BORNEO JOURNAL OF SCIENCES AND TECHNOLOGY (BJoST)
VOL: 8, ISSUE: 2, 56-72
DOI: http://doi.org/10.35370/bjost.2026.8.2-05
e-ISSN: 2672-7439, UTS Publisher.

University of Technology Sarawak

ORIGINAL ARTICLE

Beneficial Use of Dredged Sediments from Lagos Lagoon as A Resource for Environmental Reclamation: Geochemical Approach

*Omorinoye Omolayo Ajoke and Arogundade Oluwatomi Boluwatife

Department of Geology and Mineral Sciences, Faculty of Physical Sciences, University of Ilorin, Ilorin, Nigeria

ABSTRACT - The geochemical assessment of dredged sediments from the Lagos Lagoon was conducted to evaluate their suitability for environmental reclamation. The importance of reusing dredged materials has grown in Lagos as coastal urbanization and infrastructural development expand. However, there are concerns to the environment and human health from possible heavy metal contamination. In order to ascertain the concentrations of important heavy metals, this study used a systematic sampling of a sediment each from ten different dredging days throughout the lagoon, followed by their laboratory analyses. Three geochemical indices which are the Contamination Factor (CF), Enrichment Factor (EF), and Geoaccumulation Index (Igeo) were used to evaluate the degree of contamination. CF values classified a few samples as highly contaminated and EF values classified many samples as severely to extremely contaminated, especially in locations that could be possibly impacted by industrial and shipping operations. The results showed that Cd, Pb, and Co were present at quantities much higher than natural background levels. These results were supported by Igeo studies, which identified locations with moderate to severe pollution. Additionally, grain size measurement showed that some samples had good gradation and were physically appropriate for reclamation, but other samples had low gradation, which might undermine engineering stability. Not all dredged sediments are structurally or environmentally suitable for land restoration, as shown by the combination of grain size analysis and geochemical data. The study recommends pretreatment of contaminated sediments ahead of any application and indicates that only suitable sediments (with acceptable physical qualities and low contamination) should be reused. The results support a science-based paradigm for sustainable sediment management in coastal urban contexts and reaffirm the necessity of regulatory sediment quality requirements.

ARTICLE HISTORY
Received: 11 Aug 2025
Revised: 23 Dec 2025
Accepted: 13 Apr 2026

KEYWORDS
Heavy metals,
Contamination Factor (CF),
Enrichment Factor (EF),
Geoaccumulation Index (Igeo),
Sediment quality assessment.

INTRODUCTION

Globally, coastal cities are under growing pressure to achieve a balance between the needs of developing their infrastructure and urban growth as well as environmental sustainability. Due to extensive dredging activities aimed at land reclamation, flood mitigation and navigational improvement, the Lagos Lagoon which is the most populous and industrialized city in Nigeria has become a focus point for such difficulties [1; 2]. Despite being very important, dredging operations produce a lot of sediments that need to be appropriately managed to prevent environmental damage. Dredged sediments, once thought of as waste, are now being acknowledged more and more for their possible applications in soil improvement and land reclamation, as long as they satisfy the requirements for performance and security [3; 4]. Previous studies such as [1] highlighted elevated metal concentrations in Lagos Lagoon sediments, while [2] emphasized the role of industrial discharge in sediment contamination.

*Corresponding Author: Omorinoye Omolayo Ajoke. University of Ilorin, Nigeria
Email: omorinoye.oa@unilorin.edu.ng

Figure 1. Map of Lagos Lagoon [5]

However, concerns regarding heavy metal contamination in these sediments have been raised by industrial and urban pressures surrounding the Lagos Lagoon ecosystem. Surface runoff, household wastewater, and industrial discharges are only a few of the many artificial sources of inputs that contaminate the Lagos lagoon ecosystem [6]. Without adequate evaluation, these operations may make dredged materials unsuitable for useful purposes by introducing hazardous elements including cobalt (Co), lead (Pb), and cadmium (Cd) into the sedimentary environment. Long-term hazards to ecosystems and human health arise from heavy metals' persistence, non-biodegradability, and capacity for bioaccumulation [7; 8]. Determining whether dredged sediments are suitable for environmental reclamation requires evaluating their geochemical characteristics. Important information on the environmental danger and the engineering performance of the sediments can be found in parameters like heavy metal concentrations, contamination indices, and grain size distribution [9; 10].

The Contamination Factor (CF), Enrichment Factor (EF), and Geoaccumulation Index (Igeo) are among the commonly used indices used in this study to assess the level of anthropogenic influence and possible ecological hazard. Sediment texture is also analyzed to determine its physical stability and suitability for reclamation. This study adds to the expanding body of research promoting sustainable sediment reuse techniques in urban coastal environments by combining chemical and physical evaluations. The findings are intended to enable the creation of safe, economical sediment management frameworks that are in line with environmental best practices and to influence policy [11].

STUDY AREA

The investigation was carried out in Majidun, a coastal community along the Lagos Lagoon northeast of Lagos Island, Nigeria. The lagoon is a brackish body of water that is roughly 635 km² in size. It receives a lot of industrial and urban runoff and is a major site for dredging [12; 2]. Majidun, the research area, is situated in Lagos State, southwest Nigeria, on the rural-urban boundaries of Ikorodu. It is situated along the Majidun River, a branch of the Oba River that empties into the Lagos Lagoon, some 35 kilometers northeast of Lagos Island. Situated between latitude 6.6000°N and longitude 3.5000°E, the area is highly inhabited and spans around 1.71 km².

