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Health and Ecological Risks Associated with heavy metal contamination in surface soils from Lagos lagoon wetlands, Lagos, Nigeria

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ABSTRACT: Wetlands quality and spatial distribution are being threatened by anthropogenic drivers in addition to the emerging threats of climate change. In this study, selected heavy metals (Cd, Cr, Cu, Ni, Pb and Zn) in soils from Lagos lagoon wetlands were investigated to assess spatial distribution, ecological and health risks. The data obtained were subjected to statistical analysis using GraphPad 7.0 and SPSS 22.0. Spatial distribution mapping of heavy metals was performed using ArcGIS10.0 (ESRI, Redlands, CA, USA) with Kriging interpolation. Results showed that heavy metals in the soil varied significantly ($p<0.05$). The contamination factors (CF) were generally low with the values for Cr, Ni, Cu, and Zn very low (<1). The CF values for some of the sampling points showed that the soils are generally moderately contaminated by Pb, Cd and Cu. The modified degree of contamination of Pb (2.35) indicates a moderate degree of contamination while that of Cd (12.60) indicates a high degree of contamination of these wetland soils. The potential ecological risk index (RI) of Pb, Cd, Cr, Ni, Cu and Zn are 70.40, 2264.40, 0.68, 1.55, 13.65, and 2.29, respectively. The RI for Pb, Cr, Ni, Cu and Zn were less than 100, hence, low, while the RI value of Cd was a very high risk ($RI \geq 400$). Soils from this wetland's areas show serious significant potential ecological risk due to Cd. Additionally, children were more susceptible to the potential health risk irrespective of the carcinogenic or non – carcinogenic risk. There were no significant carcinogenic and non – carcinogenic risks for adults and children. This wetland assessment provided important information for policymaking to reduce the potential effects of soil contamination on humans and the eco-environment.

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Keywords: wetlands, heavy metal, potential ecological risk, health risk, soil, cancer risk, contamination factors

Wetlands are distinct ecosystems that are inundated by water, either permanently or seasonally, with their characteristic vegetation of aquatic plants, adapted to the unique hydric soil (Keddy, 2010). They are among the most productive ecosystems on earth with unique aquatic and terrestrial communities of high biodiversity (Posa *et al*., 2011; Tina 2015). Degradation of the environment due to rising rapid urbanization and industrialization is now a serious concern globally with significant effects in the estuarine and wetlands acting as a sink for receiving leachates, effluents, emissions, fossil fuels, fertilizer erosion, herbicides and pesticides from agricultural run-off, and sewage and municipal wastes (Adesuyi *et al*., 2015; Adesuyi, 2020). Extensive agriculture, drainage and urban development have greatly altered the natural hydrology and wetland ecosystem of Lagos State, Nigeria. Although these changes in the landscape have brought great economic prosperity to the state and her citizens, they have degraded and eliminated more than 90% of the wetlands in the state (Ajibola *et al*., 2012). The remaining wetlands in the landscape often have their functions and biological quality impaired by natural and anthropogenic stressors, such as invasion by non-native plants, hydrologic changes, nutrient enrichment, sedimentation and pollutants (Obiefuna *et al*., 2013). The lack of strict adherence to the waste management regulations, poor urban planning and inadequate effort by governmental agencies had also contributed to improper waste disposal in them (Ogundele *et al*., 2020). Wetland soils pollution by heavy metals has been regarded as a critical problem because of their toxicity, persistence, and bioaccumulation (Njoku *et al*., 2013; Adesuyi *et al*., 2018). They adversely affect ecosystems, and they can be associated with direct and indirect human health risks when they pollute soils. Human health risk assessment, including non-

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carcinogenic and carcinogenic risk assessments, is a method that estimates the different possible heavy metal pathways that may cause harmful effects to people living close by or inhabiting them (Dorne *et al*., 2011; Mohammadi *et al*., 2019). Three pathways that could lead to heavy metals in soils affecting humans have been suggested by several researchers to be oral, dermal absorptions and inhalation (Hu *et al*., 2017, Aluko *et al*., 2018). Metals without known biological functions (such as lead, cadmium and arsenic) and even some essential metals for human beings (copper, zinc and chromium) can cause health risks when present in excess levels. Some metals, such as Pb, As, Cd and Cr have been classified as carcinogenic elements by the International Agency for Research on Cancer (Bai and Zhao, 2020). Thus, it is necessary to understand the contaminant status and potential risks of these sites, closely related to human health, require serious consideration and effective measures to protect them. The analysis and evaluation of heavy metal pollution in wetlands has become an important area of research within the field of wetland environmental pollution (Wang *et al*., 2019). The use of contamination factor (Cf), degree of contamination, index of geoaccumulation, (Igeo), pollution load index (PLI), etc. are some of the conventional methods which had been developed and employed to evaluate the pollution status of heavy metals in the soil. The ecological risks assessment is part of the contemporary research in soil pollution studies and environmental management, it indicates the tendency of the adverse effects of heavy metals on the ecological health (Ogundele *et al*., 2020). Studies have been conducted to evaluate the possible effect on human health due to exposure to metallic contaminants in soils from mining areas (Aluko *et al*., 2018), industrial areas (Qing *et al*., 2015; Liu *et al*., 2016), agricultural areas (Abdelhafez and Li, 2015; Liu *et al*., 2018) and wetlands (Cheng *et al*., 2015; Hu *et al*., 2017). The few available published studies on the pollution of wetland in Nigeria have reported elevated concentrations of metals as well as the associated high ecological and/or health risks (Olatunji and Ajay, 2016; Enuneku *et al*., 2018). Till date, no previous work had assessed the potential ecological and health risk of heavy metals of the wetland soil for the study area. Hence, our primary aim was to determine the distribution of heavy metals, evaluate the degree of heavy metal pollution based on contamination factor, pollution index, ecological risk indices and the health risks associated with the wetland soils.

