Chapter

Toxic Heavy Metals in Soil and Plants from a Gold Mining Area, South Africa

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Abstract

The mining of mineral deposits abundant in South Africa has led to the release of toxic heavy metals into the environment. The aim of this study was to investigate heavy metal pollution from a gold mining area. The concentrations of arsenic, cadmium, lead, and zinc were analyzed in soil and plants found within 500 m and 1000 m radius of a gold mine established in North-West. The concentrations of these heavy metals were determined using Inductively Coupled Plasma Mass Spectrometry. The results showed that the concentrations of the studied heavy metals were all below the national and international threshold but higher than the concentrations found several kilometers away from the mining area, the natural background concentration. The results from the pollution load index shows that the topsoil is contaminated for the selected heavy metals. There was accumulation of the studied heavy metals in the studied *Eragrostis hypnoides* plant's leaves and roots. In this study, it was revealed that zinc and cadmium bioaccumulated in the plant via the soil. These findings suggests that the consumption of agricultural products from farms within the 1 km radius of the mining site could be detrimental to the wellbeing of direct and indirect consumers.

Keywords: arsenic, cadmium, lead, zinc, heavy metals, gold mining, South Africa, pollution load index, concentration factor, pollution

1. Introduction

South Africa as a country is regarded as one of the richest countries with abundance of mineral resources such as gold, platinum, coal, cobalt and many more [1, 2]. The exploration of gold started in the country in the 19th century [3], when the world largest gold deposit was discovered in the Witwatersrand Basin, South Africa [4]. The discovery of gold has contributed to the development of South Africa as one of the most developed and largest economy in the African continent [5]. However, the mining of gold and other minerals has led to the increase in the concentrations of toxic heavy metals in the biosphere, atmosphere, and hydrosphere [6–10]. Heavy metals are found naturally in all spheres of life at a minimal concentration. Natural sources include bedrock weathering, volcanic activities, and atmospheric fallout.

However, these concentrations have been increased due to anthropogenic activities for example, exploration of mineral deposits [11, 12].

Heavy metals are classified as metals with specific density more than 5 g/cm^3 which negatively impact the environment and living organisms [13]. Heavy metals can be classified into two types; essential heavy metals and non-essential heavy metals [14]. Essential heavy metals such as iron and zinc are important for human metabolism at low concentrations; however at higher concentrations, they are toxic [15]. For example, iron is a type of needed protein for the red blood cells that carries oxygen from the lungs to all parts of the human body [16, 17]. However, at high concentrations, iron becomes toxic to humans leading to hemochromatosis which can cause serious damage to the human heart, liver and pancreas [18, 19]. Zinc is a major player in the development of DNA, growth of the body cells, building proteins and healing damaged body cells at low concentrations [20, 21]. At high concentrations, it causes nausea, vomiting, loss of appetite, stomach cramps, diarrhea, and headaches [22–24].

The non-essential heavy metals, for example, cadmium (Cd), arsenic (As), lead (Pb), uranium (U), are toxic to humans even at low concentrations [14, 25, 26]. Cadmium is known to cause lung damage, kidney damage and fragile bones which can result in death [27, 28]. Exposure to arsenic from food and water leads to cancer, skin lesions, cardiovascular disease, and diabetes [29–32]. Lead reduces brain development, causes anemia, body weakness, kidney, and brain damage [33–35]. Uranium can cause lung cancer, liver and kidney damage [36, 37]. Most of these non-essential heavy metals are carcinogenic; they could lead to the development of cancer of vital human organs which can eventually lead to death [14, 38]. This is even worse when these toxic heavy metals are ingested indirectly by immuno-deficient humans [39].

There are several pathways for heavy metals such as through air, water, and sediments [40, 41]. While some of these heavy metals are highly mobile, such as uranium (U), arsenic (As), some are of less mobility like lead (Pb), and cadmium (Cd). Depending on the mobility of the heavy metals, high concentration of the metal can be found several miles away from the mining environment. High concentrations of heavy metals have been recorded in sediments within and outside the perimeter of a mining area in South Africa. Fashola et al. [42] reported concentrations of As, Cd, Pb and Zn above the recommended levels by South African guidelines for soils and sediment qualities guidelines from abandoned gold mining sites. In the study of the spatial assessment of heavy metals contamination in household soils in rural Limpopo Province, South Africa, Kapwata et al. [43] reported high concentration of Pb, Cd, As and mercury (Hg), exceeding the Canadian reference levels of these heavy metals in soils characterized by abandoned mines and artisan mining activities in Limpopo Province, South Africa.

Concentrations of heavy metals have also been reported in plants around a mining environment. Flefel et al. [44] reported high concentrations of Cd, 0.85–30.30 mg/kg and Pb, 21.50–68.00 mg/kg in aquatic plants higher than the sampled water. The researchers concluded that the concentrations of heavy metals in plants were above the acceptable limits of Cd, 0.02 mg/kg, Pb, 2 mg/kg set by World Health organization (WHO). In the study by Kausar et al. [45] high concentrations of Cd, Pb, and Zn were recorded in crops irrigated by heavy metal polluted water. The accumulation of Cd, Pb and Zn was recorded in the crops' leaves and root of carrot and spinach. While some of these plants are consumed directly by humans, some are used to feed animals such as cattle which exposes humans to direct and indirect carcinogenic health risks.

In mines nearby streams, high concentration of heavy metals has been recorded by several researchers [10, 46, 47]. Shapi et al. [46] reported heavy metal concentrations from water samples that have accumulated in wetlands due to the past gold mining operations in Krugersdorp, South Africa. The maximum concentrations recorded for As, Pb and Zn are 32.20 mg/L, 6.30 mg/L and 783 mg/L respectively [46]. In the study by Chetty et al. [47] on the transportation and accumulation of heavy metals in the Klip River's catchment, elevated concentrations of different heavy metals were recorded which included As, Cd, Pb. The authors concluded that the extensive accumulation of these heavy metals in the water body is the legacy of past and extensive gold mining in the Witwatersrand Basin [47]. Raji et al. [10] reported high concentration of uranium and other heavy metals in Rietspruit system because of gold mining activities that was operation at the headwater of the Rietspruit, Far West Rand goldfield. Residents of informal settlements that depend on nearby surface water from streams and dams polluted by heavy metals for their basic domestic needs eventually ingest dissolved heavy metals. The availability of these heavy metals will continuously pose an enormous health risk to downstream water users.