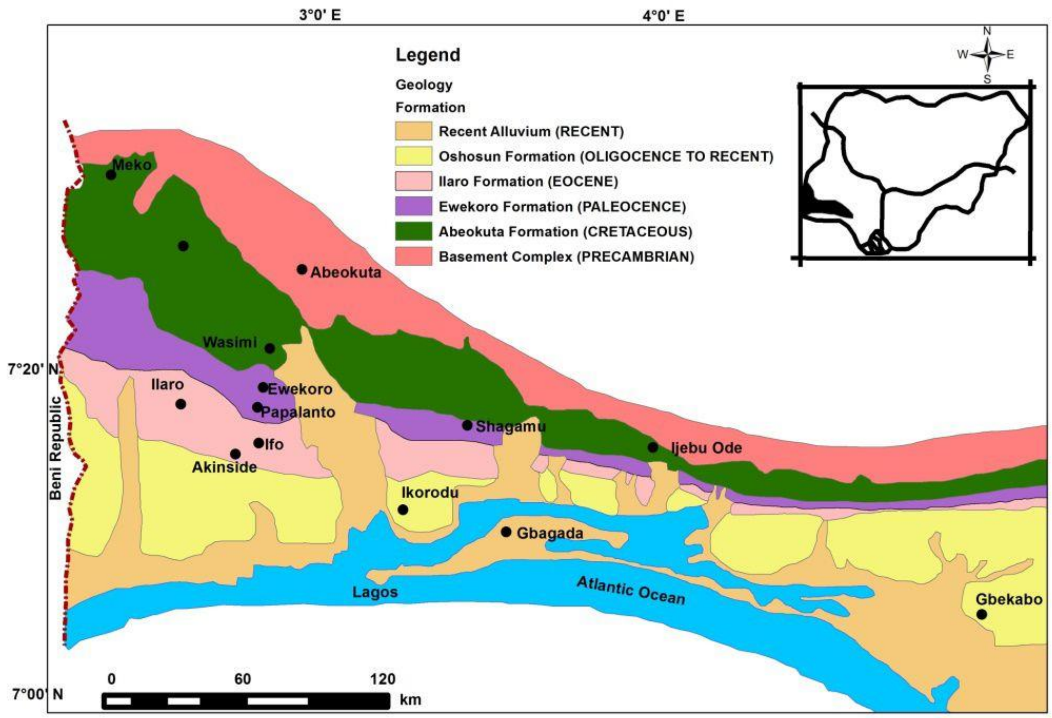

Figure 2.1. Map showing the Lagos Lagoon [13]

A vital component of regional hydrology, the Lagos Lagoon is a 635 km² brackish body of water that is connected to the Atlantic Ocean by Lagos Harbor. In addition to supporting industry, transit, and fishing, it acts as a sink for industrial emissions and urban runoff. Major highways such as the Lagos-Ikorodu Road and inland waterways provide access to Majidun. Given its accessibility, the region has become a center for marine and dredging activities. The degradation of the environment, uncontrolled dredging, and inadequate sediment management are still problems, nevertheless [12]. Transportation is made easier by its advantageous location, but it is also subject to pollution from solid waste, industrial discharge, and vehicle emissions. With an annual rainfall of 1,500 mm to 2,000 mm, Majidun has a tropical rainforest climate with two distinct seasons: a wet season (April to October) and a dry season (November to March) [14]. All year long, the temperature ranges from 25°C to 30°C, and the relative humidity stays high. Leaching and heavy metal mobility are two soil processes that are greatly impacted by these climatic conditions [15].

In terms of topography, the region is mostly flat and low-lying, with a few undulating areas. According to [16], elevations vary from 0.2 to 50 meters above sea level. Given its topography, it is vulnerable to flooding and has an impact on the movement of pollutants and sediments. The geomorphology of Lagos Lagoon is impacted by tidal movements and river intake, which are important factors in sediment redistribution, which is essential for determining whether sediment is suitable for reclamation. Mangroves and freshwater wetlands are among the tropical swamp forests that make up the majority of the area's vegetation. However, the loss of natural vegetation due to urbanization has caused secondary forests and bare land to proliferate. In order to stabilize sediments and reduce contamination, vegetation is still essential. Ecosystem recovery may benefit from restorative measures, such as the reclamation of dredged sediments [11]. Sand mining, unofficial trash disposal, and artisanal industrial operations are examples of human activities in Majidun. These include transportation emissions, industrial effluents, and inappropriate waste management, all of which lead to heavy metal contamination. The importance of geochemical evaluation in this study is supported by the interaction between these environmental processes and human activities. In order to ensure complete spatial coverage of areas impacted by industrial, residential, and maritime activity, ten sediment samples were methodically taken from various dredging periods throughout the lagoon using a stratified random sampling technique.

Figure 2.2. Sampling sites at Lagos Lagoon following Majidun Creek Channel

MATERIALS AND METHODOLOGY

Sample Collection and Preparation

Soil samples from ten distinct dredging periods (days) within the study area were gathered for the purpose of this study. A geological hand trowel was used to collect surface sediment samples, which were then placed into plastic containers that had been previously labeled according to the various days. To eliminate moisture, the samples were allowed to air dry at ambient temperature for a minimum of one week before any other procedure was taken. The fine fraction for geochemical analysis was then obtained by homogenizing them and sieving them through a 2.36 mm to less than 0.063 mm mesh. Standard dry sieving techniques using a mechanical shaker was employed to process the grain size distribution subsamples independently.

Laboratory Analysis

Atomic Absorption Spectrophotometry (AAS) was used to measure the amounts of heavy metals (Cd, Pb, Co, Zn, Cu, Ni, Mn, Fe, Cr, and K) after acid digestion processes as outlined by USEPA regulations [17]. The analysis was carried out at the University of Ilorin's Geochemistry Laboratory, a 1:3 ratio of hydrochloric acid (HCl) to nitric acid (HNO_3) was utilized to digest each sample. In order to guarantee accuracy and reproducibility, analytical quality control procedures included the use of blanks, duplicates, and verified reference materials. Prior to being checked for foreign contaminants, soil samples were allowed to air dry before being sieved to a consistent grain size of 0.112 mm. Using an analytical balance with a precision of ±0.01 g, 1.0 g of each sample was weighed and put into acid-resistant digestion tubes. To guarantee thorough digestion, freshly made aqua regia was added to the samples (usually 10–20 mL per gram of soil) and heated gradually at 90–120°C on a hot plate for two to four hours. Following cooling, the solution was diluted with distilled water to reach a final volume of 50 mL after being filtered (using Whatman No. 42 filter paper) to eliminate any remaining particles.

Atomic Absorption Spectroscopy (AAS) was used to examine the digested samples after being calibrated with standard solutions of known concentrations. Each element's absorbance was measured at its distinctive wavelength, and the absorbance measurements were compared to a calibration curve to estimate the metal concentrations. Throughout the analysis, strict quality control procedures were adhered to, which included using certified reagents, sterile equipment, and the appropriate personal protective equipment.

Contamination Assessment Indices

The following three geochemical indices were used to assess the degree of anthropogenic contamination:

i. Contamination Factor (CF): According to [18] proposal, the Contamination Factor (CF) was determined by dividing the concentration of each element in the sediment by its background value.

ii. Enrichment Factor (EF): Anthropogenic and natural metal sources were distinguished using the Enrichment Factor (EF). As a result of its relative geochemical stability, iron (Fe) was employed as a normalizing element.

iii. Geoaccumulation Index (Igeo): The Geoaccumulation Index (Igeo), which compares present concentrations to pre-industrial levels to determine the degree of pollution.