MATERIALS AND METHODS

Study Areas: The Lagos lagoon wetlands form part of an intricate system of water ways made up of lagoons and creeks that are found along the coast line of Nigeria (Figure 1).

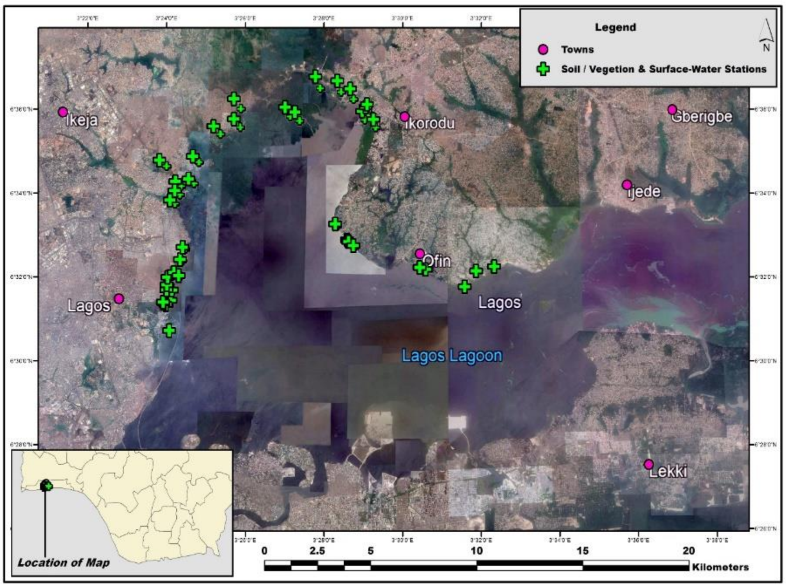

Fig 1: Sampling map of the study area

Sampling and Field Data Collections: The samples were collected in these wetlands monthly for 1 year. The coordinates for all sampling points was obtained using Garmin GPS and recorded. Soils samples were kept in foil papers and polythene bags and labelled properly as was described by Jha *et al*. (2016).

Soil sample preparation and physicochemical analyses: All of soil samples were air-dried after collection and sieved through a 2-mm nylon sieve to remove coarse debris. Heavy metals concentration was determined by inductively coupled plasma-atomic emission spectrometry (ICP-AES) as described by Zhang *et al*. (2010).

Pollution load index (PLI), contamination factor (CF) and modified contamination degree (mCd): Pollution load index is calculated as geometric mean of concentration factor (equation 1) value of *n* number of studied metals (Giri *et al*., 2013). The index is based on the CF of each metal present in the soil which is expressed as equation 2.

$$PLI = (CF_i \times CF_2 \times CF_3 \times ... \times CF_n)^{1/n} \quad (1)$$

Where *n* is the number of metals and CF is the contamination factor.

$$CF = \frac{Metal\ concentration\ in\ soil}{Metal\ concentration\ in\ average\ shale} \quad (2)$$

The modified degree of contamination was estimated according to Abraham and Parker (2008):

$$mCd = \frac{\sum_{i=1}^{i=n} CF}{n} \quad (3)$$

Where n= number of analysed elements, i=ith element and CF = contamination factor.

Assessment of potential ecological risk: Potential ecological risk assessment was to assess the degree of heavy metal pollution in soil, according to the toxicity of heavy metals and the response of the environment. E_r^i is the monomial potential ecological risk factor calculated using Eq 4, where T_r^i is the toxicity response factor and CF is the contamination factor:

$$E_r^i = T_r^i \times CF \quad (4)$$

Risk index (*RI*) is calculated as the sum of all risk factors for heavy metals in soils:

$$RI = \sum_{i=1}^{n} E_r^i \quad (5)$$

Ti is the toxic response factor for the metals and the values for As, Cd, Cu, Pb, Ni, Zn and Cr are 10, 30, 5, 5, 5, 1 and 2, respectively (Wang *et al*., 2011).

Health Risk Assessment: Exposure assessment: The health risk assessment was estimated based on the guidelines ad Exposure Factors handbook published by the US Environmental Protection Agency (1989, 1997, and 2001). The average daily doses (ADDs) [mg/kg (day)] of potentially toxic metals via ingestion (ADD_{ing}), dermal contact (ADD_{derm}), and inhalation (ADD_{inh}) for both children and adult were estimated using the following equations 9 to 11.

$$ADD_{ing} = \frac{C_i \times IngR \times EF \times ED}{BW \times AT \times 10^6} \quad (10)$$

$$= \frac{C_i \times SA \times AF \times ABS \times EF \times ED}{BW \times AT \times 10^6} \quad (11)$$

$$ADD_{inh} = \frac{C_i \times InhR \times EF \times ED}{PEF \times BW \times AT \times 10^6} \quad (12)$$

Non carcinogenic risk assessment: The HQ is the quotient for chronic daily intake, and the HQ for a single chemical is determined by Eq 13.

$$HQ = \frac{ADD}{RfD} \quad (13)$$

Where RfD is the chronic dose for the chemical [mg/kg (day)]. Hazard Index (HI) approached was used to assess the overall potential for non-carcinogenic effects posed by more than one chemical (Eq 13).

