Bamanga, Awwal

EVALUATION OF SEDIMENT PARTICLE SIZES OF HEAVY METAL CONTAMINATION IN THE LAGOS INLAND WATER SYSTEM

awwal.bamanga@port.ac.uk

School of Earth and Environmental Sciences, University of Portsmouth, Portsmouth, United Kingdom.
Environmental Technology Department, Kuwait University, Kuwait City, Kuwait.

The link to this publication is https://ajoeer.org.ng/otn/ajoeer/2022/qtr-2/06.pdf

EVALUATION OF SEDIMENT PARTICLE SIZES OF HEAVY METAL CONTAMINATION IN THE LAGOS INLAND WATER SYSTEM.

Bamanga, Awwal[1&2], Al-Anzi, Bader[2,], Neeka Jacob[3] and Bassey, Bassey[4],

[1]School of Earth and Environmental Sciences, University of Portsmouth, Portsmouth, United Kingdom.
[2] Environmental Technology Department, Kuwait University, Kuwait City, Kuwait.
[3]Research and Innovation Division, Petroleum Technology Development Fund, (PTDF), Abuja, Nigeria.
[4]Department of Biological Oceanography, Nigerian Institute for Oceanography and Marine Research, Victoria Island, Lagos Nigeria
Corresponding authors: awwal.bamanga@port.ac.uk; neeka.jacob@yahoo.co.uk.

ABSTRACT

Sediments are important in the geochemical cycles of marine and estuarine ecosystems with the ability to influence ecological processes and inhabiting biota. This study evaluated sediment particle sizes of the Lagos Harbour and inland water system with a view to determine their diversity and influence on heavy metal levels. Samples were collected using Van veen grabs, viz; dry season 2013 (DS-1), wet season 2013 (WS) and dry season 2014 (DS-2) for a period of 18 months in the Lagos Lagoon and inland water system. The sediments collected were analysed according to the British Standard (BS 1377-2, 1990) at the instrument Physical Geography Laboratory, University of Portsmouth. The mean clay, silt, course and sand were found to be 6.67± 4.51, 6.0 ± 3.0, 9.17± 3.25 and 0.37 ± 3.06 respectively. The particle size in relation with total metals/metalloids concentration in the sediment revealed positive correlation with significant differences (p<0.05) between clay and Fe (r = 0.391*), clay and Pb (r = 0.40*). While the particle size in relation and recoverable metals/metalloids concentration in the sediment revealed positive correlation with significant differences (p<0.05) between clay and Mn (r = 0.416*), silt and Mn (r = 0.414*). The particle size in relation with bioavailable metals/metalloids concentration in the sediment revealed positive correlation with were significant differences (p<0.05) between silt and Pb (r = 0.426*). This implies that the widespread dredging of the lagoon sediments and artisanal sand mining has had its toll on the structural integrity of the substratum. The strong correlation between the finer particle sizes with total, recoverable and bioavailable fractions of Fe-Mn-Pb in the sediment samples is notable and implies increased chances of retention of pollutants in the sediment matrix.

Introduction

Sediments form the physical boundary of depth in water bodies.It is said that marine sediments are products of weathering of pre-existing basement rock aggregates of different types which settle at the bottom of the sea via river depositions, wave and wind action (Weber et al., 2003). They remain in flux being also deposited by coastal erosion (Abdulkarim et al., 2013) and removed by strong currents into beaches (Titocan et al., 2018).They are well recognised as a main reservoir for many of the persistent organic and inorganic chemicals introduced into the aquatic environment by atmospheric deposition, erosion of the geochemical substrate and from anthropogenic sources (Sarkar et al., 2004). Sediment is known to act as a pollutant sink in aquatic ecosystems (Fan & Zhang, 2009) and have been noted as stores of hydrophobic pollutants in rivers (Voice & Weber, 1983). They also, are potential sources of pollution for the surrounding water as well as benthic flora and fauna by releasing sorbed contaminants back to the overlying water column should remobilisation occur through any disturbance (Sarkar et al., 2004; Adamo et al., 2005).

Investigation of marine sediments provides important information in marine, environmental and geochemical study about pollution of the marine environment (Calace et al., 2005). Sediment is a matrix of materials consisting of detritus, inorganic and organic particles and is relatively heterogeneous in terms of its physical, chemical and biological characteristics (Sarkar et al.,2004) and they consist of a varied range of particle sizes, including gravels, sand, silt and clay (Fergusson, 1990). Sauve et al. (2000), noted that grain sizes and organic matter content are key determinants of presence and availability of heavy metals and trace metals in the sediment.

Sediments play a useful role in the assessment of heavy metal contamination (Gangaiya et al., 2001). The partitioning behaviour of heavy metals is such that they tend to accumulate in sediments to levels that are several orders of magnitude higher than in the surrounding water (Denton et al., 1997). The relative texture of sediments affects their respective surface areas and therefore their ability to bid metals with the support of organic complexes they are associated with. Thus, an understanding of sediment particle sizes in a water body is crucialand

a significant factor influencing relative heavy metals distribution, transport and ecological risks.

In furtherance to understanding the complexes which influence total, recoverable and bioavailable metal concentrations in the Lagos harbour (LH) and associated Lagos Lagoon system, this study therefore is aimed at investigating the relative sediment particle size distributions and the relationship between particle size and the concentration of various heavy metals in the Lagos harbour and Lagos lagoon.

Materials and Methods

Study Area

Sampling sites were selected on the basis of the activities such as shipping, sand mining, sawmill industries and recreational/residential within the major sections of the Lagos Lagoon system (i.e Lagos Harbour, urbanized western Lagos Lagoon and Apese Lagoon)as the need for spread to reflect the true picture of the sediment structure (Figure 1). GPS coordinates of each sampling site was taken and recorded; Lagos Harbour (E $003°20^1$ and N $6°26^1$), Lagos Lagoon (E $003°22^1$ and N $6°25^1$),andApese Lagoon (E $003°27^1$ and N $6°25^1$) in order to produce the spatial distribution maps.. Twenty-six sampling sites were established within the study area and across the LH (sites: 1-16), LG (sites: 17-23), and APL (sites: 24-26).Sites were sampled in three seasons, namely: dry season-1 2013 (DS-1), dry season-2 2014 (DS-2) and wet season 2013 (WS).