Many researchers have also reported high concentrations of heavy metals in air around the mining environment. Mining wastes such as unrehabilitated tailing-dams are rich in heavy metals which are fine-grained. The top-layers of these tailing-dams can be transported by wind. Local residents within close proximity inhale this air which can lead to different respiratory diseases [48, 49]. Residents of Soweto, South Africa, residing near tailing-dams have reported several respiratory illnesses which has been linked to the presence of tailing-dams close to their community [50]. Heavy metals in air in due course settle down on land and plants. Plants uptake these heavy metals and bio-accumulate the toxic elements in their leaves, stems, and roots [51–53]. These plants are later consumed by humans either directly or indirectly through cattle that fed on those plants. In all the findings, the general conclusion was that there is an obvious decrease in the concentration of the heavy metals as the distance from the source pollutant (mining site) increases.

In this study, the concentrations of As, Cd, Pb, and Zn within a 1 km radius of a gold mining environment in North-West Province, South Africa was studied. These heavy metals are some of the most toxic heavy metals highlighted by the World Health Organization, WHO, [54–56] and they have been associated with gold mining operations [42, 57–59]. This study is important because there is currently limited published literature about the concentration of these heavy metals from the gold mine located in the North-West Province of South Africa. Considering the several agricultural activities within the proximity of the mines such as maize plantation and cattle husbandry, it is very important to determine the concentration of these selected heavy metals within a 1 km radius of the gold mine if crop safety measures need to be implemented.

The main objective of this study is to determine the concentrations of As, Cd, Zn and Pb in soils and plants within the 1 km radius of a gold mine. The specific objectives are highlighted below.

1. Determine the concentrations of selected heavy metals in the soil.

2. Determine the pollution load index of the selected heavy metals in the soil.

3. Examine the bioaccumulation of heavy metals in *Eragrostis hypnoides* within the 1 km radius of the gold mine.

4. Determine the uptake of the selected heavy metals in *E. hypnoides*.

1.1 Study area

The study area is in the Ratlou Local Municipality, North-West Province, South Africa surrounding an open pit mine (**Figure 1**). The gold mine was established in 1996 and gold is mined from the gold bearing ore in a banded ironstone formation of the Kraaipan Greenstone Belt. North-West Province is a water scarce Province because of the high-water demand and low precipitation. The rate of evaporation is more than double the rate of precipitation [58]. An extreme drought is experienced in the province.

The North-West Province is dominated by the Savannah Biome and the rest falls in the Grassland Biome. The climate of the Province is categorized by hot temperature reaching about 38°C in the summer and cold sunny winter.

Besides mining, agriculture is another mainstay of the economic activities in this region, hence, the province is regarded as the food basket of the nation. Large maize plantation and sunflowers are located within the 2 km radius of the gold mine. Grazing cattle and ranches were witnessed during fieldwork. The studied plant (*Eragrostis hypnoides*) is among the observed plants that the cattle fed on.

This study site was selected because it characterizes distinct land use landscapes. With the gold mine within proximity of established commercial farmlands, it is crucial to examine the concentrations of As, Cd, Pb and Zn in the soil and plant found within 1 km of an active gold mine.

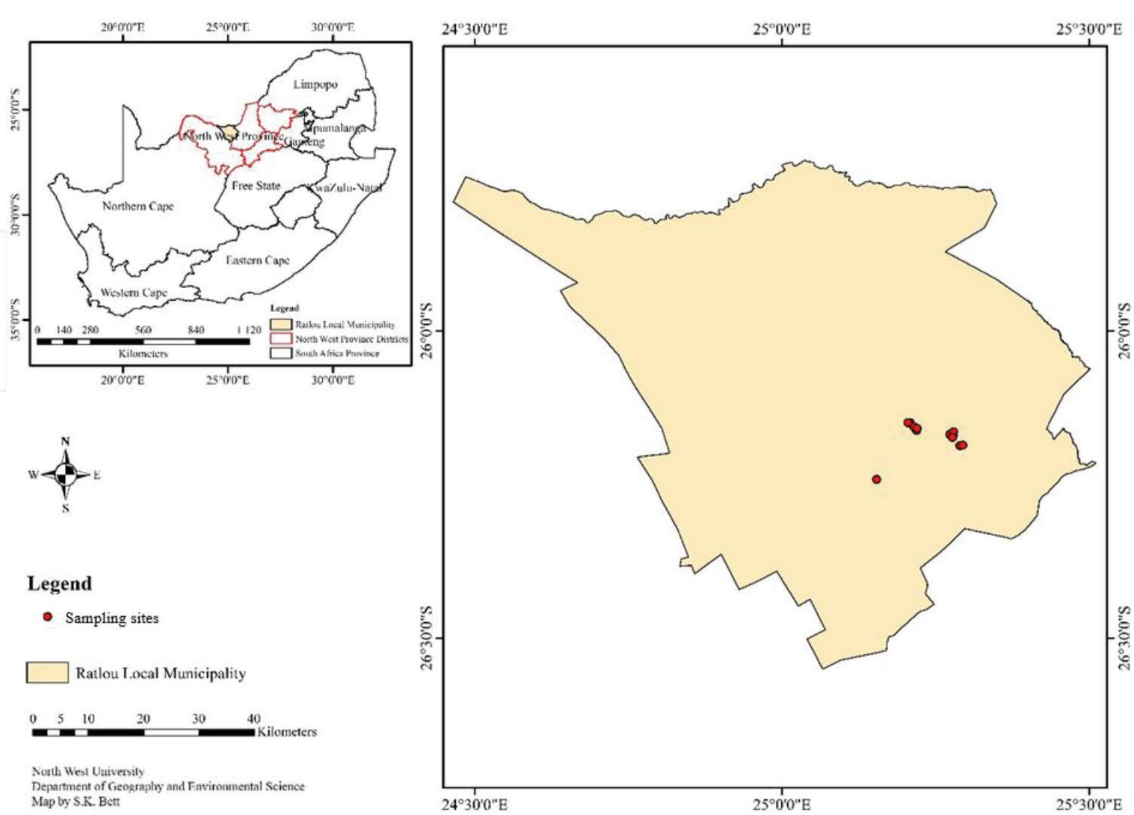

Figure 1.
Map of the study area showing the sampled sites.

2. Methodology

This report involves an experimental qualitative design which included heavy metals laboratory testing and statistical analysis.

2.1 Identification of soil and plant sampling sites

To identify sampling sites, several climatic conditions were investigated. This included the physical conditions of the study area such as the geology of the environment, type of soil as well as rainfall. Sampled sites were evenly distributed to allow the determination of possible pollution sites and to know the degree of heavy metal pollution.

Other considered factors are:

1. Sampled sites must provide a standard geostatistical fit.

2. Sampled sites must represent the different activities of land use predominate in the area.

3. Samples must be collected from flat areas to avoid sampling eroded soil materials.

4. Sample were collected several meters away from the road and residential areas to reduce human prints.

Considering the relationship between the parent rocks and non-point source pollution, it is believed that 32 samples for four metals will be sufficient to represent the study area and perform statistical and geostatistical evaluation.

