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Heavy metal and metalloid concentrations in agricultural communities around steel and iron industries in Uganda: implications for future food systems

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ABSTRACT

Poor management of effluents from steel and iron industries could increase element concentrations in the environment and threaten the health of consumers of food products from these areas. The current study assessed element concentration and physicochemical properties of soils, water, and vegetation from within 200 m around three steel and iron industries. A workable grid-based sampling design guided soil and plant sampling; upstream-downstream water quality comparisons were adapted with upstream as a control sample. Analyses were conducted following procedures by USEPA method 3051A. Element concentration was in the order Mn>As>Zn>Cr>Pb. The concentrations reduced with increase in distance from the industry. There was moderate-to-strong pollution of soils for As, and transfer factor for all elements was >1. In conclusion, industrial activity might have contributed to increased element concentrations in the soils, vegetation, and water sources around the industries. Agrarian activities may only be safely carried out 151m away from the industries.

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heavy metals; megathyrus
maximus; transfer factor

Introduction

In her efforts to attain the middle-income status, the government of Uganda has embraced industrialisation as an essential tool [1–3]. In particular, Uganda's government has earmarked the steel and iron industry due to its pivotal role in global industrialisation [4]. Consequently, there has been a steady growth in the industrial sector compared to agriculture, the backbone of Uganda [5]. Since, the country is a 'fertile ground' for industrialisation [6], it is most likely that, given the favourable political environment [7], the observed trend of industrialisation may be maintained, and/or even enhanced.

Notwithstanding the potential contribution of the steel and iron industry to Uganda's economic development, the sector may cost the country's food system, and consumer safety at large. Precisely, steel and iron industries are the leading anthropogenic sources of heavy metals and metalloids (HM & Ms) in both terrestrial and aquatic ecosystems where the wastes are emitted [8–10]. The elements in these wastes have some migratory ability and therefore end up in the food chain [11]. This poses a health threat to humans who consume food products from the two ecosystems, as high levels of HM & Ms are toxic to humans [12]. In this same line, earlier studies have reported that when crops are grown in soils laden with HMs, the HMs end up in edible parts of the crops [12–15]. Traces of heavy metals resulting from poor industrial waste disposal

have also been reported in fish [16,17], milk [18] and in meat [19,20]. Arsenic was also reported in fodder, with highest concentrations of the element occurring in grasses growing in areas with high As deposits [21]. Worse of all, several of these heavy metals and metalloids bioaccumulate in the food chain and, their toxicity has become a public health concern world over [20,22,23].

Although literature holds these facts, information on the concentration of heavy metals and metalloids in key resources in agrarian communities around steel and iron industries in Uganda is still scanty. A series of studies, for example by Muwanga and Barifaijo [24] have been conducted to quantify the heavy metal concentration in areas around several industries in the country. However, steel and iron industries have been given minimal attention. This is notwithstanding the high volumes of wastes emitted by these industries which might be heavily laden with heavy metals and metalloids. Mbabazi *et al.* [25] also studied heavy metal concentration in vegetables planted around Lake Victoria, but focused on run-offs from Kampala city as the potential source of heavy metals in the area. Alarming, lead, one of the heavy metals being study was reported to be high in blood of school-going children who depended on water from Lake Victoria [26]. However, the source of this heavy metal into the water was not established, and remedies would hardly be developed. Such information gaps on heavy metal load related to steel and iron

industrial activities hinder policy decisions that would guide agricultural activities in areas around these industries. This study, therefore, established the HM & Ms concentration in soil, water, and vegetation, and selected physicochemical properties (which could primarily be affected by industrial wastes), that is, pH and Electrical conductivity, of soil and water around highly performing steel and iron industries in Uganda. The findings will inform policy makers on the minimum safe distance from the steel and iron industries, below which agricultural activities and settlement should not be done. This will offer a platform for policymakers to formulate policies that will not only promote industrialisation, but also reduce the detrimental effects of the industries on the environment and, most importantly, the country's food systems.

Materials and methods

Study area

The study was conducted in communities around Roofings Rolling Mills, Steel and Tube Industries Limited and Muljibhai Madhivani Company Limited – Steel Division. These three industries are all located within a 15 km radius from Lake Victoria. The area was purposively selected based on the earlier reports on the

potential negative impact of the then steel rolling mills in Jinja (no longer operational) on the waters of Lake Victoria and the surrounding agricultural communities [27,28]. Furthermore, the areas are surrounded by settlements, agricultural farmlands, and streams that are used by the nearby communities. The sites, therefore, can represent the characteristics of agricultural communities and settlements surrounding iron and steel processing industries all over the country.

Roofings Rolling Mills (RRM) and Steel and Tube Industries Limited are both located in Kampala Industrial and Business Park (KIBP) in Namanve, Wakiso district (Figure 1), between 0°20'35"N, 32°41'55" E [29]. RRM is bordered by a settlement area on the eastern side; the western and southern sides of the factory are plain industrial areas. The north side of the factory has community farmlands and a water spring, which reduces into a stream. The spring serves as a significant water source to the community and the farmlands.

Steel and Tube Industries Limited (STIL) is located in the middle of the KIBP (Figure 1). On the western side of the plant is the Namanve water stream, which pours into Lake Victoria [8].