Sampling operations

Sediment samples were collected at the selected sites using a 0.1 m^2 Van-Veen Grab (wt. 25 kg; height - 20 cm) and the coordinates marked with the use of a GPS kit (Magellan, Sport rack PRO MARINE [IEC-IPX7 Model]). A composite sediment sample (3 successful grab hauls) were collected for each site. A portion of the top 1-5 cm of the haul was preserved for physical, chemical and other analyses. The labelled samples were placed in polytetrafluoroethylene (PTFE) bottles, bagged and stored in an ice chest cooler at 4°C.

Sample Analysis

The stored frozen samples were removed and allowed to defrost on a clean laboratory bench and the analysed for their respective particle sizes. The method used was developed and modified in the School of Earth and Environmental Sciences (SEES), at the University of Portsmouth in line with British Standard (BS 1377-2, 1990) and analysed using a

MASTERSIZER 2000 Laser instrument manufactured by Malvern Instruments, at the Physical Geography Laboratory, University of Portsmouth. This instrument analyses particle size ranges from 0.02 to 2000 μm using a diffraction model based on Mie Theory. Samples were prepared by defrosting to room temperature, with 100 g placed into a glass beaker. Ten mL of H_2O_2 was added to each sample in a beaker to completely remove organic materials. A solution of hexametaphosphate (SHMP) and sodium hydrogen carbonate (SHC) added to the samples in each beaker in order to separate the particles.
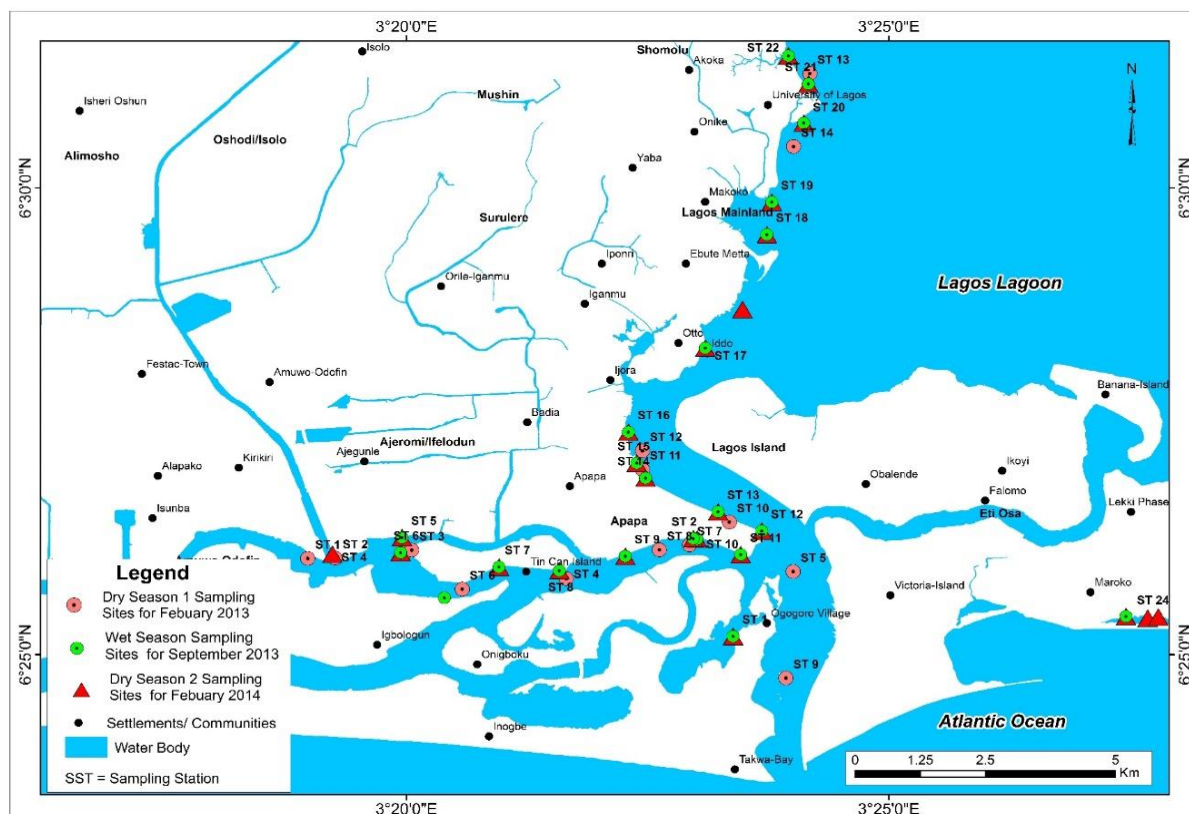

Figure 1: Sampling locations within the Lagos Lagoon system

Heavy Metal Analysis

The details of the metal analysis protocol are as outlined in Awwal et al. (2019). Total metal concentrations in sediment samples were analysed using X-ray fluorescence (XRF) technique based on the method described in the US-EPA Method 6200 (1998). The extraction of recoverable metals from the sediment samples with *Aqua regia* was carried out using the method described by the National Water Research Institute (2006) and analysis was done using inductively coupled plasma optical emission spectrometry (ICP-OES). Bioavailable metals were determined using a 1 M HCl extraction and (inductively coupled plasma mass spectrometry ICP-MS) analysis, as described by Snape et al. (2004).

Geospatial Mapping of Sediment particle size

The mean value for the measured particle size were estimated and used in the sampled locations of the Lagos harbour, Lagos lagoon and Apese lagoon to perform a geospatial kriging interpolation in the ArcGIS 10.8 software. This gave rise to a spatially explicit map showing the mean particle size of the soil types.

