WATER QUALITY AND SEDIMENT POLLUTION LOAD INDEX OF OYAN DAM, OGUN RIVER, OGUN STATE, NIGERIA

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ABSTRACT

Water and Sediment analysis are ways of evaluating the quality of a water body using different mathematical models. Samples were collected fortnightly for 3 months at 3 sampling points. Water samples were analyzed for pH, DO, EC, turbidity, BOD, COD, TDS, TN, TOP, Cl^-, Na^{2+}, Alkalinity and Ca^{2+} and sediment samples were analyzed for metals (Fe, Mg, Zn, Pb, Cr, Cu, and Ni), NO_3^-, PO_4^{3-} and pH. Water Quality Index (WQI) was used to determine the quality of water sample while the degrees of metal pollution were evaluated using the following pollution indexes; Enrichment ratio (Er), Pollution load index (PLI) and Geo-accumulation index (Igeo). All water parameters had values below the WHO standards except for Na^+. The WQI for each site indicated that the water is of good quality with values ≤ 50. The result of the metal analysis in the sediment followed the trend Mg>Fe>Zn>Cu>Pb>Ni>Cr. $N0_3^-$ and $P0_4^{3-}$ are higher than WHO standards but the metal analysis values fall within or below the range of WHO standards. The Er shows that Cu, Zn, Cr, Pb and Ni have values less than 1 (<1), PLI values are less than 1 (PLI <1). The following metals showed high values of Igeo index; Mg (Igeo >5), Fe (Igeo >2<3), Zn at sampling sites 2 and 3 (Igeo >4<5). Conclusively, the water is of good quality and the sediment showed no pollution from the metals except for Fe, Zn and Mg.

Keywords: Metals, Pollution Load Index, Sediment, Water Quality Index

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INTRODUCTION

Water is life and the quality is essential because it could pose a threat to the health of people and the environment [1-2]. Freshwater pollution is one of the major issues of water insecurity in Nigeria aside the global water crises caused by climate change. Pollution could be from many sources including municipal, industrial, agricultural waste, wastewater and nutrient runoff, power generation, heavy industry, automobiles and others [3-4].

Sediments act as sinks and sources of pollutants in aquatic systems because of their variable physical and chemical properties [5] Large quantities of metals, organic matter, nitrogen (N), and phosphorus (P) build up in the sediment and are being released to enter into water bodies under frequent changes of physical-chemical properties and hydrodynamic conditions, thus leading to water pollution and eutrophication [6-7]. Heavy metals dissolved first in water, adsorbed, and finally accumulated on the bed sediments acting as sinks [8]. Metal pollution is a major threat to human health and the environment because they can contaminate food chains, due to their environmental persistence as well as toxicity and their bioaccumulation potential. It is therefore imperative to evaluate and monitor the levels of potentially hazardous metals and metalloids in the exposed environmental areas [9-10]. Metal contamination in rivers causes increased deterioration of the water quality as well as being toxic to living organisms even at low concentrations causing significant histopathological alterations [11]. Metal contamination in the soil leads to the loss of bacteria populations that helps in the decomposition of organic matter, the improvement of soil quality, and the management of soil fertility [12-13]. One of the veritable tools in assessing water quality is the WQI [14-15]; and for sediment quality are PLI, Er and Igeo. The objective of this study is to assess the water and sediment quality of the Oyan water body.

MATERIALS AND METHODS

Description of study area

The study was conducted on Oyan Dam. The dam is owned and operated by the Ogun-Osun River Basin Development Authority (O-ORBDA) and has a surface area of 4,000 hectares and a catchment area of 9,000 km^2. It is located 7°15' North latitude and 3°16'East longitude at an elevation of 43.3 m above sea level on the confluence of Oyan and Ofiki Rivers, both tributaries of Ogun River some 20 km north-west of Abeokuta, close to Badagry-Sokoto Highway [16-17]. The dam provides fishing ground for adjoining communities, Apojola and Ibaro which are two major fishing villages located in close proximity to the bank of the Oyan Dam [18].

Collection of samples

Water and sediment samples were collected from three locations (inlet, middle and outlet of the dam) from January – March 2021. Water samples were collected 10 cm below the water surface by using well labeled plastic bottles (500 ml) and Biological Oxygen Demand (BOD) bottles in triplicates. Sediment samples were collected at the three locations in triplicates using Eckam grab in a well labeled polythene bag. The samples were kept on ice and transported to the laboratory for further analysis.

