Journal of Agriculture and Crops
ISSN(e): 2412-6381, ISSN(p): 2413-886X
Vol. 8, Issue. 3, pp: 197-207, 2022
URL: https://arpgweb.com/journal/journal/14
DOI: https://doi.org/10.32861/jac.83.197.207

Academic Research Publishing Group

Original Research

Open Access

Heavy Metal Contamination and Health Risk of Soils and Vegetables Grown Near a Gold Mine Area: A Case Study of Barberton, South Africa

Ayanda N. Shabalala (Corresponding Author)
School of Biology and Environmental Sciences University of Mpumalanga- Mbombela, South Africa
Email: Ayanda.Shabalala@ump.ac.za

Phumelele D. Ngwenya
School of Agricultural Sciences University of Mpumalanga- Mbombela, South Africa

Moses Timana
School of Agricultural Sciences University of Mpumalanga- Mbombela, South Africa

Article History
Received: 19 February, 2022
Revised: 5 May, 2022
Accepted: 7 June, 2022
Published: 14 June, 2022

Abstract

Pollution from mining operations has a direct impact on agricultural production and can lead to potential health risks because of the accumulation of heavy metals in vegetables. Vegetables and soil samples collected from Thaba Nchu farm located near a gold mining site were analysed to determine the concentration of heavy metals. Soil and vegetable samples were digested using the wet method and heavy metals were analysed using the inductively coupled plasma-mass spectrometry technique. The soil-to-plant Transfer Factors (TF) and Health Risk Index (HRI) were calculated. The highest mean levels of Fe, Mn, Ni, Pb, and Cu were detected in spinach while the highest mean level of Zn was found in onion. Iron levels in lettuce, spinach, beetroot, onion, and carrot ranged from 2203 to 3404 mg/kg which was above the permissible limits (450 mg/kg) recommended by the Food and Agriculture Organization–World Health Organization (FAO/WHO). The concentration of Pb (0.4 mg/kg) and Cr (13.8 mg/kg) in spinach exceeded the permissible level recommended by FAO/WHO of 0.3 mg/kg and 1.3 mg/kg, respectively. The metal transfer factors in vegetables were in the order: Cd>Pb>Cu>Fe>Ni>Co>Zn>Cr>Mn. The daily intake and HRI of Mn and Fe in vegetables were above safe levels. There was no obvious heavy metal contamination in the soil and irrigation water. These results suggest that the consumption of vegetables grown on the study site could pose danger to human health. High heavy metal content in crops was attributed to the accumulation of Fe and Mn, which are the major ores extracted from the mining activities in the study area. Given the potential health risks, regular monitoring of heavy metal contamination in the soils and crops is recommended.

Keywords: Health risk index; Heavy metals; Soils; Transfer factor; Vegetable crops.

1. Introduction

Depletion of mineral resources, increasing budget constraints as markets tighten up and the fall of commodity prices are among the leading causes of mine scale-down and subsequent shut down. According to Sheoran, *et al.* [1] mining activities often result in the alteration of landforms and mining waste, such as acidic dumps. These activities can lead to multiple effects, such as soil erosion, air and water pollution, toxicity, and loss of biodiversity. This brings into focus the need to convert post-mining land to new productive uses. The most common post-mining land use purposes include agriculture, forestry, recreation and construction. The current land use, infrastructure and facilities, the extent of environmental impacts, such as soil and water pollution, will determine the suitability of post-mining land use activity [2]. The re-establishment of historical land cover on an abandoned mine may be more costly than establishing a viable post-mining land use, such as agriculture, which could add value to the community and may ease the burden caused by the loss of mining-related jobs by creating employment. However, the re-use of a post-mining area is not without its limitations and can pose serious challenges for the environment and human health.

Previous studies on abandoned mines around the world show high levels of metals in soils, streams and plants, which can pose serious health problems in humans and animals. Mine sites are known to be sources of potentially harmful elements, such as Al, Pb, Zn, Cd, Mn, Cr, Co, Cu, Ni, As and Mo [3-5]. Contamination of soil and vegetables by heavy metals is not just an environmental issue but these metals can also reach the food chain through various biochemical processes. Koprivica, *et al.* [6] reported that toxic metals most often found in soil and food are Pb, Cd, As and Hg. Excessive accumulation of these heavy metals in agricultural soils not only results in soil contamination but also leads to elevated heavy metal uptake by vegetables which affect food quality [7]. Vegetables take up heavy metals and accumulate them in their edible and non-edible parts at quantities high enough to cause health problems to both animals and humans [8]. Consumption of food contaminated by heavy metals can deplete essential nutrients in the body and has been recognized as a risk to human health [9]. Ingestion of these metals can bring about weakening of the immune system, psycho-social dysfunctions, gastro-intestinal cancer, cardiovascular, renal, neurological and bone diseases [4, 7, 10].