Statistical analysis

The results obtained were presented as mean standard error and differences in particle sizes at the respective zones were compared using two- way analysis of variance (ANOVA) SPSS Version 21. Significant differences were set at $P < 0.05$ while LSD was used in post-hoc analysis to separate significant means. Pearson's correlation coefficient was done using normalised data to determine relationship between particle sizes and determined heavy metal concentrations.

Results

Distribution of sediment particle sizes

The measured particle sizes were categorized as clay, very fine silt, fine silt, medium silt, coarse silt, very fine sand, fine sand, medium sand and coarse sand.However, analysis was focused on the main categories being clay, silt, coarse and sand particles.

The mean clay, silt, coarse and sand were found to be 6.67 ± 4.51, 6.0 ± 3.0, 9.17 ± 3.25 and 0.37 ± 3.06 respectively (Figure 2). There was significant difference ($P<0.05$) between clay and sand constituents in the sediments with the former being significantly higher.Likewise, coarse and sand particles were also significantly different in distribution.
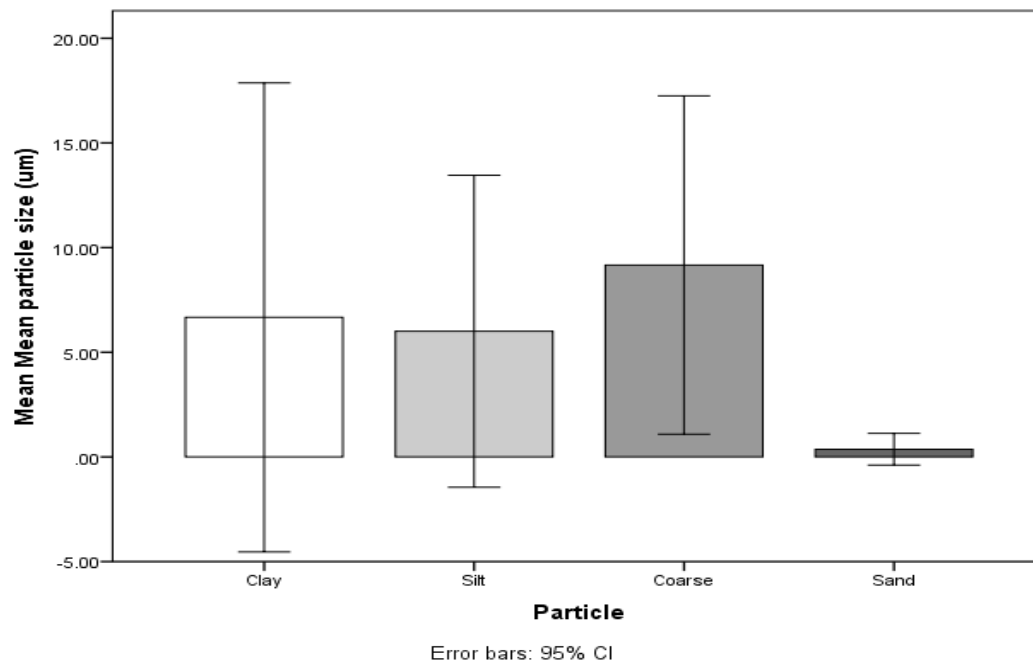
Figure 2: Comparison of different mean particle size distributions across the Lagos Lagoon system The bars on the figure represent +/- 2 Standard Error.

Distribution of Grain Particle Size

The distribution of the sand particle grain size in the three distinct sample locations, the Lagos harbour, Lagos Lagoon and Apese Lagoon varied geographically. The Lagos harbour was observed to have a mean particle size of 10.77µm, which was the lowest and increased progressively toward the Lagos lagoon and Apese lagoon, with the mean particle size of 14.305µm and 15.368µm respectively. Furthermore, the distribution of the silt particle grain size in the three sample sites varied with Apese lagoon mean measured at 5.37µm. The spatial explicit map shows the progressive increase in mean particle size away from Apese lagoon towards the Lagos lagoon and Lagos harbour with mean values of 8.8µm and 10.87µm respectively. Finally, the clay soil had a mean particle grain size of 1.63µm at Apese lagoon and exponentially increased to 7.53 µm at the Lagos lagoon and further increased to 10.84 µm at the Lagos harbour (Figure 3).

Mean metal and metalloid concentrations in sediment samples

The results of the sediment metal and metalloid concentrations indicated that bioavailable metal concentration was least for all metals with the exception of Cd and Pb. Analysis of variance indicated that the differences in the concentrations of the fractions were however not significant ($P > 0.05$). Overall, Al and Fe had the highest concentrations in the sediment samples while Cd was the least (Table 1).
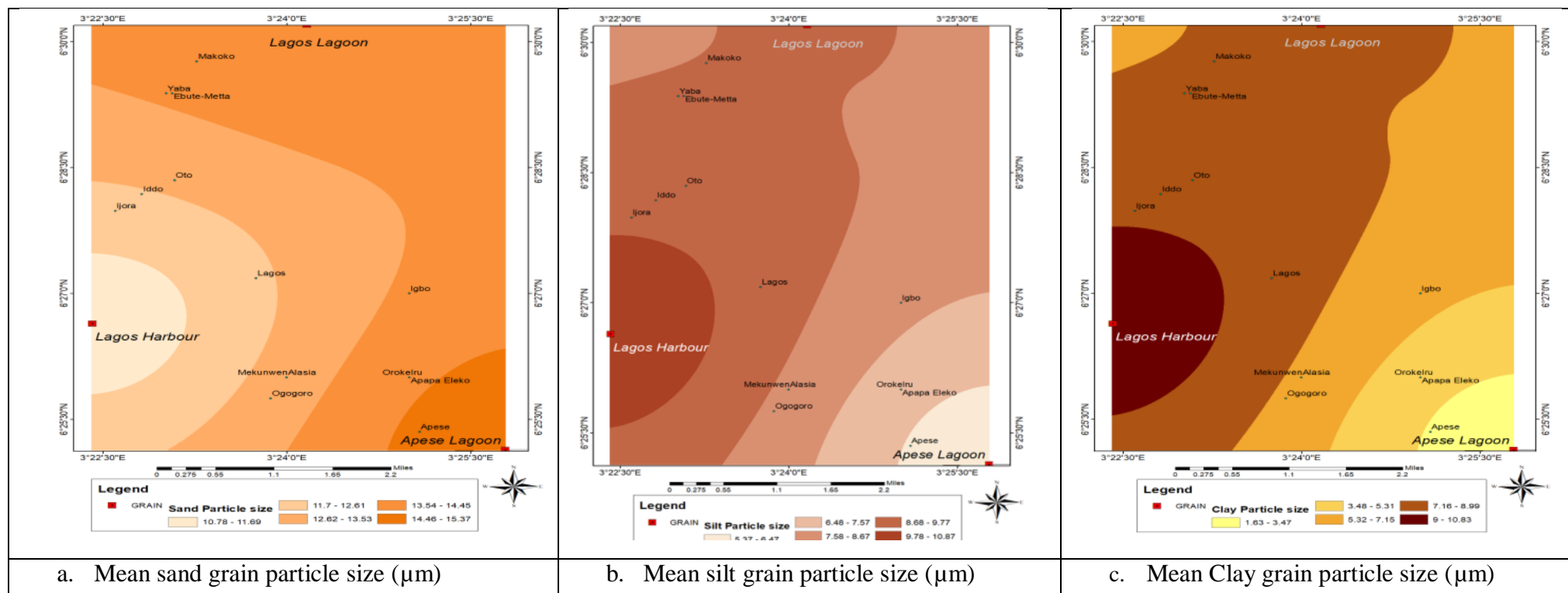
a. Mean sand grain particle size (µm)	b. Mean silt grain particle size (µm)	c. Mean Clay grain particle size (µm)

