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Concentrations and Health Risk Valuation of Possibly Toxic Metals in Soil and Sediment in Parts of Ona River, Ibadan, Nigeria

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ABSTRACT

The accumulation of contaminants in the soils and sediments may negatively affects people within the vicinity of Ona River and increase potential of human health risk. This study appraised the concentration status, probable origins and human health risks of some possibly toxic elements (Fe, Cu, Zn, Mn, Pb and Cd) in the riverbank soils (RBK) and riverbed sediments (RBS) of Ona River section bordering residential community in Ibadan, Southwest Nigeria. Therefore, six composite samples of RBK and RBD were analyzed for heavy metals using atomic absorption spectrophotometry (AAS). Enrichment factor (EF) and quantification of contamination (QoC) are used to examine potential origins of tested metals. Furthermore, hazard index (HI) and total cancer risk (TCR) have been utilized to evaluate the extent of non-carcinogenic and cancer risks of studied metals to inhabitants of the study site. The results of metal contamination assessment revealed low concentration <1.0 mg/kg for each analyzed metal in both RBK and RBD while EF and QoC advocate lithogenic origins of assessed metals with little or none anthropogenic inputs in both studied soils and sediments. The computed HI values were lower than 1.0 and thus no adversative health effects on adults and children via ingestion, skin contact and inhalation routes. The CR computation exposed that adults and children are at growing risk of developing cancer over a lifetime when exposed to RBK and RBD via ingestion and dermal pathways. Cadmium contributed largely to TCRs among the assessed metals. The study indicates the inevitability of initiating actions that reduce exposure of residents to nearby soil and sediment and safeguard their health, particularly the children.

Keywords:
Ona River,
Heavy metals,
Soil and Sediments,
Quantification of contamination,
Health risk.

INTRODUCTION

The pollution of environment by potentially harmful metals arising from diverse anthropogenic inputs has attained global devotion and are of great concern to environmental scientists and relevant stakeholders. Occurrence and concentrations of heavy metals in soils and sediments of the ecosystem worth considering due to their characteristics of pertinacity, non-biodegradable, bioaccumulation capability, toxicity and contumacious behavior (Aluko et al., 2018; Kong et al., 2021; Tashakor and Modabberi, 2021). Metals are inherent constituents of lithosphere, hence, their concentrations in the environment can be transformed via various natural actions and human-induced activities (Aluko et al., 2018; Huang et al., 2017). Atmospheric deposition, rock weathering, hydrolysis and erosion play substantial impact on the levels of heavy metals in both topsoil and sediments (Karthikeyan et al., 2018; Li et al., 2022). Heavy metals in soil/sediment can get into the human body via the routes of oral ingestion, inhalation and skin contact (Tashakor and Modabberi, 2021; Li et al., 2022). Reports have it that long- term exposure to certain heavy metals may lead to the developmental disorder, cardiovascular diseases, kidney damage and carcinogenic effects (Aluko et al., 2018; Raj and Maiti, 2020; Tashakor and Modabberi, 2021; Li et al., 2022).

Main human-induced undertakings that can sway the concentrations of HMs in the environment comprise industrial effluents discharges on soil, automobile exhaust fumes, percolating of agricultural fertilizers, smelting activity, among others (Karthikeyan et al., 2018; Ganiyu et al., 2021). Heavy metals are considered as severe contaminants in both land-dwelling and aquatic environment as a result of their capability to be integrated into food chain through polluted crops and seafood (Orisakwe et al., 2015; Adebiyi et al., 2020; Umeoguaju et al., 2023).

Heavy metals that accumulate profoundly in the soil penetrate through the pore spaces and can enter the nearby shallow aquifer units and surface water, thereby degrading the quality of available water sources (Huang et al., 2017; Bayrakli et al., 2022). Thus, it is extremely significant to assess the concentration of potentially toxic metals in soils/ sediments around sites that show great tendency of being contaminated with such metals via man-made activities. The background level of a specific metalloid in soil/sediment is decidedly dependent on physicochemical properties such as particle size distribution, mineralogical composition, soil structure, clay particles, natural organic material, soil pH, ionic strength, weathering conditions of lithological setting, organic and inorganic colloidal soil components among others (Peng et al., 2018; Alekseev and Abakumov, 2020; Bayrakli et al., 2022).

In location close to riverbank, heavy metals contamination in the aquatic ecosystem arises via atmospheric deposition, soil erosion caused by wind, and nearby man made activities like mining, fishery, unselective dumping of household refuse and industrial wastes, open defecation, spiritual bathing and percolating of inorganic pesticides from cultivated lands along the river bank (Ganiyu et al., 2022; Kadim &Risjani, 2022; Olutona, 2023). Heavy metals (mostly found as metal complexes, oxides, silicates/sulphides and hydroxides) competently and quickly attach to the flood plain deposits via adsorption, flocculation and incorporation into biological materials (Wijaya et al., 2019; Kong et al., 2021; Rezapour et al., 2022). However, metals linked with sediments would probably be dissolved into the overlying water through diffusive fluxes and sediment-water boundary, causing reduction in surface water quality and considerable impact on ecosystem health (Huang et al., 2017; Kong et al., 2021; Ganiyu et al., 2022). Chemical species of heavy metals frequently alter concurrently and thus exhibit various physical-chemical attributes in terms of chemical reactions, mobility, impending toxicity, and bioavailability (Wang et al., 2014; Huang et al., 2017). Thus, for us to get an unbiased understanding of the status of riverbank bordering residential community, it is highly important to appraise the levels, probable sources and associated human health risk of metals in the riverbank soil and sediment.

