Sediment Composition across different Land uses as an Environmental Quality Indicator in the Catchment of Tropical man-made Reservoirs

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Abstract

This study evaluates anthropogenic enrichment of reservoir bottom sediments by trace elements and nutrients to indicate the environmental quality of tropical reservoirs with differing surrounding land uses - commercial and institutional. We assess the toxic level of sampled sediment in determining the degree of pollution, and its potential effects on human health and the aquatic ecosystem. The trace elements and nutrients of bottom sediments were obtained from reservoirs using standard methods at seven different stations. The eco-toxicological analysis of trace elements and nutrients in sediment samples suggests a high toxic level due to the presence of Cd, Pb, and Cu. An Analysis of Variance (ANOVA) test shows a significant difference in the concentration of trace elements and nutrients across the sampled stations; F (7, 48) = 207.032, p < .05. The Wilcoxon W. test conducted indicates that there is no significant difference between the examined reservoirs in ecological toxic risk conditions, Ws = 50, z = −0.319, p>0.05. The results of various environmental indices suggest poorer environmental quality in the commercial catchment area compared with the institutional one. This study shows that anthropogenic activities have a significant impact on the composition of reservoir bottom sediments – and thus sediment composition could serve as an indicator of the impact of land-use changes and corresponding environmental quality within reservoir catchments, especially in tropical developing economies where multiyear environmental monitoring data is sparse.

Keywords: Bottom Sediment, Dams, Ecotoxicology, Environmental Degradation, Sediment Chemistry, Sustainability Science.

INTRODUCTION

Urbanization and industrialization are currently degrading the quality of the environment, altering the fate of natural environmental processes, and releasing harmful residual substances which are toxic to biotic life into the aquatic and terrestrial ecosystems (Wong *et al*., 2006). Since the industrial revolution, anthropogenic activities have constantly modified the physical, chemical, and biological components of the natural environment (Franz, 2015). Although urbanization is slowing down in developed countries, urbanization and the expansion of urban areas is progressing rapidly in developing countries. Previously, land-use transformations were primarily related to agriculture. However, currently, the environment is being subjected to strong multi-directional human pressure (Machowski *et al*., 2019). These human activities are a matter of concern, especially, in cities where there is an absence of/or poor physical planning and implementation of environmental regulations.

Meanwhile, contamination issues in reservoirs are most likely to arise in or close to urban-industrial areas, urban centres, and areas where vital infrastructure is sited (Balogun *et al*., 2011; Etim and Onianwa, 2013; Olanrewaju *et al*., 2017). This is a typical situation currently experienced in many developing countries. Contamination often results from uncontrolled high population density with its associated anthropogenic modification of the environment. A major challenge experienced in these countries is the lack of control and monitoring of the environmental impact of anthropogenic activities resulting in the contamination of the environment. A possible alternative to the lack of consistent environmental monitoring of this anthropogenic modification is the use of the bottom sedimentary record of reservoirs. With the help of reservoir sediments, the record of historical changes in pollutant deposition into the environment can be assessed. Such historical information on the quantity and duration of pollutant deposition is essential for assessing the time to recovery and best practices in limiting environmental degradation to achieve sustainable catchment area management.

Concerning the water bodies in urban areas, geo-media such as the bottom sediments of reservoirs can serve as an environment archive. This is because bottom sediments are an important sink for various pollutants - such as metals that are discharged into the environment (Thongra-ar *et al*., 2015; Worakhunpiset, 2018). Dam reservoirs, in particular, are vulnerable to the eutrophication process caused by biogenic substance loads (among others, nitrogen and phosphorus compounds) delivered to the reservoir both from point and diffuse sources, for example, sewage discharges from urbanized areas or runoff from agricultural areas (Lawniczak-Malińska *et al*., 2018; Ziemińska-Stolarska *et al*., 2020). Nutrients from agricultural areas can be deposited in sediments and then released into the biogeochemical cycle (Ballantine *et al*., 2008). Though without sufficient empirical evidence across geographic contexts, the basic chemical composition and trace element concentrations of bottom sediments can be good indicators of the degree of pollution and environmental quality in a catchment area (Fajer and Rzetala, 2018; Rzetala, 2015). This geographic-empirical lacuna is one of the gaps that this research attempts to fill.

The use of bottom sediments in determining the environmental quality prevailing in a catchment is a research area that has largely been ignored. In a catchment area, an energetic continuum exists between sediments - from source to ultimate sink - and as sediments move along the continuum (Apitz and White, 2014). For instance, sediment and water from land use/cover changes in upper watersheds can export pollutants from the watershed into reservoirs (Li *et al*., 2013; Yesuf *et al*., 2015). Sediment-associated pollution concentrations and loadings could vary based on the prevailing land-use types identified in each catchment area of a reservoir (Fabijańczyk *et al*., 2016). Furthermore, the quality of surface water can be severely altered by land use within the catchment such that the anthropogenic modification of the environment from rapid urbanization, industrialization, intensive agriculture, and growing demand for energy adversely affects the physicochemical parameters of surface water and sediment (Fashae *et al*., 2019; Fashae *et al*., 2017).

Overall, there is an increasing need for studies that evaluate the chemical composition of the bottom sediment of reservoirs in providing environmental archives and as indicators of the prevailing environmental condition in economically developing areas (especially in the Global South) where there is a dearth of watershed monitoring data. In contributing to the foregoing, the objective of this paper is to estimate the ecotoxicological concentration, trace element variation, and the magnitude of nutrients across sampled reservoirs influenced by anthropogenic activities and assess their usefulness as environmental quality indicators.

METHODOLOGY

Study area

The assessment carried out in this paper was conducted in southern Nigeria – specifically, Ibadan North Metropolis. Ibadan North Metropolis is located approximately between coordinates 7^{0}23'47" N and 7.396390 N, 3^{0}55$^{'0}$"E and 3.916667^{0}E. The two major rivers draining Ibadan are River Ona and River Ogunpa. The study area is characterized by a tropical humid climate with two distinct seasons: the wet season which occurs between March and October with an average annual rainfall of about 1,250mm; and a dry season from November to February, having a mean maximum temperature of 26.46 ºC, a mean minimum of 21.42 ºC and relative humidity of 74.55%.

Two study sites – Eleyele and Dandaru - were purposively selected within the metropolis due to their differing land uses. The Eleyele Reservoir (commercial land use) is situated upstream on River Ona, in the northeastern part of Ibadan city, with a surface area of 160 hectares. Commercial activities such as mini firms, markets, schools, event centres, workshops such as for auto-mechanics and a few residences are found in the Eleyele catchment area. The Dandaru reservoir/catchment area (institutional land use) on the other hand, is dominated by institutions such as the State Government Office, the Government House, Government Residential Area, University of Ibadan Teaching Hospital, Hotels, Office buildings and banks, and residential estates.