Grain Size Distribution

Grain size analysis was used to evaluate the sediments' physical characteristics. Grain size classification followed the Udden-Wentworth scale to determine sediment gradation and sorting. The samples collected were taken into a room with ambient temperature and left there to air dry at room temperature for a couple of days before it was finally sieved. In order to categorize the samples according to grading and sorting criteria and ascertain the sediment texture, the data were examined. The following formulas were used I calculating both coefficient of curvature and coefficient of uniformity respectively;

$$Cc = \frac{{D_{30}}^2}{D_{10} \, X \, D_{60}} \qquad (1)$$

$$Cu = \frac{D_{60}}{D_{10}} \qquad (2)$$

Ethical Consideration

A collection of core ideas that direct research procedures and practices are included in ethical considerations. Protecting study participants' rights and well-being requires taking into account a number of ethical factors. The appropriate authorities granted their ethical approval. In order to minimize disruption to the study locations, soil extraction was carried out in accordance with environmental requirements. Operators of dredging sites were also contacted to obtain permission to enter sample sites.

RESULTS AND DISCUSSION

Heavy Metal Concentration in Sediments

Significant geographical differences were found in the heavy metal contents in the dredged sediment samples throughout the Lagos Lagoon. Cadmium (Cd), lead (Pb), and cobalt (Co) concentrations were especially high in locations that were suspected to be close to industrial areas and shipping lanes.

Table 1. Heavy metal concentration in sediments (mg/kg)

Samples	Cd (mg/kg)	Zn (mg/kg)	Cu (mg/kg)	Pb (mg/kg)	Ni (mg/kg)	Mn (mg/kg)	Fe (mg/kg)	Co (mg/kg)	Cr (mg/kg)
S1	0.00	0.04	0.06	0.53	0.15	0.00	2.66	0.00	0.05
S2	0.09	0.05	0.03	0.67	0.05	0.03	2.67	0.13	0.00
S3	0.10	0.10	0.02	0.53	0.04	0.08	2.35	0.07	0.02
S4	0.02	0.04	0.04	1.06	0.08	0.07	2.83	0.14	0.00
S5	0.00	0.09	0.02	2.52	0.04	0.06	2.12	0.03	0.00
S6	0.02	0.06	0.00	2.48	0.06	0.05	2.25	0.00	0.00
S7	0.15	0.06	0.04	2.41	0.09	0.05	2.57	0.09	0.00
S8	0.00	0.04	0.03	2.57	0.01	0.08	0.82	0.00	0.01
S9	0.79	0.05	0.03	2.64	0.01	0.03	1.55	0.01	0.00
S10	0.09	0.11	0.05	0.65	0.07	0.06	2.42	0.28	0.00

These concentrations were higher than the typical natural background levels, indicating a substantial anthropogenic input that was probably caused by uncontrolled waste disposal, urban runoff, and industrial discharges [6; 1].

Contamination Factor (Cf)

The sediments were classified as moderately to very highly contaminated with certain metals by the Contamination Factor (CF) study. Some samples, for example sample 9 had CF values for Cd greater than 6, which indicates extremely significant contamination, in accordance with [18] classification. The widely recognized average shale and crustal abundance values published in geochemical literature served as the foundation for the background concentrations.

Table 2. Background values

S/N	ELEMENT	BACKGROUND CONC. (MG/KG)
1	Cd	0.1
2	Zn	95
3	Cu	45
4	Pb	20
5	Ni	68
6	Mn	850
7	Fe	35,000
8	Co	19
9	K	21,000
10	Cr	90

Table 3. Contamination factor in sediments

Samples	CF_{Cd}	CF_{Zn}	CF_{Cu}	CF_{Pb}	CF_{Ni}	CF_{Mn}	CF_{Fe}	CF_{Co}	CF_{Cr}
S1	0.01	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00
S2	0.91	0.00	0.00	0.03	0.00	0.00	0.00	0.01	0.00
S3	1.03	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00
S4	0.21	0.00	0.00	0.05	0.00	0.00	0.00	0.01	0.00
S5	0.01	0.00	0.00	0.13	0.00	0.00	0.00	0.00	0.00
S6	0.17	0.00	0.00	0.12	0.00	0.00	0.00	0.00	0.00
S7	1.47	0.00	0.00	0.12	0.00	0.00	0.00	0.00	0.00
S8	0.01	0.00	0.00	0.13	0.00	0.00	0.00	0.00	0.00
S9	7.87	0.00	0.00	0.13	0.00	0.00	0.00	0.00	0.00
S10	0.93	0.00	0.00	0.03	0.00	0.00	0.00	0.01	0.00

These findings highlight how industrialization and disturbances from dredging affect sediment quality over time [9]. Cadmium (Cd) stands out among the ten elements that were examined; its CF values range from 0.011 to 7.869, indicating contamination levels that range from low to quite high. In particular, sample S9 shows a significant cadmium enrichment that is most likely the result of human activity, such as industrial or municipal runoff. This implies that S9 sediment cannot be directly reclaimed from the environment without first being treated, although samples with mild CFs (such as S2, S3, S7, and S10) could be better off being stabilized or diluted.

Zinc (Zn), copper (Cu), nickel (Ni), manganese (Mn), iron (Fe), cobalt (Co), potassium (K), lead (Pb), and chromium (Cr) all had CF values that were much lower than 1, which indicates extremely low levels of contamination. These findings suggest that lithogenic (natural geology) sources predominate over human-caused input. Even the marginally higher amounts seen in certain samples are still within acceptable bounds. For example, there were slight increases in lead (Pb) in S5, S6, S7, S8 and S9, all of which fell below contamination criteria. Particularly, elements like cobalt, manganese, iron, and potassium are good for vegetation and soil fertility, thus they don't limit reclamation. The weathering of regional geologic elements such basement rocks, feldspars, and clays is primarily responsible for their existence. In conclusion, the only element in S9 that poses a serious risk of contamination is cadmium, which needs to be separated or treated before being used again.

Geoaccumulation Index (Igeo)

Sediments in certain zones were moderately to severely polluted, especially by Cd and Pb, according to the Geoaccumulation Index (Igeo), which measures pollution severity in relation to baseline levels. All Igeo values were calculated using the formula:

$$Igeo = \log_2(Cn / 1.5Bn) \qquad (3)$$

where Cn is the measured concentration and Bn is the background value, and 1.5 is a constant to account for natural variability in the background data.