Muljibhai Madhivani Company Limited – Steel Division (MMS), formerly known as Steel Corporation of East Africa, the oldest of the three

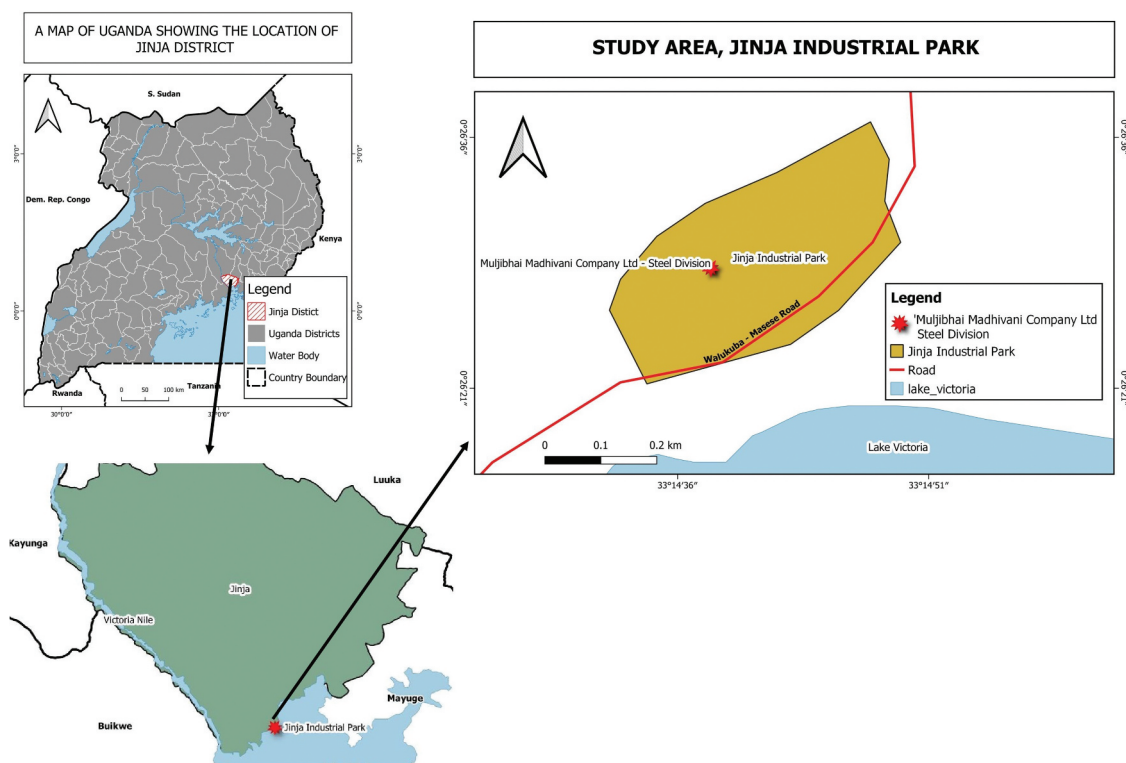


Figure 1. Kampala industrial and business park - namanve. source: Google Maps, 2020.

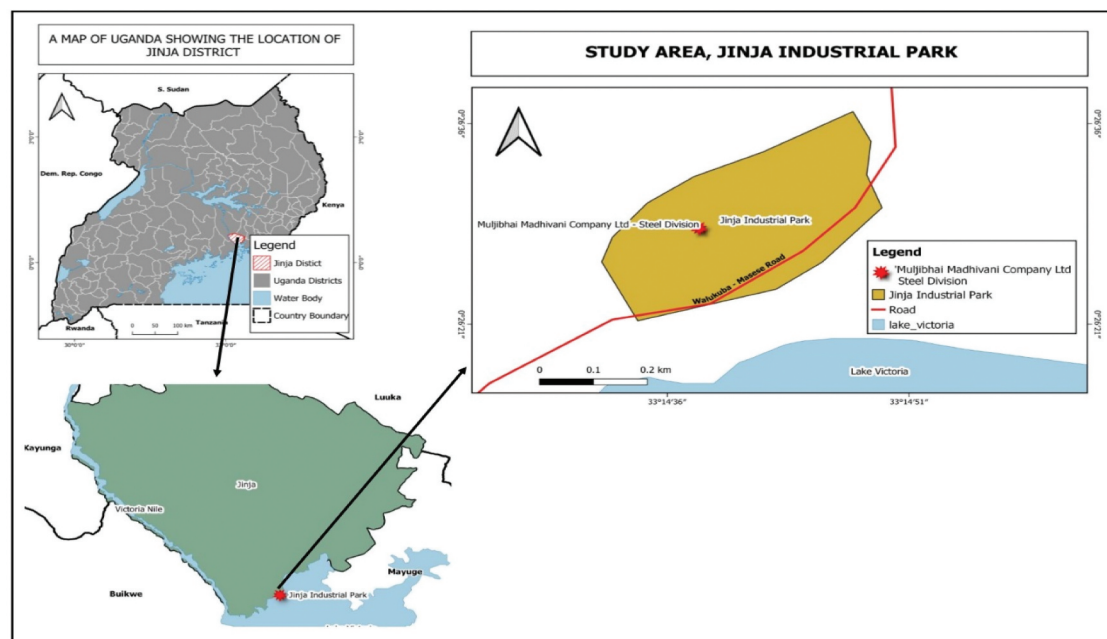


Figure 2. MMS sampling site - Jinja industrial park, masese. source: Google Maps, 2020.

selected steel plants, is located in Jinja industrial and business park, Masese division, Jinja city (Figure 2). The factory is surrounded by agricultural farmland in the Northern and Eastern sides. The southern side has a road network with a marshland connecting into Lake Victoria and the Western side of the factory has farmland and a settlement (Figure 2).