There are several frequently utilized pollution indexes that have been used to evaluate the contamination status and probable sources of contaminants in porous media (Aluko et al., 2018, Akakuru et al., 2023). Among those pollution indicators are contamination factor (CF), enrichment factor (EF), geoaccumulation index (Igeo), pollution load index (PLI), nemerow pollution index (NPI) to mention a few (Zarezadeh et al., 2017; Ganiyu et al., 2022; Tomczyk et al., 2023). These appraisal methods were utilized in extensive range of ecosystem situations and proved suitable for determining porous media contamination status and ecological risk assessment (Aluko et al., 2018; Tashakor and Modabberi, 2021; Al-Kahtany and El-Sorogy, 2023). However, when selecting an indicator, much consideration should be paid to the purpose for which the specific pollution index is computed (Tomczyk et al., 2023).

Studies on the extent of health and ecological risks associated with heavy metals in flood plain deposits were well mentioned (Zarei et al., 2014; Rezaapour et al., 2022; Akçay and Özbay, 2023; Alzahrani et al., 2023). However, there is dearth of information on the health risks assessment of riverbank soil and riverbed sediment of part of Ona River bordering Odo Ona residential layout. This present research regarding the health risks associated with heavy metals in soils along the riverbank and floodplain sediments of part of Ona River arose subsequently our earlier work disclosed mildly contamination and low ecological risk of assessed metals (Ganiyu et al., 2022). Though, contamination ranking and environmental risk due to the studied metals have already been studied, potential health risks from soils and sediments of part of Ona River adjoining housing community have not so far been addressed in previous studies. This research gap kindled the author' interest in evaluating the degree of carcinogenic and non-carcinogenic risks associated with heavy metals in soil/sediment collected along Ona River (parts of it bordering residential houses). In this regard, the United States Environmental Protection Agency (USEPA) evaluation model equations of human health risks were utilized in this study.

The specific objectives include determination of contamination distribution of Pb, Cd, Zn, Cu, Fe and Mn in soils and riverbed sediments, identification of possible origins of metal contaminants through the use of enrichment factor (EF) and quantification of contamination (QoC) and evaluation of allied human health risks originating from exposure to the studied metals in soils/sediments of Ona River.

MATERIALS AND METHODS

Description of Study location

Ona River is positioned within Ibadan, a metropolitan city in the southwest of Nigeria and has a length of 55 km and an area of 81 km^2 (Ganiyu et al., 2021, 2022). Its flow direction is from north- south, right from its source at Eleyele Catchment area via Oluyole industrial estate (Ganiyu et al., 2022]. The inhabited community adjoining Ona River has buildings sited proximity to the bank of Ona River (Plate 1). The case study site experienced flooding in the year 2011 resulting in several losses of lives and properties as well as washed away of some inter-connecting bridges (Egbinola et al., 2015). The geological setting of the study area generally falls within a basement complex formation of southwest part of Nigeria. Detailed information about the geology of Ibadan where the study site is located was fully described in Ganiyu et al. (2022). The predominant rock type in the study area is undifferentiated gneiss schist (Figure 1).