Table 3. Geoaccumulation index interpretation table [19]

Igeo Value	Pollution Class	Implication
Igeo ≤ 0	Class 0 – Unpolluted	No contamination
0 < Igeo ≤ 1	Class 1 – Unpolluted to moderately polluted	Minimal contamination
1 < Igeo ≤ 2	Class 2 – Moderately polluted	Moderate pollution
2 < Igeo ≤ 3	Class 3 – Moderately to strongly polluted	Significant contamination
3 < Igeo ≤ 4	Class 4 – Strongly polluted	Serious pollution
4 < Igeo ≤ 5	Class 5 – Strongly to extremely polluted	Very serious pollution
Igeo > 5	Class 6 – Extremely polluted	Severe anthropogenic impact

Table 4. Geoaccumulation index in sediment samples

SAMPLE ID	$I_{geo\ Cd}$	$I_{geo\ Zn}$	$I_{geo\ Cu}$	$I_{geo\ Pb}$	$I_{geo\ Ni}$	$I_{geo\ Mn}$	$I_{geo\ Fe}$	$I_{geo\ Co}$	$I_{geo\ Cr}$
S1	-7.09	-11.76	-10.25	-5.82	-9.41	-21.28	-14.27	-15.54	-11.29
S2	-0.72	-11.41	-11.00	-5.50	-10.88	-15.42	-14.27	-7.73	-18.04
S3	-0.54	-10.48	-11.49	-5.83	-11.20	-14.03	-14.45	-8.69	-12.60
S4	-2.81	-11.83	-10.57	-4.82	-10.38	-14.23	-14.18	-7.70	-18.04
S5	-7.09	-10.56	-12.11	-3.57	-11.45	-14.37	-14.59	-10.10	-18.04
S6	-3.15	-11.18	-16.78	-3.59	-10.79	-14.53	-14.51	-15.54	-18.04
S7	-0.03	-11.16	-10.74	-3.64	-10.22	-14.58	-14.32	-8.35	-18.04
S8	-7.09	-11.90	-10.94	-3.54	-13.23	-13.94	-15.97	-15.54	-13.53
S9	2.39	-11.36	-11.17	-3.51	-12.95	-15.19	-15.05	-10.92	-18.04
S10	-0.69	-10.29	-10.43	-5.53	-10.51	-14.47	-14.41	-6.65	-18.04

The excessive buildup of Cd most especially was confirmed by Igeo values greater than 1.5, in accordance with [19] categorization. The contamination levels of different heavy metals in the dredged sediment samples were evaluated using the Geoaccumulation Index (Igeo). Values for all metals examined typically dropped below zero, meaning that most samples were in "Class 0 – unpolluted" circumstances. The element with the highest risk, cadmium (Cd), has Igeo values as high as 2.39. Since cadmium is highly harmful even at small amounts, Sample S9 is a source of concern even if all results are below the contamination criterion. This emphasizes that before to reclamation at such hotspots, site-specific evaluation and possible pre-treatment are necessary. All of the samples for zinc, copper, lead, nickel, manganese, iron, cobalt, potassium, and chromium had Igeo values well below zero, indicating that human activity was not a factor. These elements are either vital nutrients or do not exhibit any dangerous bioavailability at current quantities, and they are mainly derived from natural geological sources. Lead (Pb) levels are nevertheless suitable for usage as long as post-application monitoring is maintained, particularly in sensitive areas, even though they are close to contamination standards amidst some others. Likewise, Sample S10's Cobalt (Co) value was somewhat higher but still within acceptable bounds. In conclusion, all sediment samples show no discernible pollution and are considered safe for environmental reclamation, with the exception of the cadmium anomaly in S9. The Igeo values strongly support their positive reuse in vegetation support, soil fertility enhancement, or wetland restoration, which is consistent with sustainable reclamation techniques. This is consistent with earlier research showing that heavy metals persist in urban estuarine environments because of their strong adsorption to fine sediments and limited dispersion [20; 21].

Enrichment Factor (Ef)

The Enrichment Factor (EF), with iron serving as the normalizing element assisted in distinguishing between anthropogenic and natural geogenic input.

Table 5. Enrichment factor interpretation table [22]

EF Value Range	Degree of Enrichment	Interpretation
EF < 1	No enrichment	Indicates that the metal is of natural origin and no anthropogenic input is present.
1 ≤ EF < 3	Minor enrichment	Suggests some minimal influence of human activity.
3 ≤ EF < 5	Moderate enrichment	Indicates moderate anthropogenic input.
5 ≤ EF < 10	Moderately severe enrichment	Shows significant contribution from anthropogenic sources.
10 ≤ EF < 25	Severe enrichment	Strong anthropogenic influence; likely point-source pollution.
25 ≤ EF < 50	Very severe enrichment	Very strong pollution from human activities.
EF ≥ 50	Extremely high enrichment	Extreme anthropogenic pollution; critical contamination level.

Table 6. Enrichment factor in sediment samples

Samples	Cd	Zn	Cu	Pb	Ni	Mn	Fe	Co	Cr
S1	144.88	5.71	16.19	349.30	29.09	0.01	1.00	0.42	7.92
S2	11958.52	7.23	9.63	436.53	10.42	0.45	1.00	92.44	0.07
S3	15384.29	15.66	7.77	393.09	9.50	1.34	1.00	53.95	3.60
S4	2649.83	5.11	12.24	655.52	13.89	0.97	1.00	89.09	0.07
S5	181.22	16.32	5.60	2077.10	8.82	1.17	1.00	22.46	0.09
S6	2623.41	10.05	0.21	1928.21	13.13	0.98	1.00	0.49	0.09
S7	20045.49	8.90	11.92	1642.49	17.15	0.84	1.00	62.46	0.08
S8	470.55	16.80	32.61	5499.82	6.67	4.09	1.00	1.35	5.42
S9	177893.68	12.92	14.67	2981.51	4.29	0.91	1.00	17.49	0.13
S10	13493.80	17.32	15.72	470.48	14.85	0.95	1.00	215.34	0.08

Cd, Pb, and Co were classified as considerable to extremely enriched because their EF values were typically greater than 50. These enrichment levels support suspicions that the extensive metal accumulation in the lagoon sediments may be caused by poorly managed garbage from cities and industrial wastewater [23]. Different levels of contamination and anthropogenic influence are revealed by the enrichment factor (EF) study of heavy metals in the dredged sediments. With readings ranging from 144.88 to a startling 177,893.68, cadmium (Cd) showed exceptionally significant enrichment throughout, particularly in Samples 7 and 9. These excessive levels point to severe anthropogenic pollution, most likely from leachate from e-waste, battery trash, or industrial effluents. With EF values ranging from 349.3 to 5,499.82, lead (Pb) also shown consistently high enrichment. This was particularly evident in Sample 8, which was probably caused by urban runoff, legacy gasoline use, and the dumping of paint or batteries, indicating a high level of environmental danger in that region. EF values for cobalt (Co) ranged from 0.4159 to 215.34, with most samples (especially Samples 2, 4, and 10) showing very significant enrichment. This suggests possible industrial contributions, particularly from discharges related to alloys, pigments, or batteries. Both zinc (Zn), which ranged from 5.11 to 17.32 and nickel (Ni), which ranged from 4.28 to 29.09, showed moderate to very high enrichment levels, suggesting a combination of industrial, vehicular, and urban effects, particularly close to Majidun Creek. Sample 10 had the highest zinc EF, most likely as a result of cumulative local discharges. The range of copper (Cu) enrichment was 0.207 to 32.60. Sample 8 displayed extremely high enrichment, which may be related to antifouling coatings or marine industry sources, whereas Sample 6 had negligible enrichment (EF < 1).