Previous research has suggested that in some cases, vegetables grown in the vicinity of a mining area have elevated levels of heavy metal contamination. A study by Punia and Siddaiah [11] showed that vegetables grown in a copper mining area are more contaminated with Cu and Zn compared to those far from mining activities. The primary heavy metal contaminants in vegetables grown near a Pb/Zn smelter are Pb and Cd [12]. Elevated concentrations of Pb, Zn, Cr and Mn were found particularly in leafy vegetables grown in the industrial area [13].

The rehabilitation of mined land to produce viable crops is increasingly being seen as a possible remedial solution to a large number of abandoned mines. Although agriculture can be viable post-mining land use, sustainable re-use of a post-mining area requires evaluation of land use potentials and limitations. The overall suitability of the site for agricultural production, as well as, the potential health risk to the locals who consumes the crops should also be evaluated. In the present study, we investigated the levels of contamination of heavy metals in vegetable crops that are grown near Barberton Mine, Mpumalanga Province, South Africa. In addition, we assessed the health risk associated with the consumption of these vegetables. Six types of vegetables were sampled and analysed for Cu, Zn, Mn, Fe, Co, Cd, Ni, Pb and Cr. The contamination status of the vegetables was evaluated with respect to WHO/FAO guidelines. The Hazard Index (HI) was calculated to estimate the health risk associated with heavy metal exposure through vegetable consumption.

2. Materials and Method

2.1. Study Area

The study was carried out in Thaba Nchu farm (31°3’55.274” E, 25°44’24.014” S) located in a rural community in Barberton, South Africa (Figure 1). This community surrounds the Barberton mines, which are prominent for gold mining that started in the late 19th century. Barberton mines, located in the Barberton greenstone belt of Southern Africa, is a low-cost, high grade operation comprising three underground mines namely: Fairview, Sheba and New consort [14]. The Barberton area has a mean annual rainfall of 861 mm while the average temperature is 20 °C. The hills are characterized by diverse vegetation with a representation of three biomes: Savanna, Grassland and Forest. There are eight vegetation types found in the area, namely, the Kaalrug Mountain Bushveld, Legogote Sour Bushveld, Swaziland Sour Bushveld, Barberton Serpentine Sourveld, Barberton Montane Grassland, the KaNgwane Montane Grassland, Northern Mistbelt Forests and Scarp Forests [15, 16]. Common plants grown and consumed in the area include spinach, beetroot, cabbages and tomatoes. Geologically, the main stratigraphic units of the Barberton supergroup comprise the Onverwacht group, a thick assortment of ultramafic and mafic volcanic, including several sill-like layered ultramafic complexes, which are overlaid by the fig tree group of turbiditic greywacke sandstones and associated mudstones and banded ferruginous shales [17]. Gold deposits in the area occur in association with major compressional structures, veins and stockworks of quartz, carbonate and sulphide bodies that include pyrite and arsenopyrite [18].

Figure-1. (A) Aerial image of the study area B) Thaba Nchu farm near the Fairview mines in Barberton, Mpumalanga, South Africa

2.2. Soil Sampling and Analysis

Soil samples were collected from the Thaba Nchu farm located within the Barberton gold mining area. Thaba Nchu farm which was previously a mining land that belonged to Fairview mine in Barberton was donated to the community to start a vegetable garden. The farm is located within 1 km of an existing mining operation. Samples were collected by a process of composite sampling to a depth of 15 cm. Four soil subsamples were taken and mixed together at each sampling site. The composite soil samples were then stored in labelled polythene sample bags and taken to a laboratory for physical and chemical analysis. A control soil sample was collected approximately 15 km from Thaba Nchu farm and is assumed not to be contaminated by anthropogenic heavy metals. To determine the concentration of metals, 15 ml of Diammonium ethylenediaminetetraacetic acid (EDTA) extraction solution was added to 5 g of soil in a 50 ml volumetric flask. The mixture was stirred using a rotatory stirrer for 1 h and then filtered with a 0.45 um paper filter. The filtered solutions were analysed for Cu, Fe, Mn, Zn, Co, Cd, Ni, and Pb by PerkinElmer SCIEX (Concord, Ontario, Canada) ELAN® 6000 Inductively Coupled Plasma–Mass Spectrometry (ICP-MS) system at the Agricultural Research Council (ARC) Analytical Laboratories, Pretoria, South Africa.