Plate 1: Photo displaying residential houses along Ona River

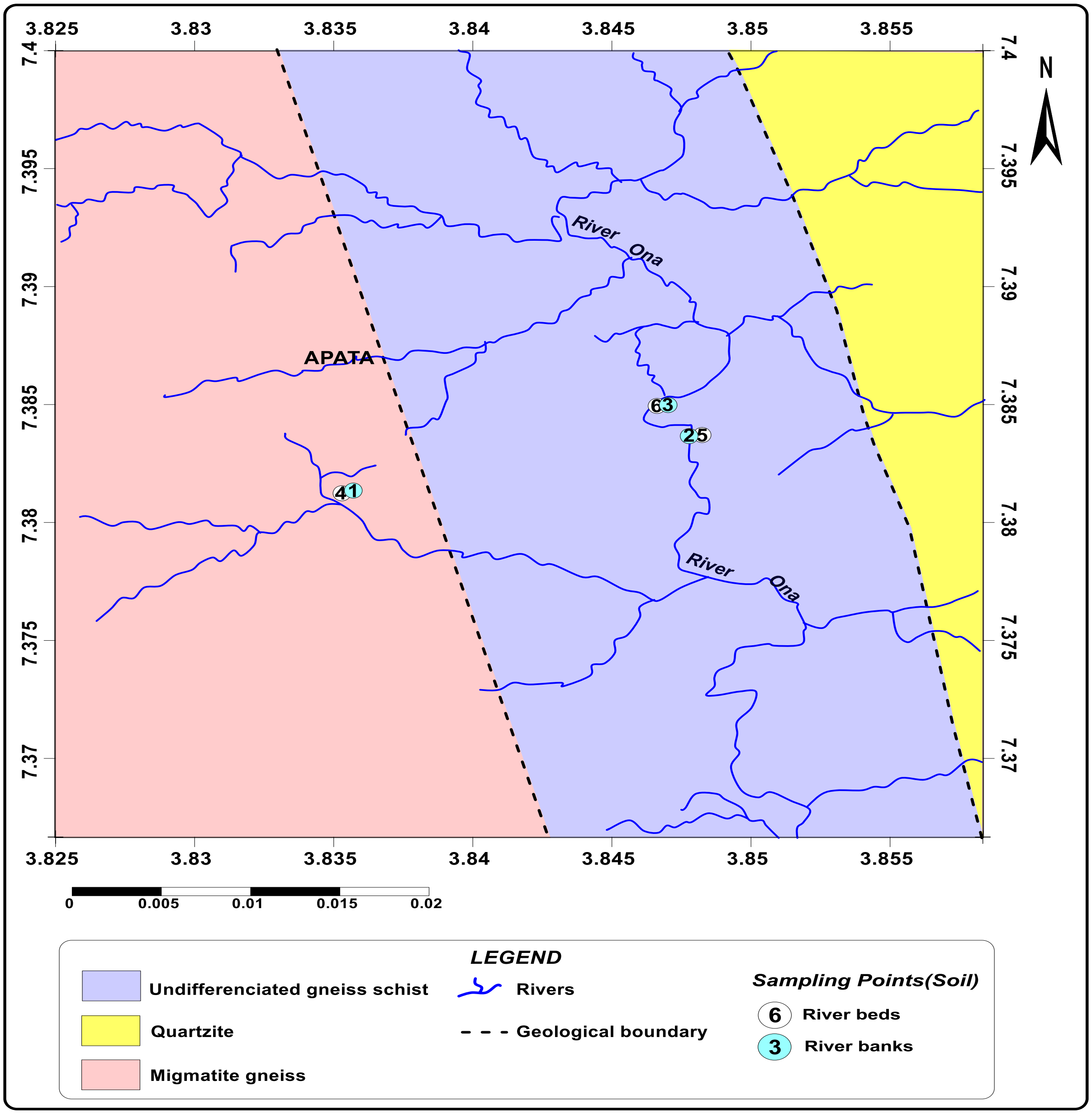

Figure 1: Geological map showing the rock type that underlies the study area and soil/sediment sampling locations

Samples Collection and Analytical Techniques

Soils along the bank of Ona River as well as riverbed sediment were collected from three dissimilar sample sites within the confines of targeted residential community neighboring Ona River. The sample locations were selected according to the cluster of households along the bank. At every sample site along the riverbank, a rectangular grid of 30 metre by 5 metre was established and 5 surface soil samples (0 - 30 cm) were collected inside the grid with the aid of soil auger. Adopting the similar framework, five floodplain sediment samples were also collected using grab sampler. Collected samples at every sample grid were comprehensively mixed together in equal ratio so as to produce a composite that was utilized in heavy metals analysis.

The collected samples were put in sterile nylons, coded appropriately to prevent confusion, stored under ice chest before being conveyed to the Soil Chemistry Laboratory of Institute of Agricultural Research & Training (IAR&T), Ibadan, Nigeria for necessary sample preparation and preservation preceding to commencement of heavy metals analysis.

At the laboratory, soil/sediment samples were air dried at room temperature for a week, ground gently and then sieved with a 2-mm sieve to eradicate undesirable large debris particles (Barket and Akǜn, 2018; Raj and Maiti, 2020). 5g of homogenous sample each was weighed into the digestion flask while 10 ml of 2:1 by volume of nitric-perchloric acid was added to the sample and digested until dense white fumes appeared (usually takes about 1 hour 30 mins). Thereafter, 1ml of HCL and few drops of hydrogen peroxide were added for complete digestion in the contaminated soil and was further kept on the digestor until a white dense fume (clear sample) was seen (Owoso et al., 2017). The digest was allowed to cool and some quantity of distilled water was added to the digest. The solution was then filtered into a 50 ml volumetric flask and diluted to volume (SSSA, 1996; Owoso et al., 2017). The filtrates were then analyzed in triplicate for Pb, Cd, Mn, Cu, Zn and Fe using the Atomic Absorption Spectrophotometer (Model 210 VGP of the Buck Scientific AAS series) with air-acetylene gas mixture as oxidant using specific lamp at a given wavelength for each of the element on an Atomic Absorption Spectrophotometer (AAS).

Quality Control/Quality Assurance

For quality control, duplicate analytical was done to ensure repeatability of the method while blank determination was also carried out (Inam et al., 2015. Adebiyi et al., 2020). A previously tested samples were run alongside the standard samples as an unknown samples and the calibration graphs for tested metals were linear for their standards. The concentrations of the standards and previously run samples were almost the same as the differences were ≥or≤0.05 for each of them respectively.

Heavy Metal Pollution Indexes

This study utilizes two pollution indexes (enrichment factor (EF) and quantification of contamination (QoC)) to evaluate the extent of heavy metals contamination as well as their probable sources in soils and sediments of Ona River (Table 1)

Table 1: Geochemical indices used for assessing probable sources of metals

Contamination Index	Definition	Source Categories	References
Enrichment factor (EF)	$EF = \frac{\left(\frac{C_i}{Fe_s}\right) soil/sediment}{\left(\frac{C_i}{Fe_b}\right) reference}$ C_i represents concentration of heavy metal in soil/sediment, Fe(s) represents concentration of Fe in soil/sediment and Fe(b) is the concentration of Fe in the earth's crust or reference background	$0.5 \leq EF \leq 1.5$, metal likely from natural weathering process EF >1.5, metal is from anthropogenic inputs/non-natural weathering process	Wang et al. (2008); Zarezadeh et al. (2017); Akakuru et al. (2023)
Quantification of contamination (QoC)	QoC (in %) = $[(C_s - C_b)/C_s] \times 100$ where C_s refers to the concentration of particular heavy metal in the sampled soil/sediment and C_b equals the concentration of the particular metal in the background.	Positive values of QoC denote anthropogenic origin Negative values of QoC denote geogenic origin	Asaah et al. (2006), Zarezadeh et al. (2017); Akakuru et al. (2023)