2.2 Soil sampling

According to Branquiho et al. [60], spatial dust effects are localized and it ranges less than 1 km from the source pollutant. To allow even distribution of soil samples, soil samples were taken at 500 m and 1000 m away from the gold mining site in various directions – north, northeast, northwest, south, southwest, southeast, east, and west. At each distance, two samples were taken using an auger at a depth of 0–10 cm (topsoil) and 10–2- cm (subsurface). These depths were used in previous studies [61, 62] and they suggest the disparity in land contamination at varied distances [61].

A site devoid of any physical human activity was selected to collect a soil sample referred to as the control or background sample. This Background sample was taken 10 km away from the study area (26^0 15′ 08″ S 25^0 11′ 32″ E) at the same depth used for other collected samples. This was essential to have an uncompromised Background sample. The climatic and physical conditions of the study area and the background site were identical.

Three samples above 1 kg were collected at each of the sampled site for precision purposes. A total of 28 soil samples were collected, stored in a plastic bag, and taken to the laboratory for further analysis. Each of the soil samples coordinate were recorded using a handheld Garmin GPSMAP 65 s Global Positioning System, manufactured by Garmin, South Africa.

2.3 Plant sampling

Plant samples were collected at the same spots where soil samples were taken. A total of four plant samples were collected at the northern and eastern location of the mine at same spot where soil samples were taken. At other sampled location, the plant of interest was not found at the specified distance, 500 m, and 1000 m. Plants rely on the physical and chemical conditions of the topsoil, hence, they are disturbed by these circumstances.

In this study, a specific plant species, *E. hypnoides,* was collected. Collected plant samples were thoroughly cleaned with tap water, followed by 0.1 mol/L of hydrochloric acid (HCl) and deionized water. The washing of the plant samples was important to remove every soil and dust particles from the sample. If the plant samples were left unwashed, the soil and dust particle will influence the determined concentration of the studied heavy metals in the sample.

In line with the method of Ma et al. [63], plant samples were placed inside an oven at 70°C for three days. This was done to remove moisture content of the plant sample. After drying, all the plant samples were then pulverized in a mill and packed in a well labeled sealable plastic bag before proceeding to aqua regia digestion of the samples.

2.4 Determination of heavy metals

The analysis of cadmium (Cd), lead (Pb), zinc (Zn), and mercury (Hg) were done using the inductively coupled plasma mass spectrometry (ICP-MS) for both the collected soil and plant samples. These selected heavy metals are toxic to humans, animals, and plants. They have been reportedly found at high concentrations within the environment of a gold mining and processing.

Before using the ICP-MS to determine the concentrations of the studied heavy metals, the collected and labeled plants and soil samples were digested using 0.6 mL of concentrated sulfuric acid (H_2SO_4), 0.6 mL of concentrated nitric acid (HNO_3) and 1.8 mL of concentrated HCl for two hours at 95°C.

After digestion and the cooling of the machine, each sample volume was brought up to 10 mL by adding deionized water. Each sample was then arranged in the ICP-MS machine accordingly to determine the concentration of the studied heavy metal in each sample. This procedure has been used in the study of Kamunda et al. [64]. The detection limit of Zn, Cd, Pb and As using the ICP-MS are 1.173 mg/kg, 0.006 mg/kg, 0.045 mg/kg and 0.026 mg/kg respectively.

2.5 Quality control

Every equipment used were firstly calibrated with reference standard. Glassware used for heavy metal analyses were rinsed in dilute HNO3 before usage. All reagents and heavy metal standards used were of analytical grades. Analyses were done in duplicate to ensure precision and accuracy of the obtained data.

2.6 Determination of pollution levels in the study area

To assess the pollution levels in the study area, the soil contamination factor (CF) was used. Therefore, the standard background value which represents the value of the elements, measured relative to the amount of the Upper Continental Crust (UCC) was used as the reference material [65].

$$CF = \frac{C_a}{C_{ref}} \quad (1)$$

Where C_a is the metal concentration in the soil (total), and C_{ref} is the background value of the pristine environment.

The contamination levels were classified based on the following classes: low contamination (CF < 1), moderate contamination (1 ≤ CF < 3), high contamination (3 ≤ CF < 6) and very high contamination (CF ≥ 6).

Pollution load index (PLI) was calculated using Eq. 2 to assess the overall contamination at each site and to distinguish natural origin from anthropogenic sources [66].

$$PLI = \sqrt[n]{CF_1 \times CF_2 \times \ldots . CF_n} \quad (2)$$

Where CF1, CF2 are CF of elements 1, 2, 3, …., n; When the PLI > 1, denotes significant deterioration in the system, 0 < PLI < 1, indicates baseline level of contamination [66].

2.7 Determination of heavy metals uptake by plant

Concentration factor (CF) was introduced to calculate the relationship between the uptake of As, Cd, Pb and Zn from soil by plants. This is a measure of soil-plant transfer that supports the understanding of plant uptake signature [62]. The determined concentration of each metal in the plant (M_{plant}) was divided by the concentration of each metal determined in the soil (M_{soil}). A quotient greater than 1 means that the plant has been influenced by the metal (accumulator). However, if the quotient is less than 1, it means that the plant has not been influenced by the metal (excluder).

$$CF = \frac{M_{plant}}{M_{soil}} \quad (3)$$

Where CF is the concentration factor, M_{plant} is the metal concentration in the plant and M_{soil} is the metal concentration in the soil.

2.8 Data analysis

Data obtained from laboratory analysis were subjected to basic descriptive statistics (i.e., mean, and standard deviations) tabulated using SPSS software. In addition, the concentrations of the selected heavy metals were compared with South African agricultural soil standards. Also, SPSS software was used for all the statistical analysis which include Chi-square and one-way ANOVA. The Chi-square evaluated the deviation between the determined concentration of the studied heavy metals from the sample site and the control site. One-way ANOVA was used to determine the significant difference in the determined heavy metal concentration while considering all the sampled sites.

3. Results and discussion

3.1 Heavy metal concentration in soil samples

The results of the described field sampling are summarized in **Tables 1–4**. The results depicted the varying concentrations of each heavy metals at each of the

Zn concentration (mg/kg)										
Location	Distance	500 m		1000 m		Background sample 1		Background sample 2		South African limit
	Depth (cm)	0–10	10–20	0–10	10–20	0–10	10–20	0–10	10–20	
North		8.9	5.7	12.8	14.7	7.3	17.1	10.1	9.2	200
Northeast		7.9	32.8	8.0	10.5					
Northwest		6.9	10.2	11.9	6.6					
East		8.8	6.5	8.2	6.7					
Southeast		8.7	12.9	6.9	8.7					
West		9.2	6.7	9.1	6.3					
Southwest		8.8	5.7	N/A	N/A					
South		4.6	8.1	N/A	N/A					
Mean		7.9	11.1	9.5	8.9					
SD		1.6	9.1	2.4	3.3					
Range		4.6–9.2	5.7–32.8	6.9–12.8	6.3–14.7					

N/A = not accessible.

