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# Quality Assessment of Deposited Surface Sediment in Badagry Creek Ecosystem, Southwest Nigeria

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***Author's contribution***

*The sole author designed, analyzed and interpreted and prepared the manuscript.*

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## ABSTRACT

**Aims:** Sediment quality of Badagry creek under diffuse sources of suspected contamination was assessed for ecosystem health, using their particles sizes, organic carbon and metal distribution characterization.
**Study Design:** Stratified random sampling.
**Place and Duration of Study:** Three (3) sampling stations were established in upper, middle and lower zones of Badagry creek, Nigeria and sampled bi-monthly from November, 2011 to September, 2013 between the hours of 9.00 am and 12.00 noon.
**Methodology:** Sediment samples were collected using a Van-Veen grab in the selected study stations and conveyed to the laboratory for preparation, digestion and analysis using standard methods. Samples were analysed using different mesh sizes sieves, titration method and Atomic Absorption Spectrophotometer for particle size, organic carbon and metals, respectively. Sediment quality guidelines for marine and estuarine sediments and metals sediment quality criteria for marine sediments from Romanian national waters were used in describing the possible contamination levels of elements.
**Results:** Sand dominated the sediment particle sizes. The mean values for the upper, middle and lower zones respectively were 2.72, 2.20 and 2.93% for organic carbon, 5185.30, 4097.10 and 4475.50 mg/kg for Fe, 10.63, 6.94 and 7.26 mg/kg for Cu, 39.47, 35.16 and 33.7 9 mg/kg for Pb,

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27.47, 6.45 and 6.45 mg/kg for Zn, 116.37, 96.31 and 96.31 mg/kg for Cr and 0.02, 0.08 and 0.32 mg/kg for Cd. Seasonal variations were organic carbon 2.45 ± 0.91%; 2.78 ± 0.83%, Fe 4406.76 ± 676.64 mg/kg; 3182.99 ± 1736.65 mg/kg, Cu 8.40 ± 4.13 mg/kg; 8.16 ± 4.04 mg/kg, Pb 29.29 ± 16.78 mg/kg, Zn 29.35 ± 12.09 mg/kg; 12.22 ± 3.79 mg/kg, Cr 92.29 ± 89.64 mg/kg; 109.35 ± 77.84 mg/kg and Cd 0.09 ± 0.09 mg/kg; 0.01 ± 0.09 mg/kg for dry and wet seasons, respectively. Significant differences ($P < 0.05$) were observed in silt and Zn among zones and seasons. While sand and Fe differed significantly among zones, Pb and Cd differed significantly between seasons. The metals mean concentrations decreased in the order; Fe>Cr>Pb>Zn>Cu>Cd, and except for Cr and Pb, were below their corresponding effect range level (ERL) values in the sediment quality guidelines, indicating toxic effect on aquatic organisms will rarely occur from these metals.
**Conclusion:** Cr and Pb could possibly have adverse effects on aquatic organisms in the study area. Regular sediment quality monitoring is recommended.

*Keywords: Deposited sediment; trace metals; Badagry creek ecosystem; contaminants.*

## 1. INTRODUCTION

Sediment plays an essential role in terms of maintaining the structure and function of aquatic ecosystems [1]. Sediment are an integral part of the aquatic environment providing habitat, feeding, and rearing areas for shellfish, fish and other fauna [2]. Considering the important roles they play in marine environment, it is undisputed that sediments represent essential elements of aquatic ecosystems. On the other hand, sediments serve as sink and sources of organic and inorganic materials in water bodies [3]. Sediments contain many contaminants and therefore pose the highest risk to the aquatic environment as a source of pollution [4]. Their remediation proves to be problematic due to the persistence and non-degradability of trace metals in the environment [5]**.** Trace metal pollution in aquatic ecosystems is markedly reflected by higher metal levels in sediments, macrophytes and benthic animals than concentrations in water. Higher concentrations of trace metals in biota can be linked to high concentration in sediments [6]. The bio-availability of metal loads in sediments influences the distribution and composition of benthic assemblage of aquactic water bodies [7]. The most obvious effect of sediment contamination is the reduction in the diversity of biological species that are unable to tolerate the toxicants [8].

Nigeria is endowed with abundant water-bodies which form excellent habitat for numerous fish species and other aquatic fauna and flora. However, these water bodies are subject to multipurpose usage and therefore, prone to various degrees of environmental pollution and degradation that are hazardous to aquatic life [6]. Contaminants are introduced into aquatic ecosystems through many routes such as industrial, municipal and domestic wastewaters, dredging activities, spills, storm water run-offs, airborne depositions and solid wastes [9]. In aquatic ecosystems, contaminants occur in sediment pore spaces in solution. They are also bounded to sediment particles and in the overlying water. Hence, the contaminated sediments in aquatic ecosystems pose potential hazards to sediment-dwelling organisms (epibenthic and infaunal invertebrate species), aquatic-dependent wildlife species (fish, amphibians, reptiles, birds, and mammals), and human health [10].