Health Risk Evaluation in riverbank soils and riverbed sediments

The human health risks constituted by exposure to heavy metals (Pb, Mn, Cd, Fe, Cu, and Zn) in composite soils and sediments is normally characterized by the hazard quotients (HQ) and incremental lifetime cancer risk (ILCR). The combination of hazard quotient and hazard index estimated through the use of established models are recommended by USEPA as reliable guiding tools to evaluate the extent of non-cancer risks associated with heavy metals in porous media such as soils and sediments while ILCR accounts for carcinogenic risks likely to be incurred by exposed persons (USEPA, 2011; Zhuang et al., 2014; Kouchou et al., 2020; Bayrakli et al., 2022) The USEPA model equations consider three major pathways of oral ingestion, inhalation, and skin absorption to appraise the degree of human health risks from contamination such as heavy metals attached to soil and sediment (Tashakor and Modabberi, 2021; Li et al., 2022). The prospective human health risk estimation due to metals in soils/sediments begins with calculation of average daily dose (ADD) of tested heavy metals by exposed person through the oral ingestion, skin absorption and inhalation/breathing pathways (Zhuang et al., 2014; Kouchou et al., 2020; Tashakor and Modabberi, 2021; Bayrakli et al., 2022).

The ADD (in mg/kg/ day) of metals in soil/sediment through the three aforementioned routes were calculated utilizing the equations 1-3

$$ADD_{ingestion} = \frac{C_s \times IR_{ingestion} \times EF \times ED \times CF}{BW \times AT} \qquad (1)$$

$$ADD_{dermal} = \frac{C_s \times ESA \times FE \times AF \times ABS \times EF \times ED \times CF}{BW \times AT} \quad (2)$$

$$ADD_{inhalation} = \frac{C_s \times IR_{inhalation} \times EF \times ED}{BW \times AT \times PEF} \quad (3)$$

where $ADD_{ingestion}$, ADD_{dermal}, and $ADD_{inhalation}$ refer to the average daily dose through oral ingestion, skin contact (dermal absorption) and inhalation/breathing pathways, correspondingly (Kamunda et al., 2016; Tashakor and Modabberi, 2021 Bayrakli et al., 2022; Chonokhuu et al., 2019); C_s refers to the level of metal in soil/sediment sample, BW refers to the body weight of exposed person, EF equals the exposure frequency, ED denotes the exposure duration, $IR_{ingestion}$ refers to the oral ingestion rate, $IR_{inhalation}$ equals the inhalation/breathing rate, ESA is the exposed skin surface area, AF = soil adherence factor; ABS equals dermal absorption factor, FE stands for dermal exposure rate, PEF= particulate emission factor, CF is conversion factor (10^{-6}) and AT is the averaging time (DoEA, 2010; USEPA, 2011; Sheikhi Ahman Abad et al., 2020; Li et al., 2022). The definition and unit of each of above-mentioned exposure parameters in both children and adults is presented in Table 2.

Table 2: Exposure factors used for computation of Average Daily Dose (ADD) via oral ingestion, inhalation and skin contact pathways for soil and sediment samples

Parameters	Definition	Units	Adults	Children	References
$IR_{ingestion}$	Ingestion rate	mg/day	100	200	(Kamunda et al., 2016; Aluko et al., 2018)
$IR_{inhalation}$	Inhalation	m^3/day	20	10	(Kamunda et al., 2016; Aluko et al., 2018)
CF	Conversion factor	kg/mg	1.0E-06	1.0E-06	(USEPA 2004, USDOE 2011, Aluko et al., 2018)
PEF	Particulate emission factor	m^3/kg	1.3E+09	1.3E+09	(USEPA 2004, DoEA, 2010; Bayrakli et al., 2022)
EF	Exposure frequency	days/year	350	350	(USEPA 2011, Kamunda et al., 2016; Sheikhi Ahman Abad, 2020)
ED	Exposure duration	years	30	6	(Kamunda et al., 2016; Aluko et al., 2018)
BW	Body Weight	Kg	70	15	(USEPA, 2004, Kamunda et al., 2016)
AT	Average time	days	25,550	25,550	(USEPA 2011, USDOE, 2011)
FE	Dermal exposure ratio	unitless	0.61	0.61	(DoEA 2010, USEPA, 2011; Aluko et al., 2018)
C_s	Concentration of heavy metals	mg/kg	-	-	
ESA	Exposed Skin surface area	cm^2	5800	2100	(USEPA, 2004, DoEA 2010, Kamunda et al., 2016)
AF	Skin adherence factor	mg/cm^2	0.07	0.2	(USEPA 2004; DoEA 2010; Aluko et al., 2018)
ABS	Dermal absorption factor	unitless	0.1	0.1	(USEPA, 2004, DoEA, 2010; Kamunda et al., 2016)

To calculate HQ, one needs the reference dose (RfD) of each of tested metals. This is usually extracted from the integrated risk information system (IRIS) of USEPA (USEPA 2002, 2011). It refers to the maximum permissible risk to exposed population through daily exposure when considering a sensitive age group during a lifetime (Zhuang, 2014; Kouchou et al., 2020; Ganiyu et al., 2021).The HQ for adults/children through a particular pathway is estimated using equation 4:

$$HQ_{pathway} = \frac{ADD_{pathway}}{RfD_{pathway}} \quad (4)$$

The hazard index (HI) is the sum total of HQs via the adopted routes (i.e. oral ingestion, inhalation, and skin contact) for several contaminants and/or multiple routes (Kouchou et al., 2020; Tashakor and Modabberi, 2021). Therefore, HI is related to the HQ by the expression:

$$HI = \frac{ADD_{ingestion}}{RfD_{ingestion}} + \frac{ADD_{dermal}}{RfD_{dermal}} + \frac{ADD_{inhalation}}{RfD_{inhalation}} \quad (5)$$

where RfD in equation 5 refers to the refrences dose (mg/kg^{-1} day) of a precise metal via a particular pathway (Sheikhi Ahman Abad et al., 2020; Tashakor and Modabberi, 2021; Al-Kahtany and El-Sorogy, 2023; Ganiyu et al., 2023). If HI <1, the non-carcinogenic health risk is insignificant and there are no adverse health effects whereas HI >1 suggests potential negative impact on human health (Aluko et al., 2018; Raad et al., 2021; Rohani and Mohamadi, 2022).