2.3. Vegetable Sampling and Analysis

Vegetable samples of cabbage (*Brassica oleracea*), lettuce (*Lactuca sativa*), spinach (*Spinacia oleracea*), beetroot (*Beta vulgaris*), onion (*Allium cepa*) and carrot (*Daucus carota subsp. Sativus*) were also collected from the same site where soils were collected. The plants were washed with tap water to remove soil particles. The plants were then placed in paper bags, properly labelled and air-dried for 7 days. Thereafter, samples were dispatched to a laboratory for analysis. To determine the concentration of heavy metals in samples, 5 ml of HNO_3 and 1 ml of H_2O_2 were added to 0.5 g of dry vegetable sample and digested at 100 °C. The extract was filtered and subject to analysis. The metals (Cu, Fe, Mn, Zn, Co, Cd, Pb, and Ni) were analysed by IMP-MS.

2.4. Irrigation Water Sampling

Water samples were collected in 1000 ml High Density Polyethylene (HDPE) plastic bottles and filtered using filter paper with a pore size of 0.45 mm. The filtrate of each sample was preserved by adding two drops of concentrated HNO_3 (standard grade). Samples were analysed by an Atomic Absorption Spectrometer (VARIAN AA240).

2.5. Data Analysis

2.5.1. Soil-to-Plant Transfer Factor (TF)

The soil-to-plant transfer factor is one of the key components of human exposure to metals through food chains. The transfer of metals from soil to plant tissues are studied using an index called Transfer Factor (TF). It is calculated as a ratio of the concentration of a specific metal in plant tissue to the concentration of the same metal in the soil [19].

$$TF = C_{plant}/C_{soil} \quad \text{(Eq.1)}$$

2.5.2. Daily Intake of Metals (DIM)

The Daily intake of vegetables was calculated using the following equation:

$$DIM = C_{metal} \times C_{factor} \times D_{food\ intake} / B_{average\ weight} \qquad (Eq.2)$$

where, C_{metal} and C_{factor} represent the heavy metal concentrations in plants (mg/kg) and the conversion factor which is 0.085 [4, 20]. The daily intake values are calculated by taking heavy metal concentration in all six varieties of vegetables, considering that human average body weight ($B_{average\ weight}$) in Africa is 60.7 kg [21] and the intake of vegetables ($D_{food\ intake}$) by South Africans is 200 g per person per day [22, 23].

2.5.3. Health Risk Index

The risk to human health by intake of metal through the consumption of vegetables in the study area was calculated using the following relationship:

$$HRI = DIM/RfD \; [24] \qquad (Eq.3)$$

where DIM represents the daily exposure of metals and R_fD represents the reference oral dose. If the ratio is lower than 1, the vegetables are not likely to induce any health hazard to humans. If HRI is equal to or higher than 1, it is considered not safe for humans as potential health risks may occur. Therefore interventions and protective measurements should be taken [20, 25]. R_fD values used in this study for Cu, Mn, Fe, Zn, Co, Cd, Ni, and Pb are 0.04, 0.014, 0.7, 0.3, 0.02, 0.001, 0.02, and 0.0035 mg/ kg bw/ day [24, 26], respectively.

3. Results and Discussion

Table 1 shows the level of heavy metal (Cu, Zn, Mn, Fe, Cd, Co, Cr, Pb and Ni) in vegetables (cabbage, beetroot, carrot, spinach, lettuce, and onion) from the study site. Results of analyses of vegetable samples showed that the copper concentrations ranged from 5 mg/kg in cabbage to 23 mg/kg in spinach, which is below the recommended [27] guidelines of 73.30 (40) mg/kg. For Zn, the concentrations ranged from 24 mg/kg for carrot and beetroot to 42 mg/kg for onion which again is much lower than the WHO/FAO recommended value of 99.40 (60) mg/kg. For iron, the values ranged from 2203 mg/kg in lettuce to 3532 mg/kg in carrot, which was above the WHO/FAO recommended value of 450 mg/kg. In the case of Mn, the values ranged from 37 mg/kg for cabbage to 245 mg/kg for spinach. The highest levels of Co, Cd and Ni in vegetable samples were reported as 1.2, 0.07, and 7.4 mg/kg, respectively. and were below the corresponding permissible limit suggested by the FAO/WHO expert committee on food additives [28]. The Concentration of Pb in the vegetable crops ranged from 0.13 to 0.4 mg/kg. The concentration of Pb in spinach exceeded the permissible level recommended by FAO/WHO of 0.3 mg/kg. Cr concentrations in cabbage, lettuce, beetroot, onion and carrot were below the detection limit. A high Cr concentration of 13.8 mg/kg in spinach was reported and exceeded the recommended maximum level of 1.3 mg/kg in vegetables. The Cr concentration in spinach exceeded by up to 13 times the Cr regulatory levels allowed for this crop. This may be due to the absorption of Cr contents from the polluted air. Hence, spinach may be helpful in the reduction of air pollution. Similar results were found by Alfaro, *et al.* [29] who reported higher concentrations of Cd, Cr, Ni, Pb, and Zn in leafy vegetables than fruits and tubers. Leafy species, such as cabbage, spinach, and lettuce have high concentration of metals, representing a significant route for human metal exposure. According to Rajan, *et al.* [30], the accumulation of metals is much higher in leafy vegetables due to the much higher translocation and transpiration rate in leafy vegetable types.

