Potentially Toxic Contamination of Cultivated Wetlands in Lagos, Nigeria

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Introduction

The Ramsar convention on wetlands defines wetlands as “areas of marsh, fen, peat-land or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or saline, including areas of marine water the depth of which at low tide does not exceed six meters”.1

Wetlands have unique characteristics that distinguish them from other water bodies or landforms. These include: hydrology (water level), soils (the soils are developed in water-saturated materials) and vegetation (plants adapted to wet conditions). As transitional areas between terrestrial and aquatic environments, wetlands serve as the depository of land-derived materials. They also contribute to water quality and act as a buffer for all surface run-off from the surrounding areas, wetlands are a depository for whatever contaminants are sourced from the catchments; hence the need to ascertain the quality of sediment on which edible crops are grown to determine suitability for agriculture.

Methods. Wetland water samples were tested for pH levels, electrical conductivity, and total dissolved solids. Randomly selected core samples from one of the cultivated wetland areas located in the city center were taken to up to 8 cm in depth, then dried, recovered from the barrel and divided into groups of the following depths: 0-2 cm, 2-4 cm, 4-6 cm, and 6-8 cm. The dried and divided samples were subsequently sieved and analyzed for metal content using inductively coupled plasma mass spectrometry. Results for copper (Cu), lead (Pb), zinc (Zn), nickel (Ni), chromium (Cr) and vanadium (V) were geochemically evaluated.

Results. The wetland water samples were found to be acidic, ranging from 5.9-6.4. The electrical conductivity was 430-500 µS/cm, and total dissolved solids, 280-320 mg/L. The metal content results (in mg/kg) for samples from 0-2, 2-4, 4-6 and 6-8 cm depths were: Cu (13-861, 12-752, 10-899 and 11-707); Pb (29-1646, 26-2660, 33-2400 and 25-1818); Zn (112-7237, 76-9908, 63-7517 and 47-6579); Ni (3-219, 3-178, 3-186 and 3-176); Cr (10-147, 9-157, 14-160 and 16-147); and V (14-72, 12-75, 17-77 and 19-77). The evaluated results showed that the selected metal concentrations exceeded various guideline values. Calculated geo-accumulation index, metal ratio, and enrichment factor showed marked enrichment of metals in the wetland sediment samples.

Discussion. For the majority of the metals observed, the correlation matrix revealed strong positive relationships. For Cu, Pb, Zn, Ni, and Cr, there was a correlation matrix >0.8. This indicates similar origin and sourcing of the sediments. Vanadium, however, displayed a negative correlation with all the other elements.

Conclusions. The study revealed that most of the cultivated sediment samples contained elevated levels of potentially toxic elements in the form of Pb, Cu, and Zn. The acidic nature of the wetlands water in the sediment samples also make them unsuitable for cultivation as the possibility of metal dissolution in transpired water and bio-accumulation of potentially toxic elements in the cultivated vegetables is high.

Competing Interests. The authors declare no competing financial interests.

Keywords. Nigeria, Lagos, wetlands, toxic metals, heavy metals, wetland sediments, potentially toxic elements, sediment quality
J Health Pollution 10: 95–102 (2016)
mind the close relationship between the quality of the sediments/soils (substrate) upon which crops are grown and the quality and health of the plants and their edibility, it is therefore very important to have a clear understanding of the elemental constituents of the sediments in the wetlands and their fate.\(^5\)\(^6\) When investigating the risks associated with soil contamination, as well as identifying appropriate remediation strategies, it is critical to determine the level, or concentration, to which contaminants are present in soil.\(^7\)

Living organisms require minute amounts of some metals, as some trace metals are essential to maintain the metabolism of the human body. However, at higher concentration they can lead to poisoning. Examples of such metals include cobalt (Co), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), vanadium (V), strontium (Sr), and zinc (Zn). Heavy metal poisoning could result, for instance, from intake of food via the food chain because of bioaccumulation over time.

The availability of these metals in soils, sediments, and plants is governed by the solubility of heavy metals in water, which is predominantly controlled by the water pH, the type and concentration of liquids into which the metal could be absorbed, and the oxidation state of the mineral components and environment of the system.\(^8\) The behavior of metals in natural waters is a function of the substrate sediment composition, the suspended sediments composition, and water chemistry. Sediments composed of fine silt and clay will generally have higher level of metals. Metals also have high affinity for humic acids, organoclay, and oxides coated with organic matter.\(^9\) These conditions exist in wetland sediments.

Health and environmental effects of heavy metals are more pronounced in urban areas, where waterways and soils are often contaminated by industrial effluents and indiscriminate industrial and domestic waste disposal. Heavy metal poisoning in humans could result from intake of contaminated water and food, and by inhaling contaminated air with a high concentration of trace metals.