The incremental lifetime cancer risk (ILCR) of each tested carcinogen in riverbank soil/ riverbed sediment is estimated using equation 6:

$$ILCR_{pathway} = ADD_{pathway} \times CSF \quad (6)$$

$$ILCR_{ingestion} = ADD_{ingestion} \times CSF_{ingestion} \quad (7)$$

$$ILCR_{dermal} = ADD_{dermal} \times CSF_{dermal} \quad (8)$$

$$ILCR_{inhalation} = ADD_{inhalation} \times CSF_{inhalation} \quad (9)$$

where $ILCR_{ingestion}$, $ILCR_{dermal}$ and $ILCR_{inhalation}$ are the cancer risk through ingestion, skin contact, and inhalation routes, respectively while CSF, $CSF_{ingestion}$, CSF_{dermal} and $CSF_{inhalation}$ represent the cancer slope factor (mg/kg/day), cancer slope factor through the oral ingestion, skin contact and inhalation/breathing pathways, correspondingly (Aluko et al., 2018; Ganiyu et al., 2023). The total cancer risk (TCR) for an individual can be calculated using the formula given in equation 10 as:

$$TCR = ILCR_{ingestion} + ILCR_{inhalation} + ILCR_{dermal} \quad (10)$$

The RfD and CSF values for tested heavy metals in soil/sediment through the three main pathways are listed in Table 3. The ILCR/TCR > 1×10^{-4} is intolerable as it signifies high lifetime cancer risk from heavy metals; between 1.00E-06 to 1.00E-04 indicate acceptable range and ILCR/TCR below 1.00E-06 suggest no carcinogenic risk (USEPA, 2011; Aluko et al., 2018; Tashakor and Modabberi, 2021; Li et al., 2022; Al-Kahtany and El-Sorogy, 2023).

Table 3: Values of references dose (RfD) and Cancer slope factor (CSF) of heavy metals

Parameters	RfDing (mg/kg day)	RfDderm (mg/kg day)	RfDinh (mg/kg day)	CSF ing	CSFderm	CSF inh	References
Pb	3.50E-03	5.34E-04	3.50E-03	8.50E-03		4.20E-02	(USEPA, 2004 DoEA, 2010)
Cd	1.00E-03	1.00E-05	1.00E-03	6.10E+00	6.10E+00	6.30E+00	(USEPA, 2004, DoEA, 2010)
Mn	1.40E-01	1.40E-01	1.43E-05	-	-	-	(USEPA, 2004, DoEA, 2010)
Zn	3.00E-01	6.00E-02	3.00E-01	0.00E+00	0.00E+00	0.00E+00	(DoEA 2010; Kareem et al., 2022)
Cu	3.70E-02	2.40E-02	4.02E-02	-	-	-	(USEPA, 2004 DoEA 2010)
Fe	7.00E-01	7.00E-01	8.00E-01	-	-	-	(USEPA 2004, DOEA 2010)

RESULTS AND DISCUSSION

Table 4 presented the mean values of tested metals in composite soils and sediments of Ona River at the three sample locations. From Table 4, the heavy metals (in mg/kg) showed the following ranges in riverbank soil (RBK) samples: Pb (0.30-0.32), Cd (0.39-0.42), Cu (0.43-0.48), Mn (0.03-0.04), Zn (0.44-0.58), and Fe (0.40-0.47). In riverbed sediment (RBD) samples, the ranges of metals are as follows: Pb (0.28-0.34 mg/kg), Cd (0.39-0.46 mg/kg), Cu (0.38-0.41 mg/kg), Mn (0.03-0.04 mg/kg), Zn (0.44 – 0.56 mg/kg), and Fe (0.41- 0.44 mg/kg). The above ranges of tested metals in RBD are below the reported ranges of aforementioned heavy metals in sediments along Ras Abu Ali Island, Saudi Arabia by Al-Kahtany and El-Sorogy (2023). The mean concentrations of all analyzed metals in RBD samples in this study were much lesser than their corresponding values in sediments of Sg Puloh mangrove estuary (Malaysia) and Lake Bafa (Turkey) by Udechukwu et al. (2015) and Algül & Beyhan (2020), respectively. Furthermore, the mean values of tested metals in both RBK and RBD samples are much lower than the reported mean values of Pb (3.50 mg/kg), Zn (6.89 mg/kg), Fe (4808 mg/kg) and Cu (4.14 mg/kg) in sediments by Al-Kahtany and El-Sorogy (2023). In addition, the average values of assessed metals in RBK samples obtained in this study were lower than the mean values of Pb (29.7 mg/kg), Cd (1.8 mg/kg), Zn (5.4 mg/kg) and Cu (204.0 mg/kg) in soil samples around Itakpe and Agbaja iron ore mining sites reported by Aluko et al. (2018). However, similar low average values of Pb (0.54 mg/kg) and Cd (0.001 mg/kg) in surface sediments from Ikpoba River, southern Nigeria were also reported by Enuneku and Ineh (2019). Our mean values of Cu (0.40 mg/kg) and Fe (0.42 mg/kg) obtained in this study were far less than 18.9 mg/kg for Cu and 1022 mg/kg for Fe reported by Enuneku and Ineh (2019). The remobilization of heavy metals in soil/sediments depends on the prevailing physico-chemical conditions in both the sediments and the water column, transport mechanisms and levels of biogeochemical reactions (which determines the levels of organic matter) (Rigaud et al., 2013; Cantera et al., 2018). Therefore low levels of clay content and organic matter/organic carbon reported by Ganiyu et al. (2022) on the same location might contribute to low concentrations of Fe and Mn in soils/sediments (Cantera et al., 2018; Guo et al.,2019). Furthermore, the forms and content of sesquioxides (Fe and Mn oxides/hydroxides) in unweathering part of basement parent material in addition to low content of organic matter could be the reason for low levels of Fe and Mn in soils/sediments of the study area.