Figure 3a – 3b: Mean distribution of sand, silt and clay grain particle sizes (µm) across the Lagos Harbour, Lagos Lagoon and Apese Lagoon

**Table 1:** Mean concentrations of total, recoverable and bioavailable metals and metalloids (mg/kg) detected in the sediment of the Lagos Lagoon system

Metal / Metalloid Fractions	Al	As	Cd	Cu	Fe	Mn	Pb	Zn
Total	67176	3	0	36	42023	547	0	148
Recoverable	3701	7	0	31	9582	595	11	53
Bioavailable	1544	2	0	9	5819	265	13	58

Spatial distribution of metal/metalloid fractions in sediment across Lagos and Apese Lagoons and Lagos Harbour

Figure 4, the sand sediment particle sizes increases progressively from the Lagos harbour to the Lagos lagoon and the control site, Apese lagoon,

During the dry season (Figure 4a); Al, As and Cu were significantly distributed at high concentrations in sediment at the Lagos Harbour; Fe, Mn and Zn were significantly distributed at high concentrations in sediment at the Lagos Lagoon. However, during the wet season (Figure 4b); Al were observed to be distributed at high concentration at Apese Lagoon; the metalloid (As) were significantly distributed in Lagos Harbour; Fe, Mn and Zn were significantly distributed at high concentrations in sediment at the Lagos Lagoon.

Figure 4a: Spatial distribution of metals/metalloid in sediment across Lagos harbour, Lagos lagoon and Apese Lagoon during the dry season

Figure 4a: Spatial distribution of metals/metalloid in sediment across Lagos harbour, Lagos lagoon and Apese Lagoon during the dry season