Table-1. Metal concentrations in vegetable crops (mg/kg)

Vegetable	Cu	Fe	Mn	Zn	Co	Cd	Cr	Ni	Pb	Σ Heavy metals
***FAO/WHO permissible level**	73	450	500	100	50	0.1	1.3	67	0.3	
Cabbage	5	95	37	26	0.22	0.024	<0.5	2.9	0.13	166,274
Lettuce	12	2203	105	33	0.42	0.066	<9.0	6.7	0.32	2360,506
Spinach	23	3402	245	28	1.2	0.042	13.8	7.4	0.4	3720,842
Beetroot	10	2958	153	24	1.03	0.028	<0.5	1,7	0.13	3147,888
Onion	10	3404	150	42	0.13	0.011	<0.5	3.5	0.13	3609,771
Carrot	9	2532	117	24	0.22	0.017	<3.5	4.5	0.3	2687,037

* Integrate World Health Organization [28] maximum permissible

The concentrations of Fe, Mn, Zn, Cu, Co, Cd, Cr, Ni and Pb in the soils are below their respective World Health Organization [28] maximum permissible levels in soils of 50 000, 2000, 300,100, 50, 3, 100, 50 and 100 mg/kg, respectively, as shown in Table 2. This implies that heavy metal contamination in the agricultural soils is at a safe level. The pH of the soils was between 4.97 and 8.06 with an average of 7.50. The soils are alkaline as 72% of the samples had a pH>8. Jia, *et al.* [31], reported that most metals tend to be available in acidic pH. At higher soil pH, the mobility and solubility of heavy metals are limited. This explains the observed low concentrations of heavy metals in the soils. Table 2 also shows the heavy metal concentrations in the control soil sample (15 km from the mine site) were higher than those at the Thaba Nchu farm with the exception of Mn and Fe concentrations which are higher in the soil samples from the study site. It may therefore be inferred that Mn and Fe concentrations recorded in the soils are a result of pollution from nearby mining activities.

Table-2. Metal concentrations in soils (mg/kg)

Vegetable	**Cu**	**Fe**	**Mn**	**Zn**	**Al**	**Co**	**Cd**	**Cr**	**Ni**	**Pb**	**Σ Heavy metals**
***FAO/WHO permissible level**	100	50000	2000	300		50	3	100	50	100	
Cabbage	0.99	49.2	236.2	3.62	2.00	0.014	0.0001	0.210	0.086	0.008	310.788
Lettuce	1.37	55.3	230.1	1.99	4.00	0.018	0.0001	0.310	0.120	0.0009	293.078
Spinach	0.10	58.1	214.3	1.13	3.00	0.017	0.0001	0.298	0.11	0.012	277.079
Beetroot	0.10	50.1	206.8	1.59	7.00	0.018	0.0001	0.3	0.12	0.012	266.027
Onion	1.65	61.6	230.9	1.77	4.00	0.019	0.0001	0.298	0.130	0.007	300.370
Carrot	1.74	47.2	230.4	0.83	5.00	18.34	0.0001	0.310	0.120	0.008	285.624
Control soil	5.15	31.7	105.6	27.9	4.00	2.02	0.000014	6.29	5.23	6.67	194.56

* Integrate World Health Organization [28] maximum permissible

The order of abundance of individual heavy metals in vegetables is;