Badagry creek is located in the Western-most of the barrier lagoon complex (one of the four coastal geomorphic divisions in Nigeria). The creek with an estimated size of 1875ha supports the artisanal fisheries, water transportations and cultural heritages in the area [6]. It provides the communities with numerous benefits. In addition to direct use, the creek replenishes the ground water table and influencing the climate of the city. The creek shore is lined with communities whose livelihood depends on the creek resources. In recent times, increasing urbanization, industrialization and intensive exploitation of natural resources as a result of considerable population growth has threatened the productive capacity of Badagry creek. Human activities along the shores such as indiscriminate direct discharge of faeces, sewage and domestic waste and sand mining activities could undermine the ecological integrity of the creek. Sediment quality is closely linked to the water quality, as many water-borne pollutant and nutrient species are predominately associated with particulate matter that can settle and become sediment [11].

Sediment analysis is important in evaluating qualities of aquatic ecosystem because it reflects

the long term quality situation. In recent times, environmentalists and regulatory agencies are increasingly interested in sediment quality. The present study therefore aimed at assessing the characterization and quality of sediment in Badagry creek, for ecosystem health.

## 2. MATERIALS AND METHODS

### 2.1 Study Area

Badagry creek (Fig. 1) is located in Lagos state, South-Western Nigeria between longitude (2°42¹; 3°23¹E) and latitude (6°23¹; 6°28¹N). The creek begins the Barrier Lagoon Complex which lies between Badagry and Ajumo east of Lekki town in Nigeria. It is estimated to be more than 51 km from Lagos. The creek is fed mainly by Yewa River in Nigeria while it also links Ologe lagoon. It is bounded in the north by the Egbado plateau and in the west by River Yewa via Ologe lagoon. In the southern boundary is the Atlantic Ocean and in the east, bounded by the expanse of the mangrove swamp [12]. Vegetation is found over the low lying plains and marshes around the creek. The predominant vegetation along the shorelines are made up of woody plants, shrubs, coconut and oil palm trees in the sandy areas [6], while the marshy areas are covered by white mangrove (*Avecenia* spp.). Increasing developmental and construction activities, such as houses, hotels and resorts along the study area are potential sources of contaminant input to the creek.

### 2.2 Collection of Sediment Samples

Samples were collected between the hours of 9.30 am and 12.00 noon, bi-monthly (once in two months) from November 2011 to September 2013 from three designated points /stations randomly selected in each of the three zones (upper, middle and lower) of Badagry creek (Fig. 1). The study site was divided into three zones: upper, middle and lower zones based on water depth and horizontal salinity range [6]. The three designated points /stations were arranged within locally homogeneous subdivisions of the study area to best represent the condition and characteristics of the area. The exact locations of the stations were fixed with the aid of the Global Positioning System (Pro Marine SporTrak GPS, Model IEC-529 IPX7) Kit. Some morphometric features of the nine (9) stations studied are shown in Table 1.

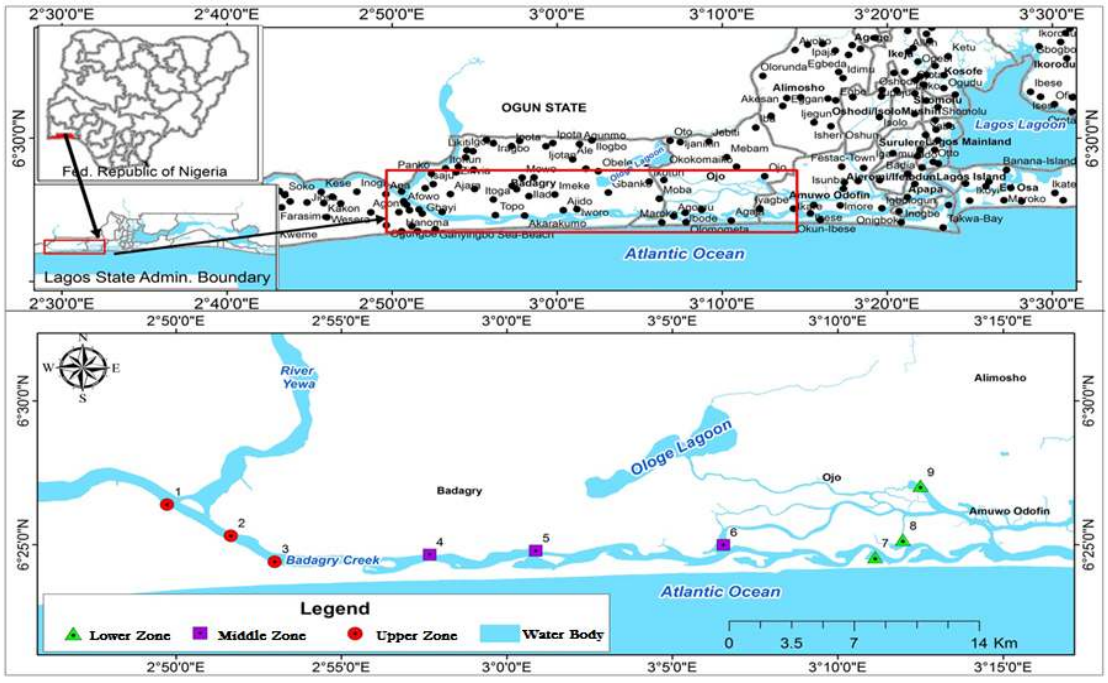


**Fig. 1. Map of Badagry creek and its environs showing the sampling stations**

*Upper zone: Stations 1(Apa), 2(Gbaji), 3(Badagry).*
*Middle zone: Stations 4(Akarakunmo), 5(Ajido), 6(Irewe).*
*Lower zone: Stations 7(Igbolobi), 8(Iyagbe), 9(Ojo).*