The control site was Uganda Christian University (UCU) main Campus at Mukono, which was identified to have negligible effect from steel and iron industries within its 5 km radius.

On top of the industries being purely steel rolling industries, they were selected because they are all located in the Lake Victoria Basin [LVB]; Latitude: $-1^{\circ} 00' 0.00''$; S Longitude: $33^{\circ} 00' 0.00''$ E. LVB is characterized by modified equatorial type of climate with substantial rainfall occurring throughout the year, and seasonal rainfall further characterized by a bimodal cycle [30]. The area has warm temperatures ranging between 23°C and 32°C and a rainfall pattern averaging approximately 1,260 mm annually. Granites and granitoid gneisses characterize the soils around the industries and the control area. Part of the industrial area soils is composed of shales, phillites, and schists [28].

Sampling of soil, water, and plant samples

Soil sampling

To investigate the HM & M load in soil, the distance between the sampling sites and the emission sources is a critical parameter. To obtain an acceptable environmental representation of the study area, soil should be obtained at a distance of no more than 500 m from the industry [31]. Therefore, this study took samples within 200 m from the industries (Table 1). Four samples were randomly collected in each sampling distance and mixed to form a composite. Therefore, at each industry site, four composite samples were obtained, each from a given sampling distance. Two composite samples were obtained from the control site.

Since the rooting zone is up to 20 cm from the ground level [32], soil samples were obtained from within this depth. Soil samples were collected using a stainless-steel spatula and kept in PVC packages until analysis following procedures by Akintan *et al.* [33]. Strict adherence to the procedures was ensured to avoid alterations in the final composition of the samples. This was employed as a quality assurance strategy so as to obtain reliable and more accurate data.

Table 1. Sampling sites and grid distances.

Sampling site	Sampling Grid Distance from the industry's outer perimeter (m)	Samples picked
Steel Industry sampling site (RRM, STIL, and MMS)	0–50	Soil and vegetation
	51–100	Soil and vegetation
	101–150	Soil and vegetation
	151–200	Soil and vegetation

Vegetation sampling

A preliminary visit to the sampling sites revealed guinea grass (*Megathyrus maximus*) as the dominant plant species around all three sites. Therefore, *M. maximus* was selected to represent the vegetation of the area for this study. The plant samples were randomly collected from each sampling site within each sampling grid (Table 1). The samples were obtained by cutting, using a clean stainless-steel knife at a height of 5 cm above the soil surface as described by Fosu-Mensah, *et al* [34], and then washed thoroughly using distilled water according to procedures by Ning *et al.* [35].

Water sampling

Water samples were drawn from the water spring at RRM and Namanve water stream along STIL sampling site using freshly rinsed Polyethylene terephthalate (PET) plastic water bottles. Since there is no immediate water channel around MMS, no water samples were obtained from this site. Samples were drawn 20 m at the upper end of the stream before reaching the industry site (control samples, also called 'upstream' samples for this study) and 20 m at the lower end of the industry site (also called 'downstream' samples).

Analysis of soil, water, and *M. maximus*

Analysis of soil samples

Laboratory analyses were conducted in Uganda Industrial Research Institute (UIRI) laboratory, which is a recognized laboratory by the National standards body, Uganda National Bureau of Standards, under the Laboratory recognition program as per ISO/IEC 17,025:2017.

The soil samples were ground in a clean dry mortar using a clean dry pestle and sieved through a 2-mm Advantech brass test sieve to fineness. Pulverized soil samples (0.5 g) were transferred to Teflon tubes, where 9 ml of HNO_3 and 3 ml of HCl were added. They were kept in a closed system in a microwave oven for 8 min and 40 s on the temperature ramp, the necessary time to reach 175°C. This temperature was then maintained for an additional 4 min and 30 s. The concentration of heavy metals and Arsenic in the soil samples was analysed using a Perk-Elmer A Analyst AAS (Atomic Absorption Spectrophotometer) based on the USEPA method 3051A [36]. This method was used because the addition of HCl provides for improvement in level of accuracy [37]. The heavy metals studied included Chromium (Cr), Lead (Pb), Zinc (Zn), and Manganese (Mn) while the metalloid studied was Arsenic (As). These above elements are of interest as they are among the possible combinations of elemental contaminants associated with steel and iron industries [38]

and have been reported among individuals living around areas with poor waste management in Uganda [39]. These elements are therefore of importance in Uganda's food system. Electrical Conductivity (EC) and pH of soil samples were determined in situ using a calibrated HQ40D portable multimeter as per methods AOAC – 973.40 and AOAC – 973.41, respectively and values recorded. Only two physico-chemical properties of soil (pH and EC) were considered for this study because these are the primarily affected properties in areas where industrial effluents are emitted [40] and these two greatly influence plant growth on a given soil [41].