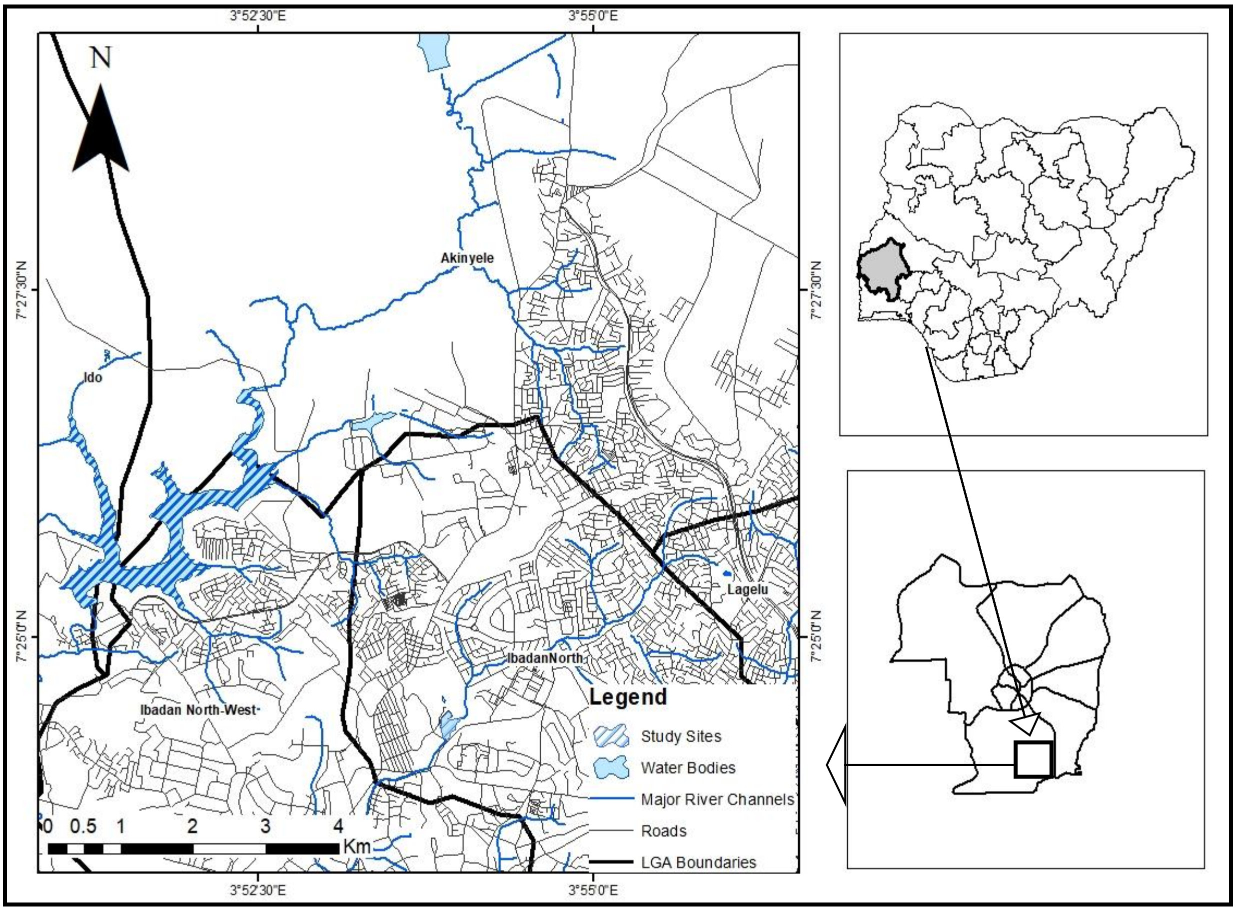

Figure 1: Study area map

Sediment sampling and collection

Sediment sampling

For each reservoir, stratified random sampling was used to determine the sampling points. Each of the reservoirs was divided into two major sections based on the entry or upper stream channels of the reservoirs and the outlet or downstream part of the reservoirs. Using analysis tools in the Quantum Geographic Information System (QGIS) software, sample stations were randomly distributed in each of the two sections of the reservoirs. Each of the stations comprises three sampling points, resulting in a total of twenty-one sampling points (Table 1 and Figure 1). The stratified random sampling method was used to reflect the influx of urban and domestic effluent discharge points and human activities, and to take into account the hydro-morphological conditions (stability of the riverbed, sediment load, low versus high flow etc.)

Sample Collection

Surface bottom sediment samples were collected at both upstream and downstream sections of Eleyele and Dandaru reservoirs using an Eckman sediment grab on July 13, 2021. At each sampling station, three different sediment samples were collected, and these samples were pooled together to obtain a representative sample for each station. Hence, a total of twenty-one (21) composite samples were collected from the seven (7) stations to account for within-site variation as shown in Table 1. The composite samples were collected and stored in well-labelled one-litre sterile bottles which were stored in a thermocool container with an iced block before being transported to the laboratory for analysis. All samples were taken to the laboratory within 4 hours of collection.

Table 1: Description of sampling points

Sites	Number of Stations	Total Number of Samples	Sample Labels
Eleyele	4	12	Station A=EA1, EA2, EA3 Station B=EB1, EB2, EB3 Station C=EC1, EC2, EC3 Station D=ED1, ED2, ED3
Dandaru	3	9	Station E=DE1, EE2, EE3 Station F=DF1, DF2, DF3 Station G=DG1, DG2, DG3

Ecotoxicological criteria and statistical analyses

Ecotoxicological criteria

Ecotoxicological criteria are based on the Sediment Quality Guidelines (SQGs), whose value sets the limit for the content of an element or chemical compound above which a toxic direct effect on organisms is noticeable. The references that were calculated to determine the ecotoxicological criteria in this study are the threshold concentration factor, metal pollution index, pollution load index, mean probable effect concentration quotient and the toxic risk index. These references are detailed below:

Threshold Concentration Factor

The Threshold Concentration Factor (TCF) is a reference to estimate the extent of metal and nutrient concentration in sediments. The TCF is calculated by using the following equation:

$$\text{TCF} = \left(\frac{C_n}{B_n}\right) \qquad 1$$

Where C_n is the measured concentration of metal n in the sediment, B_n is the geochemical background value of element n in the background sample (Yu *et al.* 2011). B_n values are provided by Taylor and McLennan (1995) and Turekian and Wedepohl (1961). The classification of the TCF is displayed in Table 2.

Table 2: Threshold Concentration Factor (TCF) classification range.