The majority of other samples showed moderate to considerable enrichment, which is indicative of continuous human activity-induced metal inputs. Manganese (Mn), on the other hand, showed EF values ranging from 0.0077 to 4.0915, suggesting a lithogenic origin with little anthropogenic input, however small spikes (like Sample 8) might be the result of local dredging or sewage effects. In line with its abundance in natural silicate minerals, potassium (K) also displayed EF values below 1 in all samples, indicating no discernible enrichment and confirming a geogenic source. The levels of chromium (Cr) varied from 0.0688 to 7.9174. The remaining samples revealed little to no enrichment, indicating sporadic localized contamination probably related to paints, tanning waste, or stainless steel, but Samples 1 and 8 demonstrated moderate to extremely high enrichment. Cadmium, lead, and cobalt are the most worrisome pollutants overall, according to the enrichment factor data, with distinctly higher anthropogenic signatures. These results highlight the necessity for remediation plans before dredged sediments are used again for environmental reclamation, as they show significant ecological risk, especially in hotspot areas. On the other hand, manganese and potassium exhibit lithogenic behavior, which suggests that these elements have underlying geochemical stability. However, if ignored, the untreated samples with significant silt and clay contents could compromise structural integrity due to their poor gradation. In reclaimed land, these physical constraints may increase consolidation and decrease load-bearing capability [4].

Grain Size Distribution and Suitability for Reclamation

Across sampling sites, a combination of poorly sorted silt-clay components and well-graded sands were found by grain size analysis. With regard to their excellent compaction and drainage qualities, sediments with consistent, coarse-to-medium grain sizes are typically appropriate for reclamation [24].

Table 7. Grain size distribution table

Sieve size	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10
2.360	18.13	2.34	3.80	4.73	5.70	3.90	4.14	3.20	5.70	4.96
2.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.000	14.99	8.14	7.35	10.86	11.25	13.30	11.01	12.80	8.66	5.10
0.600	7.20	18.40	8.63	10.04	9.60	10.50	9.60	11.31	11.97	11.86
0.500	1.73	3.80	3.55	4.10	3.59	3.52	3.80	4.23	3.65	4.80
0.300	4.09	11.91	12.75	10.84	11.02	9.88	10.40	9.90	12.21	12.75
0.250	1.00	1.40	1.68	2.58	2.74	1.68	2.15	2.34	1.72	3.13
0.112	2.50	3.63	11.42	6.23	5.64	6.75	8.12	5.66	5.50	6.77
0.075	0.16	0.13	0.36	0.30	0.13	0.19	0.38	0.19	0.18	0.27
0.063	0.07	0.08	0.18	0.11	0.17	0.16	0.18	0.12	0.15	0.16
<0.063	0.12	0.12	0.25	0.13	0.10	0.10	0.18	0.11	0.15	0.18
	49.99	49.95	49.97	49.92	49.94	49.98	49.96	49.86	49.89	49.98

Table 8. Coefficient of curvature and Coefficient of uniformity

Diameter	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10
D60	1.88	0.79	0.59	0.82	0.87	0.89	0.80	0.86	0.81	0.66
D30	0.90	0.46	0.32	0.40	0.41	0.42	0.38	0.43	0.42	0.37
D10	0.36	0.29	0.16	0.21	0.22	0.20	0.18	0.22	0.22	0.20
Cu	5.271	2.779	3.654	3.944	3.913	4.366	4.343	3.898	3.645	3.306
Cc	1.202	0.939	1.041	0.942	0.871	0.981	0.964	0.978	0.966	1.025

The uneven distribution of grain sizes suggests poor gradation. The structural performance is weakened because of either a gap (missing intermediate particles) or a dominance of specific sizes.

Table 9. Gradation table

Sample	Cu	Cc	Cu Interpretation	Cc Interpretation	Final Soil Grading
M1	5.27	1.20	Well graded (sands)	Well graded	Well graded
M2	2.79	0.94	Poorly graded	Slightly poorly graded	Poorly graded
M3	3.65	1.04	Marginally graded	Well graded	Marginal
M4	3.94	0.94	Marginally well graded	Slightly poorly graded	Near well-graded
M5	3.91	0.87	Marginally graded	Poorly graded	Marginal to poor
M6	4.37	0.98	Well graded	Slightly poorly graded	Borderline graded
M7	4.34	0.96	Well graded	Slightly poorly graded	Borderline graded
M8	3.90	0.98	Marginally graded	Slightly poorly graded	Marginal
M9	3.65	0.97	Marginally graded	Slightly poorly graded	Marginal
M10	3.31	1.03	Poorly graded	Well graded	Poorly graded

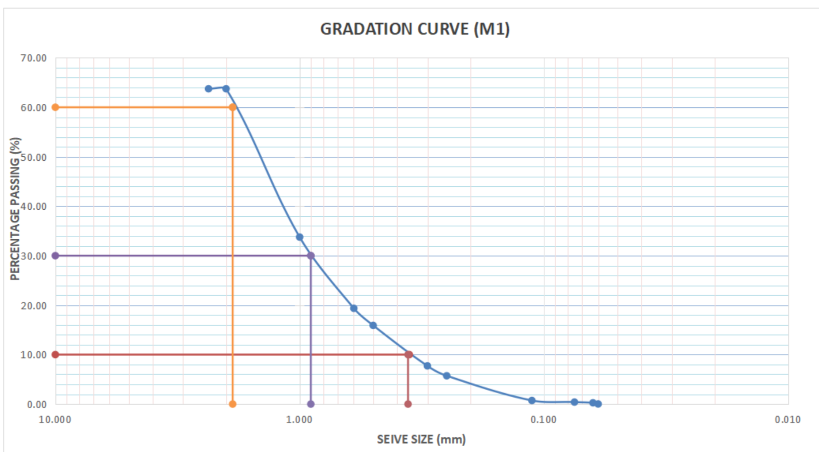

Figure 1. Graph of grain size (sieve size) plotted against percentage passing and showing D10, D30, and D60 for M1