**Table 1. Some morphometric features of the studied stations**

| Zone | Station | Approximate distance from community (M) | Co-ordinates | Maximum depth (M) | Mean depth (M) | Elevation |
|---|---|---|---|---|---|---|
| Upper | 1 (Apa) | 150 m | 6°26'21.0"N 2°49'44.7"E | 4.65 | 2.98 | 3.4 m |
| | 2 (Igbaji) | 100 m | 6°25'14.6"N 2°51'37.9"E | 9.52 | 6.72 | 7.7 m |
| | 3 (Badagry) | 150 m | 6°24'22.0"N 2°53'04.0"E | 8.84 | 6.52 | 9.2 m |
| Middle | 4 (Akarakumo) | 100 m | 6°24'37.0"N 2°57'40.9"E | 5.4 | 4.08 | 9.9 m |
| | 5 (Ajido) | 100 m | 6°24'48.6"N 3°00'30.0"E | 3.31 | 2.37 | 6.6 m |
| | 6 (Irewe) | 200 m | 6°25'16.9"N 3°08'38.4"E | 4.70 | 3.33 | 9.2 m |
| Lower | 7 (Igbolobi) | 150 m | 6°24'35.7"N 3°11'07.4"E | 2.95 | 1.38 | 5.3 m |
| | 8 (Iyagbe) | 200 m | 6°25'09.5"N 3°11'56.1"E | 4.12 | 2.32 | 2.5 m |
| | 9 (Ojo) | 150 m | 6°27'02.9"N 3°12'30.6"E | 4.25 | 1.64 | 8.2 m |

Sediment samples were collected with a stainless steel Van-veen grab from an anchored outboard boat at each sampling station. Replicates of sediment samples were taken for sediment characterization of grain size, organic carbon and trace metals determnation. The grab was rinsed thoroughly before redeployment in another station [13]. Samples were stored in well labelled metal free polyethylene bags for trace metals determination and in aluminium foils for organic constituents. Samples were then transported in a cooler box to the Nigerian Institute for Oceanography and Marine Research, Department of Biological Oceanography laboratory.

Monthly rainfall data measured in millimeter of the study area for the study periods were obtained from the Nigerian Meteorological (NIMET) Office, Oshodi, Lagos. Based on the rainfall pattern of the study area, November to April was designated as dry season period while May to October as wet season period.

## 2.3 Sediment Samples Preparation and Analyses

The samples were air-dried at room temperature, homogenized and sub-sampled for metal analysis, organic carbon content and sediment grain size distribution prior to analysis.

The granulometric analysis of each set of sediment samples from the nine sampling sites was carried out following the procedures described in [14]. Grain size analysis was performed based on a series of sieves of different mesh sizes [14].

Total organic carbon content of the sediment was determined using the Walkley – Black method [15]. 0.5 g of sediment samples was sieved through a 2 mm mesh-size before weighing into a 250 ml conical flask. A mixture of 10 ml of potassium dichromate ($K_2Cr_2O_7$) and 20 mL $H_2SO_4$ was added and left to stand for 30 minutes on asbestos after intermittent swirls. 100 ml of distilled water was added. To this was added 3 - 4 drops of ferrous indicator and titrated with 0.5 N ferrous ammonium sulphate ($FeSO_4.7H_2O$) until it goes from green to light green and finally to maroon red or brown (end point). The difference between added and residual potassium dichromate ($K_2Cr_2O_7$) gave a measure of organic carbon content of the sediment.

## 2.4 Acid Digestion and Determination of Metals

For metals, samples were digested in a mixture of concentrated acids in triplicates, according to methods described by USEPA [16]. For each sediment sample, 1 g of dried sediment sample fully crushed to the finest fraction using an acid-washed porcelain mortar and pestle was weighed into 250 ml acid cleaned beaker. 20 ml of a 4:1 mixture of concentrated nitric acid (Analytical grade) and hydrochloric acid was added and left overnight at room temperature. The beaker containing the mixture was then heated on a hot plate in fume hood at 120℃ to 5 ml. After digestion and subsequent cooling of samples to room temperature, the digested samples were each filtered using Whatman filter paper no. 41 into a 25 ml volumetric flask and made up to the mark with de-ionized water. A blank solution was similarly prepared. The filtrates were then each transferred into polyethylene bottles and refrigerated at 4℃ till metal analysis.