Analysis of *M. maximus* plant species samples

The samples were oven-dried at 100°C for 24 h, blended to fineness for easy digestion with an electrical blender, and then sieved through a 2 mm mesh sieve for easy digestion. 5 ml of 4:1 mixture of concentration $\text{HNO}_3:\text{HClO}_4$ were added to 1 g of weighed plant material and then heated at a temperature of 105°C for 1 h to dry. The samples were allowed to cool and made up to the mark of 50 ml volumetric flask with 1 M HNO_3 . The solution was then centrifuged using a HARRIER 15/80 model centrifuge for 30 min and transferred into sampling bottles for analysis. All digested samples were analysed using a Perk-Elmer Analyst AAS (Atomic Absorption Spectrophotometer) based on procedures by Ogundele, *et al* [42]. The plant samples were analysed for the same heavy metals as in the soil samples.

Analysis of water samples

The analysis followed the AWWA/APHA 3500 method for the determination of heavy metals and Arsenic in water samples. Raw water samples were filtered using a Whatman No 42 filter. 100 ml of each water sample was digested with concentrated nitric acid and concentrated by evaporation up to 50mls. The prepared samples were analysed for elemental concentrations, pH, and Electric conductivity, EC.

Analysis for Cr, Pb, As, Zn, and Mn was carried out using the atomic absorption spectrometer (AAS) at a respective wavelength, of 357.9, 324.7, 228.9, 217.0 nm. All the elements were analysed at a slit width of 0.7 nm and a lamp current of 2.0, 1.5, 2.0, 3.0 Ma, respectively. The Atomic Absorption Spectrometer (AAS) read the absorbance as in the AAS operating procedure. The recommended flame used was the air acetylene oxidizing (lean, blue), and the data were obtained using a standard nebulizer and flow spoiler. The light sources were multi-element lamps corresponding to the element to be analysed.

Electrical Conductivity and pH of water samples were also measured in situ using a calibrated HQ40D portable multimeter as per methods AOAC – 973.40 and AOAC – 973.41, respectively. Reagent blanks and standard reference materials were used in the analysis for quality assurance and control.

Heavy metal and metalloid contamination determination

The concentration of elements in soil is a commonly used index that indicates the degree of soil contamination [43]. According to He *et al* [44], assessment of soil pollution with heavy metals and metalloids after analysis, and comparison of soil contamination/pollution quantification against regulatory standards can be determined using various methods. For this research, Geoaccumulation Index, (*I_{geo}*) was used since it allows for distinguishing more degrees of soil contamination and makes it simple to assess the useable value of soil [45]. *I_{geo}* was computed accordingly as, $I_{geo} = \ln (C_n / 1.5 \cdot B_n)$

Where: C_n – is the measured concentration of the element in soil samples,

B_n - is the geochemical background value and the constant 1.5 allows for analysis of natural fluctuations in the content of a given substance in the environment and to detect a very small anthropogenic influence.

World average shale's content together with the earth's average crust content has commonly been used for background value in most *I_{geo}* determinations [46]. However, some studies recommend using regional background instead of constant value (like world average), which produces varied contamination levels with time and places. Following these recommendations, the concentration of the elements in the control sample was considered as the background value of heavy metals for this study. The samples were analysed, and the results were compared against the Geoaccumulation Index adopted from [45] (Table 2).

Transfer factor, TF

Since the uptake of HM and Ms by plants from soil is the chief pathway through which humans are exposed to heavy metal and metalloid contamination [47], the

study also determined the rate of transfer of these HM and Ms from soil to plant. The phenomenon 'Transfer factor' is used in assessing this, and it is important in assessing the risk of human exposure to elements from plant consumption. According to Cheshmazar *et al.* [48], TF refers to the migration of metals from soil to edible plant parts, in any form, making the elements available for consumption. The TF in the current study was calculated according to procedures by Mirecki *et al.* [43].

Since TF values differ in different parts of the plant Adah *et al.* [49], the current study used the entire plant, except the roots, to form a composite. Therefore, the TF value obtained was for the shoot.

Interpretation of the TF was also based on Mirecki *et al.* [43], that is: if $TF > 1$, the plants have accumulated elements, $TF = 1$ indicates that the plants are not influenced by the elements, and $TF < 1$ shows that plants exclude the elements from the uptake.

Data analysis

The Shapiro-Wilk test on elemental concentration showed non-normality of the data ($P \leq 0.05$) for most elements at all intervals from the industry sites and, therefore, a non-parametric test was conducted. Data on the element concentration in soil and *M. maximus* plant species for all the three sampling sites were subjected to Kruskal-Wallis test using R software, Version 4.2.3 [50]. The Bonferroni post hoc test was conducted to ascertain the difference between pairs of the different variables at 5% level of significance ($P \leq 0.05$).

Data on pH and EC of soil for all the three sampling sites were subjected to Analysis of Variance (ANOVA) using R software, Version 3.6.1 (5 July 2019) R Core Team [51]. The means generated in the ANOVA tables were separated using the Least Significant Difference (LSD) at a 5% significance level ($P \leq 0.05$). Whereas the data on element concentration, pH, and EC in the water samples from the RRM water spring and Namanve water channel along the STIL sampling site were subjected to descriptive analysis where averages were generated and compared to the national standards by the National Environmental Management Authority (NEMA).

Results and discussion

Concentration of heavy metals in soils around steel and iron industries

The concentration of heavy metals and metalloids in soil decreased with an increase in distance from the industry (Table 3). Among all the elements analysed for in this study, Mn had the highest concentration in the control sample and at all distances from the three sampled industry sites. These findings agree with

Table 2. The Index of geo-accumulation analysis chart.