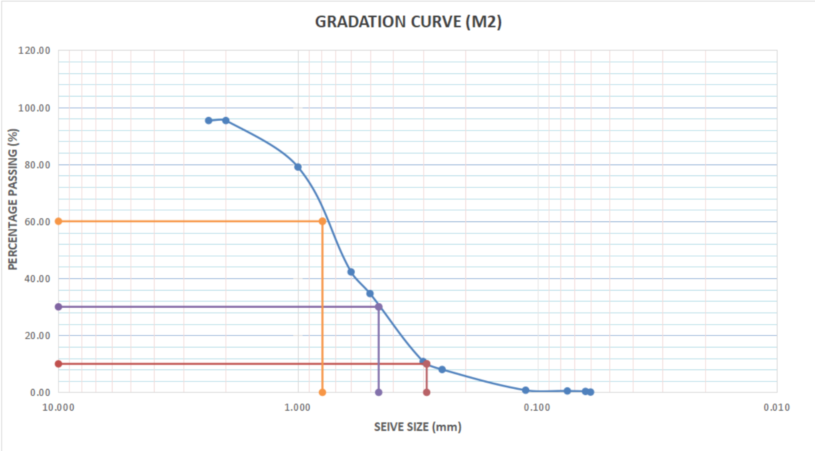

Figure 2. Graph of grain size (sieve size) plotted against percentage passing and showing D10, D30, and D60 for M2

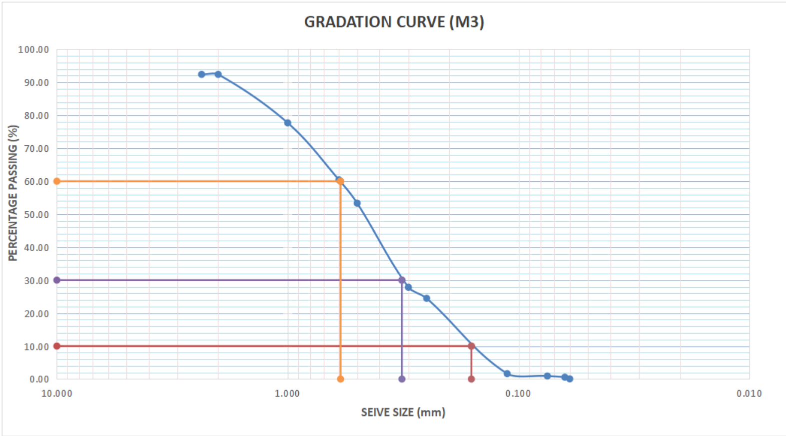

Figure 3. Graph of grain size (sieve size) plotted against percentage passing and showing D10, D30, and D60 for M3

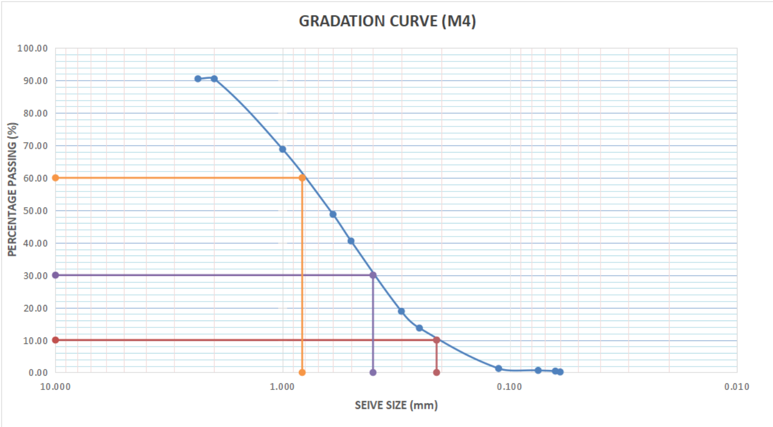

Figure 4. Graph of grain size (sieve size) plotted against percentage passing and showing D10, D30, and D60 for M4

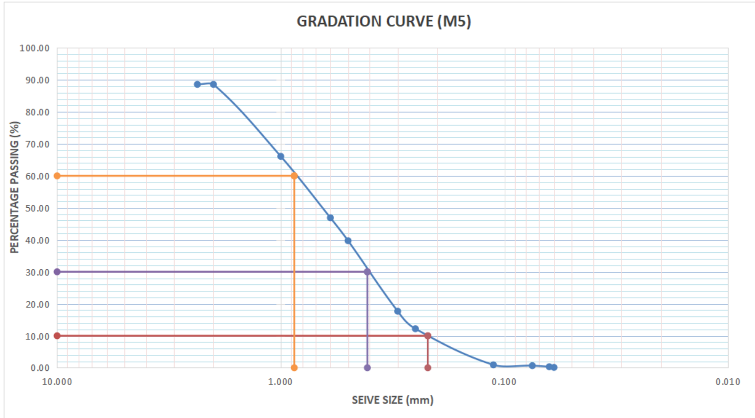

Figure 5. Graph of grain size (sieve size) plotted against percentage passing and showing D10, D30, and D60 for M5

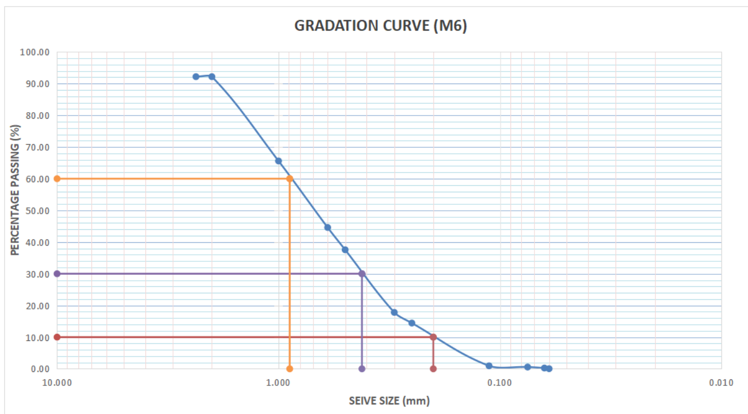

Figure 6. Graph of grain size (sieve size) plotted against percentage passing and showing D10, D30, and D60 for M6

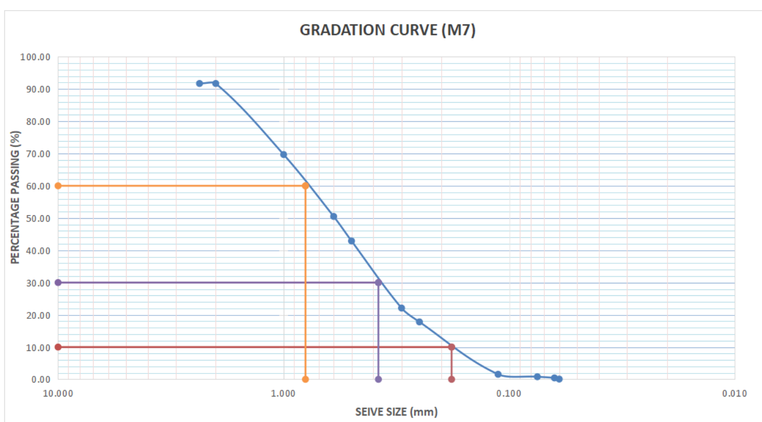

Figure 7. Graph of grain size (sieve size) plotted against percentage passing and showing D10, D30, and D60 for M7