Analogously, zinc was observed to be the most abundant heavy metal in examined RBK and RBD samples (Ganiyu et al., 2022). Moreover, every of the investigated heavy metals in this study has mean concentration lower than 1.0 mg/kg in both RBK and RBD samples (Ganiyu et al., 2022). The relatively low concentrations of tested heavy metals in RBK and RBD samples at the 3 sample locations may be as a result of reported evidence that post flood soil/sediment samples have propensity to have dwindling levels of potentially toxic metals (Rastmanesh et al., 2020; Ganiyu et al., 2022). Furthermore, Ganiyu et al. (2022) reported higher values (>10.0) of organic carbon/total nitrogen in the same RBK and RBD samples, suggesting intra continental erosion that sustained lower concentrations of heavy metals in soil/sediment. However, noteworthy accumulation (>1.00 mg/kg) of most selected heavy metals in the soil/sediment after flooding were reported by Ciesielczuk et al. (2014) and Čmelik et al. (2019). The investigated metals in both soils and riverbed sediments showed a declining inclination of Zn> Cu > Fe > Cd > Pb> Mn and Zn > Cd> Fe> Cu> Pb> Mn, correspondingly.

Table 4: **Average concentrations of heavy metals in studied soils and sediments**

Soil/sediments ID	**Fe (mg/kg)**	**Zn (mg/kg)**	**Mn (mg/kg)**	**Cu (mg/kg)**	**Pb (mg/kg)**	**Cd (mg/kg)**
River bank soil						
RBK 1	0.47	0.58	0.04	0.48	0.34	0.41
RBK 2	0.46	0.53	0.03	0.46	0.32	0.39
RBK 3	0.40	0.44	0.04	0.43	0.30	0.42
Mean	**0.44**	**0.52**	**0.04**	**0.46**	**0.32**	**0.41**
Riverbed sediment						
RBD 1	0.44	0.56	0.04	0.38	0.34	0.46
RBD 2	0.42	0.50	0.03	0.41	0.29	0.40
RBD 3	0.41	0.44	0.04	0.41	0.28	0.42
Mean	**0.42**	**0.50**	**0.04**	**0.40**	**0.30**	**0.43**

Probable Sources of Metals Pollution Indices

The values of EF for tested metal as well as their mean values at sample locations for both RBK and RBD samples are listed in Table 5. Mean EF values of metals in RBK are in the order Cu (1.04) > Mn=Pb (1.01) > Zn (0.99) > Cd (0.96). Similarly, the average EF values in RBD are in the order Cd (1.05) > Zn (1.02) > Mn (1.01) > Pb (1.00) > Cu (0.97). Therefore, the mean EFs indicate that investigated metals in sampled RBK and RBD were derived principally from geogenic sources and natural geochemical reactions, with no suggestion of anthropogenic inputs since their EF values lie within the range 0.5-1.5 (Zarei et al., 2014; Lintern et al., 2015; Zarezadeh et al., 2017; Bayrakli et al., 2022).

The results of average QoC values (negative percent) for Cu, Mn, Zn, Pb, Cd, and Fe in both RBK and RBD samples (Table 5) exposed that they were mostly obtained from geogenic factors and natural processes (Zarei et al., 2014; Zarezadeh et al., 2017; Saleh et al., 2018). There is similarity in recognition of origins of selected heavy metals in collected RBK and RBD samples by EF and QoC in this study. In conclusion, we can presume that the likely geogenic sources of all studied metals in soils and sediment of Ona River flanking the case study site were revealed by average values of EF and QoC indexes.

Table 5: Enrichment factor (EF) and Quantification of contamination (QoC) in soil and sediment samples

Soil/sediment code	**QoC**						**EF**				
	Pb	**Cd**	**Mn**	**Fe**	**Cu**	**Zn**	**Pb**	**Cd**	**Mn**	**Cu**	**Zn**
RBK 1	6.01	0.86	9.14	5.91	4.96	11.50	1.01	0.90	1.04	1.02	1.05
RBK 2	0.13	-4.22	-21.14	3.87	0.83	3.15	0.97	0.89	0.79	1.00	0.98
RBK 3	-6.53	3.22	9.14	-10.56	-6.09	-16.66	1.05	1.09	1.21	1.09	0.94
Mean	**-0.13**	**-0.05**	**-0.95**	**-0.26**	**-0.10**	**-0.67**	**1.01**	**0.96**	**1.01**	**1.04**	**0.99**
Riverbed sediment											
RBD 1	11.11	7.40	9.14	3.83	-5.20	11.14	1.08	1.09	1.12	0.88	1.10
RBD 2	-4.22	-6.49	-21.14	-0.75	2.50	0.48	0.95	0.98	0.87	0.99	1.02
RBD 3	-7.94	-1.42	9.14	-3.21	2.50	-13.09	0.97	1.08	1.05	1.03	0.93
Mean	**-0.37**	**-0.17**	**-0.95**	**-0.04**	**-0.07**	**-0.49**	**1.00**	**1.05**	**1.01**	**0.97**	**1.02**