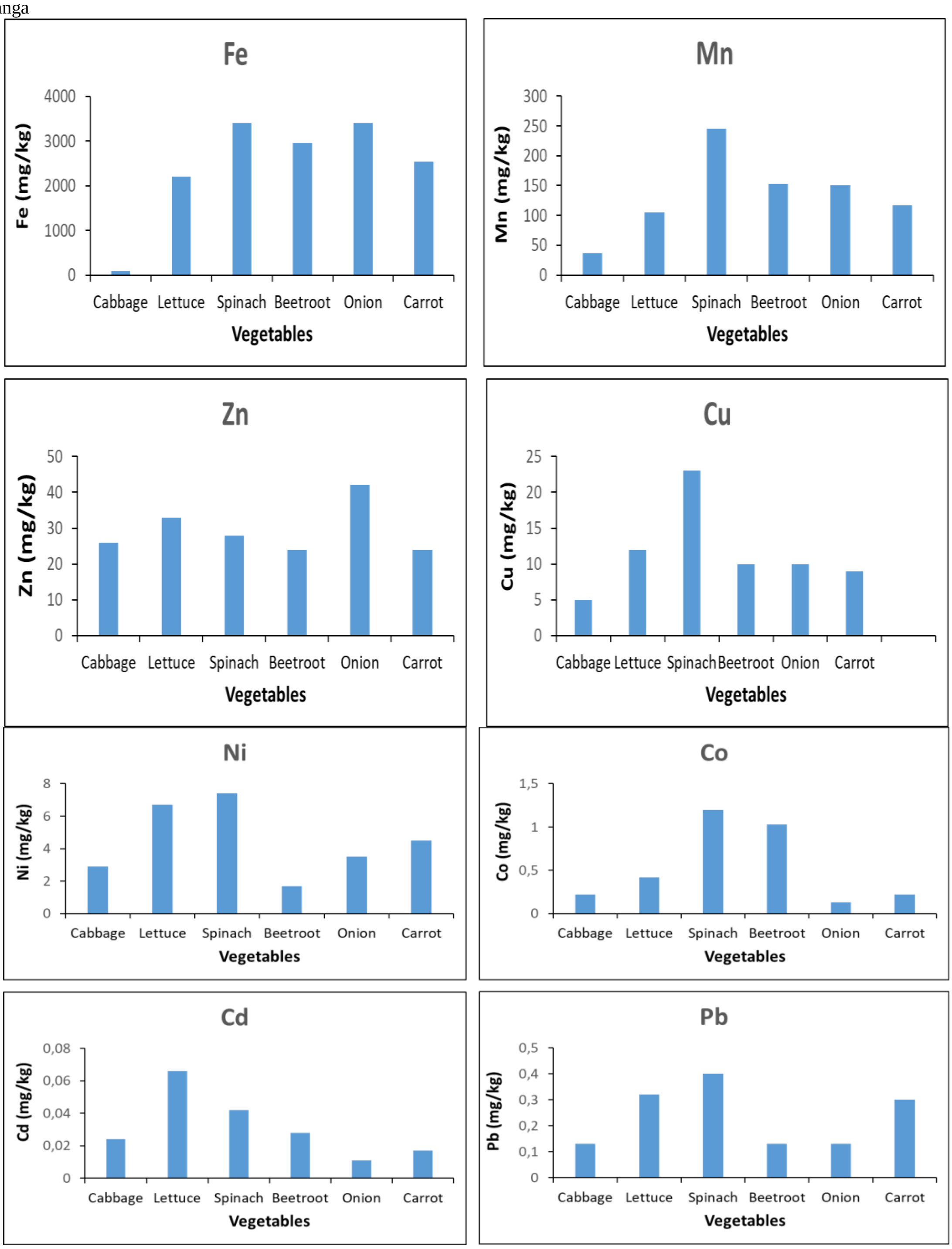
Fe > Mn > Zn > Cu > Ni > Cr > Co > Pb > Cd

The total concentration of Fe in vegetables and soils is 14594 mg/kg and 353.20 mg/kg, respectively, with Fe in vegetables being 41 times more than in soils. This indicates that Fe in vegetables may be due to external factors and the high concentrations of Fe in vegetable crops may be due to the higher absorption capacity of the crop's roots, or it may be due to the presence of higher amounts of iron in the respective soil. [32] reported that the highest uptake of heavy metals occurred in roots rather than in the leaves because roots have a binding site for metals. Different vegetables have different heavy metal accumulation capacities. The total concentration of Mn in vegetables and soils is 807 mg/kg and 1454.30 mg/kg, respectively, indicating lower absorption of Mn from the soil by plants. The sum of the concentrations of the heavy metals was higher in spinach and onion and lowest in cabbage. The rank of order of vegetables according to their decreasing metal concentrations is;

spinach > onion > beetroot > carrot > lettuce > cabbage

According to Punia and Siddaiah [11] leafy vegetables, such as spinach have a high metal accumulation capacity because leaves act as an entry point for heavy metals from the atmosphere and also because of the high surface area of these vegetables. This is consistent with a study by Xu, *et al.* [33] who suggested that foliar uptake of atmospheric particles was an important source of Pb and Cd accumulation in leafy vegetables. In addition to foliar uptake, heavy-metal uptake from roots was another major pathway of heavy-metal accumulation in leaves. Itanna [34], observed that the high transpiration rate and fast growth rate of leafy vegetables also contributed to the high accumulation of metals by these plants. The levels of heavy metals in vegetable crops are shown in Figure 2.