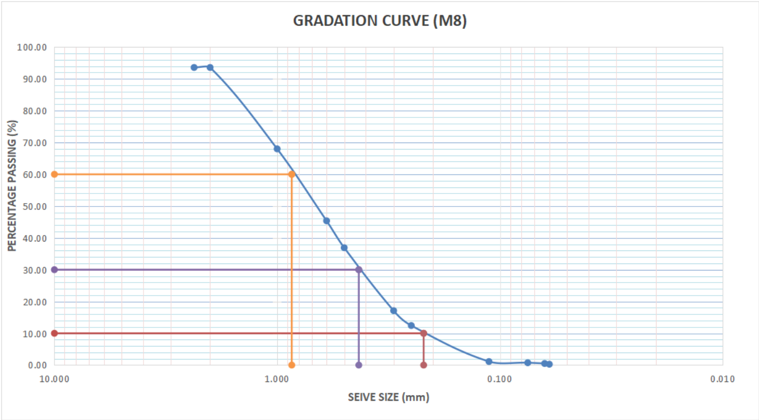

Figure 8. Graph of grain size (sieve size) plotted against percentage passing and showing D10, D30, and D60 for M8

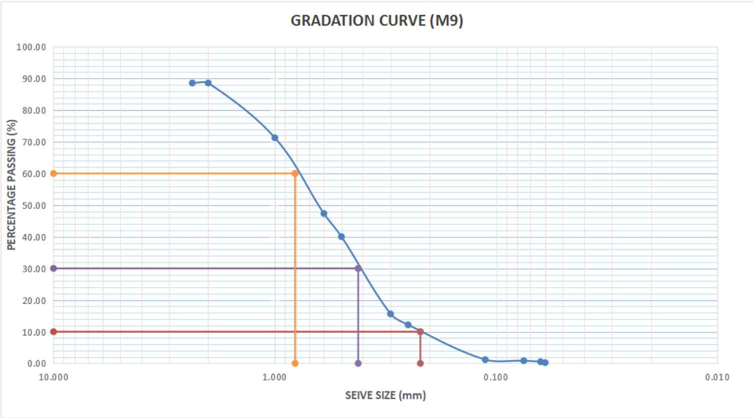

Figure 9. Graph of grain size (sieve size) plotted against percentage passing and showing D10, D30, and D60 for M9

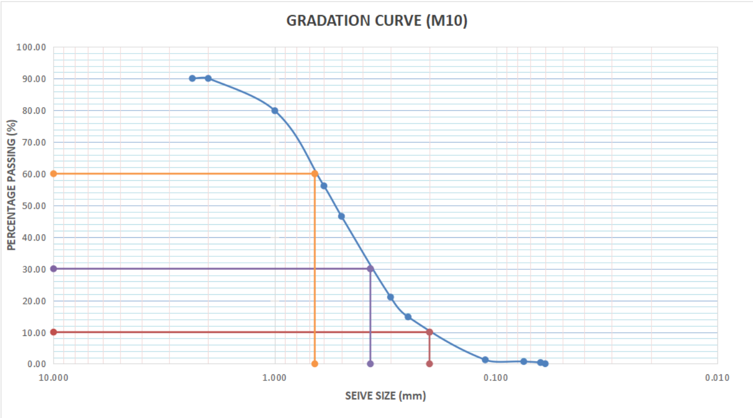

Figure 10. Graph of grain size (sieve size) plotted against percentage passing and showing D10, D30, and D60 for M10

The presence of a broad range of particle sizes, including sand, silt, and clay, in well-graded sediments (high coefficient of uniformity, and acceptable coefficient of curvature) in the field of environmental reclamation is likely to result in improved compaction, increased shear strength, and reduced permeability. Only S1 meets the Coefficient of Curvature criteria, making it the most acceptable and well-graded sediment for reclamation fill material.

Implications For Environmental Reclamation

Granulometric and geochemical data integration indicates that not all dredged sediments are safe or appropriate for direct reuse. Some samples needed prior treatment because of excessive pollutant loads, whereas others showed acceptable physical characteristics and little contamination. Reusing polluted sediments may present major dangers to vegetation development, soil quality, and public health if not handled effectively [8; 11]. In order to guide the safe reuse of dredged material in coastal development, the study is encouraging the introduction of regulatory sediment quality criteria.

CONCLUSION

In order to assess the dredged sediments from Lagos Lagoon's suitability for environmental reclamation, this study offers an in-depth geochemical analysis. The results show that several sediment samples contain varying concentrations of heavy metals, including cobalt (Co), lead (Pb), and cadmium (Cd). The lagoon's exposure to artificial pollution sources is reflected in these increased concentrations, which are mostly found in regions with high levels of industrial and marine activity. Numerous dredged samples were found to be in moderate to extreme pollution classes, according to contamination indices including the Contamination Factor (CF), Enrichment Factor (EF), and Geoaccumulation Index (Igeo), most especially for metals like Cd.

These findings draw attention to the continuous environmental harm caused by dredging activities, urban runoff, and uncontrolled industrial discharge in the Lagos coastal zone. Important new information about the environmental and engineering behavior of the dredged sediments from the Lagos Lagoon has been made possible by the thorough geochemical and geotechnical analysis. All samples showed significant regional variation in heavy metal concentrations, with low to extremely high levels of contamination being found for copper (Cu), lead (Pb), cobalt (Co), cadmium (Cd), zinc (Zn), nickel (Ni), and chromium (Cr), note that some were moderately to considerably contaminated. Cd most especially, in certain samples had Contamination Factor (CF) values greater than 6, indicating severe contamination. On the other hand, potassium (K) and manganese (Mn) displayed values close to background levels, indicating little anthropogenic influence. Strong anthropogenic contributions were confirmed by Enrichment Factor (EF) analysis, especially in the severe enrichment of Cd, Pb (especially in sample S8), Co, and Cu which can be attributed to discharges from cities, industries, and the coast. The presence of lithogenic traces for Mn and K supported the Geochemical Baseline Theory and successfully distinguished between anthropogenic and natural inputs. Together, these patterns show a heterogeneous origin of contaminants, highlighting the dangers of reusing such sediments uncontrolled, particularly in inhabited or environmentally sensitive locations. Pollution levels were further supported by Geoaccumulation Index (Igeo) values, which were consistent with EF and CF interpretations and ranged from unpolluted to moderately polluted depending on location. Some samples exhibit noticeable contamination that could be harmful to the environment if they are reused without proper treatment, whereas other samples represent natural geogenic backgrounds.