Non-carcinogenic Health Risk Evaluation

Tables 6 and 7 revealed that ADD values for all tested metals in both RBK and RBD are relatively higher in children than adults. This concurs with similar trend of ADD values of studied metals in urban Hamedan soil in Iran by Tashakor and Modabberi (2021). In RBK samples, the highest $HQ_{ingestion}$values were gotten for Cd in adults (5.57E-04) and children (5.20E-03) while the highest HQ_{dermal}values were recorded for Cd in adults (8.36E-05) and children (5.98E-04). The relatively highest $HQ_{inhalation}$were obtained for Mn in adults (5.17E-07) and children (1.21E-06).The total sum of hazard quotients (HI) values for tested metals in RBK samples through the three adopted pathways are all <1.00 (Table 6), suggesting no apparent adversative health risk due to studied metals.

In RBD samples, the highest $HQ_{ingestion}$values were obtained for Cd in adults (5.84E-04) and children (5.46E-03) and the highest HQ_{dermal}values were noticed for Cd in adults group (8.78E-05) and children (6.27E-04) (Table 7). The highest $HQ_{inhalation}$ values were recorded for Mn for adults (5.17E-07) and children (1.21E-06). The HI values computed for adults exposed to heavy metals (HMs) in RBD ranged from 6.22E-07 to 7.12E-04, and from 1.45E-06 to 6.73E-03 for children, an indication of no non-carcinogenic risks to both age groups (Table 7).

Generally, the $HQ_{ingestion}$and $HQ_{dermal}$for adults and children exposure to soils and sediments of Ona River adjoining the houses follow the order: Cd > Pb > Cu > Zn > Fe > Mn. However, $HQ_{inhalation}$ for adults and children exposed to HMs in RBK and RBD follows the order: Mn > Cd > Pb > Cu > Zn > Fe. Furthermore, for both age groups (children and adults), the impact of ingestion pathway to total HI caused by studied HMs in riverbank soil and riverbed sediments is the highest, followed by that of dermal contact while inhalation manifested as least harmful route. Nevertheless, all the HI values through ingestion, skin absorption and breathing routes are less than 1.00. Enuneku &Ineh (2019) also reported HI via the three considered routes fall below the threshold level for both adults and children exposed to surface sediment of Ikpoba River, Southern Nigeria. However, our results of HI due to tested metals in RBD for adults and children via all the three pathways were in contrast to reported HI>1.00 for the two age groups exposed to riverbed sediment of Asunle stream, southwest Nigeria by Olutona (2023). His reported HI>1.00 might be due to nearby anthropogenic source (refuse dumpsite) (Olutona, 2023).

Carcinogenic Health Risk Estimation

In RBK samples, the CR values (Table 6) for adults via ingestion route varied from 1.06E-06 (Pb) to 8.36E-03 (Cd) while it ranged from 9.94E-06 (Pb) to 7.80E-02 (Cd) for children. Through this pathway, it was observed that Cd contributed most to the valuation of CR, followed by Pb and Cu for both age brackets. The CR values (Table 6) for exposed adults due to carcinogens in RBK samples via dermal contact varied from 1.85E-09 (Pb) to 1.67E-05 (Cd) while it ranged from 1.32E-08 (Pb) to 1.20E-04 (Cd) for children. Through the dermal pathway, it was also observed that Cd contributed most to the calculation of CR, followed by Pb and Cd for both age brackets. However, the CR values due to carcinogens in RBK for adults and children through inhalation route are <1.0E-06, thus insignificant cancer risk through breathing route. The TCR values for adults and children due to HMs in RBK samples via the three main routes are 8.39E-03 and 7.83E-02, respectively. This is an indication that adults and children are prone to serious carcinogenic risks when exposed to RBK soils of Ona River as TCR values were above the threshold limit of 1.0E-06 to 1.0E-04 (Table 6).

For RBD samples, the CR values estimated for adults via ingestion route varied from 1.01E-06 (Pb) to 8.77E-03 (Cd) while it ranged from 9.42E-06 (Pb) to 8.18E-02 (Cd) for children (Table 7). It was observed that Cadmium contributed most to the estimation of CR through oral ingestion, followed by Pb and Cu for both age groups. The Cancer risk values due to carcinogens in RBDs for adults and children through inhalation route are <1.0E-06, thus no adverse carcinogenic health effect through breathing pathway. However, the CR values for adults group due to HMs via skin absorption route varied from 1.75E-09 (Pb) to 1.76E-05 (Cd) whereas it ranged between 1.25E-08 (Pb) to 1.25E-04 (Cd) for children (Table 7). The TCR values for adults and children due to carcinogens in RBD samples via all the three pathways are 8.79E-03 and 8.21E-02, respectively. This is a clear indication that both age groups are at higher carcinogenic health risks when exposed to RBD sediments in investigated part of Ona River.

Generally, ingestion route contributed most to the estimation of TCR, followed by dermal route while inhalation pathway showed a minor contribution. Similar observation was also reported by Aluko et al. (2018). Furthermore, the CR values due to Cd contributed most to the TCR values for both adults and children in RBK and RBD via ingestion and dermal routes, with children being the most susceptible age group. Similar result was also reported for floodplain soil of River Meuse by Albering et al. (1999).