Table 1.
Concentration of zinc.

respective sampling points and depths. Results were compared with the upper limit threshold for agricultural soils in South Africa [67].

3.1.1 Zinc concentration

The ICP-MS result of Zn concentration indicated that the concentration of Zn was from 4.6 mg/kg to 9.2 mg/kg at a depth of 0–10 cm (topsoil). At a depth of 10–20 cm (subsurface), it ranged from 6.9 mg/kg to 12,8 mg/kg. These were from 500 m from the gold mine.

At 1 km radius from the mining site, the maximum recorded concentration for Zn was 12.8 mg/kg and the minimum was 6.9 mg/kg at the topsoil. At 10–20 cm, the maximum recorded concentration was 14.7 mg/kg and the lowest was 6.3 mg/kg (**Table 1**). The concentration of Zn at all the sampled site were below the permissible limit of Zn in South African agricultural soil, 200 mg/kg [67].

When the concentrations of Zn from the study area were compared with the Zn concentration from the control site, the mean of Zn concentration at the sampled sites were more than the concentration of Zn from the Background sample at 10–20 cm within the 0.5 km radius of the mine (**Table 1**).

Based on the result from 500 range of the mine, the concentrations of Zn are lower at the topsoil than at the subsurface. Akin to the findings of Ekweu et al. [68] where higher concentration of Zn were reported at a depth of 15–20 cm than at a depth of 0–15 cm. Leaching effect was reported to be responsible. However, in the study of Raulinaitis et al. [69], the concentration of Zn at the topsoil, 36.8 mg/kg was higher than at the subsurface, 18.3 mg/kg.

Cd concentration (mg/kg)										
Location	**Distance**	**500 m**		**1000 m**		**Background sample 1**		**Background sample 2**		**South African limit**
	Depth (cm)	**0–10**	**10–20**	**0–10**	**10–20**	**0–10**	**10–20**	**0–10**	**10–20**	
North		0.014	0.016	0.028	0.039	0.014	0.039	0.025	0.024	3.00
Northeast		0.019	0.396	0.020	0.027					
Northwest		0.023	0.026	0.031	0.017					
East		0.013	0.011	0.019	0.014					
Southeast		0.020	0.034	0.011	0.017					
West		0.012	0.023	0.015	0.019					
Southwest		0.008	0.010	N/A	N/A					
South		0.011	0.024	N/A	N/A					
Mean		0.015	0.068	0.021	0.022					
SD		0.005	0.133	0.008	0.01					
Range		0.008–0.023	0.010–0.395	0.011–0.031	0.014–0.039					

N/A = not accessible.

Table 2.
Concentrations of cadmium.

Pb concentration (mg/kg)										
Location	**Distance**	**500 m**		**1000 m**		**Background sample 1**		**Background sample2**		**South African limit**
	Depth (cm)	**0–10**	**10–20**	**0–10**	**10–20**	**0–10**	**10–20**	**0–10**	**10–20**	
North		3.5	3.8	4.5	4.9	0.058	0.7	0.1	1.08	100
Northeast		3.3	0.3	3.2	4.4					
Northwest		3.8	4.9	5.8	3.2					
East		3.1	2.6	4.2	3.4					
Southeast		3.8	5.1	4.5	3.12					
West		3.9	2.6	3.4	4.6					
Southwest		3.3	4.9	N/A	N/A					
South		2.9	4.7	N/A	N/A					
Mean		3.4	3.6	4.2	3.9					
SD		0.3	1.7	0.9	0.8					
Range		2.97–3.855	0.334–5.077	3.191–5.787	3.155–4.987					

N/A = not accessible.

Table 3.
Concentration of lead.

As concentration (mg/kg)										
Location	**Distance from mine**	**500 m**		**1000 m**		**Background sample 1**		**Background sample 2**		**South Africa limit**
	Depth (cm)	**0–10**	**10–20**	**0–10**	**10–20**	**0–10**	**10–20**	**0–10**	**10–20**	
North		0.8	1.1	1.3	3.5	0.7	2.0	1.0	1.4	5.8
Northeast		0.8	0.2	1.0	1.4					
Northwest		0.7	1.4	1.2	0.6					
East		0.9	1.1	1.1	0.7					
Southeast		0.8	3.7	0.7	0.7					
West		0.8	1.0	0.6	1.0					
Southwest		0.7	0.7	N/A	N/A					
South		0.8	1.1	N/A	N/A					
Mean		0.8	1.3	0.9	1.3					
SD		0.1	1.0	0.3	1.1					
Range		0.7–0.9	0.2–3.7	0.6–1.3	0.6–3.5					

N/A = not accessible.

Table 4.
Concentration of arsenic.

In comparison with the permissible limit of Zn in other countries, the concentration of Zn reported in this study is lower in many folds than the following countries - Austria (111 mg/kg), China (74.2 mg/kg), Germany (225 mg/kg) and USA (60 mg/kg) [70]. As result, we can conclude that the soil within the study area is not polluted.

3.1.2 Cadmium concentrations

The maximum concentration of Cd recorded at the topsoil, 500 m away from the mining site was 0.023 mg/kg and the minimum was 0.008 mg/kg. At the subsurface, the maximum concentration recorded was 0.395 mg/kg and the lowest was 0.010 mg/kg. Similar concentrations of Cd were also recorded at 1 km radius of the mine at the specific sampling depths (**Table 2**).

The average concentration of Cd is lower at the topsoil than at the subsurface at both distances from the mine. The mean concentration of Cd at both distances showed that the study area is not polluted with Cd because they are lower than the permissible limit of Cd in South African soil used for agriculture, 3.00 mg/kg [67] and the mean concentration of Cd reported in China, 0.1 mg/kg, Japan, 0.41 mg/kg and in the United Kingdom, 0.62 mg/kg [70].

When the concentration of Cd from the study area is compared with the concentration from the Background samples, the mean concentration of Cd is more at the subsurface than the concentration of Cd at the background sample site 500 m away from the mining site (**Table 2**). Based on depths (0 10 cm and 10–20 cm), the mean concentration of Cd at the topsoil is lower is lower than the mean concentration of Cd at the subsurface. This is similar to the findings of Ekwue et al. [68] and Raulinaitis et al. [69] where they both reported higher concentration of Cd at the subsurface than the concentration of Cd at the topsoil.