$$HI = \sum_{i=1}^{n} HQ_i = \sum_{i=1}^{n} \frac{ADD_i}{RfD_i} \quad (14)$$

Table 1: Input parameters to characterize the Average Daily Doses value (DEA, 2010; USEPA, 2011; Aluko et al, 2018)

.Parameter	Unit	Description	Value	
			Adults	Children
IngR	mg/day	Ingestion rate per unit time	100	200
EF	days/year	Exposure frequency	350	350
ED	years	Exposure duration	30	6
BW	kg	Body weight	70kg	15kg
InhR	m^3/day	Inhalation rate of soil	`20	10
SA	cm^2	Exposure skin area	5800	2100
AF	mg/(cm^2 day)	Soil adherence factor	0.07	0.2
ABS	unitless	Dermal absorption factor	0.1	0.1
FE	unitless	Dermal exposure ratio	0.61	0.61
PEF	m^3/kg	Particulate emission factor	$1.3x10^9$	$1.3x10^9$
CF	kg/mg	Conversion factor	10^{-6}	10^{-6}
AT	days	Average time-non cancer risk	EDx365	EDx365
		Average time-cancer risk	70x365	70x365

Carcinogenic risk assessment: The slope factor (SF) converts estimated daily intake of a toxin averaged over a life time of exposure directly to the incremental risk of an individual developing cancer, and it is calculated using Eq (14).

$$CR = ADD \times SF \qquad (15)$$

Where CR id the unit-less probability of an individual developing cancer over a life time, and SF is the carcinogenicity slope factor (kg day/mg). Risk surpassing 1 x 10^{-4} is viewed as unacceptable, risk below 1 x 10^{-6} is not considered to pose significant. The values of the parameters used for health assessment are in table 1.

Statistical Analyses: Spatial distribution of heavy metals was performed by ArcGIS10.0 (ESRI, Redlands, CA, USA) with Kriging interpolation. Non parametric tests were used to test for significance in the physicochemical characteristics and metal contents among different sample sites at α level of $p \leq 0.05$ using SPSS 22.0.

RESULTS AND DISCUSSION

Distribution of heavy metal and their extent in the wetland soils: The descriptive analysis of Pb, Cd, Cr, Ni, Cu and Zn are presented in Table 2. Heavy metals in the wetland soil varied significantly ($p<0.05$) with values from 0.01±0.00 to 141.70±0.59 mg/kg ($p<0.05$) for Pb, 0.01±0.01 to 4.46±0.64 mg/kg for Cd ($p<0.05$). Cr ranged from 0.01±0.01 to 6.53±0.03 mg/kg and were significantly different across the sampling points ($p<0.05$). Ni ranged between 0.01±0.01 and 28.32±2.76 with higher degree of variation ($p<0.05$). Cu ranged from 0.01±0.00 to 14.09±1.10 mg/kg while Zn also ranged from 0.08±0.04 to 24.45±0.10 mg/kg for Zn ($p<0.05$). The levels of heavy metals varied significantly ($p<0.05$) across sampling months and points. The values of Pb were significantly higher ($p<0.05$) in August (9.29±10.42), September (12.68±22.64), October (6.55±6.43), November (15.32±20.15), December (7.93±9.69), January (6.40±6.74), February (5.80±5.07), March (5.44±4.78) and April (4.22±3.62) than in May (2.00±6.22), June (0.24±0.19) and July (2.52±3.44). Cadmium levels for June (0.15±0.22), December (0.35±0.41), January (0.39±0.43), March (0.27±0.27), April (0.24±0.17), May (0.17±0.17) were significantly lower than that of the months of July (0.59±0.58), August (1.17±1.06), September (1.12±0.99), October (0.94±0.86), November (0.49±0.48) and February (0.46±0.46). There were no significant differences ($p>0.05$) in the Nickel value for July (0.49±0.38), August (1.10±0.02), September (0.80±0.69), October (1.31±4.24), November (0.42±0.34), December (0.41±0.63), and January (0.60±1.86), however, they were significantly higher than that of June (0.15±0.18), February (0.17±0.13), March (0.10±0.07), April (0.21±0.17), and May (0.17±0.16). The value of Cu was significantly ($p<0.05$) lower in June (0.62±0.34) than the rest of the months. Zinc was significantly ($p<0.05$) higher in November (5.62±5.89), December (4.88±4.64) and January (4.67±4.74) than that of the remaining months. The kurtosis (a measure used to describe the normality of a distribution) and skewness for all the heavy metals were generally high and significantly very high for Pb (July, Sept, and May), Ni (Aug, Oct, and Jan), Cu (Jan) and Zn (Jul, Feb, Apr and May) which indicates a non-normality of the distributions for these heavy metals and greater variation among the soils in the study area. The spatial distribution maps of the mean metal concentration in the wetlands are presented in figure 2 – 7. The ecological maps reveal variability in the distribution patterns of heavy metals in the water and soil in the study area. There were significant spatial variations in the soil heavy metals ($p<0.05$). The mean concentrations of Cr, Cu, Zn and Ni in soil were below both the optimal and action values of the Dutch and Canadian soil quality and guidance values (SQGV) and the NESREA standard. Cd was above the optimal Dutch SQGV (1 mg/kg) while Pb was also above the optimal Dutch SQGV (85 mg/kg), and this was reflective in the metal enrichment assessment. The significantly moderate to high enrichment in the wetlands soils underscores human activities been linked with high levels of heavy metal enrichment or pollution (Wang *et al*., 2019). The order of heavy metal concentration is by Cd>Pb>Cu>Zn>Ni>Cr, indicating an ascending order of their contribution to the spatial distribution and potential ecological risk in the Lagos Lagoon wetlands. This may be associated to the siting of major industries around this wetland, domestics, municipal and waste water discharge, farming, land use landcover change intensity etc. Similar results were reported by Kyere *et al*. (2018) in the spatial assessment of soil contamination by heavy metals from informal electronic waste recycling in Agbogbloshie, Ghana.

