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CONTAMINATION STATUS AND SOURCE IDENTIFICATION OF HEAVY METALS IN THE RIVERBANK SOILS AND SEDIMENTS OF ONA RIVER, IBADAN, SOUTHWEST NIGERIA

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ABSTRACT

The present study investigated the pollution levels, sources, and contamination status of trace metals (Pb, Cd, Fe, Zn, Cu and Mn) in riverbank soils and sediments at three different sections of Ona River bordering residential area. The relationship of studied metals with selected soil chemical properties was also examined. The average concentration of each of the studied metals in soils and sediments at each sampling site was less than 1 mg/kg having a decreasing trend of Zn > Cu > Fe > Cd > Pb > Mn and Zn > Cd > Fe > Cu > Pb > Mn, respectively in soils and sediments. Results of enrichment factors (EF) were generally less than 1.5 for all assessed metals; index of geoaccumulation (Igeo) in soils and sediments of the investigated sites were less than 1 while contamination factor (CF) of assessed metals were in the range: 1< CF < 3. The results of integrated pollution indicators support lithogenic sources and a low-to-restrained pollution of the considered soils/sediments by metals. The environmental risks indices of sampling sites that could be ascribed to the metals revealed low mean ecological risks potential in soils and sediments. The values of co-efficient of variation (CV) of analyzed metals were less than 50%, indicating absence of strong anthropogenic inputs, while Fe-Zn, Fe-Pb, and Pb-Zn pairs in soils and sediments exhibited strong positive correlations, an indication of common sources due to lithogenic processes. Inverse relation between analyzed metals and organic matter further confirmed little impact of anthropogenic inputs as sources of metals in soil/sediment. This study elucidated that the area was not heavily polluted by metals and revealed that the investigated riverbank areas were mildly contaminated by assessed metals, thus posing a low ecological risk.

Keywords: Heavy metal, Ona River, Riverbank soils, Sediments, Pollution indicators, Environmental risks

INTRODUCTION

Heavy metals are regarded as serious pollutants in both terrestrial and adequate ecosystem due to their properties, such as toxicity, persistency, non-biodegradable and capacity to be integrated into food chain (Al Abdullah *et al*., 2014, Jun *et al*., 2017). The contamination of soil/sediment by heavy metals from different activities has gained worldwide attention, especially among environmental stakeholders. Metals are intrinsic components of earth crust, thus their contents in the ecosystem can be altered through different natural processes and anthropogenic inputs (Gopal *et al*., 2017). Lithogenic processes such as rock weathering, flow of water and natural erosion play significant role in the concentration of metals in soil/sediments (Karthikeyan *et al*., 2018). Major anthropogenic activities that can influence levels of heavy metals include wastewater discharges on soil/river, vehicular exhaust, leaching of chemical fertilizers, and pesticides and smelting activity (Karthikeyan *et al*., 2018; Shah *et al.,* 2019).

It is to be noted that the type of heavy metals present in the urban soils and sediments often vary with the population, type of anthropogenic activities prevalent in the area and traffic densities within the urban environment (Zhao *et al*., 2014). Soil acts as a receptor medium that plays significant role in the buildup, redistribution, conversion and mobilization of various contaminants, especially heavy metals in the ecosystem (Wu *et al*., 2017; Shah *et al*., 2019; Alekseev and Abakumov, 2020). Apart from the fact that trace metals are naturally present in soil and rock parent materials in the form of sulphides, silicates and carbonates, several anthropogenic activities introduce heavy metals in porous medium (Hu *et al*., 2018; Zhang *et al*., 2019; Alekseev and Abakumov, 2020). Therefore, it is highly important to monitor the levels of heavy metals in soils and sediments in places that have high chances of being polluted with heavy metals through anthropogenic inputs (Acosta *et al*., 2011).

The background concentration of a particular element in sediment is highly reliant on texture, grain-size distribution, mineralogical content, % clay fraction, organic matter content, and the weathering situations of geological matrix (Tiwari *et al*., 2013; Al Abdullah *et al*., 2014). Soil organic matter (SOM) plays important role in determining levels of trace metals through processes such as ion-exchange, inner/outer-sphere complex formation, and proton displacement (Schnitzer,1986). In the riverside area, metals can get into aquatic environment through atmospheric deposition, natural erosion of the geological matrix, and nearby man made activities, such as open defecation, indiscriminate dumping of wastes and leaching of chemical fertilizers from farmlands along river bank axis (Vystavna *et al.,* 2012, Al Abdullah *et al*., 2014). Trace metals readily bind with the riverbed sediments through processes of precipitation, adsorption onto surface particles and integration into biogenic materials (Jun *et al*., 2017, Song *et al*., 2019; Kim *et al*., 2020).

However, metals attached to the sediments may be released into the overspreading water through sediments-water interface chemistry, resulting in deteriorating quality of surface water (Simpson and Batley, 2007). This means that rivers act as vital channels for metal mobilization and transformation and are specifically susceptible to land use impacts (Wu *et al.,* 2017). Therefore, in order to obtain a detailed understanding of the heavy metal-induced pollution status of river environment, it is necessary to investigate the levels of metals in the sediments and riverbank soil bordering residential community.

Studies on concentrations of heavy metals in river sediments (core and surface sediments) were well cited (Al Abdullah *et al*., 2014; Islam *et al*., 2015; Park *et al*.,2011; Garrido *et al*., 2016, Hakina *et al*., 2017; Kim *et al*., 2020). However, few literature are available on heavy metals content in surface sediments of rivers in Nigeria (Ipeaiyeda and Onianwa, 2018). Specifically, most of the published research works on Ona River focused more on quality of surface water collected at different parts of the river (Osibanjo *et al*., 2011; Awomeso *et al*., 2012: Olayinka *et al*., 2017; Ojo 2018) while Ganiyu *et al*. (2021) only investigated the microbial state and heavy metals content in groundwater samples from hand bug wells adjoining Ona River.