Figure 4b: Spatial distribution of metals/metalloid in sediment across Lagos harbour, Lagos lagoon and Apese Lagoon during the wet season
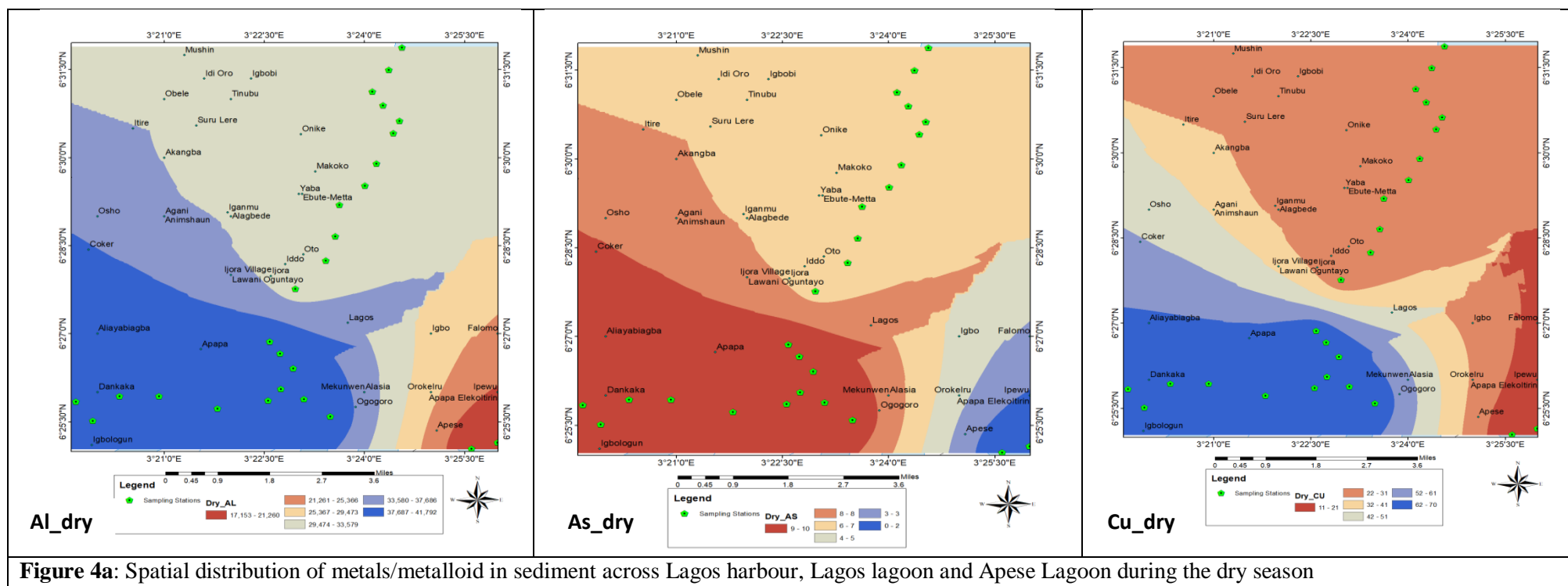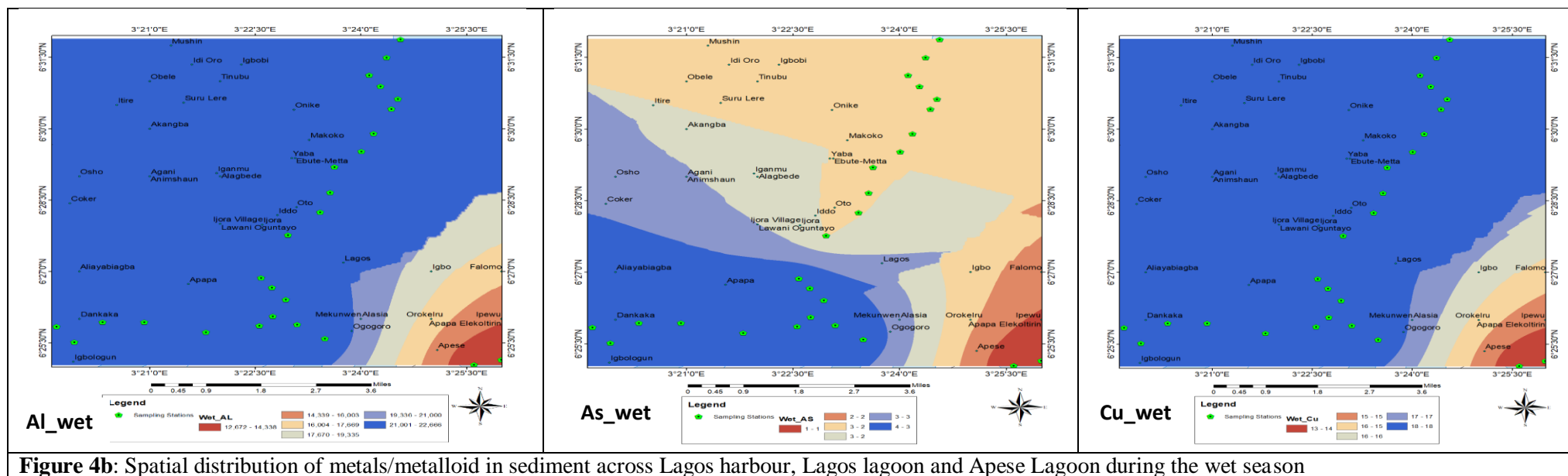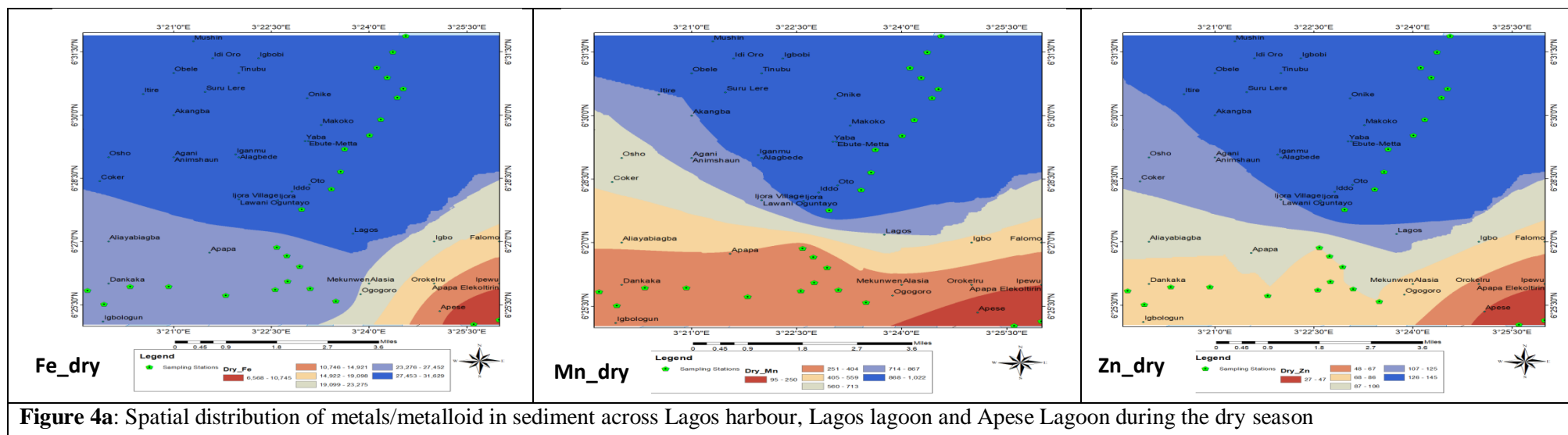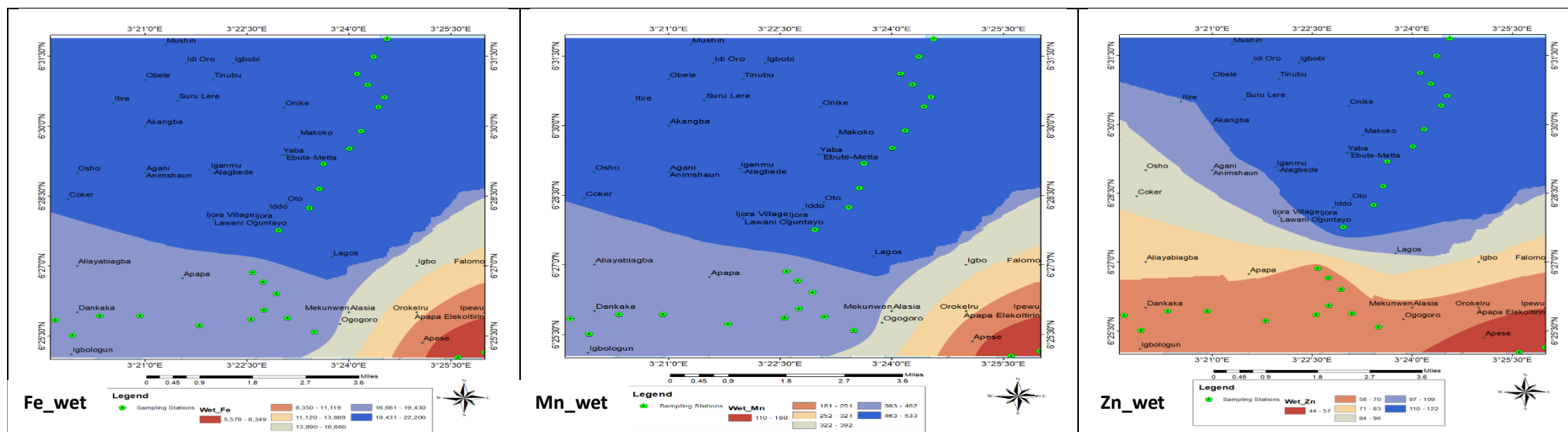
Figure 4b: Spatial distribution of metals/metalloid in sediment across Lagos harbour, Lagos lagoon and Apese Lagoon during the wet season

