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Heavy Metal Concentrations and Risk Assessment of Soil and *Vernonia amygdalina* Cultivated in Port Harcourt, Nigeria

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ABSTRACT

Background and Objective: *Vernonia amygdalina* is a vegetable used by habitats of Port Harcourt for both food and medicinal purposes. It is cultivated in most homes, its bioaccumulation of toxicants has been speculated. This study evaluated the heavy metals concentration and risk assessment of soil and *Vernonia amygdalina* (bitter leaf) cultivated in Abuloma-Trans Amadi, Port Harcourt. **Materials and Methods:** The soil and bitter leaf (BL) samples were taken randomly from 3 locations, U-(Control), Abuloma-1 and Abuloma-2. They were analyzed for heavy metals using atomic absorption spectroscopy. Transfer factor (TF), contamination factor (CF) and pollution load index (PLI) were evaluated using standard models. One-way Analysis of Variance (ANOVA) was used to determine the mean and standard deviation, the Turkey's *post hoc* Test was also carried out at a 95% confidence level ($p \leq 0.05$). **Results:** Soil samples had Fe and Mn concentrations above WHO permissible limit. Soil Abuloma-1&2 TF was in the order Co>Fe>Ni>Mn>Cu, BL Abuloma 1, Mn>Cu>Ni>Fe>Co while BL Abuloma-2, Cu>Mn>Ni>Fe>Co. Soil samples CF for Abuloma 2 had moderate contamination while Moderate and considerable CF were observed in the BL samples. The PLI for soil samples was highest in Abuloma-1 (0.003868 mg kg^{-1}), for BL samples, Abuloma-2 had the highest pollution index (1.907 mg kg^{-1}). **Conclusion:** The findings of this study revealed heavy metal contamination of both soil and bitter leaf cultivated in the study, therefore, suggesting a thorough monitoring/regulation of the industrial activities in the Abuloma/Trans Amadi Industrial area of Port Harcourt.

KEYWORDS

Heavy metals, *Vernonia amygdalina*, bitter leaf, risk assessment, transfer factor, contamination factor, pollution load index, Abuloma, Port Harcourt

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INTRODUCTION

Risk assessments are of immense benefit in pollution and contamination studies, it has been of immense benefit in Occupational Health and Safety Management Plan. Risk assessment studies and practices give information on impending hazards, the risk to humans, agricultural products, the nature of soil and groundwater, etc. They form an integral part of an occupational health and safety management plan. They create awareness of hazards and risks and identify who may be at risk e.g., humans, agricultural products, nature of the soil or groundwater etc.[1].

Heavy metals are naturally occurring elements with high atomic weight and density five times greater than water. Its application has been useful in Industries, agriculture, medicine and technology. However, its potential adverse effects on the environment and human health have raised concerns whose applications in industrial, domestic, agricultural, medical and technological applications have led to their wide distribution in the environment, with raised concerns over their potential effects on human health and the environment[2]. The threat to humans, animals and plant life by pollution due to heavy metals from industrial activities has posed health challenges over time[3]. Chronic exposure to environmental pollution can alter human stress levels and deteriorate endogenous antioxidant status[4].

Transfer factor is a term used in scientific literature as a measure for the bio transfer of heavy metals. It represents the quotient of concentration (mg kg^{-1} dry matter) in the soil. It provides information on plants' preferential take up of a certain element and accumulation of more of it than the soil[5]. The contamination factor (CF) and degree of contamination are used to determine the contamination status of the sediment[6]. The pollution load index (PLI) indicated the frequency by which the metal content in the soil exceeded the average natural background concentration and gives a summation of the overall level of heavy metal toxicity in a particular sample[7].

Soil contamination caused by industrial and anthropogenic activities has raised great concern due to its potency to alter the structure of the soil and biodegradability. This eventually leads to impaired health and the environment. Industrial activities are of prime concern because it destroys the soil structure and biodegradability and result in serious health hazards when it gets exposed to the environment[8].