Class	value	Sediment quality
0	$\text{TCF} \leq 0$	Natural geochemical background
1	$0 < \text{TCF} < 0.5$	Natural geochemical background to very low concentration
2	$0.5 < \text{TCF} < 1$	Low concentration (0.5 times higher)
3	$1 < \text{TCF} < 2$	Moderate concentration (1 time higher)
4	$2 < \text{TCF} < 5$	High concentration (2-5 times higher)
5	$5 > \text{TCF} < 10$	Very high conc. to extremely contaminated (5-10 times higher)
6	$\text{TCF} < 10$	extremely contaminated (10 times higher)

Metal Pollution Index

Metal Pollution Index (MPI) is a mathematical model for determining the combined level of concentration for all trace elements to enable the presentation of trace element concentrations as a single value (Singovszka *et al.*, 2017). The MPI was obtained with the equation:

$$\text{MPI} = (Cf_1 \times Cf_2 \times Cf_3 \ldots\ldots\ldots\ldots Cf_k)^{1/k} \qquad 2$$

where Cf_1 is the concentration of the first metal, Cf_2 is the concentration of the second metal, Cf_3 is the concentration of the third metal and Cf_k is the concentration of the kth metal.

Pollution Load Index

The Pollution Load Index (PLI) is an experimental formula developed by Tomlinson *et al.* (1980). This assessment is used to compare the pollution status of different places. PLI represents the number of times by which the metal concentrations in a sediment exceeds its background concentration. Th index indicates the level of metal toxicity in a sample or location (Mariusz *et al.*, 2019; Zhang *et al.*, 2011). PLI can provide some understanding of environmental quality and indicates the spatial and temporal trends at a site (Chuan and Yunus, 2019).

$$\text{PLI} = \left(\frac{C_{n_1}}{B_{n_1}} \times \frac{C_{n_2}}{B_{n_2}} \times \frac{C_{n_3}}{B_{n_3}} \cdots \frac{C_{n_i}}{B_{n_i}}\right)^{\frac{1}{i}} \qquad 3$$

where $\frac{C_{n_1}}{B_{n_1}}$ is the ratio of selected elements to their background values and i is the number of elements. The empirical index provides simple comparisons of site average heavy metal pollution. PLI value = 0 denotes perfection, PLI < 1 denotes no pollution, and PLI > 1 indicates pollution (Long and MacDonald, 1998; Ward, 2017).

Mean Probable Effect Concentration Quotient

The Mean Probable Effect Concentration Quotient (Mean Pec-Q) is used to assess the state of ecological conditions. The following procedure was used to calculate the Mean PEC-Qs for chemicals with reliable PECs (MacDonald and Ingersol, 2002; USEPA, 2000).

Step 1.
$$\frac{\text{chemical concentration}}{\text{corresponding PEC value}} \quad (4)$$

Step 2. Calculate the mean PEC-Q for the metals and nutrients with reliable PECs (cadmium, chromium, copper, lead, and nickel).

$$\text{mean PEC-Qmetals} = \frac{\Sigma\,\text{individual metal PEC}-\text{Qs}}{n} \quad (5)$$

$$\text{mean PEC-Qmetals} = \frac{\Sigma\,\text{individual metal PEC}-\text{Qs}}{n} \quad (6)$$

where n = number of metals with reliable PECs for which sediment chemistry data are available

Step 3. Calculate the mean PEC-Q for the three main classes of chemicals with reliable PECs.

$$\text{mean PEC-Q} = \frac{(\text{mean PEC}-\text{Qmetals} + \text{PEC}-\text{Qnutrients}}{n} \quad (7)$$

where n = number of classes of chemicals for which sediment chemistry data are available (i.e., 1 to 2). The PEC benchmark values for Cd, Cr, Cu, Ni, and Pb are 4.98, 111, 149, 48.6, and 128 respectively. The categories for Qm-PEC are classified as: not toxic (Qm-PEC < 0.5) and toxic (Qm-PEC > 0.5).

The Toxic Risk Index

The Toxic Risk Index (TRI) was developed by Bai *et al*. (2011) to assess the ecological toxic risk for certain heavy metals in sediment samples. The TRI is based on a threshold (TEL) and probable (PEL) effect levels. It was calculated using the following equations:

$$\text{TRI}_i = \sqrt{\frac{\left(\frac{C_i}{TEL}\right) + \left(\frac{C_i}{PEC}\right)}{2}} \quad (8)$$

To assess integrated risk, the TRI is calculated thus:

$$\text{TRI} = \sum_{i=1}^{n} TRI_i \quad (9)$$

where n is the number of TMs, Ci is the content of each heavy metal in the sediment sample, and TRIi is the toxic risk index of each heavy metal. Five categories of the TRI are classified as: no toxic risk (TRI ≤ 5), low (5 < TRI ≤ 10), moderate (10 < TRI ≤15), considerable (15 < TRI ≤ 20) very high (TRI > 20) (Birch and Apostolatos, 2013).

Statistical Analyses

All statistical analyses were performed using Microsoft excel and python version 3.10. The descriptive statistics used were mean, standard deviation, percentage, and cluster bar chart. One-Way Analysis of Variance (ANOVA) was analyzed using python 3.10 (scipy.stats package). The One-Way ANOVA was used to analyze the significant variation in trace element and nutrient concentration at different stations across the sampled sites. Differences in the ecological toxic risk condition resulting from anthropogenic activities in the sampled reservoirs were tested using the Wilcoxon W test (python version 3.10-scipy. stats package).

RESULTS AND DISCUSSION

Ecotoxicological analysis of Trace Elements and Nutrients in Sediment Samples

Regarding the concentration of Pb, Ni, and Cu in sediments taken from both Eleyele and Dandaru reservoirs, almost all the SQGs (TEL-Threshold Effect Level, TEC-Threshold

Effect Concentration, ISQG-Interim Sediment Quality Guidelines, LEL-Lowest Effect Level and SEL- Severe Effect Level for trace elements) indicated high-moderate concentrations (Table 3). TEL, TEC, ISQG, and LEL indicated very high concentrations of Cd. The SQGs value of TEL, TEC, ISQG, LEL, and SEL indicated low to no concentration for Cr, TEC value for Fe indicates very low concentration. In determining nutrient concentration, the Maximum Concentration Level (MCL) for nutrients indicates a very high concentration of P_4^{3-} but high to moderate concentration of NO_3^-. Overall, the ecotoxicological mean concentration value of Pb, Ni, and Cu exceeded the lowest, probable, and severe threshold effect levels of the SQG. Meanwhile, MCL revealed that the concentrations for P_4^{3-} and NO_3^- are above the acceptable toxic limit for an aquatic ecosystem.