Figure-2. The distribution of heavy metals (Fe, Mn, Zn, Cu, Ni, Co, Cd, and Pb) in vegetable crops at Thaba Nchu farm in Barberton, Mpumalanga



We also studied the extent of pollution caused by irrigation water. Table 3 shows the concentrations of heavy metals in the water from boreholes used for irrigation at the site. Physico-chemical parameters such as the pH, electrical conductivity (EC), Total Dissolved Solids (TDS), as well as, Na^+, HCO_3^-, Cl^-, Cu, Fe, Mn and Zn were analysed and compared with the Food and Agriculture Organization (FAO) irrigation water quality criteria, as well as, the South African water quality guidelines for agricultural use [35]. The values for the pH, EC, Na^+, Cl^-, Sodium Adsorption Ratio (SAR) were found to fall within acceptable levels for irrigation water use. Elevated levels of heavy metals in irrigation water would lead to an increase of these metals in agricultural soils, an increase in the uptake of the heavy metals by the crops grown on these soils and subsequently an increase in levels of heavy metals in the human body. The study revealed that Cu, Fe, Mn Zn, Co, Cd, Ni, Cr and Pb in the irrigation water were within the recommended maximum concentration for crop production and are therefore unlikely to results in the contamination of soils and crops. The TDS value for the water sample which was 461.79 mg/L, slightly exceeded the permissible limit for irrigation use. The acceptable TDS concentration for irrigation water is limited to 450 mg/L [27]. High TDS is an indication of high salinity levels in the water, which can reduce crop production and restrict or inhibit the ability of plants to take up soil water and nutrients, leading to stunted plant growth and yield reduction [36].

Table-3. Heavy metal concentrations in irrigation water samples

Parameter	Thaba Nchu farm	DWA irrigation	FAO
pH	6.61	6.5 - 8.4	6.5 - 8.0
EC (Us/cm)	659.70	400	< 700
TDS (mg/l)	461.79		< 450
Na (mg/l)	21.79	70	< 69
Cl (mg/l)	24.43	100	< 142
HCO_3 (mg/l)	295.73		< 92
SAR	0.54	2.00	
Zn (mg/l)	< 0.01	1.00	2.00
Cu (mg/l)	< 0.01	0.2	0.2
Mn (mg/l)	< 0.01	0.02	0.2
Fe (mg/l)	< 0.01	5.0	5.0
Co (µg/l)	0.22		
Cd (µg/l)	< 0.05		
Cr (µg/l)	< 3.07		
Ni (µg/l)	< 0.07		
Pb (µg/l)	0.23		

Higher TF values (≥ 1) are an indication of higher absorption of metal from the soil by plants, whereas the lower values (<1) indicate a poor response of plants towards metal absorption and the plant is thus suitable for human consumption [19]. The Transfer factor (TF) values for Cu, Mn, Fe, Zn, Co, Cd, Cr, Ni and Pb varied among crops. From Table 4 it is observed that Cu, Cd, Zn, Pb and Fe had higher transfer factors for all crops. Zn ranged from 7.18 (cabbage) to 28.92 (carrot). All vegetables exhibited significantly higher levels of Fe (1.93–59.04), Cd (110-660), Pb (10.83-444), Cu (5.05-230), Zn (7.18-28.92), and Ni (15.45-77.91). This indicated that all the crops investigated had a high accumulation capacity for these metals. The highest TF values were 660 (lettuce) for Cd and 444 (spinach) for Pb. Our results are consistent with previous studies which showed that the highest quantities of heavy metals are found in leafy vegetables [7, 37]. Mn had the lowest transfer factor (0.16 – 5.08) in all the vegetables. The trend of TF for heavy metals in vegetable samples was in order: Cd>Pb>Cu>Fe>Ni>Co>Zn>Cr>Mn. Cadmium transfer in leafy vegetables such as spinach and lettuce were significant. The higher transfer factor of cadmium was also reported in a similar study on spinach by Chang, *et al.* [38] and Ngugi, *et al.* [39] who found that leafy vegetables had differential uptake and mobility of cadmium, with spinach having the highest cadmium uptake and translocation to tissues. Apart from the high transfer factor, in the vegetable crops collected from the study area, Cd was present with low concentration among the studied heavy metals. This might be due to the reason that Cd is easily absorbed by crops and scatter readily to the other parts of the plants [40].