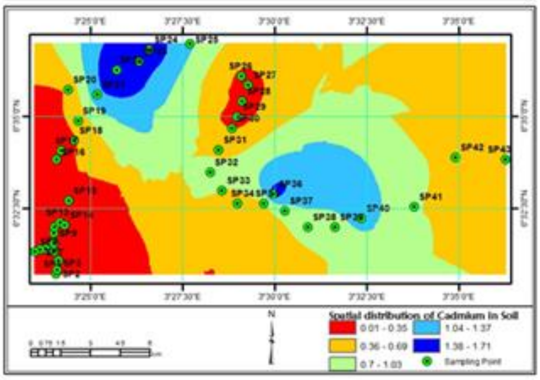

Fig 2: Spatial distribution map of Cd in the wetland soil

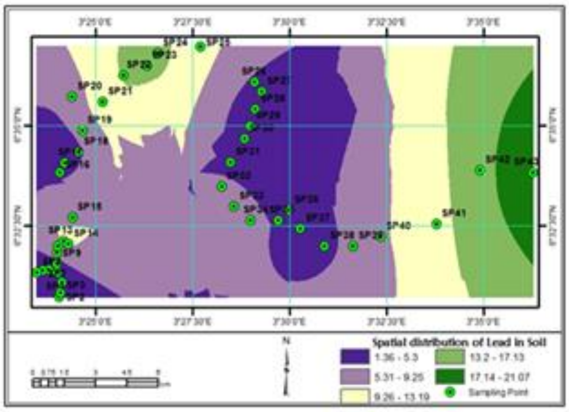

Fig 3: Spatial distribution map of Pb in the wetland soil

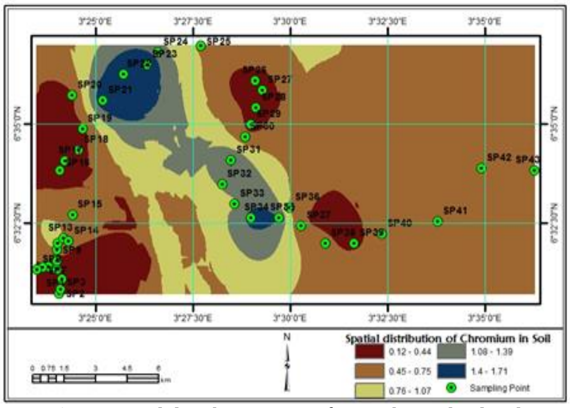

Fig 4: Spatial distribution map of Cr in the wetland soil

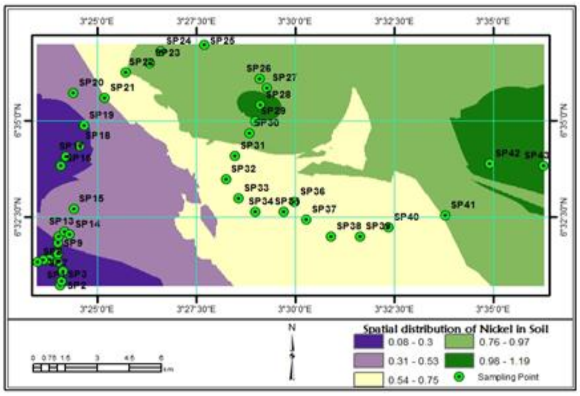

Fig 5: Spatial distribution of nickel in the wetland soil

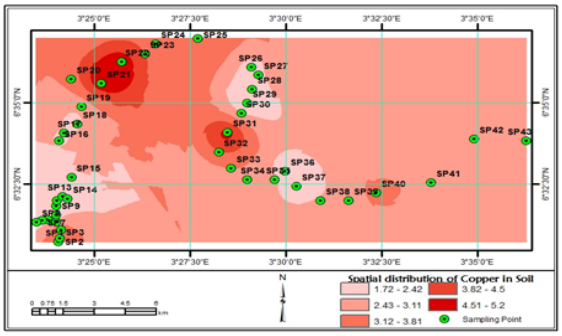

Fig 6: Spatial distribution map of Cu in the wetland soil

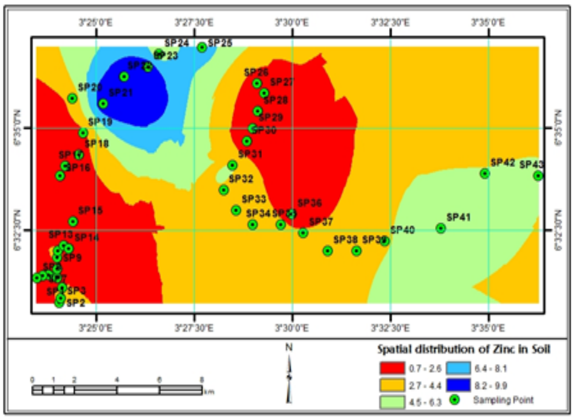

Fig 7: Spatial distribution map of Zn in the wetland soil

Contamination factor (CF), pollution load index (PLI) and Modified Degree of Contamination (mCD) of soils: The Contamination factors (CF) show that generally the values for Cr, Ni, Cu, and Zn in the wetlands were less than 1 (low) (Table 3). For Pb the contamination factor values ranged from 0.02 to 1.27, Cd ranged from 0.01 to 5,07, Cr and Ni values ranged from 0.01 to 0.02, Cu ranged from 0.04 to 0.16, and Zn ranged from 0.01 to 0.22. The CF values for sampling points 10, 12, 14,17-20, 30-35, 37-39, 41, 42 and 43 show that the soils are generally moderately contaminated by these metals especially Pb, Cd and Cu. The pollution load index value for Pb, Cd, Cr, Ni, Cu, and Zn are 14.10, 75.50, 0.34, 0.31, 2.73 and 2.29 respectively. Cr, Ni, Cu and Zn having PLI values lesser than 6 indicates low degree of contamination across the wetlands. The PLI value of 14.10 for Pb was between 12 and 24, it indicates moderate degree of contamination. However, cadmium had the highest degree of contamination for the wetland soils from this ecosystem with a PLI of 75.50. The modified degree of contamination (mCD) estimated the overall degree of contamination in the soil, Pb, Cd, Cr, Ni, Cu and Zn have a mCD value of 2.35, 12.60, 0.06, 0.05, 0.46 and 0.38 respectively. The obtained modified degree of contamination values for Cr, Ni, Cu and Zn showed a very low degree of contamination. The mCD value of Pb (2.35) indicates moderate degree of contamination while that of Cd (12.60) indicates high degree of contamination of this wetland soils. The modified degree of contamination (mCD) in the present study is based on integrating and averaging all the available analytical data for a set of soil samples. This modified method therefore provided an integrated assessment of the overall enrichment and contamination impact of groups of pollutants in the soil. For the classification and description of the modified degree of contamination (mCD) in the sediment, the following gradations are proposed: mCD <1.5 is nil to a very low degree of contamination; $1.5 \leq$ mCD < 2 is a low degree of contamination; $2 \leq$ mCD <4 is a moderate degree of contamination; $4 \leq$ mCD