Table 3: Comparison of selected trace element and nutrient concentrations in sediments from study sites based on ecotoxicological criteria.

Elements		Mean	Tel	Tec	ISQG	LEL	SEL	MCL
Pb	Threshold	79.6	35.0	35.8	35.8	32.0	250.0	
	concentration		2.3	2.2	2.2	2.5	0.3	-
Cd	Threshold	28.5	0.6	1.0	0.6	0.6	10.0	
	concentration		**47.5**	**28.8**	**47.5**	**47.5**	2.8	-
Ni	Threshold	51.5	18.0	22.7	16.0	16.0	75.0	
	concentration		2.9	2.3	3.2	3.2	0.7	-
Cu	Threshold	61.2	35.7	31.6	35.7	16.0	110.0	
	concentration		1.7	1.9	1.7	3.8	0.6	-
Fe	Threshold	4.8	NA	20000.0	-	-	-	
	concentration		0.0	0.0	-	-	-	-
Cr	Threshold	3.4	37.3	43.4	37.3	26.0	110.0	
	concentration		0.09	0.08	0.09	0.13	0.03	0.0
P_4^{3-}	Threshold	38.4						10.0
	concentration		-	-	-	-	-	**384.4**
NO_3^-	Threshold	130.9						0.1
	concentration		-	-	-	-	-	13.1
KEY	■	**Very high conc.**	▨	**Moderate-high conc.**	□	**Low-no conc.**		

The high ecotoxic level for some of the tested trace elements and nutrients can be attributed to anthropogenic activities in Eleyele and Dandaru catchment areas, which is injurious to the aquatic ecosystem and human health (Jenyo-Oni and Oladele 2016). The findings of Maanan *et al*. (2014) in Nador Lagoon, Morocco are consistent with this study as their study also reveals higher mean concentrations of Pb, Ni, and Cu. In a local study, Olayinka *et al*. (2017) document Cd as the trace element with the highest toxic concentration in Eleyele reservoir. The ecotoxicology of Cd may include kidney dysfunction, skeletal damage, and reproductive deficiency and may affect the digestive, immune, and reproductive systems of fish (Alshikh and Yousef, 2017; Olayinka *et al*., 2017). In an assessment conducted by Sałata and Dąbek (2017) in an urban Polish stormwater plant, the authors found Cu to have the highest concentration in all the stations sampled followed by Cr. But in our study Cr is one of the trace elements with the lowest concentration value.

Meanwhile, the research findings of Ayoade and Nathaniel (2018) on sediments in Ibadan agree with the findings of this study. Their results reveal higher concentrations for Pb and Cd in the sampled sediments while Cr and Fe show a lower concentration in the bottom sediments sampled. These differences may have resulted from the period in which the two studies were carried out, the slightly different urban contexts, as well as a difference in the magnitude of anthropogenic modification of the environment over the years.

Variation in concentration of Trace Elements and Nutrients in the Sampled Reservoirs

The anthropogenic enrichment of bottom sediments was computed to understand the variation in the concentration of trace elements and nutrients across the sampled stations (Table 4). The highest mean concentration of P_4^{3-} was found in Station F (42mg/L) and the lowest in station A (33.1mg/L). Meanwhile, NO_3^- loaded highest in station A (159mg/L) and lowest in station E (113mg/L). Almost all the stations sampled recorded a mean value of lead above 70mg/L, an indication of high lead concentration across all the stations. Station B recorded a higher load of cadmium than other stations. Ni (54mg/L) and Fe (4.95mg/L) loaded more in station C; Cu (70mg/L) and Cr (10mg/L) loaded more in station E than other stations. The One-Way ANOVA of elements across different stations reveal that there is a significant difference in the concentration of trace elements and nutrients across the sampled stations; F (7, 48) = 207.032, p < .05 (Table 5).

Sediment analysis reveals a significant difference in the concentration of trace elements and nutrients across the sampled stations. Particularly, trace elements and nutrients within the bottom sediments show spatial variation across the reservoirs. This finding is similar to those of Ayoade and Nathaniel (2018) and Isiuku and Enyoh (2020) regarding the spatial variation of sediment trace elements and nutrients across sampling stations. Importantly, these differences are possibly associated with the various anthropogenic activities occurring in the study sites. According to Olanrewaju *et al*. (2017), the high level of contaminants in the Eleyele reservoir could be due to domestic sewage, municipal wastes, run-off from agricultural land, and other biodegradable pollutants.

Table 4: Statistical variation of the anthropogenic enrichment level of bottom sediments

	Station A	Station B	Station C	Station D	Station E	Station F	Station G	mean	SD
P_4^{3-}	33.1	39.7	39.1	37.1	38.3	42	39.8	38.44	2.80
NO_3^-	159	140	125	130	113	115	134	130.86	15.76
Pb	81.95	72.55	72.7	57.75	87.55	92.05	92.3	79.55	12.65
Cd	31.1	36.5	32.7	21.5	28.05	23	26.5	28.48	5.35
Ni	50.75	50.9	54	51	51	51.5	51	51.45	1.15
Cu	62.5	61.5	59.5	59	70	61	55	61.21	4.57
Fe	4.75	4.85	4.95	4.9	4.6	4.6	4.85	4.79	0.14
Cr	2	1.5	0.5	4	10	2	4	3.43	3.17

Table 5: ANOVA Test for the variance of elements in different stations

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	86439.57	7	12348.51	207.032	0.00
Within Groups	2862.985	48	59.646		
Total	89302.56	55			

Variation in the Trace Elements and Nutrients Between the Inlet and Outlet Sections of the Reservoirs

As shown in Figure 2, the upstream section of the reservoirs loaded more Cu than the down streams section. Samples collected from Eleyele and Dandaru reservoirs show that Fe, Ni, and P_4^{3-} loaded almost equally both upstream and downstream of the sampled reservoirs. Pb loaded more in the upstream sections of Eleyele but in turn loaded less in the upper streams of the Dandaru reservoir compared to the downstream. Samples collected upstream show that NO_3^- loaded more in Eleyele than Dandaru, while NO_3^- loaded more downstream of Dandaru than in Eleyele. The combination of P_4^{3-} and NO_3^- makes the upper stream sections of Eleyele reservoir and downstream section of Dandaru to be characterized by the high concentration of water hyacinth growing on the reservoir, which indicates a high level of eutrophication.