Vernonia amygdalina (bitter leaf) is a shrub that grows in tropical Africa. It usually grows up to a height of 2-5M (6.6-16.4 ft). It is a dark green leave and they are usually called bitter leaf in English because of its bitter nature it is used in various cultures throughout equatorial Africa. The leaves are eaten, after crushing and washing thoroughly to remove the bitterness. The roots and leaves have been reported to have medicinal potencies against fever, hiccups, kidney diseases and stomach discomfort, among others. Both the roots and leaves are used in phytomedicine to treat fever, hiccups, kidney disease and stomach discomfort, among others[9].

The problems posed by the pollution of the environment due to industrial and anthropogenic activities are of great concern globally due to the numerous deleterious impacts it confers on the host community and the eco-system at large[10], hence, the need to evaluate the heavy metal concentrations of the soil and bitter leaf, as well as to assess its risk factors. This is because, the area, Abuloma Trans Amadi is an industrial area where various anthropogenic and industrial activities are carried out, yet, the area serves as a community where people reside, plant and cultivate agricultural products for human consumption.

MATERIALS AND METHODS

Study area: The study was carried out for six months (September, 2021 to February, 2022) at Abuloma, located in a major industrial area, 4°48'53" N latitude and 7°2'14" E longitude, Trans Amadi, Port Harcourt, Rivers State. Abuloma Community in Trans Amadi houses various manufacturing sectors involved in the production of tires, aluminium, glass bottles and paper production plant[11]. The control samples were collected from Rivers State University Campus Farm, Nkpolu-Oroworukwo, Port Harcourt, a non-industrial area.

Soil sampling: Using a New stainless steel auger, Samples of soil were collected randomly at a depth of 0-15 cm from each location and mixed thoroughly to achieve a composite sample using the quartile technique[12]. Samples were sealed in polyethylene bags and taken to the laboratory for analysis of heavy metals. The soil sample was oven dried at 105°C for 6 hrs, ground and sieved in a 1.18 mm sieve and stored until usage.

***Vernonia amygdalina* sampling:** *Vernonia amygdalina* samples were collected from three study locations and labelled (Sample 1, 2 and 3). The samples were collected from the same points where the soil samples were collected. They were labelled and taken to the laboratory in a polyethylene bag for analysis of their heavy metal composition.

Extraction procedure for samples: The soil and *Vernonia amygdalina* samples were extracted using standard procedures for extraction as described[12]. The filtrate of the soil was thereafter taken for analysis while the *Vernonia amygdalina* digested sample was filtered using Whatman filter paper No. 1 and diluted using deionized water to 100 mL. This was thereafter stored at room temperature until further analysis.

Analytical procedure: The extracted samples were subjected to analysis for Cu, Co, Ni, Fe and Mn using Perkin Elmer Atomic Absorption Spectrophotometer (AAS-700), Darmstadt, Germany. All chemicals used were high-grade chemicals of high spectroscopic purity of 99.9% (Merck Darmstadt, Germany). The Atomic Absorption Spectrophotometer (AAS) was fitted with Cu, Co, Ni, Fe and Mn lamps, while the other conditions were the same. All analysis was carried out according to Standard procedures and conditions. To ascertain quality assurance, each sample batch was analyzed in triplicate under standard conditions at a 95% confidence level[12,13].

Statistical analysis: One-way Analysis of Variance (ANOVA) was used to determine the mean and standard deviation, the Turkey's *post hoc* Test was also carried out at a 95% confidence level ($p \leq 0.05$). Health risk assessment models, transfer factor (TF), contamination factor (CF) and pollution load index (PLI) were used to evaluate the risk and health implications of the soil and plant cultivated around the sampling locations and also illustrated the existing trend around the three sampling locations to ascertain the health implications.

Risk assessment models

Transfer factor (TF): The results for soil and the bitter leaf were employed to determine the transfer factor (TF) as given in the following equation[12]:

$$TF = \frac{[\text{Heavy metals}]\ \text{bitter leaf mg kg}^{-1}}{[\text{Heavy metals}] \times \text{soil mg kg}^{-1}}$$

Where:

[Heavy metals] bitter leaf mg kg^{-1} = Concentration of heavy metal in bitter leaf (mg kg^{-1})

[Heavy metals]$\times$soil mg kg^{-1} = Concentration of heavy metal in the soil (mg kg^{-1})

Contamination factor (CF) was calculated to show site-specific contamination of toxic substances, thus[12]:

$$CF = \frac{Cm\ (sample)}{Cm\ (background)}$$

Where:
Cm (sample) = Metal concentration at a contaminated site
Cm (background) = Concentration of a given element in the background sample

The CF is based on 4 categories of contamination: Low (CF<1), moderate (1<CF<3), considerable (3>CF<6) and very high (CF>6)[12].