The TF values obtained for Cu, Co, Cd, Ni, Pb, Zn and Fe are higher than 1, which could pose health risks to humans because the vegetables under investigation are widely consumed by people. Furthermore, based on the very high TF values, it can be deduced that the soil is not the only possible source of contamination. Heavy metals may be introduced into the soil and vegetables through air deposition of contaminants from the surrounding mining activities. Plants may take up heavy metals by absorbing them from deposits on the parts of the plants exposed to the air from polluted environments [41].

Table-4. Transfer factor of heavy metals from soil to vegetables

Transfer factor						
Elements	Cabbage	Lettuce	Spinach	Beetroot	Onion	Carrot
Cu	5.05	8.76	230	100	6.06	5.17
Mn	0.16	0.46	1.14	0.74	0.65	0.51
Fe	1.93	39.84	58.55	59.04	55.26	53.64
Zn	7.18	16.58	24.78	15.09	23.73	28.92
Co	0.01	30.00	66.67	60.59	7.22	11.58
Cd	240	660	420	280	110	170
Cr	0.00	0.00	44.52	0.00	0.00	0.00
Ni	24.17	77.91	61.67	15.45	29.17	34.62
Pb	16.25	40.00	444.44	10.83	10.83	42.86

3.1. DIM and HRI of the Metals

Table 5 shows the approximate daily intake of metals by human beings from vegetables. The daily heavy metal intake of humans through the consumption of vegetables in the study area was compared to the R_fD limit set by WHO. The DIM values of Mn and Fe were high through the consumption of vegetables grown near a gold mine and exceeded the USEPA IRIS and WHO/FAO limit of 0.014 and 0.7, respectively, for daily consumption of vegetables. The intake of Cu, Cd, Ni, Pb, and Zn by all the vegetables was below the permissible limits recommended by the World Health Organisation and USEP IRIS. The highest intake of Mn and Fe was from the consumption of lettuce, spinach, beetroot, onion, and carrot. Cu, Zn, Ni and Pb intake were highest in spinach. The daily consumption of contaminated crops in the study area may cause severe health risks by ingestion of Mn and Fe in the tubers and leafy vegetables. High heavy metal content in crops is attributed to the accumulation of Fe and Mn, which are the major ores that are extracted from the mining operations in the study area. Gold mineralisation in this area is typically associated with pyrite [18, 42]. Bvenura and Afolayan [43], who observed high uptake of Mn in spinach and cabbage beyond toxic levels in their study area also stated that high levels of Mn, Zn and Cu in soils may be attributed to agricultural chemicals that are added to the soil and/or the geological origins of the soil. Barberton is located in the Barberton greenstone belt which is associated with Mn and Fe mineralization [44]. Although the geology of the area may contribute to the observed concentrations of metal in the soil and vegetables, the excessive levels of Mn and Fe, suggest that there is an anthropogenic source of contamination, in this case, the mining activities. Anthopogenic sources of heavy metals in the environment include mining, processing of metal ores, transport, burning of fossil fuels, and agricultural activities [45].

Table-5. Daily intake of metals (mg/person/day) through vegetables grown in Thaba Nchu

Vegetable	Cu	Mn	Fe	Zn	Co	Cd	Ni	Pb
R_fD^a (mg/kg per day)	0.04a	0.014	0.7	0.3	0.02	0.001	0.02	0.0035
Cabbage	0.0014	0.010	0.03	0.0073	6.16E-05	6.72E-06	0.00081	3.64E-05
Lettuce	0.0034	0.029	0.62	0.0092	0.00012	1.85E-05	0.0019	8.96E-05
Spinach	0.0064	0.069	0.95	0.0078	0.00034	1.18E-05	0.0021	0.00011
Beetroot	0.0028	0.043	0.83	0.0067	0.00029	7.84E-06	0.00048	3.64E-05
Onion	0.0028	0.042	0.95	0.0120	3.64E-05	3.08E-06	0.00098	3.64E-05
Carrot	0.0025	0.033	0.71	0.0067	6.16E-05	4.76E-06	0.0013	8.40E-05