Table 6: Average Daily Dose (ADD), Hazard Quotient (HQ) and Cancer Risk (CR) for metals in soil samples along bank of Ona River

Parameters	**ADD$_{ingestion}$**		**HQ**		**CR**	
	Children	**Adults**	**Children**	**Adults**	**Children**	**Adults**
Zn	6.61E-06	7.08E-07	2.20E-05	2.36E-06		
Pb	4.09E-06	4.38E-07	1.17E-03	1.25E-04	9.94E-06	1.06E-06
Cd	5.20E-06	5.57E-07	5.20E-03	5.57E-04	7.80E-02	8.36E-03
Mn	4.69E-07	5.02E-08	3.35E-06	3.59E-07		
Cu	5.84E-06	6.26E-07	1.58E-04	1.69E-05		
Fe	5.67E-06	6.07E-07	8.10E-06	8.68E-07		
HI			6.56E-03	7.03E-04		
Parameters	**ADD$_{dermal}$**		**HQ**		**CR**	
	Children	**Adults**	**Children**	**Adults**	**Children**	**Adults**
Zn	7.60E-09	1.06E-09	1.27E-07	1.77E-08		
Pb	4.71E-09	6.58E-10	8.81E-06	1.23E-06	1.32E-08	1.85E-09
Cd	5.98E-09	8.36E-10	5.98E-04	8.36E-05	1.20E-04	1.67E-05
Mn	5.39E-10	7.54E-11	3.85E-09	5.39E-10		
Cu	6.71E-09	9.39E-10	2.80E-07	3.91E-08		
Fe	6.52E-09	9.12E-10	9.31E-09	1.30E-09		
HI			6.07E-04	8.49E-05		
Parameters	**ADD$_{inhalation}$**		**HQ**		**CR**	
	Children	**Adults**	**Children**	**Adults**	**Children**	**Adults**
Zn	2.43E-10	1.04E-10	8.10E-10	3.47E-10		
Pb	1.50E-10	6.45E-11	4.30E-08	1.84E-08	1.80E-09	7.74E-10
Cd	1.91E-10	8.19E-11	1.91E-07	8.19E-08	2.11E-05	9.05E-06
Mn	1.72E-11	7.39E-12	1.21E-06	5.17E-07		
Cu	2.15E-10	6.45E-11	5.34E-09	2.29E-09		
Fe	2.08E-10	8.93E-11	2.60E-10	1.12E-10		
HI			1.45E-06	6.20E-07		

Table 7: Average Daily Dose (ADD), Hazard Quotient (HQ) and Cancer Risk (CR) for metals in riverbed samples of Ona River

Parameters	**ADD$_{ingestion}$**		**HQ**		**CR**	
	Children	**Adults**	**Children**	**Adults**	**Children**	**Adults**
Zn	6.39E-06	6.85E-07	2.13E-05	2.28E-06		
Pb	3.88E-06	4.16E-07	1.11E-03	1.19E-04	9.42E-06	1.01E-06
Cd	5.46E-06	5.84E-07	5.46E-03	5.84E-04	8.18E-02	8.77E-03
Mn	4.69E-07	5.02E-08	3.35E-06	3.59E-07		
Cu	5.11E-06	5.84E-07	1.38E-04	1.48E-05		
Fe	5.41E-06	5.80E-07	7.73E-06	8.28E-07		
HI			6.73E-03	7.21E-04		
Parameters	**ADD$_{dermal}$**		**HQ**		**CR**	
	Children	**Adults**	**Children**	**Adults**	**Children**	**Adults**
Zn	7.35E-09	1.03E-09	1.23E-07	1.71E-06		
Pb	4.76E-09	6.24E-10	8.35E-06	1.17E-06	1.25E-08	1.75E-09
Cd	6.27E-09	8.78E-10	6.27E-04	8.78E-05	1.25E-04	1.76E-05
Mn	5.39E-10	7.54E-11	3.85E-09	5.39E-10		
Cu	5.88E-09	8.23E-10	2.45E-07	3.43E-08		
Fe	6.22E-09	8.71E-10	8.89E-09	1.24E-09		
HI			6.36E-04	8.90E-05		
Parameters	**ADD$_{inhalation}$**		**HQ**		**CR**	
	Children	**Adults**	**Children**	**Adults**	**Children**	**Adults**
Zn	2.35E-10	1.01E-10	7.83E-10	3.36E-10		
Pb	1.43E-10	6.11E-11	4.07E-08	1.75E-08	1.71E-09	7.33E-10
Cd	2.01E-10	8.60E-11	2.01E-07	8.60E-08	2.22E-05	9.50E-06
Mn	1.72E-11	7.39E-12	1.21E-06	5.17E-07		

Cu	1.88E-10	8.06E-11	4.68E-09	2.00E-09
Fe	8.53E-11	1.99E-10	2.49E-10	1.07E-10
HI			1.45E-06	6.22E-07

CONCLUSION

This research presented the average concentrations, possible origins and health risk assessment of tested heavy metals in soils and sediments of parts of Ona River within the axis of built-up site. The study revealed that the mean concentration of each of investigated HMs in soils and sediments at every sample point was less than 1.00 mg/kg, perhaps as a result of post flooding account of the site. Pollution indicators of EF and QoC revealed natural geochemical processes as the main source of tested metals in both RBK and RBD of investigated sections of Ona River. The HI values for adults and children due to exposure to HMs in both RBK and RBD were less than threshold limit, indicating negligible non-carcinogenic risks. The CR values for adults and children due to Cd through ingestion and dermal pathways in both RBK and RBD were greater than the acceptable verge limit (1.0E-06 to 1.0E-04), postulating substantial carcinogenic risk for the two age groups. Furthermore, the TCR values for adults and children due to exposure to carcinogens in RBK and RBD through the three main routes surpass the permissible limit, with major contribution via the ingestion route. Based on the findings of this study, it is highly suggested that adults and children should circumvent chance ingestion and dermal contact of riverbank soils and riverbed sediments of Ona River.

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