<8 is a high degree of contamination; 8 ≤ mCD <16 is a very high degree of contamination; 16 ≤ mCD <32 is an extremely high degree of contamination; mCD ≤ 32 is an ultra-high degree of contamination. In this study, the modified degree of contamination (mCD) indicates moderate degree of contamination by Pb (2.35) and very high degree of contamination by Cd (12.60) of this wetland soils. Similar high degree of contamination (14.765) by Cd was also reported by Chandramohan *et al*. (2018) in coastal sediments of East Coast of Tamil Nadu, India.

Table 3: Contamination factor (CF), Pollution load indices (PLI) and Modified Degree of Contamination (mCD) of soils of the wetland

Sampling points	Contamination factor					
	Pb	**Cd**	**Cr**	**Ni**	**Cu**	**Zn**
Sampling Point 1	0.11	0.04	0.00	0.00	0.09	0.03
Sampling Point 2	0.11	0.04	0.00	0.00	0.07	0.07
Sampling Point 3	0.06	0.05	0.00	0.00	0.09	0.06
Sampling Point 4	0.04	0.04	0.00	0.00	0.07	0.06
Sampling Point 5	0.02	0.10	0.00	0.00	0.07	0.04
Sampling Point 6	0.02	0.34	0.01	0.00	0.05	0.03
Sampling Point 7	0.03	0.63	0.00	0.00	0.05	0.02
Sampling Point 8	0.02	0.73	0.00	0.00	0.04	0.02
Sampling Point 9	0.04	0.58	0.00	0.00	0.04	0.02
Sampling Point 10	0.07	1.01	0.01	0.00	0.06	0.02
Sampling Point 11	0.51	0.91	0.01	0.00	0.06	0.07
Sampling Point 12	0.59	1.04	0.01	0.00	0.04	0.07
Sampling Point 13	0.48	0.82	0.01	0.00	0.04	0.03
Sampling Point 14	0.85	1.04	0.01	0.02	0.04	0.03
Sampling Point 15	0.46	0.93	0.01	0.01	0.05	0.03
Sampling Point 16	0.17	0.96	0.00	0.00	0.05	0.05
Sampling Point 17	0.15	1.08	0.00	0.00	0.05	0.04
Sampling Point 18	0.08	1.04	0.00	0.00	0.05	0.04
Sampling Point 19	0.24	1.58	0.00	0.00	0.05	0.04
Sampling Point 20	0.10	1.26	0.00	0.00	0.08	0.07
Sampling Point 21	0.99	4.30	0.02	0.01	0.16	0.22
Sampling Point 22	0.64	5.70	0.02	0.01	0.11	0.21
Sampling Point 23	0.91	4.66	0.02	0.02	0.09	0.21
Sampling Point 24	0.76	5.21	0.01	0.01	0.08	0.11
Sampling Point 25	0.59	3.64	0.01	0.01	0.08	0.08
Sampling Point 26	0.21	0.93	0.01	0.01	0.05	0.02
Sampling Point 27	0.18	0.87	0.00	0.01	0.05	0.03
Sampling Point 28	0.11	0.02	0.01	0.04	0.04	0.01
Sampling Point 29	0.08	0.56	0.00	0.01	0.04	0.02
Sampling Point 30	0.09	1.17	0.01	0.01	0.05	0.01
Sampling Point 31	0.29	1.93	0.02	0.01	0.11	0.05
Sampling Point 32	0.29	2.97	0.02	0.01	0.08	0.05
Sampling Point 33	0.38	2.28	0.01	0.01	0.07	0.04
Sampling Point 34	0.28	1.73	0.02	0.01	0.06	0.04
Sampling Point 35	0.35	2.01	0.02	0.01	0.06	0.03
Sampling Point 36	0.17	5.09	0.01	0.01	0.04	0.01
Sampling Point 37	0.12	2.73	0.01	0.01	0.04	0.03
Sampling Point 38	0.16	2.85	0.01	0.01	0.05	0.04
Sampling Point 39	0.27	2.79	0.00	0.01	0.06	0.04
Sampling Point 40	0.50	3.91	0.01	0.01	0.08	0.04
Sampling Point 41	0.58	2.41	0.01	0.01	0.07	0.06
Sampling Point 42	0.71	2.09	0.01	0.02	0.06	0.05
Sampling Point 43	1.27	1.37	0.01	0.01	0.06	0.05
PLI	14.1	75.5	0.34	0.31	2.73	2.29
MCD	2.35	12.6	0.06	0.05	0.46	0.38