The present study examined the levels of heavy metals in riverbank soils and riverbed sediments collected along Ona River, established the relationships between the metals and selected physico-chemical characteristics, identified potential sources of metal contaminants and evaluated the associated risks of the metals in soils/sediments of the study area.

MATERIALS AND METHODS

Description of the study area and its geological setting

Ibadan, the capital of Oyo state, lies within the latitudes $7^{\circ}20^{'}$–$7^{\circ}40^{'}$ and longitudes $3^{\circ}35^{'}$–4°$10^{'}$ east of Greenwich Meridian (Ganiyu, 2018). With a mean annual rainfall of about 1230 mm and a mean maximum temperature of 32 °C, Ibadan has a humid and sub humid tropical climate of southwest Nigeria (Ganiyu *et al*., 2021). The wet season in Ibadan starts from April and ends in October while the dry season commences from November and ends in March, with peak average monthly rainfall of about 180 mm in the month of September (Ganiyu *et al*., 2021).

Ona River is situated in the northern part of Ibadan, with a length of 55 km and an area of 81 km^2 (Ojo *et al*., 2018; Ganiyu *et al*., 2021). It flows in a North- South direction from its basis at Eleyele Catchment area through Oluyole in Oluyole Local government (Awomeso *et al*., 2012; Ganiyu *et al*., 2021). The residential area bordering Ona River has houses located within close nearness to the bank of Ona River (Ganiyu *et al*., 2021). The study area witnessed flooding during the year 2011 (Agbola *et al*., 2011; Egbinola *et al*., 2015). There is an overhead road network above Ona River in the study area (Ganiyu *et al*., 2021). Presence of light vegetation and anthropogenic activities such as operation of farmland, mechanic workshops, and mini dumpsite were noticed along the riverbank.

The geology of Ibadan falls within a basement complex formation of southwest Nigeria. The main rock types present within Ibadan are the quartzite of the meta-sediment series, banded gneiss, augen gneiss and migmatites (Bolarinwa, 2017; Ganiyu, 2018). Nevertheless, the schist and the quartz schist are regular and well uncovered within Ibadan metropolis (Osinowo and Arowoogun, 2020; Ganiyu *et al.*, 2021). Minor rock types present within the city comprise quartz veins, pegmatites, aplites, amphibolites and xenoliths (Okunlola *et al.*, 2009; Ganiyu, 2018). The major rock type in the study area is undifferentiated gneiss schist (Figure 2).

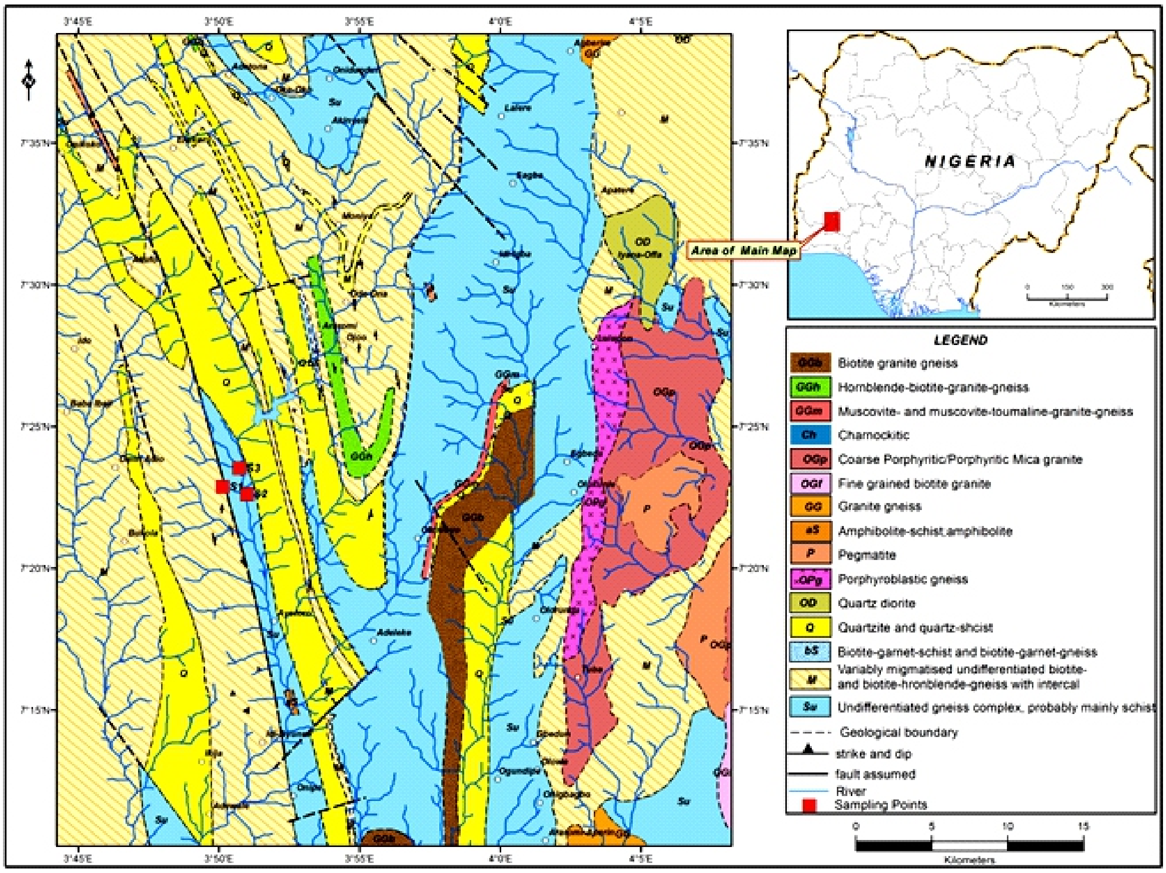

Figure 1 Geological map showing soil/sediment sampling locations of the study area

Soil/Sediment Samples Collection and Analytical Methods

Riverbank soil and sediment samples were collected from three different sampling points within residential area that was in close proximity to Ona River. The sampling points were chosen based on the concentration of houses along the stretch of riverbank used in the study as well as prevailing activities/features within few meters to the bank of the river. At each sampling point along the riverbank, a grid of 30 m by 5 m was created and five (5) top soil samples (0-30 cm) were collected within the grid using the stainless steel auger. Following the same grid pattern, 5 riverbed sediment samples were also collected with the aid of grab sampler. Such samples of soil and sediment at each sampling point were thoroughly mixed together in equal proportion to form a composite sample that was later used for chemical analyses.