Class	Value	Soil Quality
0	$I_{geo} \leq 0$	Uncontaminated
1	$0 < I_{geo} < 1$	Uncontaminated to moderately contaminated
2	$1 < I_{geo} < 2$	Moderately contaminated
3	$2 < I_{geo} < 3$	Moderately to heavily contaminated
4	$3 < I_{geo} < 4$	Heavily contaminated
5	$4 < I_{geo} < 5$	Heavily to extremely contaminated
6	$I_{geo} \geq 5$	Extremely contaminated

Lukin and Zhuikov [52] and Schulin *et al.* [53] who reported that Mn is naturally present in the soil in larger quantities than any other trace elements except Fe. In addition, Mn increases with increase in disposal activities in the area [54], hence the higher concentration of the element in the soil.

The element concentration in soils from all three sampling sites was generally higher ($p \leq 0.05$) than in the control. This could be because of the probable presence of these elements in industrial wastes, which may have escaped into the environment. These foreign elements might have increased the elemental load around the industry sites. These findings agree with Gautam *et al.* [55], who reported that the type of element contamination found in soil depicts the operations that occur within that particular area. Similar findings were also reported by Su *et al.* [56]; Wang *et al.* [57] and Zhou and Wang [58] who also reported increase in element concentration with industrial activity. Since all the soils (both from the control and industrial sites) are Granites and granitoid gneisses, it is undisputable that the high concentration of the elements in the soils around the industries as compared to the control samples could be because of industrial activity.

Around the industries, the mean concentration of HM & Ms in their level of abundance was in the order: Mn>As>Zn>Cr>Pb around RRM (except between 51 and 100 m), Mn>Zn>As>Cr>Pb around MMS and STIL while the level of abundance of the elements in the control sample was: Mn>Cr>Zn>Pb>As. This trend was maintained around the industries up to the sampling distance of 101–150 m, indicating industrial effect might have diminished beyond this level. The order of HM & Ms concentration in the control sample concurs with Islam *et al.* [59], who on analysing the composition of Cr, Pb, and As in ideal agricultural soil reported their concentration to be in the order Cr>Pb>As. Similar orders

(Mn>Cr>Zn>Pb) and (Zn>Pb) were also reported by Shahbazi *et al.* [60] and Guo *et al.* [61] to be the ideal for agricultural soils in Iran and China, respectively.

The higher concentration of As in samples obtained from around the industries could be due to its accumulation in the soil since, unlike other trace elements, As is not readily taken up by plants. Evidence from related studies indicates that arsenate and phosphate share the same transport pathway in higher plants, with the transporters having a higher affinity for phosphate than for arsenate [62]. Similarly, Li *et al.* cited in Corguinha *et al.* [63] reported low As concentration in corn grown in areas where phosphate fertilisers had been applied for a long time. Furthermore, there is a reduced uptake of As by plants as a tolerance mechanism by which plant cells resist toxicity [64].

Nevertheless, the high As concentration in soils around the industries poses a health risk to humans since the element is carcinogenic. Consumption of As is also reported to be detrimental in pregnant mothers among whom the element inhibits embryonic development and increases incidences of spontaneous abortion [65], and it is also carcinogenic [66]. The current study has revealed a higher concentration of elements around the industries than the control. Although elements concentrations around the three industries in the current study are still within the average permissible levels reported by Kabata-Pendias and Mukherjee [67], there is a possibility that concentrations will rise with continued production. It is therefore important to establish the main pathways through which the elements are transmitted into the soils to check the probable tragedy that would befall the food consumers who obtain their food from these areas.

Table 3. Concentration of heavy metals and metalloids in soil.

Distance (m)	Heavy metal (mg/kg)	X ²	p-value	Control (soil)	RRM (Soil)	STIL (soil)	MMS (soil)
0–50	Cr	10.495	0.015	0.921 ^d	1.449 ^a	1.103 ^b	1.339 ^c
	Pb	10.532	0.015	0.173 ^d	0.728 ^a	0.559 ^b	0.757 ^c
	As	10.645	0.014	0.123 ^d	3.339 ^a	2.100 ^b	2.339 ^c
	Zn	10.822	0.013	0.513 ^c	2.440 ^a	2.245 ^b	2.245 ^b
	Mn	10.839	0.013	1.025 ^d	3.897 ^a	8.990 ^b	4.850 ^c
51–100	Cr	10.495	0.015	0.921 ^d	1.342 ^a	0.992 ^c	1.322 ^b
	Pb	10.645	0.014	0.173 ^d	0.675 ^a	0.352 ^c	0.425 ^b
	As	10.645	0.014	0.123 ^d	1.313 ^a	0.985 ^c	1.302 ^b
	Zn	10.839	0.013	0.513 ^d	1.940 ^c	2.120 ^a	2.010 ^b
	Mn	10.772	0.013	1.025 ^d	3.550 ^c	4.243 ^a	3.890 ^b
101–150	Cr	10.772	0.013	0.921 ^d	1.213 ^a	0.574 ^c	1.031 ^b
	Pb	10.761	0.013	0.173 ^d	0.571 ^a	0.335 ^b	0.287 ^c
	As	10.761	0.013	0.123 ^d	1.184 ^b	0.664 ^c	1.293 ^a
	Zn	10.839	0.013	0.513 ^d	0.910 ^c	1.760 ^a	1.550 ^b
	Mn	10.839	0.013	1.025 ^d	1.590 ^c	1.950 ^b	2.560 ^a
151–200	Cr	10.772	0.013	0.921 ^b	1.010 ^a	0.246 ^d	0.682 ^c
	Pb	10.761	0.013	0.173 ^d	0.489 ^a	0.300 ^b	0.243 ^c
	As	10.761	0.013	0.123 ^d	0.012 ^a	0.165 ^b	0.982 ^c
	Zn	10.839	0.013	0.513 ^d	0.150 ^a	0.750 ^b	0.670 ^c
	Mn	10.839	0.013	1.025 ^d	1.510 ^b	1.240 ^c	1.600 ^a