3.1.3 Lead concentrations

The highest concentration of Pb recorded was 3.9 mg/kg and the lowest was 2.97 mg/kg at 0.5 km distance away from the mine at the topsoil. At the subsurface, the maximum concentration recorded was 5.1 mg/kg while the lowest recorded concentration of Pb was 0.3 mg/kg.

1 km away from the mine, the concentration of Pb was between 3.2 mg/kg and 5.1 mg/kg at the topsoil and 3.2 mg/kg and 4.9 mg/kg at the subsurface. Lead's average concentration in the topsoil 0.5 km away from the mine is lower than at the subsurface and vice-versa when compared with the mean concentration of Pb at 1 km away from the mine (**Table 3**). This is a result of atmospheric deposition from vehicular activity [71] because most of the sampled sites about 1 km from the mine are closer to roads leading to the farms.

Overall, the study area is not polluted because the mean concentration of Pb is lower than the permissible limit of Pb in South African soil used for agriculture, 100 mg/kg [67]. The mean concentration of Pb is also lower than the mean reported in China, 26 mg/kg, Japan, 20.4 mg/kg and the UK, 29.2 mg/kg at every sampled location [70].

In addition, the average concentration of Pb at all the sampled sites and depths are lower than the concentration of Pb from the control sites. This means human activities are responsible for the elevation of Pb at the study area such as gold mining and farming [72].

3.1.4 Arsenic concentrations

The maximum concentration of As recorded at the topsoil was 0.99 mg/kg and 3.66 mg/kg at the subsurface. The minimum concentration of As recorded was 0.66 mg/kg at the topsoil and 0.15 mg/kg at the subsurface (**Table 4**) at 500 m away from the mining area.

At 1 km away from the mine, the maximum concentration recorded at the topsoil and subsurface are 1.3 mg/kg and 3.5 mg/kg respectively. The lowest recorded concentration of As were approximately 0.6 mg/kg at both the topsoil and subsurface (**Table 4**).

The mean concentration of As were higher at the subsurface than at the topsoil at both 500 m and 1000 m away from the gold mine. This is comparable to the findings of Wahl [73] which reported the same trend in As concentration in soils around a gold mine in Kwa-Zulu-Natal Province, South Africa. The mean concentration of As at both locations and depths are below the permissible limit of As in South African soils used for agriculture, 5.8 mg/kg [67]. This means that the soil is not contaminated.

At the control sites, the higher concentrations of As recorded at a depth of 10–20 cm than at a depth of 0–10 cm. the recorded concentration of As at the control sites were all higher than the mean concentration of As at both depths and distance except the mean concentration of the topsoil at a distance of 500 m from the mine (**Table 4**). Similar to the study of Ekwue et al. [68], the concentration of As increase from the topsoil to the subsurface.

Higher As concentrations have been reported in other countries - Germany (50 mg/kg) [74], Australia (20 mg/kg), [75], China (30 mg/kg), [76]; and Canada (12 mg/kg), [77] at every sampled location.

Generally, the total soil concentrations of As, Cd, Pb and Zn are below the upper limit threshold in comparison to the background samples and to other country's concentration. It suggests that the mining activity has not yet impacted the concentration of heavy metals in the soil because the concentration of the background sample has similar soil concentration as that obtained around the mine.

3.2 Pollution load index

The eq. 1 and 2 were used to calculate the contamination factor, CF, and pollution load index, PLI, of each studied heavy metal, respectively. The results are shown in **Tables 5**–**8**. The CF of Zn ranged from 0 to 2 within the 500 m radius of the mine. It means the area contamination ranged from a low contamination, CF < 1, to moderate contamination, $1 \leq CF < 6$, at all the sampled sites (**Table 5**). The PLI of Zn indicated that all the sampled sites are polluted (**Table 5**).

For Pb, the CF shows that the area is very highly contaminated, CF > 6, at the subsurface (0–10 cm) at both distances (**Table 6**). At 10–20 cm depth, the CF ranged from low contamination to high contamination, $3 \leq CF < 6$ (**Table 6**). The PLI for Pb shows that the study area is polluted.

The CF for As ranged from low contamination to moderate contamination at all the sites (**Table 7**). The PLI result indicated that the studied area is polluted except at the depth of 10–20 cm with PLI < 1.

The CF of Cd results show 82% of the sampled sites are moderately contaminated while 14% are lowly contaminated. However, at a depth of 10–20, the Northeastern site has a very high contamination, CF > 6 (**Table 8**). The PLI result indicated that all the sampled sites are polluted except at a depth of 10–20 cm with a PLI below 1 (**Table 8**).

3.3 Heavy metal concentrations in plant samples

E. hypnoides, was investigated to establish the metal concentrations and the results are presented in **Tables 9** and **10**. The accumulation of heavy metals in plants show the site's heavy metal pollution status and also the potential of the plant species to uptake heavy metal from the soil [62].

Sampled sites	**CF (0–10 cm) at 500 m**	**CF (10–20 cm) at 500 m**	**CF (0–10 cm) at 1000 m**	**CF (10–20 cm) at 1000 m**
North	1	0	1	2
Northeast	1	2	1	1
Northwest	1	1	1	1
East	1	0	1	1
Southeast	1	1	1	1
West	1	0	1	1
Southwest	1	0	N/A	N/A
South	1	0	N/A	N/A
PLI	**1**	**1**	**1**	**1**

N/A = means no access to take samples.

Table 5.
The contamination factor and pollution load index of zinc at various sites and depths.

Sampled site	CF (0–10 cm) at 500 m	CF (10–20 cm) at 500 m	CF (0–10 cm) at 1000 m	CF (10–20 cm) at 1000 m
North	60	5	32	5
Northeast	57	0	23	4
Northwest	66	7	42	3
East	54	4	31	3
Southeast	65	7	33	3
West	66	4	24	4
Southwest	57	7	N/A	N/A
South	51	6	N/A	N/A
PLI	**59**	**4**	**30**	**4**

N/A = means no access to take samples.

Table 6.
The contamination factor and pollution load index of lead at various sites and depths.

Sampled sites	CF (0–10 cm) at 500 m	CF (10–20 cm) at 500 m	CF (0–10 cm) at 1000 m	CF (10–20 cm) at 1000 m
North	1	1	1	2
Northeast	1	0	1	1
Northwest	1	1	1	0
East	1	1	1	1
Southeast	1	2	1	0
West	1	0	1	1
Southwest	1	0	N/A	N/A
South	1	1	N/A	N/A
PLI	**1**	**0**	**1**	**1**

N/A = means no access to take samples.