The samples were put in polythene nylons, labeled appropriately to avoid mix up, stored in ice chest before being transported to the soil chemistry laboratory of Institute of Agricultural Research & Training (IART&T), Ibadan, Nigeria. The samples were air dried at room temperature, mildly crushed and grinded before being sieved with a 2 mm sieve to remove unwanted materials preceding the commencement of chemical analyses (Al Abdullah et al., 2014; Ganiyu, 2018; Ipeaiyeda and Onianwa 2018). The pH of soil/sediment sample was determined with the aid of digital pH meter following the ASTM standard (ASTM G51-59, 2012). Analysis of selected heavy metals (HMs) (Fe, Zn, Mn, Cu, Pb and Cd) on digested soil and sediment samples solution were carried out in triplicate by direct aspiration into BUCK 211 Atomic Absorption Spectrophotometer model against the standard level of the metals (Ganiyu *et al*., 2018). Particle size distribution of soil/sediment samples was determined through modified Bouyoucous hydrometer method as discussed by Gee and Or (2002) whilst soil textural class was done using the USDA textural triangle. The total carbon was measured by loss on ignition method according to Cambardella *et al.* (2001) while Organic Matter (OM) was determined using $K_2Cr_2O_7.H_2SO_4$ as adapted by Nelson and Somners (1982). Total Nitrogen (TN) was measured using the Kjeldahl method (Bremner, 1986). All the chemical analyses were run in triplicate whilst the mean values of assessed parameters in riverbank soil and riverbed sediments are presented in the study.

Statistical Analysis

Descriptive statistics was applied on the results of analyzed parameters on soil and sediment samples. Furthermore, Pearson's correlation and analysis of variance (ANOVA) were also performed on the data obtained. All the statistical analyses were done with the use of SPSS statistical software version 20.0.

Integrated Metal Pollution Index

Integrated metal pollution index concerning contamination factor, degree of contamination, modified degree of contamination (mDC), geoaccumulation index (Igeo), enrichment factor (EF), pollution load index (PLI), and ecological risk factors (ecological risk and potential ecological risk) was employed in the study.

Geo accumulation Index (I_{geo})

This is an index method of pollution evaluation that provides required information about the extent of soil contamination by target metals in a porous medium (Ganiyu *et al*., 2021). It is expressed mathematically as:

$$I_{geo} = log_2\left(\frac{C_n}{1.5Bn}\right) \qquad (1)$$

where C_n is the measured level of the metal in soil/sediment and Bn is the geochemical background value of the element (Ganiyu *et al*., 2021). Constant 1.5 in equation (1) is the correction factor that caters for likely deviation as a result of geogenic effects and to identify little anthropogenic impact (Alekseev and Abakumov, 2020, Kulikova *et al*., 2019). The extent of soil pollution by metals based on I_{geo} values follow the categorization proposed by Muller (1979), Chandrasekaram *et al.* (2015) and Barbieri (2016) as: $I_{geo} < 0$ signifies practically unpolluted, $0 < I_{geo} < 1$ expresses slightly polluted, $1 < I_{geo} < 2$ refers to moderately polluted, $3 < I_{geo} < 4$ as severely polluted; $4 < I_{geo} < 5$ as severely to extremely polluted state while $I_{geo} > 5$ signifies extremely polluted state of the metal.

Contamination factor (CF) represents the pollution condition as directly reflected by the ith metal in the soil/water system (Muller, 1971). It is expressed as:

$$CF = \frac{C_m}{C_b} \qquad (2)$$

where $_{m}C$ is the measured level of ith metal in the sample and $_{b}C$ is the background concentration of the ith metal. The classification of pollution status by ith metal according to Hakanson (1980); Likuku *et al.* (2013) follows: CF < 1 as low pollution, 1 ≤ CF < 3 as moderate pollution; 3 ≤ CF < 6 indicates considerable pollution whilst CF > 6 signifies very high pollution (Ganiyu *et al*., 2021).

The degree of contamination (DC) expresses the contamination status of a particular sample due to all investigated metals (Hakanson, 1980). It is expressed mathematically as:

$$DC = \sum_{i=1}^{n} CF_i \qquad (3)$$

where Cf_i is the contamination factor for the ith metal in soil/sediment sample and n is the number of assessed metals in the study. According to Odukoya (2015) and Devanesan *et al.* (2017), DC < 7 suggests low degree of pollution, 7 ≤ DC < 14 indicates mild degree of pollution, 14 ≤ DC < 21 signifies considerable degree of pollution while

DC ≥ 21 indicates extremely high degree of pollution.

The modified degree of contamination (mDC) pioneered by Abraham and Parker (2008) allows evaluation of general degree of contamination at a particular sampling point and is expressed as:

$$\text{mDC} = \frac{DC}{n} \qquad (4)$$

where n is the number of target metals in the sample at a particular sampling point and DC is the degree of contamination at that particular sampling point. The classification of pollution status based on mDC value as projected by Brady *et al.* (2015); Gargouri *et al.* (2018) follows mDC < 1.5 = unpolluted; mDC (1.5–2.0) = slightly polluted; mDC (2–4) = moderately polluted; mDC (4–8) = moderately heavily polluted; mDC (8–16) signifies ruthlessly polluted; mDC (16–32) = profoundly polluted while mDC >32 = extremely polluted state.