Prior to metal determination, working standard solutions for system calibration and control of analytical accuracy were prepared from the certified standard of Fe, Cu, Pb, Zn, Cr and Cd supplied by PG Instruments with each in neat

form of 1000 mg/l respectively by serial dilutions in distilled water.

The instrument calibration was done using working standard solutions of known and increasing concentrations for each analyte element of interest in order to determine the instrument signal response to changes in concentration. In measuring the signals of the working standards, the Atomic Absorption Spectrophotometer (AAS) constructs a suitable calibration curve of absorbance verses concentration. The AAS uses this suitable graph to determine concentrations of unknown analyte.

The concentrations of Fe, Cu, Pb, Zn, Cr and Cd in the digested sediment (filtrates) for each set of samples were measured on Atomic Absorption Spectrophotometer (Model PG-990) unit by comparing their absorbance's with those of standards. All the instrumental adjustments had been as recommended in the manual by the manufacturer. For Quality Assurance/Quality Control (QA/QC) purposes, AAS standard solutions (factory prepared) were run as samples for accuracy check after every five samples measurements [16]. The detection limit was taken to be 3s where s is the standard deviation of the blank. Hence instrumental detection limits in mg/kg for Fe, Cu, Pb, Zn, Cr, and Cd were 0.0046, 0.004, 0.012, 0.003, 0.005, and 0.0028 respectively.

Additionally, the chemical contaminations in the sediments were evaluated by comparison with the unpolluted sediment and standard values reported by GESAMP [17], Salomons and Förstner [18] and EPA [19] respectively.

In further describing the possible contamination levels of metals in the study, the metals concentration were compared with sediment quality guidelines (SQGs) for marine and estuarine sediments reported by Long et al. [20] and trace metals sediment quality criteria (SQC) proposed as GES (Good Environment Status) boundaries for the marine sediments from Romanian national waters. SQGs include ERL (effect range low) and ERM (effect range medium) which are general guidelines for evaluating sediment contamination. ERL represent concentrations below which a toxic effect on aquatic organisms will rarely occur, while ERM refer to concentrations above which adverse effects are likely to occur [20].

Sediment quality criteria are used to make the initial screening of risk to aquatic life from contaminants in sediment. If the concentrations of all of the metals are below the Level 1 threshold values, the sediment is considered to present a low risk to aquatic life (i.e. GES). If the concentration of one or more metals exceeds the Level 2 threshold values, then the sediment is considered highly contaminated, and likely to present a high risk to aquatic life (i.e. non-GES). If the concentration of one or more metals lies between the Level 1 and Level 2 threshold values and no contaminants exceed the Level 2 threshold values, then the sediments are considered to be moderately contaminated (i.e. non-GES).

## 2.5 Statistical Analysis

Statistical analysis was done using an IBM SPSS Statistics 20 version. All data were tested using normality and equal variance tests. Data were then subjected to one way analysis of variance (ANOVA) and significant differences accepted at $P \leq 0.05$ [21]. The mean values were separated using post-hoc Tukey's (HSD) test, where significant differences were found. Correlation analysis was done to determine associations among various variables measured. The particles size distribution (%), organic carbon (%) and metal concentrations (mg/kg dry mass) values are presented as Means ± SD.

## 3. RESULTS

The results of the grain size analyses, organic carbon and metals content in Badagry creek, Nigeria are presented in Tables 2 and 3.

Clay content ranged from 0 (zero) in November, 2011 at station 2, 3, 4 and 6 (Igbaji, Badagry, Akarakumo and Irewe) to 16% at station 2 and 6 (Igbaji and Irewe in January, 2013) and station 5 (Ajido in March, 2013). Silt ranged from 0.0% at station 2 (Igbaji) in November, 2011 and January, 2012 to 26% in January, 2012 at station 7 (Igbolobi). While the highest sand content of 100% was obtained in November, 2011 and January, 2012 at station 8 (Igbaji), the lowest of 62% occurred at station 7 (Igbolobi) in January, 2012. Organic carbon varied from 0.32% in January, 2012 at station 2 (Igbaji) to 8.90% at station 7 (Igbolobi) in November, 2011.

Iron concentration in this study was from 463.02 to 7519.95 mg/kg. The highest and lowest were

recorded at station 1 (Apa) in March, 2012 and January, 2013 respectively. Copper content varied between 1.07 mg/kg at station 8 (Iyagbe) in November, 2011 and 27.03 mg/kg in March, 2012 at station 1 (Apa). Lead concentration was from below detection limit (BDL) at stations 5 and 8 (Ajido and Iyagbe) in January, 2012, stations 3, 4 and 5 (Badagry, Akarakumo and Ajido) in September, 2012, stations 1, 3, 4, 5 and 7 (Apa, Badagry, Akarakumo, Ajido and Igbolobi) in September, 2013 to 101.31 mg/kg at station 1 (Apa) in July, 2013. Zinc levels was from below detection limit (BDL) in several stations and sampling months to 98.58 mg/kg at station 1 (Apa) in January, 2012. Chromium concentration varied between 2.36 mg/kg and 303.52 mg/kg. The lowest and highest values were recorded at station 9 (Ojo) in November, 2011 and station 1 (Apa) in March, 2012 respectively. Cadmium contents were from below detectable limits (BDL) to 1.43 mg/kg. Cadmium levels were detected at station 3 (Badagry) in November, 2012; station 4 (Akarakumo) in January, 2012; station 6 (Irewe) in November, 2011, January, 2013 and September, 2013; and station 9 (Ojo) in November, 2011, January, 2012 and November, 2012.