Sediment analysis further reveals a difference in the concentration of trace elements and nutrients between the outlet and inlet sections of the streams. The findings of Sałata and Dąbek (2017) in an urban Polish stormwater plant agree with our findings in this instance. Their study shows those trace elements loaded more in the inlet channels than in the outlet channels of the study reservoir. Meanwhile, Zhu *et al.* (2019) have suggested that local anthropogenic activities increase the bottom sediments' contamination with heavy metals, especially upstream. This suggestion differs from the findings of Zhao *et al.* (2015) where elements loaded more downstream. These variations in findings could be attributed to the nature of the geological substrate, how the catchment is utilized, and types of atmospheric deposition. The variation in the chemical composition of bottom sediments could also be reflective of strong human impacts (Catianis *et al.*, 2018; Machowski *et al.*, 2019).

Table 6: Threshold indicators of land use

	Eleyele	Dandaru
Mean PEC-Q	7.1	4.8
MPI	2.0	1.8
NPI	71.8	69.5

Table 7: Ecological Threshold indicator

	Eleyele	Dandaru
TRI-Mentals	18.24	15.53
TRI-Nutrients	46.04	40.67

Influence of land use on the concentration of trace elements within reservoirs.

To evaluate the resultant influence of the anthropogenic use of land within the catchment area of Eleyele and Dandaru reservoirs; the Mean Probable Effect Concentration Quotient (Mean PEC-Q), Metal Pollution Index (MPI) and Nutrient Pollution Index (NPI) were used to determine a single concentration value comprising of all trace elements and nutrients for each reservoir (Table 6). The calculated Mean PEC-Q values reveal that both Eleyele (Mean PEC-Q=7.1) and Dandaru (Mean PEC-Q = 4.8) reservoirs exceeded the non-toxic threshold value of Mean PEC-Q which is <0.5 and therefore fall into the class of toxic. The MPI and NPI also indicated a higher value for Eleyele (MPI = 2.0; NMI = 71.8) than Dandaru (MPI = 1.8; NMI = 69.5). The higher Mean PEC-Q and MPI of Eleyele possibly result from the form of land utilization.

Further analysis of the ecological Toxic Risk Index was used to assess the toxic risk of trace elements and nutrients in the bottom sediment samples (Table 7). The reservoirs' ecological toxic index values are under the TRI class of >5. The risk index of the Eleyele reservoir is approximately TRI-Metals = 18.24; TRI-Nutrients =46.04, which falls in the class of very high toxic risk. However, the Dandaru reservoir shows a lower value of ecological risk index

(TRI-Metals = 15.53; TRI-Nutrients =40.67) although it still falls within the TRI class of considerable toxic risk. The overall ecological toxic risk for nutrients can be considered high for both Eleyele (TRI=32.558) and Dandaru (TRI=33.208) reservoirs as their values fall within the TRI class of very high toxic risk. The Wilcoxon W test reveals no significant difference in the ecological toxic risk condition resulting from anthropogenic activities in the sampled reservoirs; W (50) = -0.319, p >0.05 (Table 8).

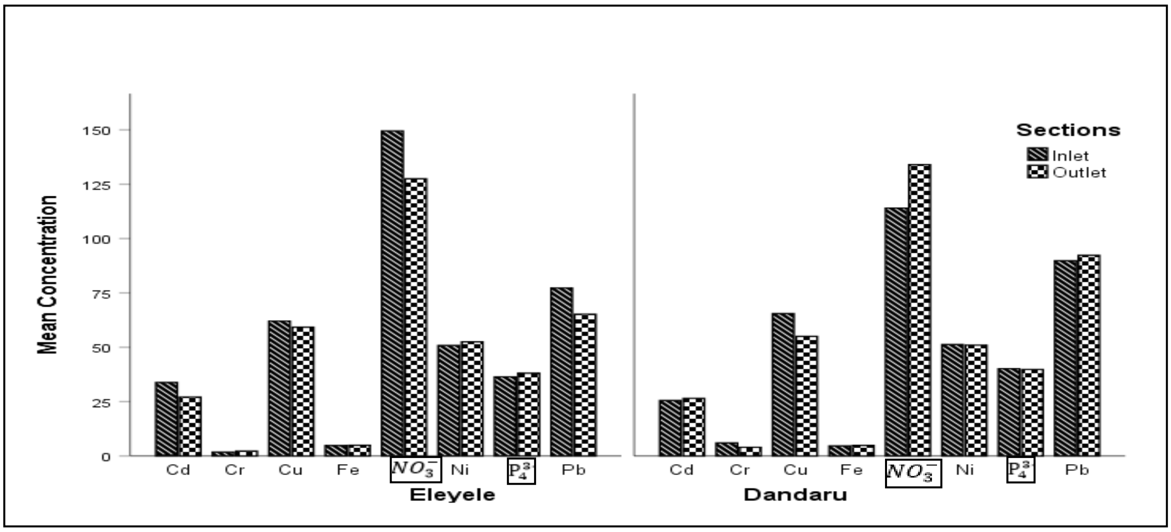

Figure 2: Variation in trace element and nutrient concentration across study sites

Table 8: Test for ecological toxic risk variance between reservoirs

Test Statistics	TRI_Value
Mann-Whitney U	22
Wilcoxon W	50
Z	-0.319
Asymp. Sig. (2-tailed)	0.749
a Grouping Variable: Reservoir1	

The catchment area of Eleyele specifically has experienced highly dynamic land-use changes since 1960 after the establishment of the Eleyele dam in 1942. The State Government set up the State Water Corporation solely for the treatment and supply of potable water within the Eleyele catchment area. However, over the years, these changes in land use have caused the catchment area to undergo a substantial shift from natural vegetation area to urbanization, commercial, and agricultural land uses as a result of an increase in the number of people migrating into the area in search of greener pastures (Olanrewaju *et al.*, 2017; Ojelabi *et al.*, 2018). Thus, there has been an increase in the number of residential buildings within the catchment area; in some cases, existing residential buildings have been reconstructed into commercial buildings, resulting in more releases of untreated effluents into the catchment environment. The presence of high Pb and Fe contaminants in Eleyele Reservoir is indicative of the heavy metal contamination that has developed within the metropolis. The analysis of sediments deposited in water bodies reflects the impact of land-use changes and sources of pollution on the catchment (Nascimento and Mozeto, 2008; Rendina and Fabrizio de Iorio, 2012).

Dandaru reservoir is also currently affected by the presence of government institutions around the catchment area, such as the State Government Secretariat, a University Teaching Hospital, Hotel, and a recreational centre. Dandaru has a laundry and car washing facility, which discharges its dye and detergent-concentrated wastewater into the river situated within its catchment area. This is a clear case of point source discharge and may account for the high phosphorus level recorded at this site. The present land uses in the catchment area have less impact on the release of trace elements into the catchment area, as shown by the low concentration of trace elements in the aquatic ecosystem. This, however, does not mean that the low concentration does not cause adverse ecological effects since the presence of one metal can significantly affect the impact that another metal may have on an organism (Aremu *et al*., 2011; Reynolds *et al*., 2008).