Laboratory analysis

The water samples were analyzed for 10 physicochemical parameters according to established procedures of the Association of Official Analytical Chemists [19]. Parameters assessed included pH, dissolved oxygen (DO), electrical conductivity (EC), turbidity, biological oxygen demand (BOD), chemical oxygen demand (COD), total dissolved solids (TDS), Total Nitrate (TN), Total phosphate (TOP), Alkalinity, Chlorides (Cl^-), Na^{2+} and Ca^{2+}. The following sediment chemical parameters were determined using appropriate laboratory methods as described by APHA, AWMA & WPCF [20]; pH, NO_3^-, PO_4^{3-} and heavy metals (Mg, Cu, Fe, Zn, Cr, Pb and Ni).

Statistical analysis

Water Parameters: Water quality parameters were subjected to analysis of variance and Duncan follow up procedure. Measured Values were compared to standard values.

Water Quality Index (WQI): Water quality status and classification were presented by using the Water Quality Index (WQI). The Water Quality Index (WQI) was calculated following standards recommended by the World Health Organization [21]. Calculations were done by entering the 10-water quality parameter mean values into the WQI formula. The overall WQI of the water was calculated using the following formulae:

$$\boldsymbol{WQI} = \frac{\sum(\boldsymbol{qi\ X\ wi})}{\sum \boldsymbol{wi}}$$

………………………………. equation 1

$$qi = 100\ X\ \left(\frac{vi}{si}\right)$$

……………………………… equation 2

$$wi = \frac{k}{si}$$

……………………………… equation 3

Where, q^i is the quality rating

W^i is the unit weight of the I^{th} parameter

V^i is the measured value of the I^{th} parameter

S^i is the standard for the I^{th} parameter

K is the constant of proportionality

WQI range is determined according to the rating below [14-15]

WQI	Rating
0–25	Very good
26–50	Good
51–75	Moderate
> 75	Poor

Sediment Parameters

The chemical parameters were subjected to Analysis of variance and Duncan follow up procedure. The degree of metal pollution in the sediments was determined using Enrichment Ratio (ER), Pollution Load Index (PLI) and Geo-accumulation Index (Igeo).

Enrichment Ratio (ER): Enrichment factor analysis, a method proposed by Simex and Helz [22] to assess trace element concentration, is mathematically expressed as:

$$Enrichment\ ratio\ (ER) = \frac{\left(C_x/_{Fe}\right)sample}{\left(C_x/_{Fe}\right)background}$$

…………………… equation 4

Where, Cx stands for concentration of metal ‘x’.

The background value is that of the world surface rock average [23] given in Table 1. Fe is taken as a normalization element while determining enrichment ratio (ER) because even at a low percentage, $Fe(OH)_3$ in aquatic system, has a controlling influence on heavy metal distribution [24-25].

Pollution Load Index (PLI): Pollution load index (PLI), for a particular site, was evaluated following the method proposed by Tomlinson *et al.* [26]. This parameter is expressed as:

$$PLI = (CF1 \times CF2 \times CF3 \times \ldots\ldots \times CFn)^{1/n}$$

………………. equation 5

where, n is the number of metals (seven in the present study) and CF is the contamination factor.

The contamination factor was calculated from the following relation:

$$CF\ (Contamination\ factor) = \frac{Metal\ concentration\ in\ the\ sediments}{Background\ value\ of\ the\ metal}$$

…….. equation 6

The PLI value of >1 is polluted, whereas <1 indicates no pollution

Geo-accumulation Index (Igeo): The geo-accumulation index (Igeo), introduced by Muller [27] for determining the extent of metal accumulation in sediments, and has been used by various workers in their` studies [24-25, 28-30]. Igeo is mathematically expressed as:

$$Igeo = log_2\ {Cn}/{1.5Bn}$$

………………. equation 7

where, Cn is the concentration of element ‘n’ and Bn is the geochemical background value [world surface rock average given by [23]].

The factor 1.5 is incorporated in the relationship to account for possible variation in background data due to lithogenic effect. The geo-accumulation index (Igeo) scale consists of seven grades (0-6) ranging from unpolluted to highly polluted.