PLI = Pollution Load Index; MCD = Modified Contamination Degree

Ecological risk factors and the spatial extent of the potential ecological risk of the soil: The ecological risk index (RI) for the wetlands represents the sensitivity of biological communities to hazardous substances (Amuno, 2013). It was originally used to assess the degree of heavy metal pollution in the soil and is based on the toxicity of the heavy metal and the toxicity response of the environment (Hakanson, 1980). The ecological risks associated with these heavy metal concentrations in the soils of the wetlands are presented as the ecological risk factors and the potential ecological risk in table 4. RI is defined by the following: < 150 is low; 150-300 is moderate; 300-600 is high; and ≥ 600 is significantly. The ecological risk factors for Pb ranged from 0.01 to 6.35, Cd ranged from 0.60 to 171.00, Cr ranged from 0.02 to 0.04, Ni ranged from 0.05 to 0.20, Cu and Zn ranged from 0.20 to 0.80 and 0.01 to 0.22 respectively. The ecological risk factors (E^i_r) for Pb, Cr, Ni, Cu and Zn values show low ecological risks of single factor pollution as the factors were all below 40. The E^i_r for cadmium (Cd) at sampling 21 to 25, 36, and 40 shows considerable ecological risk ($80 \leq E_r^i < 160$) at single factor pollution with values of 129.00, 171.00, 139.80, 156.30, 109.20, 152.70, and 117.30 correspondingly.

The potential ecological risk index (RI) of Pb, Cd, Cr, Ni, Cu and Zn were 70.40, 2264.40, 0.68, 1.55, 13.65, and 2.29 respectively. The RI for Pb, Cr, Ni, Cu and Zn were less than 100 (low potential ecology risk = RI<100). Cadmium has a RI value of 2264.40 (very high risk = $RI \geq 400$), the soils showing a significantly high potential ecological risk with high level of Cd.

Hence, soils from this present study areas show serious significant potential ecological risk due to Cd. Cadmium and lead contributed over 95% of the potential ecological risk. With parts of the wetlands having very serious potential ecological risk for Cd been used for vegetable production, and fishing of aquatic species in the nearby surface water, these constitute current and future health risks.

Table 4: Ecological risk factors (E^i_r) and the potential ecological risk index (RI) of the pollutants in the wetlands soil

Sampling points	Ecological Risk Factors					
	Pb	**Cd**	**Cr**	**Ni**	**Cu**	**Zn**
Sampling point 1	0.55	1.20	0.00	0.00	0.45	0.03
Sampling point 2	0.55	1.20	0.00	0.00	0.35	0.07
Sampling point 3	0.30	1.50	0.00	0.00	0.45	0.06
Sampling point 4	0.20	1.20	0.00	0.00	0.35	0.06
Sampling point 5	0.10	3.00	0.00	0.00	0.35	0.04
Sampling point 6	0.10	10.20	0.02	0.00	0.25	0.03
Sampling point 7	0.15	18.90	0.00	0.00	0.25	0.02
Sampling point 8	0.10	21.90	0.00	0.00	0.20	0.02
Sampling point 9	0.20	17.40	0.00	0.00	0.20	0.02
Sampling point 10	0.35	30.30	0.02	0.00	0.30	0.02
Sampling point 11	2.55	27.30	0.02	0.00	0.30	0.07
Sampling point 12	2.95	31.20	0.02	0.00	0.20	0.07
Sampling point 13	2.40	24.60	0.02	0.00	0.20	0.03
Sampling point 14	4.25	31.20	0.02	0.10	0.20	0.03
Sampling point 15	2.30	27.90	0.02	0.05	0.25	0.03
Sampling point 16	0.85	28.80	0.00	0.00	0.25	0.05
Sampling point 17	0.75	32.40	0.00	0.00	0.25	0.04
Sampling point 18	0.40	31.20	0.00	0.00	0.25	0.04
Sampling point 19	1.20	47.40	0.00	0.00	0.25	0.04
Sampling point 20	0.50	37.80	0.00	0.00	0.40	0.07
Sampling point 21	4.95	129.00	0.04	0.05	0.80	0.22
Sampling point 22	3.20	171.00	0.04	0.05	0.55	0.21
Sampling point 23	4.55	139.80	0.04	0.10	0.45	0.21
Sampling point 24	3.80	156.30	0.02	0.05	0.40	0.11
Sampling point 25	2.95	109.20	0.02	0.05	0.40	0.08
Sampling point 26	1.05	27.90	0.02	0.05	0.25	0.02
Sampling point 27	0.90	26.10	0.00	0.05	0.25	0.03
Sampling point 28	0.55	0.60	0.02	0.20	0.20	0.01
Sampling point 29	0.40	16.80	0.00	0.05	0.20	0.02
Sampling point 30	0.45	35.10	0.02	0.05	0.25	0.01
Sampling point 31	1.45	57.90	0.04	0.05	0.55	0.05
Sampling point 32	1.45	89.10	0.04	0.05	0.40	0.05
Sampling point 33	1.90	68.40	0.02	0.05	0.35	0.04
Sampling point 34	1.40	51.90	0.04	0.05	0.30	0.04
Sampling point 35	1.75	60.30	0.04	0.05	0.30	0.03
Sampling point 36	0.85	152.70	0.02	0.05	0.20	0.01
Sampling point 37	0.60	81.90	0.02	0.05	0.20	0.03
Sampling point 38	0.80	86.70	0.02	0.05	0.25	0.04
Sampling point 38	1.35	83.70	0.00	0.05	0.30	0.04
Sampling point 40	2.50	117.30	0.02	0.05	0.40	0.04
Sampling point 41	2.90	72.30	0.02	0.05	0.35	0.06
Sampling point 42	3.55	62.70	0.02	0.10	0.30	0.05
Sampling point 43	6.35	41.10	0.02	0.05	0.30	0.05
Risk Indices (RI)	**70.40**	**2264.40**	**0.68**	**1.55**	**13.65**	**2.29**