Further analysis of the ecological Toxic Risk Index (TRI) indicates that none of the reservoirs' ecological toxic index values is within a low-risk level. The overall ecological toxic risk for nutrients can be considered high for the Eleyele and Dandaru reservoirs. The high trace element and nutrient concentrations recorded in this study possibly result from the highly uncontrolled anthropogenic activities around the Eleyele catchment area, such as the dumping of human waste and the indiscriminate disposal of refuse. Other activities are resulting in constant land cover changes as naturally-vegetated areas are cleared for local resort centres, cement block moulding industries, crop cultivation, fishing, and dump sites for refuse and scavenges, among others. Overall, the type of land utilization appears to influence the toxic level of the Eleyele and Dandaru environments.

The recent appearance, uncontrolled growth, and boom of water weeds such as hyacinth and algae over the lake section of Eleyele and Dandaru reservoirs is evidence of the massive amount of nutrients released into the catchment area. Further investigation shows that the current situation has resulted in temporary job loss for speed boat drivers and is a significant hindrance to fishing, as fishermen have complained about ferns and water weeds, such as Pistia stratiotes, Scirpus cubensis, and Rhnchospora corymbosa. Fishing in the reservoirs is difficult because water weeds provide a haven for fish to hide, resulting in dwindling catches that negatively impact their business.

The prevailing environmental condition of reservoir catchment as deduced from sediment quality analysis

Regarding the quality of the environment and based on the variables of its computation, the Pollution Load Index (PLI) can serve as a proxy for understanding the prevailing environmental conditions in a catchment area. Eleyele reservoir recorded a higher PLI value than Dandaru reservoir, suggesting poorer environmental quality (Table 9). The lower PLI value of the Dandaru reservoir is possibly due to the reduced presence of anthropogenic activities that cause pollution and expose the environment to trace elements. Also, the presence of environmental control and management, as well as fewer commercial activities taking place in the area surrounding the catchment is possibly responsible for lower pollution.

The higher PLI value and other related toxic level indicators for Eleyele reservoirs are due to the high concentrations of copper (Cu), lead (Pb), nickel (Ni), and phosphate (P) in the sediments. Processes such as smelting, waste incineration, and fossil fuel combustion produce high levels of trace elements. Copper (Cu) and nickel in the Eleyele area are derived from vehicle brake pad wear and car tires, which are used as fuel. Also, auto-mechanic workshops are located along the main access road to Eleyele Dam from the southern axis. Activities at this workshop result in the spillage of engine oil and even condemned oil from vehicles and motorcycle parts during repairs. These land uses continually degrade the Eleyele environment. Other modifications affecting the natural environmental condition in Eleyele include the presence of commercial centres, markets, motor parks, schools, private residences, and a whole cassava processing community located about 500m away from the dam that disposes waste into the environment. These uncontrolled and indiscriminate anthropogenic activities in the Eleyele area contribute to the increase in trace elements and nutrients (Olanrewaju *et al.*, 2017). In support of these findings, Saleem *et al.* (2018) report a relatively high heavy metal content at sites adjacent to urban and semi-urban areas. These heavy metals may also come from the discharge of untreated urban or industrial wastes and agricultural runoff.

Table 9: Concentration Factor (CF) of Pollution Load Index (PLI)

Location	Concentration Factor (CF)								PLI
	P_4^{3-}	NO_3^-	Pb	Cd	Ni	Cu	Fe	Cr	
Eleyele									
Station A	331.00	15.90	4.10	103.67	0.75	1.39	0.00	0.02	5
Station B	397.00	14.00	3.63	121.67	0.75	1.37	0.00	0.02	
Station C	391.00	12.50	3.64	109.00	0.79	1.32	0.00	0.01	
Station D	371.00	13.00	2.89	71.67	0.75	1.31	0.00	0.04	
Dandaru									
Station E	383.00	11.30	4.38	93.50	0.75	1.56	0.00	0.11	4
Station F	420.00	11.50	4.60	76.67	0.76	1.36	0.00	0.02	
Station G	398.00	13.40	4.62	88.33	0.75	1.22	0.00	0.04	

Agricultural activities in the Dandaru catchment area may be responsible for high NO_3^- and P_4^{3-} in that environment due to the phosphate content of fertilizers and the chemicals used to improve the detergent performance (Abowei and Sikoki, 2005; Ezekiel *et al.*, 2011). The findings of Ayoade and Nathaniel (2018) suggest that the water and sediment of the Dandaru Reservoir are contaminated with trace elements (Pb, Cd, and Zn) from various livelihood activities along the Ogunpa River watershed.

CONCLUSION

Research on the ecotoxicological level of tested trace elements and nutrients confirmed Pb, Ni, and Cu are above the specified limits for the lowest, probable and severe threshold effect levels of the Sediment Quality Guidelines (SQGs) in sampled reservoirs. The Maximum Concentration Level (MCL) revealed a higher ecotoxicological concentration for P_4^{3-} and NO_3^-. The impacts of anthropogenic activities on the enrichment of trace elements and nutrients of bottom sediment are hypothesized to result in a significant difference in the accumulation of trace and nutrient elements in bottom sediments across sample stations in the commercial and institutional catchment areas. A one-way ANOVA test of the elements in different stations reveals that there is a significant difference in the concentration of trace elements and nutrients across the sampled stations. Further analysis shows a difference in the concentration of trace elements and nutrients between the outlet and inlet sections of the streams. The ecological Toxic Risk Index (TRI) indicates that none of the reservoirs' ecological toxic index values is within a low-risk level. Meanwhile, the Mean Probable Effect Concentration Quotient (Mean PEC-Q), Metal Pollution Index (MPI), and Nutrient Pollution Index (NPI) reveal that both reservoirs exceed the non-toxic threshold value. The higher Mean PEC-Q and Metal Pollution Index (MPI) of Eleyele (commercial land use) result from the form of land utilization. The Dandaru Reservoir (institutional land use) is surrounded by an agricultural and forest catchment, so the contamination of its sediments with heavy metals seems relatively small.

In determining the prevailing environmental quality in the studies' catchment area, the PLI value of the Dandaru reservoir (institutional) and the threshold indicators analyzed in this study recorded a low pollution level compared with the Eleyele catchment area (commercial) – and suggesting that the commercial area is more degraded than the institutional one. The commercial catchment area, specifically, has experienced highly dynamic land-use changes over the years. As a result of these changes in land use, the catchment area has shifted significantly from natural vegetation to urbanization, commercial, and agricultural land use, resulting from an influx of migrants looking for greener pastures. Our analysis suggests that sample stations differ in exposure to contaminant inflow, which could explain the variation of heavy metals and nutrients within and around the study catchment areas. Over time, environmental exposure to contaminants has contributed to the poor environmental quality prevailing within and around the catchment areas. This study shows that anthropogenic activities have a significant impact on the composition of reservoir bottom sediments – and thus sediment composition could serve as an indicator of the impact of land-use changes and corresponding environmental quality within reservoir catchments, especially in tropical developing economies where multiyear environmental monitoring data is sparse.