RESULTS AND DISCUSSION

Table 1: Mean values and WHO standards for water quality parameters

Parameters	Mean Observed values	NESREA*	WHO Standards*
Ph	8.09	6.5-8.5	6.5-8.5
Conductivity (µS/cm)	97.44	1000	500
Turbidity (NTU)	1.03	5.0	5
Dissolved Oxygen (mg/L)	3.54	4.0	5
Total Nitrates (mg/L)	1.46	40	50
Total Organic Phosphates (mg/L)	1.85	3.5	5
Total Dissolved Solids (mg/L)	72.59	500	600
Alkalinity (mg/L)	0.94		120
Chlorides (mg/L)	6.20		250
BOD (mg/L)	2.32	6.0	6
COD (mg/L)	5.01		10
Na^+(mg/L)	**159.07**		65
Ca^{++}(mg/L)	75.37		100

*NESREA - National Environmental Standards and Regulation Enforcement Agency
*WHO – World Health Organization

The mean of the observed values for the water quality parameters are shown in table 1 compared with the World Health Organization standards [21] and National Environmental Standards and Regulation Enforcement Agency standards [31]. All parameters had values below the WHO standards except for Na^+, which had a value greater than the recommended standard, this could pose a public health risk to the population of people that uses the water for drinking purposes without treatment.

Parameters such as pH, COD, BOD, Alkalinity, Total Phosphorus, Total Nitrogen and Turbidity showed no significance difference across the sampling site (Table 2), while other parameters (Conductivity, Dissolved oxygen, Chlorides, TDS, Na^+ and Ca^{2+}) showed significance differences across the sampling sites. The value for the water quality index for each sampling sites was also presented in Table 2, the quality index for each site indicated that the water is of good quality with values ≤ 50.

Table 2: Mean values, Analysis of Variance and WQI of parameters at each site

Parameters	Site 1	Site 2	Site 3	*P- value*	*Sig.*
pH	8.13±0.109	8.07±0.017	8.07±0.017	0.704	No
Conductivity	96.00±2.398^a	96.22±2.539^a	100.11±3.822^b	0.012	Yes
Turbidity	1.00±0.559	0.78±0.441	1.31±0.679	0.157	No
DO	3.54±0.300^b	3.23±0.158^a	3.84±0.194^c	0.0001	Yes
TN	1.28±0.233	1.59±0.183	1.51±0.465	0.119	No
TOP	1.80±0.332	2.02±0.311	1.72±0.708	0.411	No
TDS	65.00±5.000^a	70.56±9.167^a	82.22±13.944^b	0.004	Yes
Alkalinity	1.13±0.122	1.11±0.395	1.17±0.464	0.947	No
Chlorides	4.59±0.419^a	7.13±1.13^b	6.87±1.33^b	0.0001	Yes
BOD	2.44±0.269	2.40±0.412	2.12±0.273	0.095	No
COD	5.23±0.339	4.98±0.899	4.83±0.684	0.463	No
Na^+	135.00±6.124^a	163.33±14.58^b	178.89±16.159^c	0.0001	Yes
Ca^{2+}	63..89±3.333^a	76.11±6.009^b	86.11±4.859^c	0.0001	Yes
WQ1	**50.00**	**50.47**	**49.87**		

The results of the sediment chemical parameters and metals analysis, according to Table 3, showed that chemical parameters; Nitrate and Phosphate are higher than WHO standards but the results for metal analysis showed that the values fall within or below the range of standards provided by the WHO. The values of Nitrates and Phosphates in sediments sample are higher than the values recorded at Eleyele River bed, Oyo State [32]. The statistical analysis of variance revealed that the parameters showed significant differences across the sampling station except for Phosphates, Chromium and Nickel. Information on the World Surface Rock Average of the metals observed in the analysis is also provided in Table 3.

The result of the metal analysis followed the trend Mg>Fe>Zn>Cu>Pb>Ni>Cr in the sediment samples. Mg was significantly higher in all the sampling sites. Many of Mg compounds are always very soluble in water, highly mobile and present mostly as Mg^{2+}. Magnesium is essential for all living organisms and is not toxic under normal circumstances. Toxicity of Magnesium is not much of a concern as its deficiency because it is a key plant nutrient which is essential for photosynthesis in plants, where it forms the active site in the chlorophyll enzyme molecule.

The Enrichment ratio/factor provides information to judge enrichment (or depletion) of a given element relative to the reference element, which is Fe in this case. The Enrichment ratio/factor in Table 4 shows that Cu, Zn, Cr, Pb and Ni have values less than 1 (<1) showing no enrichment from the metals, a similar result showing no enrichment from Ni and Cr in Eleyele river sediment was also observed by Oyetunji *et al.* [32]. Mg on the other hand was observed to have high enrichment value which is greater than 3 in contrary to the result of Oyetunji *et al.* [32], where Mg showed no enrichment in the sediment samples with values lower than 1.