Pollution load index (PLI) evaluates the extent of contamination load of assessed metals in soil/sediment (Tripti *et al.*, 2019; Alekseev and Abakumov, 2020). It is related to the CF by the relation proposed by Tomlison *et al.* (1980) as:

$$PLI = (CF_1 \times CF_2 \times CF_3 \times \ldots\ldots\ldots\ldots \times CF_n)^{1/n} \qquad (5)$$

where n is the number of evaluated elements in the soil/sediment and CF is the contamination status of each assessed metal in each sample. A PLI = 0 is an indication of background level, 1< PLI ≤ 2 signifies unpolluted to moderately polluted; 2< PLI ≤ 3 indicates mildly polluted, 3 < PLI ≤ 4 expresses highly polluted and PLI > 5 indicates extremely polluted (Barakat *et al.*, 2012; Barbieri, 2016).

Enrichment factors (EF) is an index method used to evaluate the source(s) of metals in soil/sediment as well as the degree of contribution by anthropogenic inputs to the metal pollution of soil/sediment medium. Iron (Fe) was adopted as the references metal in the estimation of EF results where it is calculated by the expression:

$$EF = \frac{\left(\frac{C_i}{Fe_s}\right)}{\left(\frac{C_i}{Fe_b}\right) reference} \qquad (6)$$

where C_i is the measured value of ith metal, Fe_s is the measured level of Fe in the sample, C_b is the world shale average of the ith metal (Taylor, 1964) and Fe_b denotes the world shale mean value of references metal Fe. Based on classification by Looi *et al.* (2018), Barbieri (2016) and Mashiatullah *et al.* (2013), EF <1 equals absence of enrichment, 1 < EF < 2 signifies minor enrichment, EF (2–5) signifies modest enrichment, EF (5–10) suggests mild severe enrichment, EF (10–25) denotes ruthless enrichment, EF(25–50) equals very severe enrichment while EF greater than 50 expresses extremely severe enrichment. As a way of identifying the probable sources of the contaminants, EF results ranging from 0.5 to 1.5 indicate lithogenic (geological/material weathering) source while EF results greater than 1.5 signify sources from man-made activities (Barbieri, 2016; Zhang *et al.*, 2019; Ahamad *et al.*, 2020).

The ecological risk factor (ERF) is used to estimate the ecological risk for individual assessed contaminant in the soil/sediments based on its toxicity response (Alekseev and Abakumov, 2020). The ERF is expressed mathematically as:

$$ERF = Tr_i \times CF_i \qquad (7)$$

where Tr_i denotes the toxicity response of each metal, and CF_i is the contamination factor of corresponding metal. The metals in the present study are assigned toxicity response as follows: Pb = Cu = 5; Zn = 1, Cd = 30, Mn = Fe = Zn = 1 (Alekseev and Abakumov, 2020; Egbueri *et al.*, 2020).

The potential ecological risk index (PERI) on the other hand can be used to evaluate the extent of environment sensitivity due to heavy metals existence in the soil (Sahoo *et al.*, 2016). The PERI is calculated as the summation of all computed ERFs of assessed metals in soil/sediment at a specific sampling point. It is expressed as:

$$PERI = \sum_{i=1}^{n} ERF_i \qquad (8)$$

where ERF_i is the computed ERF of ith metal in soil/sediment at a particular sampling point. According to Tomlison *et al.* (1980), ERF < 40 signifies low ecological risk, ERF (40–80) expresses mild ecological risk, ERF (80–160) means considerable high risk, ERF (160–320), means high ecological risk, while ERF > 320 suggests very high ecological risk (Hakanson, 1980). In case of PERI categorization, Hakanson (1980) proposed that PERI < 150 denotes low ecological potential risk, PERI (150–300) is moderate ecological risk potential, PERI (300–600) indicates high ecological risk potential, and PERI > 600 is extremely high ecological risk potential.

RESULTS AND DISCUSSION

Tables 1and 2 present the average values of analyzed physico-chemical and heavy metals in soils and sediments at the three sampling sites. The average pH in riverbank soil (RBKS) ranged from 6.42–6.50 and from 6.45–6.60 in riverbed sediment (RBD), an indication of slightly acidic state of soil/sediment at all the sampling points. The average %OC in RBK soils ranged from 1.35 to 1.49 and from 1.38–1.50 in RBD sediments. Riverbank soil at sampling site 1 (RBK1) recorded lowest value of %OC while sediment at sampling site 3 (RBD3) had relatively highest value of % OC (1.50). The average %OM in soil and sediment samples varied from 2.33 to 2.58 and 2.37 to 2.59, respectively. Highest average values of OC and OM were noticed at sediment sampling site 3 (RBD3) while lowest values of average OC and OM were recorded at soil sampling site 1 (RBK1). The average values of TN in riverbank soil and riverbed sediment ranged from 0.01 to 0.02. Very low TN values at all sampling points indicate that pollution was not from organic matter of planktonic origin, but rather of inland pollution sources (Dinçer *et al.*, 2019). Furthermore, decrease in TN values below 1% indicated that the denitrification and nitrification reactions occur at all the sampling sites (Dinçer *et al.*, 2019). The ratio OC : TN in analyzed soil and sediments ranged from 71.5 to 135 and from 70.5 to 150, respectively. Sediment samples at sampling point 2 (RBD2) had lowest average result of OC : TN while composite sediment at RBD3 had highest value of OC : TN. In similar manner, OM : TN values in soil/sediment at all sampling sites ranged from 123.5 to 233.0 and from 121.5 to 259.0, respectively. The lowest and highest values of OM: TN for soil and sediment samples were recorded at RBD2 and RBD3, respectively. Highest values of OC : TN and OM : TN at RBD3 suggest high accumulation of more organic matter of inland origin, but less of organic acids of plants at this site relative to other sampling points (Kosiorek and Wyszkowski, 2017; Dinçer *et al.*, 2019; Alekseev and Abakumov, 2020). All the collected soil and sediment samples at the 3 sampling sites belong to sandy loam class.