The mean concentrations of clay (Table 2), showed gradual increase in the upper zone (4.25 ± 2.15%) to the lower zone (6.18 ± 1.44%), with seasonality mean clay content of 5.43 ± 2.51% in the dry season, which was slightly higher than the wet season values of 5.37 ± 1.31%. The average values of silt (Table 2) slightly varied from upper zone (2.77 ± 0.96%) and middle zone (2.77 ± 0.64%) to lower zone value of 5.28 ± 3.31%. Dry season mean silt (4.34 ± 1.20%) was higher than wet season 2.85 ± 0.70% value (Table 3). Sand mean value (Table 2) gradually decreased from the upper zone (92.93 ± 3.06%) to the lower zone (88.66 ± 3.86%). Wet season mean sand value of 91.83 ± 1.99% was higher than the dry season (90.23 ± 1.98%). While the lowest mean organic carbon value (Table 2) was recorded at middle zone (2.20 ± 0.87%), the highest mean of 2.93 ± 1.27% was obtained at lower zone. The mean organic carbon of 2.78 ± 0.83 % in the wet season was higher than the dry season mean value of 2.45 ± 0.91% (Table 3).

Iron mean values (Table 2) was highest at upper zone (5185.30 ± 1144.90 mg/kg) and lowest at middle zone (4097.10 ± 788.01 mg/kg). Wet season iron mean content (3182.99 ± 1736.65 mg/kg) was higher than the dry season (4406.76 ± 676.64 mg/kg) value (Table 3). Copper lowest mean value of 6.94 ± 4.19 mg/kg (Table 2) was obtained at the middle zone and the highest average at upper zone (10.63 ± 5.15 mg/kg). Copper dry season mean value of 8.40 ± 4.13 mg/kg was greater than 8.16 ± 4.04 mg/kg mean recorded for wet season (Table 3). The mean Lead content (Table 2) gradually decreased from the upper zone (39.47 ± 27.95 mg/kg) to the lower zone (33.79 ± 19.12 mg/kg). Wet season mean lead concentration (45.40 ± 21.45 mg/kg) exceeded 29.29 ± 16.78 mg/kg for dry season (Table 3). Zinc average levels were (27.47 ± 26.39 mg/kg), (6.45 ± 11.48 mg/kg), and (5.64 ± 5.21 mg/kg) for upper, middle and lower zone respectively (Table 2). Dry season zinc mean content (29.35 ± 12.09 mg/kg) was higher than the wet season (12.22 ± 3.79 mg/kg) value (Table 3). The mean concentration of chromium (Table 2) gradually increased from the lower zone (89.78 ± 76.45 mg/kg) to the upper zone (116.37 ± 91.86 mg/kg). Wet season (Table 3) had higher Chromium mean value (109.35 ± 77.84 mg/kg) than dry season (92.29 ± 89.64 mg/kg). Mean Cadmium (Table 2) slightly increased from the upper zone (0.02 ± 0.06 mg/kg) to the lower zone (0.32 ± 0.58 mg/kg). Dry season had higher mean Cadmium (0.09 ± 0.09 mg/kg) than wet season (0.01 ± 0.09 mg/kg) (Table 3).

Silt values differed significantly across zones ($P$ = .006) and seasons ($P$ = .023). There was a significant difference ($P$ = .014) in sand values between the zones. Iron concentrations differed significantly across zones ($P$ = .016), but the difference was not seasonally significant ($P$ = .352). Significant differences in zinc levels were found between the zones ($P$ = .004) and seasons ($P$ = .008). Cadmium contents differed significantly between seasons ($P$ = .041), but the difference was not spatially significant ($P$ = .090).

A significantly positive relationship existed between clay and organic carbon ($P$ = .000). Highly significant negative correlation were found between clay with sand ($P$ = .000). Significant negative relationship existed between silt and sand ($P$ = .036), and silt and rainfall ($P$ = .019). Silt and zinc ($P$ = .02), and Organic carbon and iron ($P$ = .015) concentrations were significantly (positive) correlated. Significant inverse correlation occurred between Organic carbon and sand ($P$ = .031), and Organic carbon and cadmium ($P$ = .045) (Table 4).

A significantly positive relationship existed between Copper and lead ($P$ = .008), copper and

chromium (*P* = .000), chromium and lead (*P* = .000), and zinc and cadmium (*P* = .007). A highly significant inverse correlation was found between lead and cadmium (*P* = .000), zinc and rainfall (*P* = .000), cadmium and chromium (*P* = .014), and cadmium and rainfall (*P* = .031) (Table 4).