The Low PLI value (Table 5) shows that there is no appreciable input from anthropogenic sources, with values less than 1 (PLI <1) in all the three sampling sites showed that the water body is not polluted by the metals. This result is validated and in line with the findings of [32].

Table 3: Mean value, Analysis of Variance, WHO standards of Sediment parameters and the World Surface Rock Average (WSRA) of observed metals.

Parameters	**Site 1**	**Site 2**	**Site 3**	***P***	**WHO**	**WSRA**
pH	$5.97 \pm .250^{a}$	$6.33 \pm .800^{ab}$	$6.867 \pm .550^{b}$	0.011	6.5–8.5	-
Nitrates (mg/kg)	63.33 ± 2.500^{a}	51.67 ± 3.536^{b}	48.89 ± 5.4	0.0001	40	-
Phosphates (mg/kg)	41.67 ± 3.536	41.67 ± 3.536	37.78 ± 5.069	0.089	5.0	-
Mg^{2+} (mg/kg)	113.33 ± 10.31^{b}	103.33 ± 6.614^{a}	104.44 ± 3.909^{a}	0.016		1.64
Cu^{2+} (mg/kg)	$3.41 \pm .232^{a}$	$3.22 \pm .199^{a}$	$3.81 \pm .162^{b}$	0.0001	25	32.0
Fe^{2+} (mg/kg)	$23.99 \pm .651^{a}$	$25.06 \pm .240^{b}$	$26.27 \pm .381^{c}$	0.0001	30	3.59
Zn^{2+} (mg/kg)	$4.68 \pm .303^{a}$	$6.19 \pm .593^{b}$	$6.66 \pm .296^{c}$	0.0001	123	127
Cr^{2+} (mg/kg)	$.344 \pm .1013$	$.311 \pm .078$	$.300 \pm .0500$	0.476	100	71
Pb^{2+} (mg/kg)	$.544 \pm .113^{b}$	$.400 \pm .122^{a}$	$.611 \pm .060^{b}$	0.001	10	16
Ni^{2+}(mg/kg)	$.389 \pm .154$	$.367 \pm .100$	$.467 \pm .132$	0.253	20	49

The geo-accumulation index (Igeo) scale (0-6) ranges from unpolluted to very strongly polluted. From table 6, the sediment is very strongly polluted with Mg (Igeo >5), mildly

Table 4: Enrichment ratio (ER) Values of heavy metals in Oyan Lake sediment

Sampling Location	Mg	Cu	Zn	Cr	Pb	Ni
1	10.38	0.015	0.054	0.0005	0.004	0.001
2	9.02	0.014	0.007	0.0004	0.003	0.001
3	8.70	0.016	0.007	0.0004	0.004	0.001

Table 5: Contamination factor and Pollution Load Index (PLI) of metals in sediments of Oyan Lake

Sampling Location	Mg		Cu		Fe		Zn		Cr		Pb		Ni		PLI
	A	**B**	**A**	**B**	**A**	**B**	**A**	**B**	**A**	**B**	**A**	**B**	**A**	**B**	
1	113.33	69.11	3.41	0.11	23.99	6.68	4.678	0.04	0.344	0.004	0.544	0.03	0.389	0.008	0.219
2	103.33	63.01	3.22	0.11	25.06	6.98	6.189	0.05	0.311	0.003	0.400	0.02	0.367	0.008	0.148
3	104.44	63.68	3.81	0.12	26.27	7.32	6.658	0.05	0.300	0.003	0.611	0.03	0.467	0.009	0.162

A: Mean value of metal, B: contamination factor of metal

Table 6: Geo-accumulation Indices of Heavy metals in Oyan Lake sediment

Sampling Location	Mg	Cu	Fe	Zn	Cr	Pb	Ni
1	5.53	-3.82	2.15	-5.38	-8.97	-5.80	-7.64
2	5.39	-3.90	2.22	4.97	-8.97	-6.23	-7.64
3	5.41	-3.66	2.29	4.88	-8.97	-5.64	-7.38

polluted with Fe (Igeo >2<3), and no pollution from Cu, Cr, Pb, Ni and Zn only in sampling sites 1 (Igeo <1), but it is strongly polluted by Zn at sampling sites 2 and 3 (Igeo >4<5).

CONCLUSION

Water parameters observed falls within the acceptable standards by WHO except for Nitrate, Phosphate in sediment and sodium and the WQI showed that the water is of good quality. The sediment showed no pollution form the metals according to the PLI, it showed no enrichment except for Mg according to the enrichment factor/ratio, and according to Geo accumulation Index; there was no pollution from the metals except for Fe, Zn and Mg.

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