Pollution load index (PLI):

$$PLI = (CF1 \times CF2 \times CF3 \times CF4 \times CF5 \ldots CFn)^{1/n}$$

Where:
CF = Contamination factor
n = Number of study metals
C_{metal} = Metal pollutant concentration in soil
$C_{background}$ = Metal background value[14]

RESULTS AND DISCUSSION

The heavy metal concentrations of soil samples in all locations of the study are shown in Fig. 1.

The soil U (control) recorded a concentration range for Cu as 1.3×10^{-1} mg kg^{-1}, 13.127 mg kg^{-1}, Co as 0.109 mg kg^{-1}, Ni as 4.809 mg kg^{-1}, Fe as 1.6×10^{-3} mg kg^{-1}, 1629.737 mg kg^{-1} and Mn as 7.1×10^{-1} mg kg^{-1}, 70.956 mg kg^{-1} as shown in Fig. 1.

The mean concentration of heavy metals in *Vernonia amygdalina* (BL) samples from the locations of study are as shown in Fig. 2.

The BL-U (control) sample recorded a concentration range for Cu as 8.818 mg kg^{-1}, Co as 0.001 mg kg^{-1}, Ni as 3.7 mg kg^{-1}, Fe as 2.9×10^{-2} mg kg^{-1} and Mn as 4.6×10^{-1} mg kg^{-1}. The *Vernonia amygdalina* (BL) sample in BL-Abuloma 1 location recorded a concentration range for Cu as 7.54 mg kg^{-1}, Co as 0.001 mg kg^{-1}, Ni as 3.33 mg kg^{-1}, Fe as 5.0×10^{-2} mg kg^{-1}, 502.91 mg kg^{-1} and Mn as 7.1×10^{-1} mg kg^{-1}, 70.15 mg kg^{-1} as shown in Fig. 2.

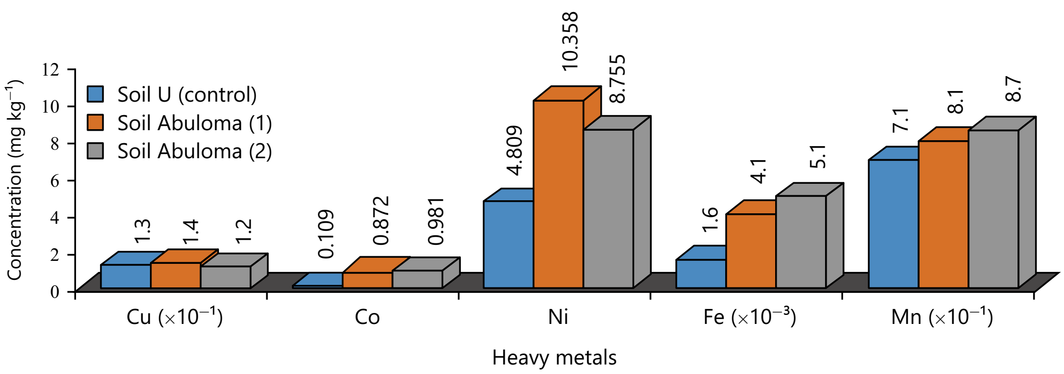

Fig. 1: Mean concentration of heavy metals in soil samples
WHO permissible limit (mg kg^{-1}): Cu: 36, Co: 7, Ni: 35, Fe: 300 and Mn: 50