Means with different superscripts within the rows are significantly different at a 5% level of significance; Distance = Distance from the industry (m); RRM = Roofings Rolling Mills; MMS = Muljibhai Madhivani Company Limited – Steel Division; STIL = Steel and Tube Industries Limited.

Concentration of heavy metals and metalloids in the *M. maximus* plant species around steel and iron industries

Generally, the concentration of the elements in *M. maximus* plants around the industrial sites was higher ($P \leq 0.05$) for all elements than that of the control sample, especially within 100 m (Table 4). This evidences the potential contribution of these steel and iron industries to pollution of the surrounding resources. In agreement with these findings, Ekhlaspour *et al.* [68] reported increase in heavy metal concentration in plant samples around Khuzestan steel factory in Iran due to industrial activity. Similarly, Remon *et al.* [69] reported higher heavy metal concentrations in vegetation samples obtained from a dumpsite of steel and iron industry wastes which had been neglected for over 50 years in France. This proposes the non-biodegradability of these heavy metals in the environment. Similarly, Arsenic concentration was reported to be higher in vegetation around industrial sites [70]

The concentration of the elements in *M. maximus* plant species also decreased with increase in distance from the steel industries. At all sampling distances and at the control site, Mn concentration was highest. The high concentration of Mn in *M. maximus* plant species could be because of the physiological importance of the element in plants. Alejandro *et al.* [71] assert that Mn is one of the essential elements needed for plant growth and reproduction.

Around the three industries, Pb recorded the least concentration at all sampling distances. With the WHO permissible levels of Pb at 10 mg/kg [67], it is noted that its concentration in *M. maximus* plant species around all the industries is below the permissible levels. The concentration of As, Mn, and Zn whose permissible levels are 1.5, 300, and 150 mg/kg, respectively, were also below the permissible levels.

However, for Cr, whose permissible level is 0.5 mg/kg, the mean concentrations around the industries were above the permissible threshold values within 100 m of all the industrial sites.

This high Cr concentration around the industries poses a threat to human health since Cr is carcinogenic [72]. *M. maximus* plant species are consumed as feed by animals hence, Cr ends up in the food chain following the forage-animal-human short food chain [73,74]. A study by Odongo *et al.* [75] reported some trace concentrations of Cr in milk from Oyam district of Uganda, which place is not highly industrialised. Since the element is existent in animal products from such place, higher concentrations may be realised in products from animals feeding around steel and iron industries. Livestock products from animals around these areas are therefore worth testing for concentration of Cr, and other heavy metals.

Geoaccumulation index, *igeo* - assessment of contamination levels of heavy metals and metalloids in the soil

At all distances from the three factory sites, the *Igeo* values revealed moderate to strong pollution for As in the order of RRM>MMS>STIL (Table 5). All factory sites were, however, unpolluted with respect to Cr at the different sampling distances. Similar findings were also reported by Su *et al.* [56] around industrial areas in China where no Cr pollution was realised. With respect to Pb, Zn, and Mn, all factory sites and sampling distances were moderately polluted, except between 151 and 200 m where RRM and STIL were unpolluted with Zn. The moderate contamination by Pb, Zn and Mn may be because the two elements are readily absorbed and translocated in plants, except at higher levels in the soil [76,77].

Table 4. Concentration of heavy metals and metalloids in *M. maximus* plant species.