Table 1 Average concentration of physico-chemical properties in studied soils and sediments

Soil/sediments ID	pH in water	OC (%)	OM (%)	TN (%)	$\frac{OC}{TN}$	$\frac{OM}{TN}$	% Sand	% Silt	% Clay
Riverbank soil									
RBK 1	6.61	1.35	2.33	0.01	135	233	60.23	26.41	13.36
RBK 2	6.42	1.43	2.47	0.02	71.50	123.50	76.23	14.02	9.75
RBK 3	6.50	1.49	2.58	0.02	74.50	129	66.31	27.74	5.95
Riverbed sediment									
RBD 1	6.55	1.38	2.37	0.01	138	237	74.25	13.99	11.77
RBD 2	6.45	1.41	2.43	0.02	70.5	121.50	80.44	12.38	7.42
RBD 3	6.60	1.50	2.59	0.01	150	259	78.26	8.41	13.33

Table 2 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
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

The mean concentrations of investigated metals in soils and sediments at all investigated sites were 0.40–0.47 mg/kg (Fe), 0.44–0.58 mg/kg (Zn), 0.03–0.40 mg/kg (Mn), 0.38–0.48 mg/kg (Cu), 0.28–0.34 mg/kg (Pb) and 0.39–0.46 mg/kg for Cd. Comparatively, Zinc was the most abundant element in the investigated soil and sediment samples. Furthermore, each of the studied metals had average concentration below 1 mg/kg in both riverbank soil and riverbed sediment samples. The low values of analyzed metals in soil/sediment at all the 3 sampling sites might be due to reported information that post flood samples have tendency to have decreasing concentration of heavy metals in soil/sediment (Saint-Laurent *et al.*, 2014; Rastmanesh *et al.*, 2020). Furthermore, higher values of OC : TN >10 at all the 3 sampling sites indicated high intra continental erosion that supported reduced levels of metals in soil (Kosiorek and Wyszkowski, 2017). Result of < 1 mg/kg in each of analyzed metals in this study is different from the result obtained by Alekseev and Abakumov (2020) that reported relatively high concentrations of Pb, Cu, and Zn in penguin-influenced soils in Antarctica as well as that of Algül and Beyhan (2020) that reported >1 mg/kg in each of studied metals in shallow sediments in Lake Barfa, Turkey. The obtained results of concentrations of Pb, Cu, and Zn in the collected sediments were lower than their corresponding values in Alaro River sediments that received industrial effluents (Ipeaiyeda and Onianwa, 2018). The order of abundance of mean concentrations of studied metals in riverbank soil is Zn > Cu > Fe > Cd > Pb > Mn while that of the riverbed sediment is Zn > Cd > Fe > Cu > Pb > Mn.

The result of analysis of variance (ANOVA) of assessed parameters (Table 3) exposed significant differences in the concentrations of Cu, % sand, and % silt between soil and sediment samples. Cu^{2+} and % silt were significantly higher at the riverbank while % sand was significantly higher at the riverbed as observed from the descriptive statistics table (Table 4). Table 4 further show that coefficient of variation (CV) values of analyzed parameters ranged from 1.33-38.80 (i.e < 50%), an indication of absence of strong anthropogenic activities in the study area (Wu *et al.*, 2017). It should be noted that only TN and % silt had CV values above 10% (Table 4).

Table 3 ANOVA result for the assessed parameters

		Sum of Squares	df	Mean Square	F	Sig.
pH	Between Groups	.002	1	.002	.231	.641
	Within Groups	.071	10	.007		
	Total	.072	11			
% OC	Between Groups	.000	1	.000	.009	.928
	Within Groups	.039	10	.004		
	Total	.039	11			
% OM	Between Groups	.000	1	.000	.006	.938
	Within Groups	.117	10	.012		
	Total	.117	11			
% TN	Between Groups	.000	1	.000	1.250	.290
	Within Groups	.000	10	.000		
	Total	.000	11			
Fe^{2+}	Between Groups	.002	1	.002	2.356	.156
	Within Groups	.007	10	.001		
	Total	.009	11			
Zn^{2+}	Between Groups	.001	1	.001	.160	.698
	Within Groups	.033	10	.003		
	Total	.034	11			
Mn^{2+}	Between Groups	.000	1	.000	.294	.599
	Within Groups	.000	10	.000		
	Total	.000	11			
Cu^{2+}	Between Groups	.008	1	.008	19.938	**.001**
	Within Groups	.004	10	.000		
	Total	.012	11			
Pb^{2+}	Between Groups	.001	1	.001	2.069	.181
	Within Groups	.006	10	.001		
	Total	.007	11			
Cd^{2+}	Between Groups	.001	1	.001	2.093	.179
	Within Groups	.005	10	.000		
	Total	.006	11			
% Sand	Between Groups	299.500	1	299.500	10.042	**.010**
	Within Groups	298.257	10	29.826		
	Total	597.758	11			
% Silt	Between Groups	371.631	1	371.631	13.957	**.004**
	Within Groups	266.274	10	26.627		
	Total	637.905	11			
% Clay	Between Groups	3.853	1	3.853	.394	.544
	Within Groups	97.912	10	9.791		
	Total	101.766	11			