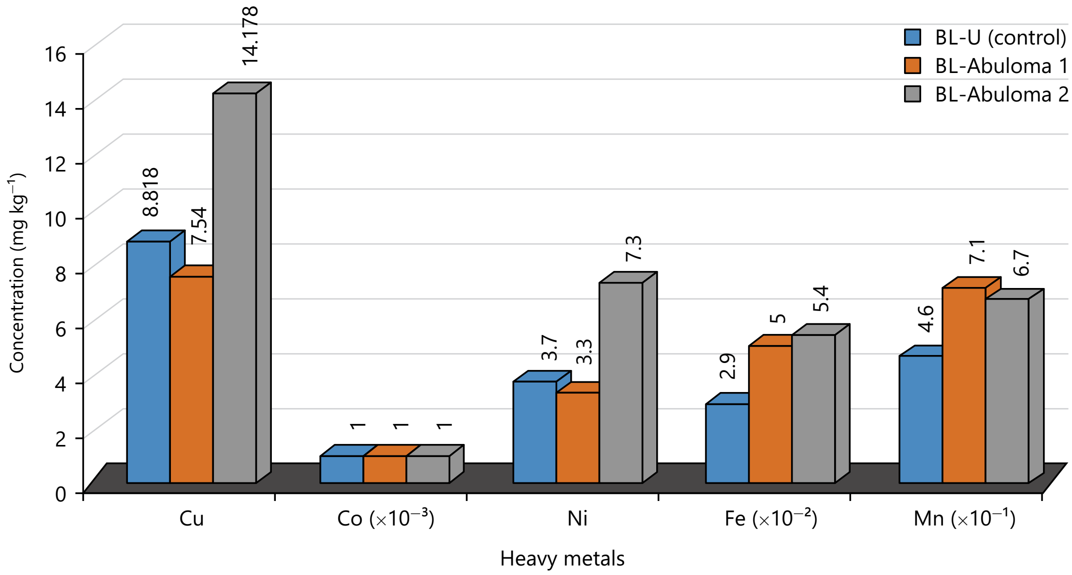

Fig. 2: Mean concentration of heavy metals in *Vernonia amygdalina* (BL) samples
WHO permissible limits (mg kg^{-1}): Cu: 10, Co:0.01, Ni: 10, Fe: 300 and Mn: 50

Table 1: Risk assessment model for soil: Transfer factor (TF) and contamination factor (CF)

Heavy metals (mg kg^{-1})	TF (Soil Abuloma 1)	TF (Soil Abuloma 2)	CF (Soil Abuloma 1)	CF (Soil Abuloma 2)
Copper	1.0265	0.8874	0.9741	1.1268
Cobalt	8.0	9.0	0.125	0.111
Nickel	2.153	1.8205	0.4642	0.5492
Iron	2.573	3.1004	0.3886	0.3225
Manganese	1.135	1.233	0.8807	0.8112

Table 2: Risk assessment model for *Vernonia amygdalina* (BL): Transfer factor (TF) and contamination factor (CF)

Heavy metals (mg kg^{-1})	TF (BL-Abuloma 1)	TF (BL-Abuloma 2)	CF (BL-Abuloma 1)	CF (BL-Abuloma 2)
Copper	0.549	1.033	1.819	0.966
Cobalt	0.001	0.001	0.001	0.001
Nickel	0.333	0.729	3.000	1.329
Iron	0.211	0.230	4.722	4.392
Manganese	8.150	0.764	1.255	1.309

The transfer factor for soil in location Abuloma 1 was 1.0265, 8.0, 2.153, 2.573 and 1.135 mg kg^{-1} for Cu, Co, Ni, Fe and Mn, respectively, while that of Abuloma 2 location had 0.8874, 9.0, 1.825, 3.1004 and 1.233 for Cu, Co, Ni, Fe and Mn respectively as shown in Table 1.

The contamination factor (CF) for Soil-Abuloma 1 location were 1.819, 0.001, 3.000, 4.722 and 1.255 for Cu, Co, Ni, Fe and Mn, respectively. Soil-Abuloma 2 location had CF of 0.966, 0.001, 1.329, 4.392 and 1.309 for Cu, Co, Ni, Fe and Mn, respectively as shown in Table 2.

The PLI value for *Vernonia amygdalina* in BL-Abuloma 1 was 0.809 mg kg^{-1} while the soil had 0.003868 mg kg^{-1}. The BL-Abuloma 2 had a PLI of 1.907 mg kg^{-1} for *Vernonia amygdalina* and 0.003597 mg kg^{-1} for soil.