## 3.1 Assessment of Sediment Quality

The comparisons of contaminations in the sediments with standard values are shown in Tables 2 and 3. The results of the study show that the mean concentrations of metals were within the standard values, except for Pb and Cr. The average concentrations of metals of Badagry creek compared with SQGs and SQC are presented in Table 5. Iron (Fe) as a trace metal is often not considered to have toxic effect on aquatic organisms, hence was excluded from the SQGs and SQC. In this study, with the exception of Pb and Cr, metals range concentrations were below ERL (Table 5). The mean concentrations of Cu (8.28 mg/kg), Pb (37.34 mg/kg), Zn (20.78 mg/kg) and Cd (0.02 mg/kg) in the sediment samples were lower than ERL values of 34 mg/kg, 46.7 mg/kg, 150 mg/kg and 1.2 mg/kg for Cu, Pb, Zn, and Cd, respectively. Cr mean level of 100.82 mg/kg obtained in the study lies between ERL (81 mg/kg) and ERM (370 mg/kg).

In the study, no concentration of metals exceeds the Level 2 threshold values. The mean concentrations of metals, with an exception of Cr, were below the Level 1 threshold values. Mean Cr value lies between the Level 1 and Level 2 (intermediate) threshold values.

**Table 2. Spatial variation of Variables measured in sediment of Badagry creek and unpolluted sediment (standards) values (mg/kg)**

| Variables | Upper zone | Middle zone | Lower zone | (F-value) *P* value | Standards | |
|---|---|---|---|---|---|---|
| | | | | | US | EPA |
| Clay (%) | 4.25 ± 2.15 | 5.79 ± 3.03 | 6.18 ± 1.44 | (2.37) .11 | | |
| Silt (%) | 2.77 ± 0.96[b] | 2.77 ± 0.64[b] | 5.28 ± 3.31[a] | (6.00) .00 | | |
| Sand (%) | 92.93 ± 3.06[a] | 91.50 ± 3.30[ab] | 88.66 ± 3.86[b] | (4.84) .01 | | |
| OC (%) | 2.72 ± 1.18 | 2.20 ± 0.87 | 2.93 ± 1.27 | (1.33) .28 | | |
| Fe (mg/kg) | 5185.30 ± 1144.90[a] | 4097.10 ± 788.01[b] | 4475.50 ± 645.10[ab] | (4.68) .02 | 41000 | - |
| Cu (mg/kg) | 10.63 ± 5.15 | 6.94 ± 4.19 | 7.26 ± 3.94 | (2.53) .09 | 33 | 16 |
| Pb (mg/kg) | 39.47 ± 27.95 | 35.16 ± 22.98 | 33.79 ± 19.12 | (0.19) .83 | 19 | 31 |
| Zn (mg/kg) | 27.47 ± 26.39[a] | 6.45 ± 11.48[b] | 5.64 ± 5.21[b] | (6.45) .00 | 95 | 120 |
| Cr (mg/kg) | 116.37 ± 91.86 | 96.31 ±74.83 | 89.78 ± 76.45 | (0.35) .71 | - | 26 |
| Cd (mg/kg) | 0.02 ± 0.06 | 0.08 ± 0.12 | 0.32 ± 0.58 | (2.59) .09 | 0.11 | 0.6 |

*OC: organic carbon; Fe: iron; Cu: copper; Pb: lead; Zn: zinc; Cr: chromium; Cd: cadmium; - : no values presented; US: Unpolluted Sediments by GESAMP [17], Salomons and Förstner [18] and standards from EPA [19]).*
*Means that do not share a letter are significantly different. (P value less than or equal to .05 signifies significant difference, while values greater than .05 signifies no significant difference)*

**Table 3. Seasonal variation of variables measured in sediment of Badagry creek and unpolluted sediment (standards) values (mg/kg)**

| Variables | Dry Season | Wet Season | (F-value) *P* value | Standards | |
|---|---|---|---|---|---|
| | | | | US | EPA |
| Clay (%) | 5.43 ± 2.51 | 5.37 ± 1.31 | (0.00) .96 | | |
| Silt (%) | 4.34 ± 1.20 | 2.85 ± 0.70 | (7.18) .02 | | |
| Sand (%) | 90.23 ± 1.98 | 91.83 ± 1.99 | (1.95) .19 | | |
| OC (%) | 2.45 ± 0.91 | 2.78 ± 0.83 | (0.42) .53 | | |
| Fe (mg/kg) | 4406.76 ± 676.64 | 3182.99 ± 1736.65 | (0.95) .35 | 41000 | - |
| Cu (mg/kg) | 8.40 ± 4.13 | 8.16 ± 4.04 | (0.01) .92 | 33 | 16 |
| Pb (mg/kg) | 29.29 ± 16.78 | 45.40 ± 21.45 | (2.10) .18 | 19 | 31 |
| Zn (mg/kg) | 29.35 ± 12.09 | 12.22 ± 3.79 | (10.97) .01 | 95 | 120 |
| Cr (mg/kg) | 92.29 ± 89.64 | 109.35 ± 77.84 | (0.12) .73 | - | 26 |
| Cd (mg/kg) | 0.09 ± 0.09 | 0.01 ± 0.01 | (5.52) .04 | 0.11 | 0.6 |