Heavy metals such as lead (Pb) can interfere with the uptake of certain essential nutrients, such as calcium ions and zinc ions. Lead molecules, for instance, are a similar size and charge as calcium molecules and can be stored in bones in the place of calcium. Lead stored in bones may also be replaced by calcium and re-mobilized. Once free in the system, lead may cause nephrotoxicity, neurotoxicity and hypertension. The effects of lead poisoning vary depending on the age of the individual and the amount of exposure. Children are susceptible to lead poisoning because they require high levels of calcium for the development of their skeletal system.\(^8\)

| Abbreviations | Description |
|---------------|-------------|
| ASC | Average shale contents |
| Bn | Calculated background value |
| CDeg | Contamination degree |
| CF | Contamination factor |
| Co | Cobalt |
| Cr | Chromium |
| Cu | Copper |
| Fe | Iron |
| Ip0 | Geoaccumulation index |
| Mn | Manganese |
| Mo | Molybdenum |
| MR | Metal ratio |
| Ni | Nickel |
| Pb | Lead |
| S | Strontium |
| SPSS | Statistical Program for the Social Sciences |
| V | Vanadium |
| Zn | Zinc |

Lead exposure may cause children to be less playful, clumsy, irritable, and sluggish (lethargic). In some cases, symptoms include headaches, vomiting, abdominal pain, lack of appetite (anorexia), constipation, slurred speech (dysarthria), changes in kidney function, unusually high amounts of protein in the blood (hyperproteinemia), and unusually pale skin (pallor) resulting from a low level of iron in the red blood cells (anemia). Neurological symptoms associated with lead exposure include: an impaired ability to coordinate voluntary movements (ataxia), brain damage (encephalopathy), seizures, convulsions, swelling of the optic nerve (papilledema), and/or impaired consciousness. Some affected children experience learning or behavioral problems such as mental retardation and selective deficits in language, cognitive function, balance,
Owing to the potential health effects posed by the presence of heavy metals in the food chain via uptake from the sediments and soils, several guidelines have been prescribed in order to mitigate the impact of metals on the health of people. These guidelines include the Canadian Environmental Quality Guidelines and the United States Environmental Protection Agency.

Space constraints in cities and urban centers, as well as the need to have fresh farm produce all year round have increased vegetable and fruit cultivation within wetlands.

Exposure to too much chromium may cause lung and respiratory tract cancer as well as kidney diseases. In addition, overexposure to chromium may also cause gastrointestinal symptoms, such as diarrhea and vomiting, often with blood. Symptoms may lead to severe water-electrolyte disorders, increased mild acidity of blood and body tissues (acidosis), and/or inadequate blood flow to its tissues resulting in shock. Lesions on the kidneys, liver, and muscular layer of the heart (myocardium) may also develop.

Copper may cause a flu-like reaction called metal fume disease and disturbances in the blood and zinc overexposure may cause the flu-like symptoms of metal fume fever; stomach and intestinal disturbances; and/or liver dysfunction.

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Study Area
This work was undertaken to determine the geochemical quality of the cultivated wetland in an area of Lagos, southwest Nigeria known as Alapere wetland. The study area is defined by longitude 3°23′29.7″ E and 3°23′31.4″ E, and latitude 6°34′49.2″ N and 6°34′44.3″ N (Figure 1). The area is an extensive wetland running almost parallel to the Oworonshoki-Third mainland axial way. The wetland drains a large part of the Lagos metropolis with huge industrial estates and sprawling residential areas. This wetland is currently being massively cultivated for various types of vegetables (Figure 2).

Methods
Sediment core samples were collected randomly with the use of 8x5 cm core barrels made from high density polyvinyl chloride pipes. Seventeen (17) core samples were obtained in all from the area being cultivated in the selected wetland. Sampled cores were limited to a maximum depth of 8 cm because only very shallow-rooted leafy vegetables (lettuce,
then pulverized in a porcelain mortar and pestle, and sieved through a 0.063 mm mesh sieve. Five to 10 grams of each sub-sample were then packaged in resealable sample bags for geochemical analysis at the AcmeLabs in Canada (www.acmelab.com) by inductively coupled plasma atomic emission spectrometry. Six elements of significant agricultural and environmental concern in terms of potential to become toxic were selected for further evaluation: Cu, Pb, Zn, nickel (Ni), chromium (Cr), and V.