Table 7.
The contamination factor and pollution load index of arsenic at various sampled sites and depths.

3.3.1 Zinc concentration

The maximum concentration of Zn in the root of *E. hypnoides* was 77.3 mg/kg and the minimum was 21 mg/kg. In the root, the maximum concentration of Zn was 76 mg/kg and 20 mg/kg were the lowest (**Table 9**). Higher concentration of Zn was recorded in the root of the plant than the leaf with the mean concentration of Zn in the root being 44.98 mg/kg while the average concentration of Zn in the leaf was 44.1 mg/kg. The concentration of Zn in the parts of plants were all more than the concentration of Zn in the soil where the plant sample was taken. This shows that plant bioaccumulate heavy metals in many folds than the soil under normal growing condition [78].

The recommended permissible limit of Zn in plant is 50 mg/kg according to the World Health Organization (WHO) [79]. This is higher than all the concentration of Zn in the roots and leaves of *E. hypnoides* except the eastern plant sample at 500 m (**Table 9**). The

Sampled sites	CF (0–10 cm) at 500 m	CF (10–20 cm) at 500 m	CF (0–10 cm) at 1000 m	CF (10–20 cm) at 1000 m
North	1	0	1	2
Northeast	1	10	1	1
Northwest	2	1	1	1
East	1	0	1	1
Southeast	1	1	0	1
West	1	1	1	1
Southwest	1	0	N/A	N/A
South	1	1	N/A	N/A
PLI	**1**	**1**	**1**	**1**

N/A = means no access to take samples.

Table 8.
The concentration factor and pollution load index of cadmium at various sampled sites and depths.

Location	Distance (m)	Zn Concentration (mg/kg)	
		Root	Leaf
North	500	37.7	35.2
	1000	21.0	20.0
East	500	**77.3**	**76.0**
	1000	47.9	45.1
Mean		44.9	44.1
SD		23.7	23.7
Range		21.0–77.3	20.0–76.0
WHO limit		50	

Bold to indicate concentrations above the permissible limit.

Table 9.
Concentration of zinc in plant sample.

proximity of the eastern side to mine waste and the dispersion of Zn by wind is responsible for the high concentration of Zn recorded at 500 m away from the mine [80].

3.3.2 Cadmium concentration

The concentration of Cd recorded in the roots and leaf of the plant were all higher than the permissible limit of Cd in plant, 0.025 mg/kg [81]. This means that the plant is polluted and therefore not suitable for consumption. The grazing of cattle in this environment must be avoided at all costs.

Overall, the average concentration of Cd in the root is more than the average concentration of Cd in the leaf. This is similar to Zn concentration in the plant which means the plant cannot translocate heavy metals from the root to the leaf [82].

The concentration of Cd in the plant's root and leaf are all more than the concentration of Cd recorded in the soil where the plant samples was taken. Lower concentrations of Cd were also recorded 1000 m away from the mine than at 500 m

Location	Distance (m)	Cd Concentration (mg/kg)	
		Root	**Leaf**
North	500	0.06	0.056
	1000	0.03	0.02
East	500	**0.18**	**0.16**
	1000	**0.15**	**0.14**
Mean		0.11	0.09
SD		0.07	0.07
Range		0.02–0.18	0.02–0.16
WHO limit		0.02	

Bold to indicate concentrations above the permissible limit.

Table 10.
Concentration of cadmium in plant sample.

(**Table 10**). The deposition of cadmium oxide in the air due to mining activities in the rea is responsible for the wide spread of Cd in the area. It has been reported that Cd is dispersed widely by aid from melting and smelting activities plus additional anthropogenic pathways [83].

3.3.3 Lead concentration

The concentration of Pb in the plant's leaf and root were all higher than the permissible limit of Pb in plant, 2 mg/kg according to WHO [84] except the concentration of Pb in plant grown 1 km away from the mine in the northern part of the mine (**Table 11**).

Punshon et al. [85], reported a direct proportion between the concentration of heavy metal in soil and plant. Similar to the trend noticed in Zn and Cd, the concentration of Pb in the leaf is lower than the recorded concentration of Pb in the root.

3.3.4 As concentration

In the root of E. hypnoides, the maximum concentration of As recorded was 2.8 mg/kg and the lowest was 0.2 mg/kg. The minimum concentration recorded in the

Location	Distance (m)	Pb Concentration (mg/kg)	
		Root	**Leaf**
North	500	0.7	0.5
	1000	**15.0**	**14.8**
East	500	0.9	0.8
	1000	0.7	0.6
Mean		4.3	4.1
SD		7.1	7.1
Range		0.7–15.0	0.5–14.8
WHO limit		2	

Bold to indicate concentrations above the permissible limit.

Table 11.
Concentration of lead in plant sample.

Location	Distance (m)	As Concentration (mg/kg)	
		Root	Leaf
North	500	**0.2**	0.2
	1000	**2.8**	**1.5**
East	500	**0.3**	**0.3**
	1000	**0.3**	**0.3**
Mean		0.9	0.6
SD		1.2	0.6
Range		0.2–2.8	0.2–1.5
WHO limit		0.2	

Bold to indicate concentrations above the permissible limit.

Table 12.
Concentration of arsenic in plant samples.

plant's leaf was 0.2 mg/kg and 1.5 mg/kg as the maximum concentration (**Table 12**). Overall, the mean concentration of As in the soil is higher than the concentration recorded in the plant. This shows that the plant has a low potential of taking As from the soil.

The permissible limit of As in plant is 0.2 mg/kg [85]. With the recorded concentration of As in the studied plant all above 0.2 mg/kg, except the leaf concentration of the north within 500 m which is approximately 0.2 mg/kg. It means that the plant is contaminated therefore not suitable to feed cattle.

In order to determine the dependency of As, Cd, Pb and Zn concentration in the root and leaves of *E. hypnoides*, Chi-square test was used. Using SPSS to evaluate the result of heavy metal concentration in plant samples, it was revealed that the P-value, 0.05, is lower than the significance level of 0.213. This means that the null hypothesis can be rejected, and we can conclude that the concentration of As, Cd, Pb, and Zn in the roots and leaf of *E. hypnoides* are independent.

In conclusion, the results of all the evaluation are the same for all the metals. This means the studied heavy metals bioaccumulated in the plant by absorption through the roots and are translocated to the leaf. Hence, the reason for the consistency observed in all the studied heavy metals.

3.4 Heavy metal uptake by plants

Importantly, it must be noted that plants have the potential and mechanism to uptake heavy metals by absorption from the soil through the roots [86]. To calculate the uptake of As, Cd, Pb and Zn by *E. hypnoides* eq. 3 was used and the result is in table **Figures 2**–**5** below.