*OC: organic carbon; Fe: iron; Cu: copper; Pb: lead; Zn: zinc; Cr: chromium; Cd: cadmium; - : no values presented; US: Unpolluted Sediments by GESAMP [17], Salomons and Förstner [18] and standards from EPA [19])*

**Table 4. Correlation (Spearman's) matrix among variables measured in sediments of Badagry creek**

| | Rainf | Fe | Cu | Pb | Zn | Cr | Cd | pclay | psilt | psand |
|---|---|---|---|---|---|---|---|---|---|---|
| Fe | 0.084 | 1 | | | | | | | | |
| Cu | -0.091 | 0.399 | 1 | | | | | | | |
| Pb | 0.427 | 0.378 | .713** | 1 | | | | | | |
| Zn | -.839** | -0.392 | 0.035 | -0.531 | 1 | | | | | |
| Cr | 0.091 | 0.427 | .965** | .832** | -0.175 | 1 | | | | |
| Cd | -.616* | -0.53 | -0.499 | -.889** | .717** | -.678* | 1 | | | |
| pclay | 0.14 | 0.312 | 0.344 | 0.267 | -0.084 | 0.425 | -0.458 | 1 | | |
| psilt | -.657* | -0.042 | -0.231 | -0.476 | .636* | -0.35 | 0.46 | 0.14 | 1 | |
| psand | 0.28 | -0.252 | -0.189 | 0.056 | -0.322 | -0.168 | 0.086 | -.846** | -.601* | 1 |
| pOC | 0.238 | .671* | 0.28 | 0.294 | -0.385 | 0.378 | -.577* | .811** | 0.063 | -.615* |

*Rainf: Rainfall (mm); Fe: Iron (mg/kg); Cu: Copper (mg/kg); Pb: Lead (mg/kg); Zn: Zinc (mg/kg); Cr: Chromium (mg/kg); Cd: Cadmium (mg/kg); pclay: Clay (%); psilt: Silt (%); psand: Sand (%); pOC: Organic carbon (%). (*P < .05, **P < .01)*

**Table 5. Trace metals concentration in sediment of Badagry creek versus sediment quality guidelines and criteria in mg/kg**

| Metals | Range (Mean) | (Long et al. 1995) | | (SQC proposed as GES boundaries) | | |
|---|---|---|---|---|---|---|
| | | ERL | ERM | Level 1 | Intermediate | Level 2* |
| Fe | 463.02 - 7519.95 (4585.96) | NA | NA | NA | NA | NA |
| Cu | 1.07 – 27.03 (8.28) | 34 | 270 | < 40 ** | 40 – 270 | > 270 |
| Pb | BDL – 101.31 (37.34) | 46.7 | 218 | < 47 * | 47 – 220 | > 220 |
| Zn | BDL – 98.58 (20.78) | 150 | 410 | < 150 * | 150 – 410 | > 410 |
| Cr | 2.36 – 303.52 (100.82) | 81 | 370 | < 81 * | 81 - 370 | > 370 |
| Cd | BDL – 1.43 (0.02) | 1.2 | 9.6 | < 1.2 * | 1.2 – 9.6 | > 9.6 |

*BDL: below detection limit; NA: not applicable.*

*ERL: effect range low; ERM: effect range medium; * ERL/ERM from Long et al. (1995). ** SQCs national legislation (Ord. 161/2006), SQC: sediment quality criteria; GES: Good Environment Status.*

*Level 1 sediments: low risk to aquatic life. Intermediate level sediments: slightly - moderately contaminated and additional testing is required to evaluate the potential risks to aquatic life. Level 2 sediments: highly contaminated and likely to pose a risk to aquatic life. (Trace metals SQC proposed as GES boundaries for the marine sediments from Romanian national waters)*

## 4. DISCUSSION

Monthly rainfall as observed in the study period was a typical bi-modal rainfall distribution pattern reported previously by earlier authors [22,23]. Rainfall influences changes in the hydrographical characteristics of the marine and estuarine ecosystem in the tropical countries [6].