Of particular concern are the significantly high-risk levels in the farm areas, which could negatively impact plants as the detrimental effects of heavy metals on plants and the subsequent transfer to humans and other organisms can be expected. Also, areas close to water bodies are at high ecological risk as deposits of these contaminants can seep into these water bodies, thus impacting aquatic species. Hence soils of the present study area show the potential ecological risk due to Cd. Similar ecological risks were reported for the mangrove wetland in Donghai Island, Zhanjiang and the Yellow River wetland in Yancheng, Jiangsu in China (Cheng *et al*., 2015; Luo *et al*., 2018). Thus, the relatively high value of Cd indicating significantly high potential ecological risk is noteworthy. Moreover, moderate degree of contamination by Pb and high degree of contamination by Cd is potentially of health and environmental concerns. Interestingly, other researchers have reported that Cd contribution to potential ecological risk index of the environment is very significant (Luo *et al*., 2012; Qing *et al*., 2015).

Health risk assessment

Non-carcinogenic risk assessment: The results of non-carcinogenic risk of HM exposure in soils through ingestion, inhalation, and dermal contact on adults and children are presented in Table 5 and 6. The contribution of ingestion route to HI was the highest at more than 75% for children and 60% for adults for the daily intake. This suggests that ingestion was the main exposure pathway to threaten human health. These results agreed with previous reports (Xiao *et al*., 2015; Akuko *et al*., 2018).

The HQ of ingestion, inhalation and dermal peaked for Cr and their minimal level for Ni for the adult population, while the children population showed different trends. In risk assessment, when HQ and HI values are below 1, there is no obvious risk to the population, but if these values exceed 1, there may be some concern for potential non-carcinogenic effects (USEPA, 2004). The heavy metal HI values for children and adults were in the following order: Cr > Pb > Ni > Cd > Zn > Cu and Cd > Pb > Ni > Cu > Cr > Zn, respectively. The HQ and HI values for all the metals were lower than 1, which indicated that there was no non-carcinogenic risk to children and adults. The health risk to children due to heavy metal exposure from the soils was higher than for adults. The high non-carcinogenic risk to children is mostly due to their behaviour and hand or finger sucking (Zhao *et al*., 2014).

Cancer risk assessment: The excess lifetime cancer risks for adults and children were calculated distinctly from the average contribution of individual heavy metals in soil for all the pathways. The carcinogenic risk values of the calculated ADI (average daily intake) and the excess lifetime cancer risks are presented in table 7 and 8.

The values of ADI for children for all the pathways of heavy-metal exposure routes for all metals was generally in the order: Ingestion > dermal > inhalation while for the adults in the order, dermal > ingestion > inhalation. The carcinogenic risk was calculated based on Pb, Cd, and Cr, with the former being discovered as the highest contributor to cancer risk. The cancer risk values for the metals for both adult and children increased in the following order: Cr > Pb > Cd and Pb > Cr > Cd respectively. It was observed that all the samples showed cancer risk (CR) far below the acceptable threshold value of 1.0E-04 established by USEPA, indicating no significant long-term health effects. Lifetime carcinogenic risk values for adults and children were 1.02×10^{-5} and 1.68×10^{-5}, respectively. The lifetime carcinogenic risks for both adults and children were thus within tolerable of acceptable risk (1.0E-06 – 1.0E-04). This finding was in good agreements with Jia *et al.* (Jia *et al*., 2018). In this study, it was also obvious that children were more susceptible to the potential health regardless of the carcinogenic or non – carcinogenic risk.

Table 5: Average Daily Intake (ADI) values in mg/kg/day for adults and children in the wetlands soil for non-carcinogenic risk calculations

Receptor Pathways		Average Daily Intake (ADI) Values for Heavy Metals in mg/kg/day						Total
		Pb	Cd	Cr	Ni	Cu	Zn	
Adult	Ingestion	2.10E-05	1.60E-06	8.95E-06	1.80E-06	1.93E-05	3.35E-05	8.62E-05
	Inhalation	3.23E-15	2.46E-16	3.12E-16	2.76E-16	1.02E-15	1.18E-15	6.26E-15
	Dermal	8.53E-06	6.52E-07	8.23E-07	7.29E-07	2.68E-06	3.13E-06	1.65E-05
	TOTAL	2.95E-05	2.25E-06	9.77E-06	2.53E-06	2.20E-05	3.66E-05	1.03E-04
Child	Ingestion	1.96E-04	1.96E-04	1.96E-04	1.96E-04	1.96E-04	1.96E-04	1.18E-03
	Inhalation	7.04E-16	5.38E-17	6.80E-17	6.02E-17	2.22E-16	2.58E-16	1.37E-15
	Dermal	4.11E-06	3.14E-07	3.97E-07	3.52E-07	1.29E-06	1.51E-06	7.97E-06
	TOTAL	2.00E-04	1.96E-04	1.96E-04	1.96E-04	1.97E-04	1.98E-04	1.18E-03