Table 4 Descriptive Statistics of analyzed Soil/Sediment Parameters

Parameters	Locations	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum	Coefficient of Variation
						Lower Bound	Upper Bound			
pH	River Bank	6	6.5100	0.0865	0.0353	6.4192	6.6008	6.40	6.62	1.33
	River Bed	6	6.5333	0.0817	0.0333	6.4476	6.6190	6.40	6.60	1.25
	Total	12	6.5217	0.0811	0.0234	6.4701	6.5732	6.40	6.62	1.24
% OC	River Bank	6	1.4250	0.0657	0.0268	1.3561	1.4939	1.34	1.50	4.61
	River Bed	6	1.4283	0.0585	0.0239	1.3670	1.4897	1.37	1.51	4.09
	Total	12	1.4267	0.0593	0.0171	1.3890	1.4643	1.34	1.51	4.16
% OM	River Bank	6	2.4567	0.1152	0.0470	2.3358	2.5775	2.31	2.59	4.69
	River Bed	6	2.4617	0.1007	0.0411	2.3560	2.5673	2.36	2.60	4.09
	Total	12	2.4592	0.1032	0.0298	2.3936	2.5247	2.31	2.60	4.20
% TN	River Bank	6	0.0167	0.0052	0.0021	0.0112	0.0221	.01	.02	30.90
	River Bed	6	0.0133	0.0052	0.0021	0.0079	0.0188	.01	.02	38.80
	Total	12	0.0150	0.0052	0.0015	0.0117	0.0183	.01	.02	34.80
Fe^{2+}	River Bank	6	0.4433	0.0345	0.0141	0.4072	0.4795	.40	.48	7.77
	River Bed	6	0.4200	0.0141	0.0058	0.4052	0.4348	.40	.44	3.37
	Total	12	0.4317	0.0279	0.0081	0.4139	0.4494	.40	.48	6.47
Zn^{2+}	River Bank	6	0.5133	0.0615	0.0251	0.4488	0.5779	.43	.58	11.99
	River Bed	6	0.5000	0.0537	0.0219	0.4437	0.5563	.44	.56	10.73
	Total	12	0.5067	0.0555	0.0160	0.4714	0.5419	.43	.58	10.95
Mn^{2+}	River Bank	6	0.0367	0.0052	0.0021	0.0312	0.0421	.03	.04	14.06
	River Bed	6	0.0350	0.0055	0.0022	0.0293	0.0407	.03	.04	15.66
	Total	12	0.0358	0.0052	0.0015	0.0326	0.0391	.03	.04	14.39
Cu^{2+}	River Bank	6	0.4533	0.0216	0.0088	0.4307	0.4760	.42	.48	4.77
	River Bed	6	0.4017	0.0184	0.0075	0.3824	0.4209	.38	.42	4.57
	Total	12	0.4275	0.0331	0.0095	0.4065	0.4485	.38	.48	7.73
Pb^{2+}	River Bank	6	0.3200	0.0190	0.0078	0.3001	0.3399	.30	.35	5.93
	River Bed	6	0.3000	0.0283	0.0116	0.2703	0.3297	.27	.34	9.43
	Total	12	0.3100	0.0252	0.0073	0.2940	0.3260	.27	.35	8.14
Cd^{2+}	River Bank	6	0.4083	0.0147	0.0060	0.3929	0.4238	.39	.43	3.61
	River Bed	6	0.4267	0.0273	0.0112	0.3980	0.4553	.40	.46	6.40
	Total	12	0.4175	0.0230	0.0066	0.4029	0.4321	.39	.46	5.51
% Sand	River Bank	6	67.5900	7.2240	2.9492	60.0089	75.1711	60.22	76.24	10.69
	River Bed	6	77.5817	2.7322	1.1154	74.7144	80.4490	74.22	80.26	3.52
	Total	12	72.5858	7.3717	2.1280	67.9021	77.2696	60.22	80.26	10.16
% Silt	River Bank	6	22.7233	6.8260	2.7867	15.5599	29.8868	13.66	29.10	30.04
	River Bed	6	11.5933	2.5807	1.0536	8.8850	14.3016	8.38	14.38	22.26
	Total	12	17.1583	7.6152	2.1983	12.3199	21.9968	8.38	29.10	44.38
% Clay	River Bank	6	9.6867	3.4460	1.4068	6.0703	13.3030	4.50	13.40	35.57
	River Bed	6	10.8200	2.7763	1.1334	7.9065	13.7335	7.33	13.40	25.66
	Total	12	10.2533	3.0416	0.8780	8.3208	12.1859	4.50	13.40	29.66

The results of Pearson's correlation coefficients for riverbank soil and riverbed sediment are presented in Tables 5 and 6, respectively. Table 5 revealed that strong negative correlations existed between % clay and each of OC, OM, and TN. However, clay exhibited positive correlation with Fe, Cu, Zn, and Pb. A strong negative correlation existed between % sand and pH($r > -0.9$). Negative correlation was shown between each of Fe, Zn, Mn , Cu, and Pb and OC/OM in riverbank soil sample. This is an indication that OM affected migration of these metals in soil samples along the studied portions of riverbank. A very strong positive correlation ($r^2 > 0.85$) was noticed for Zn-Fe, Cu-Fe, Cu-Zn, Pb-Fe, Pb-Zn, and Pb- Cu pairs. However, Cd exhibited negative weak correlations with other metals except with Mn. Similarly, strong positive correlation ($r^2 > 0.85$) was found between OM-OC, OC-TN, and OM-TN pairs. Similar strong positive correlation between OC and TN was obtained by Liu *et al.* (2009).

In Table 6, clay only exhibited strong negative correlation ($r^2 > -0.95$) with TN while % silt exhibited negative strong association with OC and OM. A strong direct association was implied between Fe and Zn, Pb and Fe, and Pb and Zn. However, negative correlation occurred between Cu-Fe, Cu-Zn, Cu-Mn, and Pb-Cu pairs. Inverse association between each of OM and OC with Fe, Mn, Zn, Pb and Cd in riverbed sediment reflected non-influence of OM and OC on aforementioned metals (Shaheen and Rinklebe, 2014). This negative relation between aforementioned metals and each of OC and OM indicate little influence of anthropogenic input on those metals.

Generally, strong positive correlations between Fe and Zn, Fe and Pb, Pb and Zn in both soil and riverbed sediment along the investigated parts of Ona River indicate their common sources and similar behaviours during transportation (Karthikeyan *et al.*, 2018; Song *et al.*, 2019; Rastmanesh *et al.*, 2020; Ekoa Bessa *et al.*, 2020). The strong positive relation between aforementioned pair might also suggests that they mainly originated from the weathering process of parent rocks (Al Abdullah *et al.*, 2014).