References

Abowei, J. F. N., and Sikoki, F. D. (2005). Water Pollution Management and Control. *Double Trust. Publication Company, Port Harcourt*, 234.

Alshikh, A., and Yousef, O. . (2017). Histological changes induced by heavy metals in fishes at Red Sea Jazan. *KSA. Life Sci J*, *10*(3), 1918–1923.

Apitz, S., and White, S. (2014). A conceptual framework for river-scale sediment management. *J Soils & Sediments*, *3*, 132–138.

Aremu, M. O., Atolaiye, B. O., Gav, B. L., Opaluwa, O. D., Sangari, D. U., and Madu, P. C. . (2011). Metal concentrations in sediments and water from Rivers Doma, Farinruwa and Mada in Nasarawa State, Nigeria. *Journal of Environmental Chemistry and Ecotoxicology*, *3*(9), 242–249.

Ayoade, A., and Nathaniel, O. (2018). Assessment of Heavy Metals Contamination Of Surface Water And Sediment Of A Tropical Manmade Lake Southwestern Nigeria. *International Journal of Environment and Pollution Research*, *6*(3), 1–16.

Bai, J., Cui, B., Chen, B., Zhang, K., Deng, W., Gao, H., and Xiao, R. (2011). Spatial distribution and ecological risk assessment of heavy metals in surface sediments from a typical plateau lake wetland, China. *Ecological Modelling*, *222*(2), 301–306.

Ballantine, D. J., Walling, D. E., Collins, A. L., and Leeks, G. J. L. (2008). The phosphorus content of fluvial suspended sediment in three lowland groundwater-dominated catchments. *Journal of Hydrology*, *357*(1), 140–151.

Balogun, K. J., Ladigbolu, I. A., and Ariyo, A. A. (2011). Ecological assessment of a coastal shallow lagoon in Lagos, Nigeria : A bio-indicator approach. *Journal of Applied Sciences and Environmental Management*, *15*(1), 41–46. https://doi.org/10.4314/jasem.v15i1.65673

Birch, G.F. and Apostolatos, C., 2013. Use of sedimentary metals to predict metal concentrations in black mussel (Mytilus galloprovincialis) tissue and risk to human health (Sydney estuary, Australia). *Environmental Science and Pollution Research*, *20*(8), pp.5481-5491.

Catianis, I., Secrieru, D., Pojar, I., Grosu, D., Scrieciu, A., Pavel, A. B., and Vasiliu, D.

(2018). Water quality, sediment characteristics and benthic status of the razim-sinoie lagoon system, Romania. *Open Geosciences*, *10*(1), 12–33. https://doi.org/10.1515/geo-2018-0002

Chuan, O. M., and Yunus, K. (2019). Sediment and Organisms as Marker for Metal Pollution. *In Monitoring of Marine Pollution* (Vol. 32).

Etim, E. U., and Onianwa, P. C. (2013). Impact of Effluent of an Industrial Estate on Oruku River in Southwestern Nigeria. 21(7), 1075–1083.

Ezekiel, E., Hart, A. ., and Abowei, J. (2011). The Sediment Physical and Chemical Characteristics in Sombreiro River, Niger Delta, Nigeria. *Research Journal of Environmental and Earth Sciences, 3*(4), 341–349.

Fabijańczyk, P., Zawadzki, J., and Wojtkowska, M. (2016). Geostatistical study of spatial correlations of lead and zinc concentration in urban reservoir . Study case Czerniakowskie Lake , Warsaw , Poland. 484–492. https://doi.org/10.1515/geo-2016-0043.

Fajer, M. and Rzetala, M.A., 2018. Mill pond sediments as the indicator of the environment of the drainage area (an example of Liswarta River, Odra basin, Poland). *Environmental Science and Pollution Research*, *25*(6), pp.5832-5847.

Fashae, O. ., Ayorinde, H. ., Olusola, A. ., and Obateru, R. . (2019). Land use and surface water quality in an emerging urban city. *Applied Water Science*, *9*(2), 25.

Fashae, O. A., Ayomanor, R., and Orimoogunje, O. Uwagbeng. O. I. (2017). Land Use Dynamics and Surface Water Quality in a Typical Urban Centre of South-Western, Nigeria. *Analele Universităţii Din Oradea: Seria Geografie*, *7*(1).

Franz, C. (2015). Sediments in a fast urbanizing catchment in Central Brazil – an analysis of anthropogenic impacts on sediment geochemistry and sediment sources (Vol. 2015)

Isiuku, B. O., and Enyoh, C. E. (2020). Pollution and health risks assessment of nitrate and phosphate concentrations in water bodies in South Eastern, Nigeria. *Environmental Advances*, *2*(August), 100018.

Jenyo-Oni, A. and Oladele, A.H., 2016. Heavy metals assessment in water, sediments and selected aquatic organisms in Lake Asejire, Nigeria. *European Scientific Journal*, *12*(24).

Lawniczak-Malińska, A., Ptak, M., Celewicz, S., and Choiński, A. (2018). Impact of Lake Morphology and Shallowing on the Rate of Overgrowth in Hard-Water Eutrophic Lakes. In *Water* (Vol. 10, Issue 12).

Li, F., Huang, J., Zeng, G., Yuan, X., Li, X., Liang, J., Wang, X., Tang, X., and Bai, B. (2013). Spatial risk assessment and sources identification of heavy metals in surface sediments from the Dongting Lake, Middle China. *Journal of Geochemical Exploration*, *132*, 75–83.

Long, E.R., Field, L.J. and MacDonald, D.D., 1998. Predicting toxicity in marine sediments with numerical sediment quality guidelines. *Environmental Toxicology and Chemistry: An International Journal*, *17*(4), pp.714-727.

Maanan, M., Saddik, M., Maanan, M., and Chaibi, M. (2014). Environmental and ecological risk assessment of heavy metals in sediments of Nador lagoon, Morocco. *Ecological Indicators*, *48*, 616–626.

MacDonald, D. D., and Ingersol, C. G. (2002). EPA A Guidance Manual to Support the Assessment of Contaminated Sediments in Freshwater Ecosystems A Guidance Manual to Support the Assessment of Contaminated Sediments in Freshwater Ecosystems (C. G. Ingersoll and D. D. MacDonald (eds.)). MacDonald MacDonald Environmental Sciences Ltd.