Distance (m)	Heavy metal (mg/kg)	X ²	p-value	Control (plants)	RRM (plants)	STIL (plants)	MMS (plant)
0–50	Cr	10.495	0.010	0.157 ^d	1.187 ^b	0.997 ^c	1.294 ^a
	Pb	10.607	0.014	0.102 ^d	0.700 ^a	0.457 ^b	0.203 ^c
	As	10.532	0.015	0.052 ^d	1.273 ^b	0.997 ^c	1.294 ^a
	Zn	10.839	0.013	0.086 ^d	1.980 ^b	1.900 ^c	2.080 ^a
	Mn	10.839	0.013	0.863 ^d	3.480 ^b	6.140 ^a	3.020 ^c
51–100	Cr	10.607	0.014	0.157 ^d	1.114 ^b	0.786 ^c	1.234 ^a
	Pb	10.839	0.013	0.102 ^d	0.543 ^a	0.311 ^b	0.195 ^c
	As	10.645	0.014	0.052 ^d	1.143 ^b	0.776 ^c	1.213 ^a
	Zn	10.839	0.013	0.086 ^d	1.460 ^b	0.830 ^c	1.840 ^a
	Mn	10.839	0.013	0.863 ^d	1.380 ^c	2.310 ^b	3.020 ^a
101–150	Cr	10.607	0.014	0.157 ^d	0.917 ^a	0.352 ^c	0.410 ^b
	Pb	10.607	0.014	0.102 ^d	0.405 ^a	0.311 ^b	0.169 ^c
	As	10.671	0.013	0.052 ^d	0.600 ^b	0.517 ^c	0.613 ^a
	Zn	10.839	0.013	0.086 ^d	0.350 ^c	1.500 ^a	1.240 ^b
	Mn	10.839	0.013	0.863 ^c	1.230 ^b	0.530 ^d	2.15 ^a
151–200	Cr	10.607	0.014	0.157 ^d	0.866 ^a	0.165 ^c	0.422 ^b
	Pb	10.772	0.013	0.102 ^d	0.431 ^a	0.181 ^b	0.127 ^c
	As	10.368	0.016	0.052 ^c	0.620 ^a	0.520 ^b	0.527 ^b
	Zn	10.839	0.013	0.086 ^d	0.240 ^c	0.480 ^b	1.200 ^a
	Mn	10.839	0.013	0.863 ^c	1.210 ^b	0.680 ^d	1.310 ^a

Means with different superscripts within the rows are significantly different at a 5% level of significance;

Distance = Distance from the industry (m); RRM = Roofings Rolling Mills; MMS = Muljibhai Madhivani Company Limited – Steel Division; STIL = Steel and Tube Industries Limited;

Table 5. Geoaccumulation and Transfer factor of the different elements.

Distance (m)	Heavy metal (mg/kg)	RRM (<i>I_{geo}</i>)	STIL (<i>I_{geo}</i>)	MMS (<i>I_{geo}</i>)	RRM (TF)	STIL (TF)	MMS (TF)
0–50	Cr	0.043	–0.23	–0.035	0.819	0.904	0.966
	Pb	1.03	0.76	1.06	0.962	0.816	0.267
	As	2.89	2.42	2.53	0.381	0.476	0.553
	Zn	1.15	1.07	1.07	0.811	0.846	0.927
	Mn	0.93	1.77	1.15	0.893	0.683	0.623
51–100	Cr	–0.03	–0.33	–0.05	0.830	0.792	0.933
	Pb	0.95	0.3	0.49	0.799	0.889	0.453
	As	1.96	1.66	1.95	0.871	0.788	0.932
	Zn	0.92	1.01	0.96	0.753	0.392	0.915
	Mn	0.83	1.03	0.92	0.389	0.536	0.776
101–150	Cr	–0.13	–0.88	–0.3	0.756	0.613	0.398
	Pb	0.78	0.25	0.1	0.711	0.915	0.583
	As	1.85	1.27	1.94	0.507	0.779	0.474
	Zn	0.17	0.82	0.7	0.385	0.852	0.800
	Mn	0.03	0.24	0.51	0.774	0.272	0.840
151–200	Cr	–0.32	–1.73	–0.71	0.857	0.671	0.619
	Pb	0.63	0.14	0.07	0.880	0.603	0.529
	As	1.78	–0.11	1.66	0.613	3.152	0.526
	Zn	–0.14	–0.03	0.6	0.358	0.640	0.800
	Mn	–0.02	–0.21	0.04	0.801	0.548	0.819

Distance = Distance from the industry (m); RRM = Roofings Rolling Mills; MMS = Muljibhai Madhivani Company Limited – Steel Division; STIL = Steel and Tube Industries Limited.

Generally, the level of contamination was highest between 0 and 50 m, which indicates that element contamination of the soils could be linked to the presence of steel and iron industries. The high *I_{geo}* value of As is probably attributable to its high accumulation, low mobility, and high retention time within the soil [78]. Around RRM, a higher *I_{geo}* value of As around could be due to high industrial activity as depicted by the high production volumes compared to the counterpart steel industries.

TF of heavy metals and metalloids from soil to *M. maximus* plant species

From the findings, all the HM & Ms had TF values < 1 indicating low levels of bioaccumulation of the HM & Ms in plants and more exclusion of the elements from the uptake (Table 5). Differences in TF values among sampling sites were recorded for the different heavy metals, and this could be due to the registered variations in HM & Ms concentrations in soil amongst the sites, as was also reported by Ibrahim and Muhammad [79].

pH and electrical conductivity in soils around steel and iron industries

The pH of soils obtained within a radius of 50 m from the three factory sites did not differ ($p \geq 0.05$) from the

pH of soils from the control site (Table 6). Beyond 50 m, soil became less acidic around the industries with variations observed amongst the three industries. At different sampling distances, variations in EC were observed, with the highest EC value recorded at 151–200 m around MMS. Generally, high EC values were recorded around MMS at the different sampling distances, probably due to the long-term effect of industrial activities on soil since this is the oldest industry amongst the three that were studied.

Concentration of heavy metals and metalloids within water sources around steel and iron industries

The concentrations of elements were not detectable upstream, around RRM but concentrations above NEMA permissible levels were detected downstream, indicating that the industry has a great influence on water quality (Table 7). This could imply that the industrial wastes are directly emitted into the water with minimal or no treatment. In support of the current findings, Angiro *et al.* [8] reported that wastes from Ugandan industries are disposed of with no treatment.