Correlation of sediment particle sizes and metal concentrations

A correlation analysis was conducted to assess the inter-relationship between the variables of significance towards understanding adsorption, mobility and bioavailability of metals with respect to particle sizes. The results indicated a strong correlation between the sediment particle sizes; clay, silt and coarse (Tables 2-4). Generally, clay, sit and coarse particles showed strong positive correlation compared between themselves but were weakly negatively correlated with sand.

There was significant positive correlation between mean total sediment concentrations of As, Fe, Pb and Mn with the clay constituents across the water bodies. Total Mn concentration indicated significantly strong correlation ($p<0.01$) with clay and silt; while As, Fe and Pb showed significant correlation ($p<0.05$) with clay (Table 2). Positive significant correlations ($p<0.05$) were observed between recoverable Mn with silt and clay particles (Table 3). The results also indicated that bioavailable Al, Cd, Fe and Mn showed strong significant positive correlation ($p<0.01$) with Clay and Silt, while Pb was positively correlated ($p<0.05$) with silt (Table 4).

Table 2: Correlation between sediment particle size and total metals/metalloids concentration in the sediment samples of the Lagos Lagoon system

	CLAY	SILT	COARSE	SAND
CLAY	1.00			
SILT	0.965**	1.00		
COARSE	0.644**	0.697**	1.00	
SAND	-0.27	-0.24	-0.14	1.00
Al	0.10	0.04	-0.15	-0.09
As	0.409*	0.37	0.06	0.06
Cd	-0.09	-0.04	-0.01	0.03
Cu	0.08	0.06	-0.06	-0.06
Fe	0.391*	0.33	0.14	-0.15
Mn	0.531**	0.535**	0.32	-0.17
Pb	0.400*	0.36	0.04	0.06
Sn	-0.04	-0.04	-0.12	0.12
Zn	0.01	0.00	-0.13	0.02

*   Indicates correlation with significant difference (p<0.05)
**   Indicates correlation with significant difference (p<0.01)

Table 3: Correlation between sediment particle size and recoverable metals/metalloids concentration in the sediment samples of the Lagos Lagoon system

	CLAY	SILT	COARSE	SAND
CLAY	1.00			
SILT	0.965**	1.00		
COARSE	0.644**	0.697**	1.00	
SAND	-0.27	-0.24	-0.14	1.00
Al	0.08	0.04	-0.22	-0.10
As	0.11	0.06	-0.18	-0.19
Cd	0.12	0.19	0.30	-0.11
Cr	0.11	0.12	0.03	-0.15
Cu	-0.06	-0.12	-0.23	-0.16
Fe	0.31	0.31	0.07	-0.18
Mn	0.416*	0.414*	0.15	-0.21
Pb	0.11	0.16	0.00	0.04
Sn	-0.19	-0.15	-0.11	-0.06
V	0.32	0.31	0.03	-0.12
Zn	0.07	0.10	-0.08	-0.03

*   Indicates correlation with significant difference (p<0.05)
**   Indicates correlation with significant difference (p<0.01)

Table 4: Correlation between sediment particle size and bioavailable metals/metalloids concentration in the sediment samples of the Lagos Lagoon system

	CLAY	SILT	COARSE	SAND
CLAY	1.00			
SILT	0.965**	1.00		
COARSE	0.644**	0.697**	1.00	

SAND	-0.27	-0.24	-0.14	1.00
Al	0.526**	0.568**	0.27	0.01
As	0.35	0.38	0.04	-0.15
Cd	0.559**	0.612**	0.31	-0.03
Cr	0.15	0.17	0.17	-0.04
Cu	0.19	0.30	0.12	0.02
Fe	0.552**	0.587**	0.28	-0.08
Mn	0.559**	0.557**	0.21	-0.21
Pb	0.32	0.426*	0.24	0.23
Zn	0.10	0.17	0.01	0.22

*   Indicates correlation with significant difference (p<0.05)

**   Indicates correlation with significant difference (p<0.01)

Discussion

The findings from this study indicated that the overall sediment diversity was low in terms of the particle size. A similar observation was found in the sediment in Lake Kariba (Balogun, 2017). According to Allan (1995), sediments depend on the parent material available and deposits of materials. The inverse association observed between sand with clay and silt was also reported by Davies &Tawari (2010) from Trans-Okpoka Creek, Upper Bonny Estuary, Nigeria. The observed nature of the particle sizes in the Lagos Lagoon system can be attributed to sand mining/ routine maintenance dredging at the Lagos Harbour as well as drifts from loss of beach shorelines at Apese Lagoon which can be related to the drifts associated with sea water incursion and outflow with tide. Constant dredging can remove the larger aggregates which protect the finer sediment particles and therefore predispose the sediment to greater levels of pollutant uptake.