Figure 1 revealed a higher concentration of Cu and Ni in the Soil Abuloma 1 location than Soil Abuloma 2 location, while for Co, Fe and Mn, Soil Abuloma 2 location had higher concentrations than Soil Abuloma 1 when compared to the control group as revealed in Fig. 1. All heavy metal concentrations assessed in soil for all the locations were below WHO/FEPA permissible range, except for Fe which was above the permissible range. Figure 2 shows that for all sample locations, *Vernonia amygdalina* ranges for Fe and Mn were above WHO/FEPA permissible limits (300 and 50 mg kg^{-1}, respectively), Co and Ni were below the permissible range, but in Abuloma 2 sample, Cu was above the permissible range. Iron (Fe) is an essential element in plants for the enzyme system which brings about oxidation-reduction reactions and elect on transport in the plant, synthesizes chlorophyll and maintains the structure of chloroplast and enzyme activity, it regulates respiration and photosynthesis when found in excess, it can be detrimental and might affect plant growth[15,16]. The concentration of iron (Fe) in the *Vernonia amygdalina* shown in Fig. 2 was the highest in comparison with the other metals of study in all sample locations. This might be a result of excess water in the soil, particularly in acidic soils, which increases iron availability even to the point of toxicity. Aeration/poorly aerated soils have an increased Iron availability, particularly if the soil is acidic[17].

The concentration of manganese (Mn) in the *Vernonia amygdalina* Abuloma 1 and 2 samples in comparison with the U-control sample showed to be higher. This might be a result of an excess level of acidity in the soil. Manganese is often used in plants as a major contributor to various biological systems including photosynthesis, respiration and nitrogen assimilation[18]. The Mn is released into the environment from emissions, fossil fuel combustion and erosion of manganese-containing soil. Volcanic eruptions can also contribute to levels of manganese in the air which finds its way into the soil[19].

The Nickel concentration in Fig. 2 was higher in the BL-Abuloma 2, a lower concentration of BL Abuloma-1 in comparison to the BL-Ucontrol was observed. Nickel is a plant micronutrient that has its usefulness in the fixation of Nitrogen and urea metabolism. It has also been found to be an important element in seed germination and plant growth, it is also persistent in the atmosphere. It contributes to nitrogen fixation and the metabolism of urea (a nitrogen-containing compound) and is important for seed germination[20]. Nickel (Ni) is released into the atmosphere via anthropogenic and industrial activities. It accumulates on ground surfaces after precipitation reaction by various processes and industries, such as power plants and trash incinerators, which accumulate on ground surfaces after precipitation reactions and Ni is persistent in the atmosphere[21]. From the Table 1 and 2, the concentration of Nickel in all locations was lower than the permissible limits as approved by WHO.

Cobalt is important for nitrogen fixation by the bacteria that associate with legumes. Industrial and vehicular-prone areas have been reported to have the most occurrence of cobalt concentration in the soil. Cobalt is absorbed by soil via di-and trivalent cations and areas that are most exposed to the occurrence of high cobalt contents of the soil of anthropogenic origin are mainly industrial and transport areas. Cobalt is taken up by plants in various forms, most often in the form of di-and trivalent cations[22]. From the result in Fig. 2, the concentration of cobalt in *Vernonia amygdalina was* recorded to be lower than the permissible limit of 0.001 mg kg^{-1} for all sample locations.

Copper (Cu) from the evaluation of the above result in Fig. 2, was recorded to be lower than the WHO permissible range of 10 mg kg^{-1} in plants. Copper is required for many enzymatic activities in plants and chlorophyll and seed production. The Cu has found importance in respiration and photosynthesis in plants, thus, its deficiency results in increased vulnerability of plants to diseases like ergot, leading to yield loss in small grains. On the other side, a high Cu level in the soil is due to the use of copper-containing fungicides, mining activities in the soil and other industrial activities it facilitates respiration and photosynthesis and is important for plant metabolism. Deficiency of Cu can lead to increased susceptibility to disease like ergot which can cause significant yield loss in small grains. Whereas, high plant copper levels can occur as a result of excessive use of copper-containing fungicides and industrial activity (such as mining) in the soil. When reviewing the results of a soil copper test, be alert for copper levels that are close to the maximum recommended value as well as excesses.