The average percentage values for sand, clay and silt obtained in the study was a reflection of the soil texture of the study area. The overall low sediment diversity results of the particle size of the study area dominated by sand indicating sandy substratum nature of the creek. Similar observation has been reported in Lake Kariba sediment [24]. Sand component was found in highest proportion over silt and clay in all the stations and zones. According to Allan [25], sediments depend on the parent material available and deposits of materials. Sand inverse association with clay and silt observed in the study was also reported by Davies and Tawari [26] from trans-okpoka creek, upper bonny Estuary, Nigeria. The low organic carbon observed across stations and zones could be attributed to rapid mineralization and depletion due to intensive demand for nutrients by the macro fauna and flora, as well as the effect of leaching experienced during the heavy rainfall [27]. Similar findings have been reported in Lake Kariba [24]. The occasionally high content of organic carbon at some stations could be probably as a result of the direct discharge of domestic sewage or insufficiently treated waste that come from the mainland activities. The strong positive relationship of organic carbon with clay, weak positive correlation with silt and strong inverse association with sand as observed in the present study was previously reported in downstream of Central Himalayan river, Tawi, India [28]. The organic carbon content in the study compared favourably with the report of Jamabo [27] in mangrove swamps of the upper Bonny River, but higher than finding by Sharma et al. [28] from lower sections of a Central Himalayan river, Tawi, Jammu (J&K), India. The elevated organic carbon during wet season could be attributed to high urban runoff, discharge of waste and organic matter contents received in

the creek. Similar opinion has been reported in mangrove swamps of the upper Bonny River study [27]. Finny and Huh [29] reported that the organic carbon content is associated with urban waste, domestic sewage and cage culture.

The high concentrations of Fe observed in the study may be attributed to abundance of iron in the creek, as iron is one of the most abundant metals in the environment.

The elevated concentrations of Fe, Cu, Pb, Zn, Cr, and Cd observed in the deposited surface sediment of the creek could be attributed to long time accumulation of trace metals in the sediment. It has also been reported that the bottom sediment serves as a reservoir for trace metals [30]. The mean concentrations of metals with the exception of Pb and Cr in sediments compared favourably with some previous studies in Lagos lagoon complex and adjoining water bodies [31-33]. Lead and chromium concentrations in the sediment of the study area were higher than the background levels. This was a clear evidence of Pb and Cr contaminant build up within the sediments. Human activities may have probably accounted for the increase in concentrations. Diffuse sources of Lead into the surface waters arising from increase in automobile traffic emissions from lead tetraethyl in petroleum and emissions from heavy duty generators around the Badagry creek catchment may have increased the concentrations in sediments [6]. Lead is a great threat to life if present in substantial quantity. It is toxic even at low concentrations and has no known function in biochemical processes [34]. The possible cause of the elevated chromium could be attributed to human activities that discharge effluents from electropainting and metal finishing industries into the creek and adjoining water bodies. The relatively higher metal concentrations except cadmium in upper zone as compared to other zones are probably as a result of human activities that indiscriminately dump wastewater materials into the creek. Yewa river empty into Badagry creek in the upper zone, is most likely to contain contaminants which may have contributed to the concentrations in the sediment of the zone. The level of heavy metal concentrations was a reflection of anthropogenic inputs of domestic sewage, municipal and urban run-off to the creek.

The relatively lowest concentrations of Cadmium (Cd) observed among the metals ranking in the study was in agreement with the result of Opaluwa et al. [35] in which Cd was found to have the lowest concentration in both sediment and water.

The higher levels of trace metals determined in the dry season for Zn and Cd may be attributed to evaporation effects. However, insignificant higher concentrations of Pb and Cr observed during the wet season could be attributed to runoffs from Badagry environs, Yewa river, including domestic sewage discharges into the creek. The strong positive association between Cu and Pb, Cu and Cr, Cr and Pb, and Zn and Cd suggest a common source of contamination of these metals. Positive correlation between organic carbon and iron may be explained by a common source of inputs.

The lower mean concentrations of Cu, Pb, Zn, and Cd in the sediment samples when compared with the corresponding ERL value of Long et al. [20], is an indication that toxic effect on aquatic organisms will rarely occur from these metals. Chromium mean level (in-between ERL and ERM) in the study is implying that Cr could possibly have adverse effects on aquatic organisms present in this ecosystem [20]. The very higher concentrations of Pb, Cr and Cd in some stations when compared to ERL and Level 1 threshold values of sediment quality guidelines, is an indication that the stations were the hot spot for metal contamination.

## 5. CONCLUSION

The study has supplied valuable information on levels of some sediment characteristics and quality of Badagry creek ecosystem. The results of the sediment particle size revealed dominance of sand followed by clay and silt, an indication that Badagry creek is a sandy substratum habitat. The mean concentration of trace metals in Badagry creek sediment decreased in the order; Fe > Cr > Pb > Zn > Cu > Cd. The metal distribution indicated that contaminants are predominantly received in the creek as a result of the proximity of Badagry creek to diffuse sources; particularly motorways, ports, urbanized and industrialized areas. The range of Pb, Cr and Cd in the study lies between the Level 1 and Level 2 threshold values of trace metals SQC (sediment quality criteria), hence sediments of Badagry creek are considered to be moderately contaminated. The present study recommend that relevant authorities/agencies should conduct regularly sediment quality monitoring of the creek, promote and increase conservation education and control the discharge

of untreated wastes and sewage into the water body.

## ETHICAL APPROVAL

Author hereby declares that "Principles of laboratory animal care" (NIH publication No. 85-23, revised 1985) were followed, as well as specific national laws where applicable. All experiments have been examined and approved by the appropriate ethics committee.

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## COMPETING INTERESTS

Author has declared that no competing interests exist.

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