Machowski, R., Rzetala, M. A., Rzetala, M., and Solarski, M. (2019). Anthropogenic enrichment of the chemical composition of bottom sediments of water bodies in the neighborhood of a non-ferrous metal smelter (Silesian Upland, Southern Poland). *Scientific Reports*, *9*(1), 1–13.

Mariusz, S., Joanna, J., and Siepak, M. (2019). Heavy Metals in Bottom Sediments of Reservoirs in the Lowland Area of Western Poland : Concentrations. *Sustainability*, 1–20. https://doi.org/10.3390/w11010056

Nascimento, M. R. ., and Mozeto, A. . (2008). Reference values for metals and metalloids concentrations in bottom sediments of Tiete river basin, Southeast of Brazil. Soil Sediment Contam. *Soil Sediment Contam*, *17*(3), 269–278.

Ojelabi, S. A., Agbede, O. A., Wahab, B. A., Aiyelokun, O. A., and Ojelabi, O. . (2018). Water Quality Assessment of Eleyele Dam, Ibadan, South-Western, Nigeria. *Civil and Environmental Research*, *10*(8), 52–59.

Olanrewaju, A., Ajani, E., and Kareem, O. (2017). Physico-Chemical Status of Eleyele Reservoir, Ibadan, Nigeria. *Journal of Aquaculture Research & Development*, *08*(09).

Olayinka, O. O., Adedeji, H. O., Akinyemi, A. A., and Oresanya, O. J. (2017). Assessment of the pollution status of Eleyele Lake, Ibadan, Oyo State, Nigeria. *Journal of Health and Pollution*, *7*(15), 51–62.

Rendina, A., and Fabrizio de Iorio, A. (2012). Heavy metal partitioning in bottom sediments of the Matanza-Riachuelo River and main tributary streams. *Soil Sediment Contam*, *21*(1), 62–81.

Reynolds, K. A., Mena, K. D., and Gerba, C. P. (2008). *Risk of Waterborne Illness Via Drinking Water in the United States BT - Reviews of Environmental Contamination and Toxicology* (D. M. Whitacre (ed.); pp. 117–158). Springer New York.

Rzetala, M. A. (2015). Assessment of Toxic Metal Contamination of Bottom Sediments in Water Bodies in Urban Areas. *Soil and Sediment Contamination: An International Journal*, *24*(1), 49–63.

Sałata, A., and Dąbek, L. (2017). Methods of assessment sediments quality of stormwater. *Methods of Assessment of Stormwater Sediments Quality.In E3S Web of Conferences*, *17*, 00080. https://doi.org/: 10.1051/e3sconf/20171700080

Saleem, M., Iqbal, J., Akhter, G., and Shah, M. H. (2018). Fractionation, bioavailability, contamination and environmental risk of heavy metals in the sediments from a freshwater reservoir, Pakistan. *Journal of Geochemical Exploration*, *184*, 199–208.

Singovszka, E., Balintova, M., Demcak, S., and Pavlikova, P. (2017). Metal Pollution Indices of Bottom Sediment and Surface Water Affected by Acid Mine Drainage. *Metals*, *15*.

Taylor, S.R. and McLennan, S.M., 1995. The geochemical evolution of the continental crust. *Reviews of geophysics*, *33*(2), pp.241-265.

Thongra-ar, W., Musoka, C., and Wongsudawan, W. Munhapon, A. (2015). Distribution and accumulation of some heavy metals in mangrove sediments of Ban Laemchabang community, Chon Buri Province. *In Proceedings of the Burapha University International Conference 2015: Moving Forward to a Prosperous and Sustainable Community, Burapha University, Chon Buri, Thailand*, 780–788.

Tomlinson, D.L., Wilson, J.G., Harris, C.R. and Jeffrey, D.W., 1980. Problems in the assessment of heavy-metal levels in estuaries and the formation of a pollution index. *Helgoländer meeresuntersuchungen*, *33*(1), pp.566-575.

Turekian, K. K., and Wedepohl, K. . (1961). Distribution of the elements in some major units of the earth’s crust. *Geological Society of America Bulletin*, *72*, 175–192.

USEPA. (2000). Prediction of sediment toxicity using consensus-based freshwater sediment quality guidelines. In *U.S. Environmental Protection Agency, Great Lakes National Program Office, Chicago, IL. EPA 905/R-00/007.*

Ward, C. H. (2017). Habitats and biota of the Gulf of Mexico: Before the deepwater horizon oil spill. In *Habitats and Biota of the Gulf of Mexico: Before the Deepwater Horizon Oil*

Spill (Vol. 1, Issue Usepa 1989).

Wong, C.S., Li, X. and Thornton, I., 2006. Urban environmental geochemistry of trace metals. *Environmental pollution*, *142*(1), pp.1-16.

Worakhunpiset, S. (2018). Trace elements in marine sediment and organisms in the gulf of Thailand. *International Journal of Envi. Research and Public Health*, *15*(4), 1–15.

Yesuf, H. M., Assen, M., Alamirew, T., and Melesse, A. M. (2015). Modeling of sediment yield in Maybar gauged watershed using SWAT, northeast Ethiopia. *CATENA*, *127*, 191–205.

Yu, J., Fu, Y., Li, Y., Han, G., Wang, Y., Zhou, D., Sun, W., Gao, Y. and Meixner, F.X., 2011. Effects of water discharge and sediment load on evolution of modern Yellow River Delta, China, over the period from 1976 to 2009. *Biogeosciences*, *8*(9), pp.2427-2435.

Zhang, C., Qiao, Q., Piper, J. D. A., and Huang, B. (2011). Assessment of heavy metal pollution from a Fe-smelting plant in urban river sediments using environmental magnetic and geochemical methods. *Environmental Pollution*, *159*(10), 3057–3070.

Zhao, S., Zhu, L., and Li, D. (2015). Microplastic in three urban estuaries, China. *Environmental Pollution*, *206*, 597–604.

Zhu, H., Bing, H., Wu, Y., Zhou, J., Sun, H., Wang, J., and Wang, X. (2019). The spatial and vertical distribution of heavy metal contamination in sediments of the Three Gorges Reservoir determined by anti-seasonal flow regulation. *Science of The Total Environment*, *664*, 79–88.

Ziemińska-Stolarska, A., Imbierowicz, E., Jaskulski, M., and Szmidt, A. (2020). Assessment of the Chemical State of Bottom Sediments in the Eutrophied Dam Reservoir in Poland. *International Journal of Environmental Research and Public Health*, *17*(10), 3224.