3.4.1 Zinc uptake by plant

The CF of Zn based on the recorded concentration of Zn in the plant and soil indicated that the plant is a good accumulator of Zn. The CF value of Zn is greater than 1 (**Figure 2**). This means that *E. hypnoides* can be useful to phyto-remediate a Zn polluted soil. Unfortunately, the consumption of plants with a high concentration of Zn is not healthy for both human and animals [87].

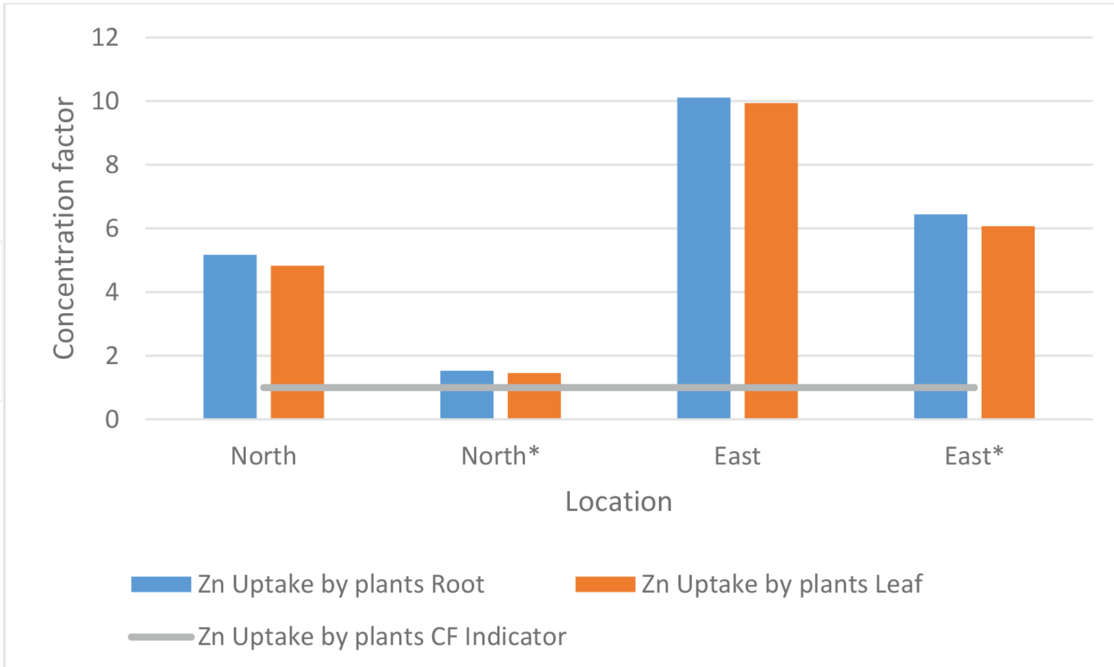

Figure 2.
Zinc concentration factor in Eragrostis hypnoides. (north and east* were taken at 1000 m while north and east were taken at 500 m).*

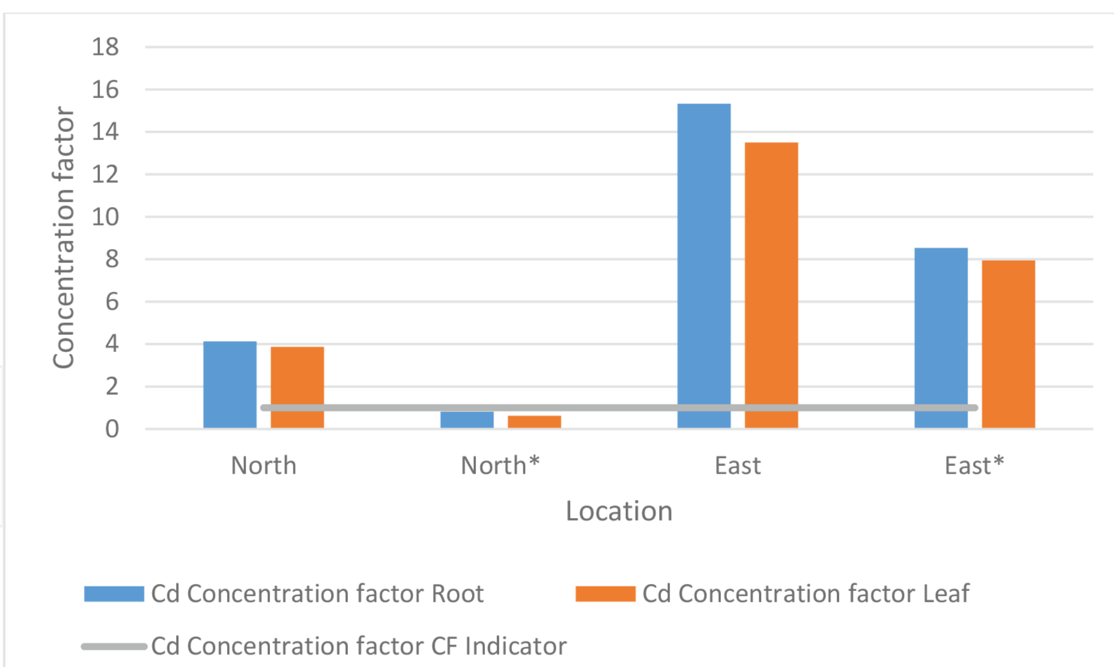

Figure 3.
Cadmium concentration factor in Eragrostis hypnoides. (north and east* were taken at 1000 m while north and east were taken at 500 m).*

3.4.2 Cadmium uptake by plant

The CF result indicated that 75% of the sampled sites have Cf greater than 1 in the root and leaf. The CF of the plant from the northern location of the sampled area is the only exception (**Figure 3**).