Table 5 Pearson Correlation matrix of assessed metals and physico-chemical parameters in Riverbank Soils

	pH	% OC	% OM	% TN	Fe^{2+}	Zn^{2+}	Mn^{2+}	Cu^{2+}	Pb^{2+}	Cd^{2+}	% Sand	% Silt	% Clay
pH	1												
% OC	-.616	1											
% OM	-.614	1.000**	1										
% TN	-.896*	.885*	.885*	1									
Fe^{2+}	.201	-.893*	-.894*	-.600	1								
Zn^{2+}	.436	-.955**	-.960**	-.776	.937**	1							
Mn^{2+}	.806	-.059	-.056	-.500	-.375	-.147	1						
Cu^{2+}	.450	-.931**	-.935**	-.777	.896*	.953**	-.060	1					
Pb^{2+}	.512	-.963**	-.961**	-.816*	.918**	.908*	.000	.927**	1				
Cd^{2+}	.393	.176	.185	-.088	-.460	-.390	.702	-.168	-.143	1			
% Sand	-.961**	.427	.425	.789	.005	-.234	-.926**	-.298	-.355	-.539	1		
% Silt	.742	.037	.041	-.418	-.450	-.242	.988**	-.173	-.083	.657	-.881*	1	
% Clay	.544	-.969**	-.972**	-.826*	.881*	.969**	-.014	.966**	.909*	-.171	-.351	-.134	1

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Table 6 Pearson Correlation matrix of assessed metals and physico-chemical parameters in Riverbed Sediments

	pH	% OC	% OM	% TN	Fe^{2+}	Zn^{2+}	Mn^{2+}	Cu^{2+}	Pb^{2+}	Cd^{2+}	% Sand	% Silt	% Clay
pH	1												
% OC	.391	1											
% OM	.381	1.000**	1										
% TN	-.791	-.243	-.244	1									
Fe^{2+}	-.173	-.944**	-.941**	.000	1								
Zn^{2+}	-.274	-.956**	-.955**	.000	.949**	1							
Mn^{2+}	.447	-.156	-.163	-.707	.258	.408	1						
Cu^{2+}	-.178	.749	.756	.352	-.771	-.853*	-.697	1					
Pb^{2+}	.173	-.774	-.773	-.411	.900*	.870*	.516	-.886*	1				
Cd^{2+}	.418	-.442	-.441	-.756	.621	.655	.802	-.824*	.880*	1			
% Sand	-.412	.444	.442	.754	-.620	-.657	-.807	.826*	-.878*	-1.000**	1		
% Silt	-.486	-.979**	-.977**	.236	.898*	.967**	.224	-.743	.736	.455	-.458	1	
% Clay	.860*	.473	.473	-.964**	-.224	-.252	.588	-.124	.182	.564	-.561	-.479	1

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).

Table 7 Contaminations factor, Enrichment factor and Pollution load index in soil and sediment samples

Soil/sediment code	**CF**						**EF**					**PLI**
	Pb	Cd	Mn	Fe	Cu	Zn	Pb	Cd	**Mn**	**Cu**	**Zn**	
RBK 1	1.10	0.99	1.13	1.09	1.12	1.14	1.01	0.90	1.04	1.02	1.05	1.07
RBK 2	1.04	0.95	0.85	1.07	1.07	1.04	0.97	0.89	0.79	1.00	0.98	1.00
RBK 3	0.97	1.01	1.13	0.93	1.01	0.87	1.05	1.09	1.21	1.09	0.94	0.99
Riverbed sediment												
RBD 1	1.09	1.10	1.13	1.01	0.89	1.11	1.08	1.09	1.12	0.88	1.10	1.04
RBD 2	0.93	0.96	0.85	0.97	0.97	0.99	0.95	0.98	0.87	0.99	1.02	0.96
RBD 3	0.91	1.01	0.99	0.94	0.96	0.87	0.97	1.08	1.05	1.03	0.93	0.96

Extent of Pollution by Metals

The analysis of contamination factor (CF) revealed that CF values of assessed metals at all the 3 sampling sites fell under low to moderate pollution range (Table 7). According to Hakanson (1980) classification, Pb, Fe, Cu, and Zn show moderate pollution ($1 < CF < 3$) at RBK1 and RBK2. However, Cd, Mn and Cu indicated moderate pollution at RBK3, while Pb, Fe, and Zn indicated low pollution ($CF < 1$) at RBK3. For riverbed sediments, all the analyzed metals except Cu showed moderate pollution at RBD1. All assessed metals except Cd were in low pollution status at RBD3, while each of the studied metals were in low pollution state at site RBD2. This is an indication that moderate pollution status exist for most of analyzed metals at RBK1 and RBD1 relative to other sampling sites. This may also be due to lowest values of OC and OM at these two sampling sites (RBK1 and RBD1) relative to other sampling sites. The results of CFs further revealed that none of the assessed metals at all the sampling sites indicate strong contamination status. The PL1 values for the studied metals in soils and sediments as presented in Table 7 ranged from 0.96 to 1.07. Sampling sites (RBK1 and RBD1) reflected "unpolluted to moderately polluted" load whereas 66.7% of total sampling sites for soil (RBK2 &RBK3) and sediments (RBD2 and RBD3) showed "unpolluted" pollution load ($0 < PLI \leqslant I$) with lowest level at RBD2 and RBD3 (Tomlinson *et al.*, 1980; Alekseev and Abakumov, 2020).