By determining the sediments' appropriateness for engineering, grain size analysis supplemented geochemical data. Based on its Coefficient of Uniformity (Cu) and Coefficient of Curvature (Cc), Sample S1 showed ideal properties, such as low permeability, strong compaction potential, and high shear strength. The majority of the remaining samples, however, were either contaminated or poorly graded, indicating that stabilization or mechanical blending would be necessary to satisfy reclamation requirements. Overall, this study emphasizes how important it is to combine physical appropriateness with geochemical safety when evaluating dredged materials for land restoration. Only a small percentage of the sediments are physically and chemically suitable for direct reclamation usage, while others need remediation to protect human health and the environment. In order to promote sustainable development goals in Lagos and other coastal areas, these findings confirm the applicability of the Pollution Pathway Theory and call for strict monitoring, management, and treatment of dredging sediments. These findings underscore the need for regulatory sediment quality thresholds and site-specific pretreatment protocols prior to reclamation. Future studies should explore bioavailability and long-term ecological impacts of residual heavy metals.

ACKNOWLEDGEMENT

The authors would like to thank God first of all for his constant care and love, and also their families for all their support love and patience.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

REFERENCES

[1] Odukoya, A. M., Abimbola, A. F., & Lawal, O. (2011). Potential soil contamination with toxic metals in the vicinity of active and abandoned dumpsites. Agriculture and Biology Journal of North America, 2, 785-790.

[2] Ihenyen, A. E., Ejechi, B. O., & Omofonmwan, S. I. (2020). Dredging and environmental sustainability in Lagos Lagoon, Nigeria. Journal of Environmental Science and Engineering B, 9, 7–18.

[3] Apitz, S. E., & Brils, J. (2005). Contaminated sediments in European river basins. Environmental Science & Technology, 39(22), 9077-9086.

[4] Mattei, P., Pastorelli, R., Rami, G., Mocali, S., Giagnoni, L., Gonnelli, C., & Renella, G. (2017). Evaluation of dredged sediment co-composted with green waste as plant growing media assessed by eco-toxicological tests, plant growth and microbial community structure. Journal of Hazardous Materials, 333, 144-153.

[5] WATER, M. L. L. (2022). SPATIO-TEMPORAL TRENDS IN THE PHYSICOCHEMICAL PARAMETERS OF. Nigerian Journal of Fisheries, 19(1).

[6] Adewumi, A. A., & Laniyan, T. A. (2020). Heavy metals contamination and ecological risk assessment in coastal sediments of Lagos Lagoon. Environmental Monitoring and Assessment, 192(5), 1-15.

[7] Jaishankar, M., Tseten, T., Anbalagan, N., Mathew, B. B., & Beeregowda, K. N. (2014). Toxicity, mechanism and health effects of some heavy metals. Interdisciplinary toxicology, 7(2), 60.

[8] Sharma, R. K., Agrawal, M., & Marshall, F. M. (2021). Heavy metal contamination of soil and vegetables in suburban areas of Varanasi, India. Environmental Monitoring and Assessment, 89(1), 103–112.

[9] Brils, J. (2008). Sediment monitoring under the European Water Framework Directive. Journal of Soils and Sediments, 8(3), 130-132.

[10] Manap, N., & Voulvoulis, N. (2015). Environmental management for dredging sediments–The requirement of developing nations. Journal of environmental management, 147, 338-348.

[11] Gwenzi, W., Muhoyi, e., and Mukura, T. J. (2022). Emerging Contaminants in the Terrestrial-Aquatic-Atmosphere Continuum, Occurrence, Health Risks and Mitigation. In Health risk assessment and mitigation of emerging contaminants, A call for an integrated approach. Pg 325-342

[12] Oresanya, O. (2000). Methods of landfill and landfill equipments. In A Technical Paper on Workshop on the role of sanitary landfilling in Integrated Solid Waste Management. 60p.

[13] Ikhane, P. R., Folorunso, A. F., Shonibare, O. L., Odukoya, A. M., & Shomoye, C. O. (2010). Hydrogeochemical study, health implications and interpretation of surface water analysis around rural settlements of Itasin and Oki-gbode, Southwestern, Nigeria.

[14] Fasona, M., Omojola, A., Odunuga, S., Tejuoso, O., & Amogu, N. (2005). An appraisal of sustainable water management solutions for large cities in developing countries through GIS, the case of Lagos, Nigeria.; 49–57.

[15] Adeyemi, M. O., Olusola, J. A., Akpobasah, O., Adidi, N. E., & Shelle, R. O. D. (2019). Assessment of heavy metals pollution in sediments from Ologe Lagoon, Agbara, Lagos, Nigeria. Journal of Geoscience and Environment Protection, 7(07), 61.

[16] United Nations Centre for Human Settlements (UNCHS). The State of the World's Cities; HABITAT, Nairobi, Kenya, 2001.

[17] United States Environmental Protection Agency (USEPA). Handbook—Remediation of Contaminated Sediments; United StatesEnvironmental Protection Agency, Washington, DC, USA, 1991

[18] Hakanson, L. (1980). An ecological risk index for aquatic pollution control. A sedimentological approach. Water research, 14(8), 975-1001.

[19] Müller, G. (1969). Index of geoaccumulation in sediments of the Rhine River. GeoJournal, 2(3), 108–118.

[20] Lu, X., Wang, L., Li, L. Y., Lei, K., Huang, L., & Kang, D. (2012). Multivariate statistical analysis of heavy metals in street dust of Xi'an, Central China. Science of the Total Environment, 426, 11–22.

[21] Guo, G., Wu, F., Xie, F., & Zhang, R. (2012). Spatial distribution and pollution assessment of heavy metals in urban soils from southwest China. Journal of Environmental Sciences, 24(3), 410–418.

[22] Sutherland, R. A. (2000). Bed sediment-associated trace metals in an urban stream, Oahu, Hawaii. Environmental Geology, 39(6), 611–627.

[23] Gaur, A., & Adholeya, A. (2004). "Prospects of Arbuscular Mycorrhizal fungi in phytoremediation of heavy metal contaminated soils. Current Science, 86(4),528–534.

[24] Folk, R. L., & Ward, W. C. (1957). Brazos River bar: A study in the significance of grain size parameters. Journal of Sedimentary Petrology, 27(1), 3–26.