The results derived from the chemical analyses (Supplemental Material I) were subjected to statistical analyses, including descriptive analysis and Pearson correlation using Microsoft Excel and the Statistical Program for the Social Science (SPSS) 17.0. The spatial concentration and distribution of the selected heavy metals in the wetland were plotted using ArcGIS software, while the environmental implications and geochemical associations were evaluated using geochemical and statistical analyses. The geochemical indices calculated included metal ratio, geo-accumulation index, contamination factor and contamination degree.

### Results

**Physicochemical Parameters**
The sediment samples were mainly dark grey in color. Measured pH levels ranged from 5.9 to 6.4, indicating slightly acidic conditions. Electrical conductivity ranged from 430 to 500 μS/cm. Total dissolved solids ranged from 280 to 320 mg/L (Table 1).

| Parameter                        | Range   |
|----------------------------------|---------|
| pH                               | 5.9–6.4 |
| Electrical Conductivity (μS/cm)  | 430–500 |
| Total Dissolved Solids (mg/L)    | 280–320 |

Table 1 — Summary of Physicochemical Parameters

**Metal Distribution and Geochemical Profiles**
Results are presented in their entirety in Supplemental Material I, while a summary is presented in Tables 2 and 3. Zn, Pb, and Cu were found to be the most elevated metals in the sediments at all depths (Figure 3). Samples AL/WT/25, AL/WT/26, AL/WT/32, AL/WT/30 and AL/WT/33 were observed to have Cu, Zn, Pb, and Cr concentrations greater than the Canadian Guidelines for Soil Quality.

The concentrations of the metals revealed an almost uniform distribution down the profile with a few locations showing increased concentration up the profile.

### Discussion

**Metal Associations**
Correlation is a very useful tool in...
the determination of a relationship between two different elements; it is a measure of the strength of the relationship between different metals. A Pearson correlation analysis of the results was undertaken using the SPSS 17.0 software package. The correlation coefficients ranged from -1 (indicating a negative or decreasing relationship or inverse relationship), 0 (which indicates an absence of relationship between the variables), to +1 (which indicates a perfect relationship).

A correlation coefficient between 0.9 to 1 is deemed very high; between 0.7 to 0.9, high; between 0.5 to 0.7, moderate; 0.3 to 0.5, low; and <0.3 very low. High correlation indicates that the elements have a similar source of input or they are co-precipitated in the sediment in the same form. Inter-element correlations are often necessary to explain observed geochemical distributions and associations.\(^{12}\)

The correlation analysis for the metal analysis from the wetland (Table 4) revealed strong positive relationships, with a correlation matrix >0.8 among Cu, Pb, Zn, Ni, and Cr, an indication of similar origin and sourcing into the sediments. Vanadium however, displayed a negative correlation with all the other elements.

### Environmental Assessment of Heavy Metals

The sediment quality was assessed by using various geochemical evaluation methods to determine the metal ratio, geoaccumulation index, contamination factor, and contamination degree.

### Metal Ration

The metal ratio (MR) is a pollution quantification index obtained by comparing the observed heavy metal concentration with calculated background value or with average shale contents (ASC).\(^{13}\) This comparison is then used to indicate if there is an enrichment or depletion in the concentration of the analyzed metals. Sites having metal ratios of < 1 are deemed indicative of low metal enrichment or ideal metal concentration, while sites with metal ratio >1 indicate areas with elevated metal concentration.\(^{14}\)

The MR is calculated as:

**Equation 1:**

\[
MR = \frac{C_m}{B_n}
\]

and

**Equation 2:**

\[
MR = \frac{C_m}{ASC}
\]

where

- \(C_m\) is the measured concentration of the metal in the sample,
- \(B_n\) is the calculated background value,
- and \(ASC\) is the average shale content.
Most of the wetland sediments (using calculated and ASC values) revealed Cu, Pb and Zn as the most enriched metals in the area, ranging from considerable to very high contamination, while Ni, V, and Cr fall within the range of low contamination on the basis of ASC (Table 5). The concentration of the metals noted in the sediments of the Alapere wetland are much higher than those reported for the Lagos lagoon sediments.12

Geoaccumulation Index
The geoaccumulation index \( I_{geo} \) was used for the assessment of contamination in the wetland sediments.12,14-16 It was computed and interpreted using the equation below. The classes of contamination usually ranged from practically uncontaminated to extremely contaminated (Table 5).

The geoaccumulation index is expressed by:

\[
I_{geo} = \log_2 \frac{C_n}{1.5 \text{ASC}}
\]

where

\[C_n = \text{actual concentration of element in analyzed sample; and } \text{ASC} = \text{calculated background value (ASC in this case).}\]

Average shale content was used as the background for calculating the geoaccumulation values in this study. The constant 1.5 allowed for the analysis of natural fluctuations in the content of a given substance in the environment and to detect even minimal anthropogenic influences.