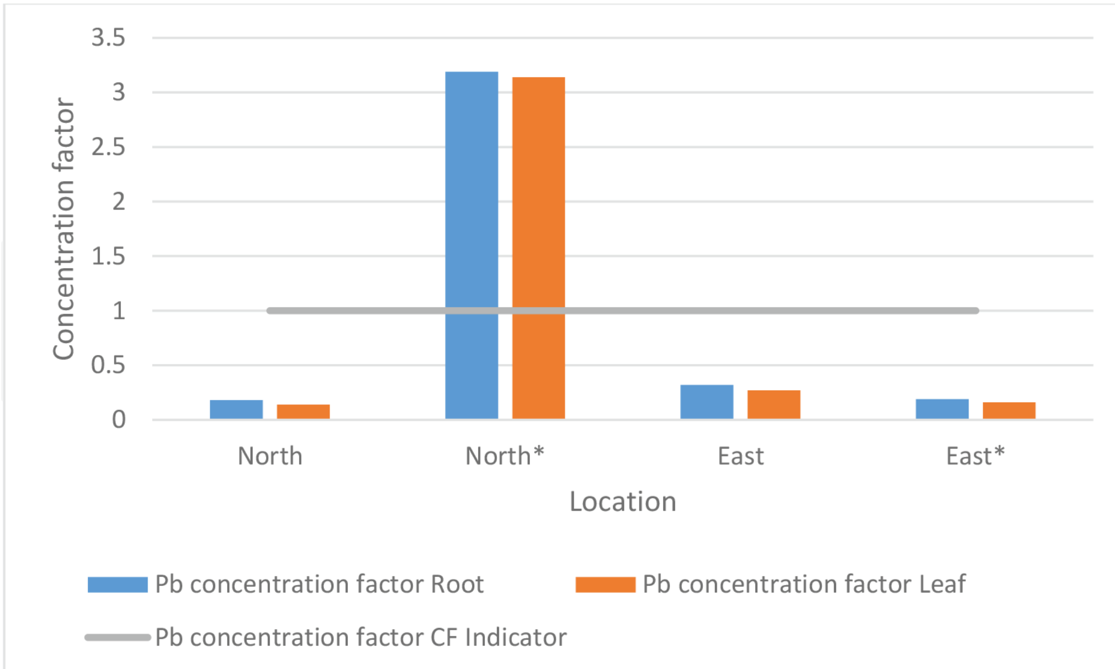

Figure 4.
Lead concentration factor in Eragrostis hypnoides. (north and east* were taken at 1000 m while north and east were taken at 500 m).*

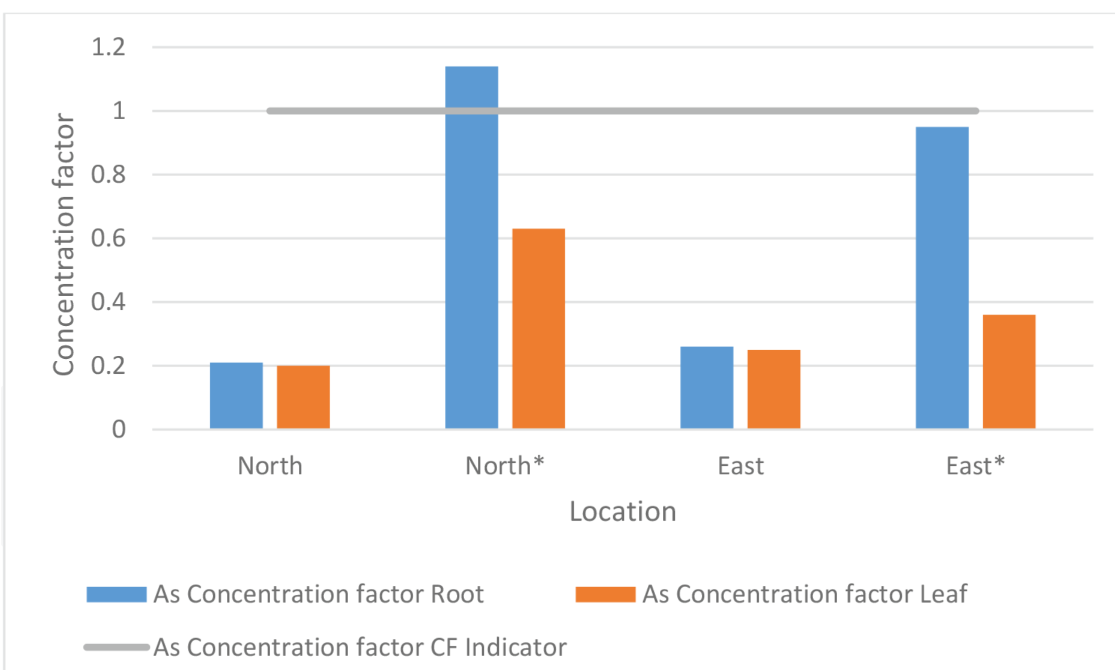

Figure 5.
Arsenic concentration factor in Eragrostis hypnoides. (north and east* were taken at 1000 m while north and east were taken at 500 m).*

Similar to Zn, this confirms that *E. hypnoides* can be used for the phytoremediation of Cd polluted soil. One of the most important factor considered in order to evaluate the ability of a plant to be used for phytoremediation is that the plant must have a high tolerance to high heavy metal concentration and must be able to bioaccumulate these heavy metals in their stem, leaves and fruits [88].

3.4.3 Lead uptake by plant

Due to the ability of Pb to bind to organic matters in soil, the ability of plants to uptake Pb is limited [89]. This is confirmed by the result of Pb CF which wsere all below 1 except for the northern sample at 1 km from the mining site (**Figure 4**). This exception is warranted due to the high concentration of Pb recorded in the plant (**Table 11**) and soil (**Table 3**) at this site.

It can be concluded that *E. hypnoides* cannot be used for the phyto-extraction of Pb from the soil. According to Islam et al. [90], they reported that a plant can be used for the phyto-extraction if the plant species can bioaccumulate toxic metals in the soil.

3.4.4 Arsenic uptake by plant

Similar to the uptake of Pb by the studied plant, the CF of As is below 1 in all the sampled sites besides in the root of the northern site at 1 km away from the gold mine (**Figure 5**). This means that the studied plant cannot bioaccumulate As and as a result cannot be used for the phytoremediation of As polluted soil [91].

4. Conclusions

From the results of the concentrations of As, Cd, Pb and Zn in both the soil and plants samples, the following conclusions have been reached to meet the objectives of this study:

1. There is a direct relationship between the concentrations of the studied heavy metals in soil and plants. This means *E. hypnoides* bioaccumulate Zn and Cd within the mining area. This constitutes a health risk to both humans and animals (cattle that grade in this environment)

2. The concentration of the studied heavy metals in soil within the gold mine are all below the permissible limit of soil used for agriculture as approved by the South African government agency. Therefore, the soil is not polluted.

3. The concentration of the studied heavy metals in plants are more than the permissible limit s proposed by the WHO. This can negatively compromise the health of animals and human that feed directly and indirectly on the plant. This means that the feeding of cattle with the *E. hypnoides* from the area should be discouraged and the grazing of animals within the 1 km radius of the gold mine must be discontinued.

4. *E. hypnoides* has the potential to bioaccumulate Zn and Cd. Due to this, the plant can be used for the phytoremediation of Zn and Cd polluted soil.

It is highly recommended that thorough research should be done within the proximity of gold mines to ascertain the concentration of various toxic heavy metals in the environment. This is essential because commercial farms and animal husbandry are commonly established within mining areas. This study is important to safeguard the health of the citizens and food security.

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