Particle size plays an important role in many sediment processes such as aggregate stability (Zauca et al., 2013), fluvial morphology (Cartacuzencu et al., 2014), and pollution (Karbassi et al., 2014). The coastal plain sand is the youngest within the Dahomey Basin, which is the principal geological formation in the area within which the Lagos Lagoon system lies. It is not rocky but characterized by soils which are soft, poorly sorted clayey sands, pebbly sands, and sandy clays (Agagu, 1985). Given that routine dredging is required to create enough room for navigation of large vessels via the LH into the ports, it is apparent that the larger parent surface soil/ sediment materials would have been evacuated over the years leaving only finer forms which are typically at lower strata. This has implications for macrobenthic fauna, because such extensive damage would result in drastic alterations of the sediment and loss of organic materials which characterize their typical habitat. Doherty (2014) reported very low benthic species diversity around the Apapa port areas which lies within the Lagos Harbour.

Also, heavy metals are usually associated with organic and inorganic complexes which characterize natural sediments of water bodies (Ferro, 2003). Removal of the top surface by dredging invariably leads to release of bound metals from their complexes into the water column. Clay and silts are also known to enhance metal adhesion via their surface properties (Grabowski et al., 2011). Thus, their loss would result in the release of the metals, increasing the chances of high concentrations in the sediments due to large amounts of unbound phases.

The high clay and silt component of the sediment implies that they have a high risk of heavy metal uptake as noted in Awwal et al. (2019).Onyena and Okoro (2019) and Nwankwo et al. (2003) reported on the spatio-temporal variations in water and sediment parameters of AbuleAgege, AbuleEledu, Ogbe, creeks adjoining Lagos Lagoon, Nigeria which indicates high level of contamination due to the increase in human population, industries and influx of contaminants from adjoining creeks. The degree of this contamination can be affected by the seasonal variations in time and space.

Typically, the bottom sediments within aquatic ecosystems serve as efficient natural trap for diverse substances such as nutrients – carbon and nitrogen and other contaminants, and as a natural regulator of the processes that occur under the sea floor. They can store large amounts of organic matter and affect the oxygen content of the bottom water. Bottom sediments also constitute a source of nutrients for the water column above leading to benthic-pelagic coupling and thereby influencing primary productivity (Leticia et al., 2003).

The strong and positive correlation between clay and silt with Fe and Mn is notable. Fe-Mnoxide complexes are important in the retention of metals in ligands within sediments while fine particles such as clay minerals provides large surface area for binding of metals compared to larger forms like quartz and feldspar (Kongchum et al., 2011, Tessier et al., 1982). Also Montalvo et al (2014) reported strong positive correlation between Fe-Mn (r = 0.5131),Fe-clay (r = 0.5978), Cu-clay (0.8501) and Mn- clay (0.9311)in the Gulf of Mexico, which they attributed to the affinity of the elements to finer sediment particles. The presence of Fe in sediments does not necessarily imply negative consequences. For instance,Hutchins & Bruland,1998 (in Montalvo et al., 2014), noted that the presence of Fe oxides in sediments increases productivity at shallow coastal regions. However, these oxides enhance the binding of other metals to sediments which is further enhanced by the dominance of particles with large surface areas.The strong and significant positive correlation between bioavailable Cd and clay-silt particles observed in this study is also notable and this raises important toxicological risk in view of the bioaccumulative potential of Cd in aquatic biota and the likely effects of shell fish consumers.

Conclusion

The sediments of the Lagos Lagoon system were found to be mostly dominated by finer particles including clay and silt providing characteristically large surface area for binding of metals and metalloids. This implies that the widespread dredging of the lagoon sediments and artisanal sand mining has had its toll on the structural integrity of the substratum. The strong correlation between the finer particle sizes with total, recoverable and bioavailable fractions of Fe-Mn in the sediment samples is notable and implies increased chances of retention of pollutants in the sediment matrix. There is need for caution in the practice of dredging in the lagoon as this has far reaching effects on pollution transport in the lagoon system and associated food webs.

References

Adamo, P., Arienzo, M., Imperato, M., Naimo, D., Nardi, G. &Stanzione, D. (2005). Distribution and partition of heavy metals in surface and sub-surface sediments of Naples city port. Chemosphere, 61(6): 800-809.

Agagu, O.K. (1985). A Geological Guide to Bituminous Sediments in Southwestern Nigeria, (Unpubl Monograph). Dept of Geology, University of Ibadan.

AwwalBamanga (2019). An investigation of Heavy Metal Sediments geochemistry in Lagos Harbour, Nigeria. Thesis submitted to the University of Portsmouth, 326p.

Balogun, K. J. (2017). Quality Assessment of Deposited Surface Sediment in Badagry Creek Ecosystem, Southwest Nigeria. JALSI, 11(1): 1-11.

Calace, N., Ciardullo, S., Petronio, B. M., Pietrantonio, M., Abbondanzi, F., Campisi, T. &Cardellicchio, N. (2005). Influence of chemical parameters (heavy metals, organic matter, sulphur and nitrogen) on toxicity of sediments from the Mar Piccolo (Taranto, Ionian Sea, Italy). Microchemical Journal, 79(1-2): 243-248.

Carlos Montalvo, Claudia A. Aguilar, Luis E. Amador, Julia G. Cerón,(2014). Metal Contents in Sediments (Cd, Cu, Mg, Fe, Mn) as Indicators of Pollution of Palizada River, Mexico. Environment and Pollution; Vol. 3, No. 4; 2014.

Cartacuzencu, S., Lazar, I., Nedeff, V. & Lazar, G. (2014). Technical solution to reduce soil erosion produced by Tazlau river in Tarata perimeter, Romania, Environmental Engineering and Management Journal, 13, 1971-1978.