The calculated \( I_{geo} \) revealed that Pb and Zn fall within the range of strong to extreme contamination. Cu falls within the range of moderate to strong contamination, while other selected metals fall within the range of practically uncontaminated in all the locations (Table 6).

Contamination Factor and Contamination Degree
Contamination factor (\( C_F \)) and contamination degree (\( C_{Deg} \)) were also evaluated to ascertain the level of deterioration or otherwise in the quality of the environmental media.19,20 \( C_F \) indicates the individual impact of each metal on the sample while \( C_{Deg} \) is the sum of all the elements in the sample. \( C_F \) was expressed as:

\[
C_F = \frac{C_{metal}}{\text{background (ASC)}}
\]

Equation 4:

\[C_{Deg} = \frac{C_F(\text{selected Metal})}{\Sigma C_F} * 100\]

Equation 5:

The calculated \( C_F \) and \( C_{Deg} \) in the sediment were interpreted using the proposed classification (Table 7).
Cu, Pb, and Zn fall within the range of considerable contamination to very high contamination, while Ni, V, and Cr fall in the low contamination range (Supplemental Material II).

### Conclusions

The study revealed that the cultivated sediment samples from the Alapere wetland contained elevated levels of potentially toxic elements in the form of Pb, Cu, and Zn. It also revealed that the quality of the sediment samples was greatly impaired as deduced from the calculated contamination and pollution indices. A comparison with guideline values for agricultural soils indicated that quite a substantial portion of the wetland sediment samples have concentrations that surpass permissible safety levels for Pb, Cu and Zn. Ni, Cr and V were found to be within permissible levels.

The acidic nature of the water in which the sediments were collected, indicated by the low pH measured, also poses serious challenges as it implies that the metals could readily be in more soluble phases, making their bio-absorption much easier. This is a major problem as the vegetables grown

### Table 5 — Summary of Calculated Metal Ratios for Alapere Wetland Sediment Samples

| Metal | Range of Metal Ratio | Range of Geoaccumulation Index |
|-------|----------------------|--------------------------------|
| Cu    | <-1 - 18             | <0 - 4                         |
| Pb    | <-1 - 133            | <1 - 7                         |
| Zn    | <-1 - 111            | <0 - 7                         |
| Ni    | <-1 - 3              | <0 - 1                         |
| Cr    | <-1 - 2              | <0 - 1                         |
| V     | <-1 - 1              | <0 - 1                         |

Key: MR ≤ 1 = low contamination, 1 ≤ MR < 3 = moderate contamination, 3 ≤ MR < 6 = considerable contamination, MR > 6 = very high contamination.

### Table 6 — Summary of Interpreted Geoaccumulation Index of Alapere Wetland Sediment Samples

| Metal | Geoaccumulation Index Range | Interpretation |
|-------|-----------------------------|----------------|
| Cu    | <-2-4                       | Practically uncontaminated to extremely contaminated |
| Pb    | 0-7                         | Practically uncontaminated to extremely contaminated |
| Zn    | <-1-7                       | Practically uncontaminated to extremely contaminated |
| Ni    | <-5-1                       | Practically uncontaminated to moderately contaminated |
| Cr    | <-3-1                       | Practically uncontaminated to moderately contaminated |
| V     | <-3-1                       | Practically uncontaminated to moderately contaminated |

### Table 7 — Interpretation of the C_f and C_deg Classification

| Class | Indication          | Class | Indication          |
|-------|---------------------|-------|---------------------|
| C_f <1 | Low contamination   | C_deg < 8 | Low contamination   |
| 1 < C_f < 3 | Moderate contamination | 8 ≤ C_deg < 16 | Moderate contamination |
| 3 < C_f < 6 | Considerable contamination | 16 ≤ C_deg < 32 | Considerable contamination |
| 6 < C_f | Very high contamination | 32 ≤ C_deg | Very high contamination |

Table 7 — Interpretation of the C_f and C_deg Classification.
on the sediments of these wetlands are in very high demand by the local population. This assertion should be better verified with further study on the elemental composition of vegetables being currently grown on the sites to determine the level of bio-accumulation or otherwise.

This study further strengthens the need to have continuous monitoring of environmental media with which humans are in contact, in order to mitigate the untoward effects of unsustainable practices.

Authors Contributions.
Olatunji Akinade conceived and designed the study, Funmilayo Ajayi undertook the fieldwork and sample preparation. Both authors were involved in the analysis of the data, while the manuscript was written by Olatunji Akinade.

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