High values of TF indicate low retention capacity. Transfer factor above 1 indicates hyper-accumulation, especially in soil[22]. The TF values for all BL samples in BL-Abuloma 1 were all below 1, except for Mn (8.15). BL Abuloma 2 sample location also had TF values all below one except for Cu (1.033). This result implies the hypo-accumulation ability of *Vernonia amygdalina.* This study agrees with previous findings on the accumulation of heavy metals in bitter leaves, although not in high concentration compared to the soil[22]. The Soil Abuloma 1 location showed a higher TF concentration for Cu and Ni, while Soil Abuloma 2 location had higher TF concentrations for Co, Fe and Mn. All soil sample locations calculated for the TF had TF higher than one. This is implicative of the hyper-accumulation of heavy metals in the soil of the sample location.

The order of contamination factor for the study locations in soil samples is in the order: Soil-Abuloma 1 and Abuloma 2: Cu>Mn>Ni>Fe>Co. BL-Abuloma 1 contamination is in the order: Fe>Ni>Cu>Mn>Co and for BL-Abuloma 2: Fe>Ni>Mn>Cu>Co. Table 1 revealed that the contamination of the soil for Abuloma 1&2 locations was all low (<1) except for Cu concentration in Abuloma 2 location (1.1268). Also, Table 2 revealed that BL Abuloma 1&2 had Considerable contamination of Fe (4.722 and 4.392), moderate Ni (3.00 and 1.323), Moderate Mn (1.255 and 1.309) contamination and moderate contamination in BL-Abuloma 1 (1.819). The CF has been reported to occur due to vehicular emission, industrial activities and anthropogenic activities, leading to severe contamination of both soil and plant around its vicinity[22]. This agrees with the contamination observed in this study.

The pollution load index (PLI) evaluation showed that PLI for Soil Abuloma 1 and Soil Abuloma 2 were low. BL-Abuloma 1 and BL-Abuloma 2 *Vernonia amygdalina* recorded 1.907 and 0.809 mg kg^{-1}, respectively. The result obtained showed that the level of pollution was higher in BL-Abuloma 1 in comparison with the BL-Abuloma 2 location. The PLI indicated the deterioration level of soil due to heavy metal accumulation[22]. This may be attributed to both soil-root system flow and anthropogenic input, such as vehicular emissions and waste dumping site, which is common around the study region. The risk assessment and heavy metal evaluation of more locations within Port Harcourt should be considered to have a broader conclusion.

The study, therefore, recommends regulation and monitoring of the Industry's activities around the area of study, in line with standards. by the government and relevant agencies. This will forestall the toxicity of the soil and agricultural products consumed by residents of the communities. This study did not analyze the heavy metal concentration of other agricultural produce in the area of study.

CONCLUSION

The findings of this study revealed that soil and bitter leaf cultivated at Abuloma, Trans Amadi had concentrations of Fe and Mn above the WHO permissible limit with the highest concentrations in the Abuloma-2 location. The TF for soil in all locations were in the order, Co>Fe>Ni>Mn>Cu. The TF for bitter leaf had the heavy metal order in both locations as, BL Abuloma 1, Mn>Cu>Ni>Fe>Co while BL Abuloma-2 had Cu>Mn>Ni>Fe>Co. Various degrees of contamination were observed in all sample locations as shown in the CF. The PLI for soil samples recorded the highest pollution in the Abuloma-1 location and for BL samples, Abuloma-2 had the highest pollution index). The study revealed heavy metal contamination of both the soil and bitter leaf cultivated in the locations of study. It is therefore, suggested that, a thorough monitoring/regulation of the industrial activities in the Abuloma/Trans Amadi Industrial area of Port Harcourt is expedient by the government/regulatory bodies to reduce pollution and heavy metal contamination in both soils and bitter leaf.

SIGNIFICANCE STATEMENT

The threat to humans, animals and plant life by pollution due to heavy metals from industrial activities has posed health challenges over time. This study revealed the high contamination of heavy metals in the soil of the experimental locations and the concurrent bioaccumulation of these metals in the bitter leaf cultivated in the same soil, with Iron and manganese above WHO permissible limits. The study further revealed the moderate and considerable contamination status of both the soil and bitter leaf of the study and a high pollution load index, thus a high-risk assessment factor. The study thus calls for thorough monitoring and regulation of activities in the area by regulatory bodies and the government to forestall future health hazards.

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