Davies, O. A. &Tawari, C.C. (2010). Season and tide effects on sediment characteristics of trans-okpoka creek, upper bonny Estuary, Nigeria. Agricultural Biology Journal of North America, 1(2): 89-96.

Denton, G.R.W., Wood, H.R., Concepcion, L.P., Siegrist, H.G., Eflin, V.S., Narcis, D. K. and Pangelinan, G.T. (1997). Analysis of In-Place Contaminants in Marine Sediments from Four Harbor Locations on Guam: A Pilot Study, Water and Environmental Research Institute of the Western Pacific, Technical Report No. 87, University of Guam, Mangilao, Guam.

Doherty, V. F. (2014). Antioxidant enzymes and histopathological biomarkers of exposure to monocyclic hydrocarbons in Clariasgariepinus (Catfish) and Eudriluseuginiae (Earthworm) (Doctoral dissertation, PhD. Thesis, University of Lagos, Nigeria).

Fan, C. & Zhang L. (2009). Preface. In Lake Taihu: Principles of Sediment Pollution and Remediation; Fan, C., Zhang, L., Eds.; Science Press: Beijing, China, Pp. 3–4.

Fergusson, J. (1990). The heavy elements-chemistry, environmental impact and health effects. Pergamon Press, Oxford, 614pp

Gangaiya, P., Tabudravu, J., South, R. &Sotheeswaran, S. (2001). Heavy metal contamination of the Lami coastal environment, Fiji. The South Pacific Journal of Natural and Applied Sciences, 19(1): 24-29.

Grabowski, R. C., Droppo, I. G. & Wharton, G. (2011). Erodibility of cohesive sediment: the importance of sediment properties. Earth-Science Reviews, 105(3-4): 101-120.

Hutchins, D. A., &Bruland, K. W. (1998). Iron-limited diatom growth and Si:N uptake ratios in a coastal upwelling regime. *Nature, 393*, 561-564. http://dx.doi.org/10.1038/31203

Karbassi, A., Nasrabadi, T., Rezai, M. &Modabberi, S. (2014). Pollution with metals (As, Sb, Hg, Zn) in agricultural soil located close to Zarshuran gold mine, Iran, Environmental Engineering and Management Journal, 13: 1971-1978.

Kongchum, Manoch ,Hudnall, Wayne H. and Delaune, R. D.(2011) 'Relationship between sediment clay minerals and total mercury', Journal of Environmental Science and Health, Part A, 46: 5, 534 — 539, First

Leticia, B., Pablo, M., Ana Maria, S., Pires-Vanin, K. & Marcelo, R. (2003). Spatial distribution of organic matter in the surface sediments of Ubatuba Bay (Southeastern – Brazil). Annals of the Brazilian Academy of Sciences, 75(1): 77-90

National Water Research Institute (2006). Canada Centre for Inland Waters National Laboratory for Environmental Testing Certified Reference, Materials & Quality Assurances Services (Version 5.7). Burlington, Ontario.

Nwankwo, D. I, Onyema, I. C. and Adesalu TA (2003). A survey of harmful algae in coastal waters of South-western Nigeria. Journal of Nigerian Environmental Society 1(2):241-246.

Onyena A. P.andOkoro C. A (2019). Spatio-temporal variations in water and sediment parameters of AbuleAgege, AbuleEledu, Ogbe, creeks adjoining Lagos Lagoon, Nigeria. Journal of Ecology and thee Natural Environment. 11(4): 46-54

Rabiu, E. A. Akinnigbagbe, D. O. Imo, M. T. Imhansoloeva, V. O. Aniebone, M. P. Ibitola, B. R. Faleye, O. ShondeAnd Y. J. Appia (2013). Grain Size Analysis Of Beach Sediment Along The Barrier Bar Lagoon Coastal System, Lagos, Nigeria; Its Implication On Coastal Erosion. Global Journal Of Geological Sciences Vol. 12, 2014: 31-37

Sarkar, S. K., Paulo, J.C.F., Rakshit, D and Satpathy, K. K. (2014). Geochemical speciation and risk assessment of heavy metals in soils and sediments. DOI: 10.5772/57295

Sauve, S., Hendershot, W. and Allen H. (2000). Solid solution partitioning of metals in contaminated soils: dependence on pH, total metal burden, and organic matter. Environmental Science and Technology 34: 1125 – 1131.

Sauvé, S., Hendershot, W., & Allen, H. (2000). Solid-solution partitioning of metals in contaminated soils: dependence of pH, total metal burden and organic matter. *Environmental Science & Technology, 34*,1125-1131. http://dx.doi.org/10.1021/es9907764

Snape I, Scouller RC, Stark SC, Stark J, Riddle MJ, Gore DB. (2004). Characterisation of the dilute HCl extraction method for the identification of metal contamination in Antarctic marine sediments. *Chemosphere.* 57(6):491-504.

Tessier, A.; Campbell, P.G.C.; Bisson, M. Particulate trace metal speciation in stream sediments and relationships with grain size implications for geochemical exploration. J. Geochem. Explor. **1982**,*16*, 77–104.

Titocan, M. I., Ibitola, M. P., Faleye, B. R., and Akinade-Solomon, O. C. (2018). Spatial assessment of the textural characteristicsand sorting of beachdeposits on the Barrier Lagoon Coastal Complex Lagos Nigeria. J. Geol. Geophys. 7(3): 334 – 341

U.S. EPA, (1998). Field portable x-ray fluorescence spectrometry for the determination of elemental concentrations in soil and sediment. Method 6200.

Voice, T. C and Weber, W. J. (1983). Sorption of hydrophobic compounds by sediments, soils and suspended solids. DOI:10.1016/0043-1354(83)90275

Weber, M. E., Wiedicke-Hombach, M., Kudrass, H. and Erlenkeuser, H. (2003). Bengalfan sediment transport activity and response to climate forcing inferred from sediment physical properties: Sedimentology Geology, 155: 361-38.

Zauca, D.C., Statescu, F. & Pavel, L.V. (2013). Soil structure and water-stable aggregates, Environmental Engineering and Management Journal, 12: 741-746.