Table 6: Hazard Quotient (HQ) and Health Index (HI) values for heavy metals in adults and children for the wetlands soil

Receptor Pathways		Hazard Quotient (HQ)					
		Pb	Cd	Cr	Ni	Cu	Zn
Adult	Ingestion	5.83E-03	3.20E-03	2.98E-03	9.00E-05	5.22E-04	1.12E-04
	Inhalation	3.23E-15	4.32E-12	1.04E-11	6.90E-15	1.02E-15	1.18E-15
	Dermal	6.09E-02	1.30E-03	2.74E-02	9.11E-04	1.12E-04	4.17E-05
	Health Index (HI)	6.67E-02	4.50E-03	3.04E-02	1.00E-03	6.34E-04	1.54E-04
Child	Ingestion	5.44E-02	3.00E-02	6.30E-03	8.40E-04	1.67E-03	2.40E-04
	Inhalation	7.04E-16	9.44E-13	2.27E-12	1.51E-15	2.22E-16	2.58E-16
	Dermal	2.94E-02	6.28E-04	2.04E-05	4.40E-04	5.38E-05	2.01E-05
	Health Index (HI)	8.38E-02	3.06E-02	6.32E-03	1.28E-03	1.72E-03	2.60E-04

Table 7: Average Daily Intake (ADI) values in mg/kg/day for adults and children in wetlands soil for carcinogenic risk calculations

Receptor Pathways		Average Daily Intake (ADI) values for Heavy metals mg/kg/day						**Total**
		Pb	**Cd**	**Cr**	**Ni**	**Cu**	**Zn**	
Adult	Ingestion	8.99E-06	8.99E-06	8.99E-06	8.99E-06	8.99E-06	8.99E-06	5.39E-05
	Inhalation	1.38E-15	1.05E-16	1.33E-16	1.18E-16	4.34E-16	5.07E-16	2.68E-15
	Dermal	3.65E-06	2.79E-07	1.62E-06	3.12E-07	1.15E-06	1.34E-06	8.35E-06
	Total	**1.26E-05**	**9.27E-06**	**1.06E-05**	**9.30E-06**	**1.01E-05**	**1.03E-05**	**6.23E-05**
Child	Ingestion	1.68E-05	1.28E-06	1.62E-06	1.44E-06	5.29E-06	6.16E-06	3.26E-05
	Inhalation	6.46E-16	4.93E-17	6.24E-17	5.52E-17	2.03E-16	2.37E-16	1.25E-15
	Dermal	3.53E-06	2.69E-07	3.41-E-07	3.02E-07	1.11E-06	1.29E-06	6.50E-06
	Total	**2.03E-05**	**1.55E-06**	**1.62E-06**	**1.74E-06**	**6.40E-06**	**7.45E-06**	**3.91E-05**

Table 8: Cancer risk values of heavy metals for adults and children

Receptor Pathways		**Cancer Risk for all Pathways**						**Risk Total**
		Pb	**Cd**	**Cr**	**Ni**	**Cu**	**Zn**	
Adult	**Ingestion**	5.99E-06	-	1.74E-06	-	-	-	
	Inhalation	9.20E-17	2.19E-16	3.24E-16	-	-	-	
	Dermal	2.43E-06	-	-	-	-	-	
	Total	**8.42E-06**	**2.19E-16**	**1.74E-06**	**-**	**-**	**-**	**1.02E-05**
Child	**Ingestion**	1.12E-05	-	3.24E-06	-	-	-	
	Inhalation	4.31E-17	7.83E-18	1.52E-16	-	-	-	
	Dermal	2.35E-06	-	-	-	-	-	
	Total	**1.36E-05**	**7.83E-18**	**3.24E-06**	**-**	**-**	**-**	**1.68E-05**

The health risk assessment demonstrates capacity to distinguish the toxic chemical and various exposure pathways. However, this assessment has several inherent uncertainties in quantitative risk evaluation. First of all, bioavailable concentration rather than the total amounts of heavy metals can obtain more reliable risk assessments for eco-environment and human health, which suggests that total concentration of heavy metals potentially results in overestimation of the ADI and the resulting HI. Furthermore, the widely used exposure parameters were majorly from the USEPA, which may not be applicable in Nigeria. Also, there is no exposure assessment guideline for human health risk assessment posed by heavy metals in soils in Nigeria. However, our study scored the eco-environmental and human health effects based on a temporal-spatial sampling assessment, particularly, three exposure pathways and variable heavy metals leading to potential ecological and human health risks in a typical wetlands area in Lagos lagoon are highlighted.

Conclusion: Integrated multiple modern indices were used to completely assess ecological risk and human health risks based on a temporal – spatial based sampling in a typical lagoon wetland area of Lagos in Nigeria. This study established that Pb and Cd are the major heavy metals that currently pose an ecological risk in the studied wetlands. If Cd pollution remains unchecked, the manifestation of toxic effects in the organisms inhabiting the wetlands and man is imminent. However, there were no significant carcinogenic and non – carcinogenic risks for adults and children, although, it showed that children were more susceptible to the potential health risk irrespective of the carcinogenic or non – carcinogenic risk. This wetland assessment provided important information for policymaking to reduce the potential effects of soil contamination on humans and the eco-environment in the wetlands.

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