The values of EF (Table 7) indicated background enrichment of Cd and minor enrichment of Pb, Mn, Cu, and Zn at RBK1. At RBK2 site, only Cu

Table 8 Geo accumulation index (I_{geo}), Degree of contamination, and modified degree of contamination

Soil/sediment code	I_{geo}							
	Pb	Cd	Mn	Fe	Cu	Zn	DC	mDC
River bank soil								
RBK 1	-0.45	-0.61	-0.41	-0.46	-0.43	-0.39	6.57	1.09
RBK 2	-0.53	-0.66	-0.83	-0.49	-0.49	-0.53	6.02	1.00
RBK 3	-0.63	-0.58	-0.41	-0.69	-0.57	-0.78	5.92	0.99
Riverbed sediment								
RBD 1	-0.47	-0.44	-0.41	-0.57	-0.75	-0.43	6.33	1.06
RBD 2	-0.71	-0.64	-0.83	-0.62	-0.64	-0.60	5.67	0.95
RBD 3	-0.73	-0.57	-0.62	-0.68	-0.64	-0.78	5.68	0.95

Table 9 Ecological Risk factor (ERF) and Potential Ecological Risk Index (PERI) of studied metals in soils and sediments

Soil/sediment ID	ERF						
	Pb	Cd	Mn	Fe	Cu	Zn	PERI
Riverbank soil							
RBK 1	5.50	29.70	1.13	1.09	5.60	1.14	44.16
RBK 2	5.20	28.50	0.85	1.07	5.35	1.04	42.01
RBK 3	4.85	30.30	1.13	0.93	5.05	0.87	43.13
Riverbed sediment							
RBD 1	5.45	33.00	1.13	1.01	4.45	1.11	46.15
RBD 2	4.65	28.80	0.85	0.97	4.85	0.99	41.11
RBD 3	4.55	30.30	0.99	0.94	4.80	0.87	42.45

showed minor enrichment while all other metals exhibited background concentrations. At RBK3 site, all the analyzed metals except Zn had minor enrichment. With respect to sampling sites for sediments, RBD2 site was characterized by minor enrichment of Zn and background enrichment of other studied metals. However, RBD3 site had background enrichment of Pb and Zn but minor enrichment of Cu, Mn and Cd. The mean EF follows the order: Pb = Cd = Mn = 1.01 and Cu = Zn = 1.00. Furthermore, the calculated EF values for all assessed metals at all the 3 sampling sites were <1.5, suggesting that all analyzed metals are not anthropogenic, but may have lithogenic sources (Algül and Beyhan, 2020).

The geoaccumulation index ($_{geo}I$) results (Table 8) for Pb, Cd, Mn, Fe, Cu, and Zn for soil/sediments at each sampling site fall under < 1, suggesting practically unpolluted state of aforementioned metals in soils and sediments at the 3 investigated sites within the residential area along Ona River. Possible geogenic sources of all studied metals in soils and sediments at the 3 sites were revealed by the obtained values of Igeo that were less than zero. Natural geochemical processes as the sources of studied heavy metals were also buttressed by their EF values (Table 7) that fell within the range 0.5-1.5 (Alekseev and Abakumov, 2020; Algül and Beyhan, 2020).

All the sampling sites showed low degree of pollution as DC values ranged from 5.67–6.57 (Table 8), based on Odukoya (2015) and Devanesan *et al.* (2017) classification. From Table 8, the mDC values at the 3 sampling sites for soils and sediments ranged from 0.95 to 1.09, suggesting unpolluted state since their mDC values were less than 1.5 (Brady *et al.*, 2015; Gargouri *et al.*, 2018; Alekseev and Abakumov, 2020).

Ecological Risk Factor of the Studied Metals

The results of ERF assessment for 6 target metals (Table 9) varied significantly as Pb ranged from 4.55 to 5.50, Cd from 28.50 to 33.00, Mn from 0.85 to 1.33, Fe from 0.93 to 1.09, Cu from 4.45 to 5.65 and Zn from 0.87 to 1.14. The ERF of each of the assessed metals at RBK1–RBK3 and RBD1–RBD3 corresponds to low mean ecological risk (ER < 40) based on Hakanson (1980) classification. Specifically, Zn and Fe showed very low mean ecological risk (ER= 1.00) while Cd showed relatively high mean ecological risk (ER=30.1), however, this value still resembles low ecological risk according to Hakanson (1980) classification. The results of PERI (Table 9) for all sampling sites of soils/sediments ranged from 41.11 to 46.15. All the sampling sites for soils and sediments were characterized by PERI values less than 150, signifying low ecological risk potential. In addition, it was revealed that mean PERI value of the studied area is 43.17, which still corresponds to low ecological risk potential.

CONCLUSION

The study presented the concentration, distribution, and probable sources of selected metals in riverbank soils and sediments of Ona River within axis bordering residential houses. The study revealed that the riverbank area was not heavily concentrated with assessed metals in soil/sediments, with concentration of each studied metal at all sampling sites less than 1 mg/kg, probably due to post flooding history of the place. The studied metals exhibited a diminishing trends of Zn > Cu > Fe > Cd > Pb > Mn and Zn > Cd > Fe > Cu > Pb > Mn in riverbank soils and riverbed sediments, respectively. Pearson's correlation analysis revealed strong direct association for Fe-Zn, Fe-Pb, and Pb-Zn pairs in both soil and sediment, suggesting common sources and identical behaviours during transportation. The adopted integrated pollution indicators (CF, EF, Igeo and PLI) revealed that the investigated RBK and RBD sites were of low –to-moderately polluted status with respect to the studied metals. The environment risk indices (ERF and PERI) of sampling sites revealed that the investigated parts of Ona River belonged to a low mean ecological risk zone in terms of the analysed metals in soils/sediments. The values of coefficients of variation (CV) of analysed parameters being less than 50%, together with geoaccumulation index < 1 for all the studied metals, suggested dearth of strong anthropogenic inputs. The correlation matrix confirmed the similarity in source between metals and little impacts of anthropogenic inputs. Negative correlation exists between each of the studied metals and OM/OC. In general, the heavy metal status in soils and sediments of investigated riverbank area was found to be of no serious threat to the surrounding ecological environment.

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