean values of 0.012mg/l and 0.010mg/l exceed the maximum allowable limits for WHO and USEPA. Water quality categorization and pollution assessment based on heavy metal pollution index HPI are 40.77% and

39.08% for the dry season and rainy season, respectively. This implies that the Oguta lake surface water can be categorized as good (based on HPI).

The enrichment factor EF values of As, Cd, Cr, Ni, Hg and Zn showed no indication of enrichment. However, heavy metal enrichment in sediment was shown by Pb.

Results of the Pearson Correlation of Multivariate Analyses of Variance (MANOVA) suggests that the origins of the analysed heavy metals are mainly natural, and to a certain degree, anthropogenic. This assertion is also supported by the results of the Principal Component Analysis (PCA). Component 1 for both seasons comprising of As, Cd and Pb with the exemptions of nickel Ni, have values greater than the average continental crust as proposed by William, 2017.The mean concentrations of lead Pb in water was slightly higher than those of the regulatory bodies. It recorded the highest values in the HPI for dry and rainy seasons. Enrichment factor of >2 indicates minor enrichments. This implies that significant amount of Pb originated from anthropogenic processes. The main sources of Pb in the Oguta Lake may be ascribed to Industrial activities, unsustainable agricultural practices, transportation, sand mining activities, oil spills and other natural sources.

RECOMMENDATION

A fully equipped, year-round, permanent field station that uses the whole ecosystem approach and long-term, whole-lake investigations of freshwater focusing on heavy metal pollution should be planted as part of the monitoring strategies. This can ensure a sustainable and healthy seafood supply for the population, while identifying and eliminating point-sources of heavy metals pollution within the lake environment.

Mapping heavy metal contaminant distribution in sediments to assess the distribution of historical inputs and assessing potential biological impacts of heavy metal contamination on human health via food chains, sustainable land-use practices and pollution control measures, should be considered as part of the focal objectives of future research on the Oguta Lake.

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