Around STIL, even the water upstream registered element concentrations higher than the NEMA permissible values signifying that, besides industrial activities, there are other sources of water contamination, either

Table 6. pH and Electrical conductivity ($\mu\text{S}/\text{cm}$) of soil samples.

Variable	Distance (m)	Control	RRM	STIL	MMS	SE	p-value
pH	0–50	4.19	4.04	3.13	4.13	0.090	.43
	51–100	4.19 ^a	4.47 ^b	3.8 ^c	4.12 ^a	0.050	.00
	101–150	4.19 ^b	4.13 ^a	3.53 ^c	4.17 ^{ab}	0.083	.00
	151–200	4.19 ^a	4.17 ^a	3.91 ^b	4.31 ^c	0.034	.00
	0–50	121.33 ^a	110.67 ^b	120.67 ^a	132.00 ^c	1.00	.00
EC ($\mu\text{S}/\text{cm}$)	51–100	121.33 ^a	114.67 ^b	122.67 ^a	126.67 ^c	1.179	.00
	101–150	121.33 ^b	124.00 ^a	122.67 ^{ab}	119.67 ^c	1.080	.02
	151–200	121.33 ^a	118.00 ^b	127.33 ^c	194.67 ^d	1.080	.00

Means with different superscripts within the rows are significantly different at a 5% level of significance; Distance = Distance from the industry (m); RRM = Roofings Rolling Mills; MMS = Madhivani Steel; STIL = Steel and Tube Industries Limited; SE = Standard Error of the means.

Table 7. Concentration of heavy metals in water (mg/L) around the iron and steel industries.

Sampling point	Heavy metal (mg/L)	RRM	STIL	NS(NEMA) (mg/L)
Upstream	Cr	ND	1.80	0.5
	Pb	ND	1.26	0.1
	As	ND	3.93	0.1
	Zn	ND	1.86	2
	Mn	ND	1.65	1
Downstream	Cr	1.511	2.052	0.5
	Pb	0.940	1.975	0.1
	As	2.442	2.591	0.1
	Zn	2.142	2.138	2
	Mn	2.831	2.019	1

ND = Non detectable levels; RRM = Roofings Rolling Mills; STIL = Steel and Tube Industries Limited; NS(NEMA) = National Standard, Standard Statutory limits.

natural or anthropogenic. Although the water upstream STIL had detectable levels for all the elements, it is still observable that the industry's activities contributed to water pollution since the element concentrations downstream were higher than those upstream. The current findings seem to indicate that steel and iron industries influenced the concentration of the elements of water in the sampling sites. This agrees with Samarina *et al.* [80] who also pinned steel industries for raising heavy metal and metalloid concentrations in surrounding waters

The level of abundance of the elements as per concentrations around STIL was in the order: As>Zn>Cr>Mn>Pb. The abundance of As may probably be because of the high abundance of Iron, Fe in the sediment as there is a high positive correlation of As with Fe²⁺ (0.79) [81] and steel is majorly composed of Fe, therefore, the wastes too may be rich in Fe.

pH and electrical conductivity of water around steel and iron industries

The waters downstream were more acidic for both sampling sites than the waters upstream, implying that industrial activities might have increased the acidity of the waters flowing downstream (Table 8). The pH levels of water downstream were both lowered to beyond the NEMA permissible levels, making the water unsuitable for human use.

In addition, industrial activity also increased the EC levels downstream beyond permissible levels. From the above results, it is observed that iron and steel industries might have an influence on pH and EC of water within their vicinity. In a related study, Oyeku and Eludoyin [82], reported an increase in EC and

acidity with increased heavy metal concentration, which also agrees with the current findings.

Conclusions and recommendations

This study has revealed that steel and iron industries influence the concentrations heavy metals and metalloids of the surrounding soils, water, and vegetation; and selected physicochemical properties of these soils and water. The concentration of the studied elements in soil and *M. maximus* plant decreased with increase in distance from the industry, with the highest concentrations observed within the 50 m radius around the steel and iron industries. All industrial sites showed no contamination by Cr, moderate contamination by Pb, Zn, and Mn and moderate to strong pollution by As, as depicted by their respective *Igeo* values. Furthermore, all the Heavy Metals and Metalloids were readily excluded and no case of bioaccumulation in plants was recorded.

Within 50 m from the industries, soil pH did not differ from that of the control sample, while the highest EC value was recorded at 151–200 m around MMS. The element concentration in the water was beyond NEMA permissible levels indicating toxicity levels at these points

From the current findings, it is recommended that agrarian activities and settlement can only be safely done at least 151 m away from the steel and iron industries. However, similar studies need to be conducted more often to establish the temporal effect of the industries on the surrounding natural resources. This would give a more reliable conclusion based on the time factor on what is the safest distance below which settlement and agricultural activities are unsafe soil around the steel and iron industries.

Table 8. pH and electrical conductivity, EC (µS/cm) water around steel and iron industries.

Sampling point	Physicochemical Property	RRM	STIL	NS(NEMA)
Upstream	pH	6.297	5.967	5.0–8.5
	EC	100.00	113.33	1000
Downstream	pH	4.167	4.467	5.0–8.5
	EC	1322.33	1301.00	1000

RRM = Roofings Rolling Mills; STIL = Still and Tube Industries Limited; NS(NEMA) = National Standard, Standard Statutory limits.

Disclosure statement

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