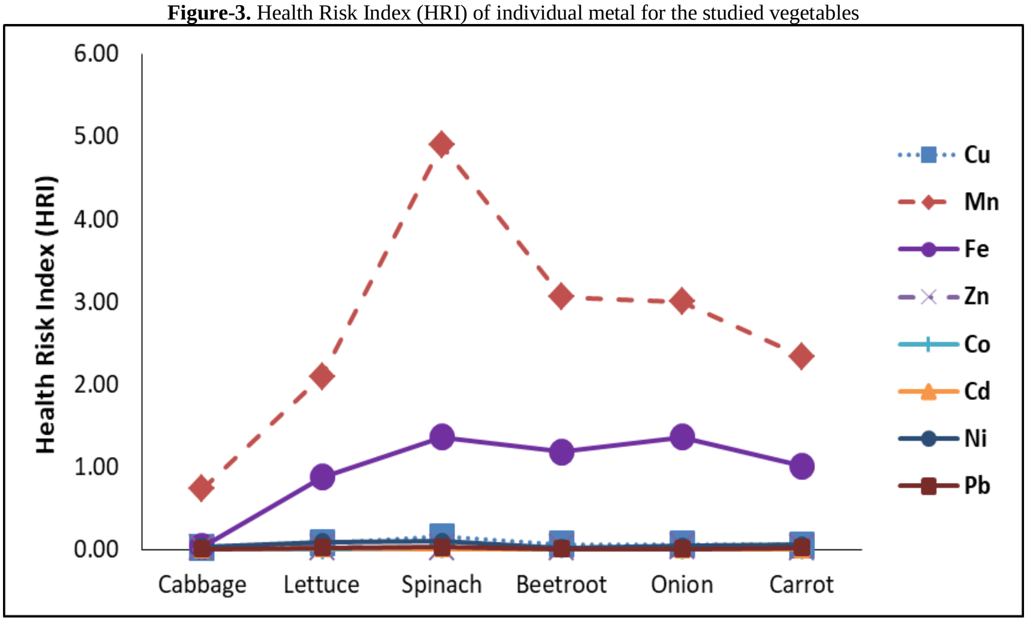
Integrated Risk Information Systems (IRIS), US EPA [24]

Table 6 presents the health risk index (HRI) of metals for adults as a result of the consumption of vegetables. The HRIs for Cu, Mn, Fe and Zn ranged from 0.0350 to 0.1890, 0.7402 to 5.0812, 0.0380 to 1.3619 and 0.0224 to 0.0756 in average adults, respectively. The HRIs for Co, Cd, Ni, and Pb ranged from 0.0018 to 0.017, 0.0031 to 0.019, 0.024 to 0.1 and 0.010 to 0.032, respectively. The highest HRI value of 4.90 was observed through the consumption of Mn in spinach while the lowest (0.0018) was observed through Co consumption in onion. The HRI values for all studied elements except Mn and Fe were below 1, which meant that the health risk of heavy metal exposure through the food chain was unlikely and is considered to be safe. The HRI values for Mn and Fe, which were higher than 1 for lettuce, spinach, beetroot, onion and carrot pose potential health risks. High Mn content in the human body can cause skeletal abnormalities and brain damage [46]. The health risk index of individual metals is presented in Figure 3.

Table-6. Health risk index (HRI) of metals for adults as a result of the consumption of vegetables

Vegetable	Cu	Mn	Fe	Zn	Co	Cd	Ni	Pb
Cabbage	0.035	0.74	0.04	0.02	0.0031	0.0067	0.041	0.010
Lettuce	0.084	2.10	0.88	0.03	0.0059	0.019	0.094	0.026
Spinach	0.16	4.90	1.36	0.03	0.017	0.012	0.10	0.032
Beetroot	0.07	3.06	1.18	0.02	0.014	0.0078	0.024	0.010
Onion	0.07	3.00	1.36	0.04	0.0018	0.0031	0.049	0.010
Carrot	0.063	2.34	1.01	0.02	0.0031	0.0048	0.063	0.024

Figure-3. Health Risk Index (HRI) of individual metal for the studied vegetables



4. Conclusion

The heavy metal contamination of 6 vegetables and soils at the Thaba Nchu farm which is located near a gold mine was investigated in this study. The sum of the concentrations of the heavy metals was higher in spinach and onion and lowest in cabbage. The rank of order of vegetables according to their decreasing metal concentrations is spinach> onion> beetroot> carrot> lettuce> cabbage. Mn levels in spinach and Fe levels in most of the vegetables were above the FAO/WHO recommended levels. The amounts of Cu, Fe, Mn, Zn, Co, Cd, Ni,Pb and Cr in the irrigation water were within the recommended maximum concentration for crop production. Cu, Zn, Co, Ni, Pb and Fe had higher transfer factors for all crops. Daily intake of metals and health risk estimates indicate that most of the crops are safe from heavy metals except Fe and Mn. The DIM values of Mn and Fe were high through the consumption of vegetables grown near a gold mine and exceeded the USEPA IRIS and WHO/FAO limit of 0.014 and 0.7, respectively. The highest intake of Mn and Fe was from the consumption of lettuce, spinach, beetroot, onion, and carrot. HIR values for Fe and Mn also exceeded the recommended safe limits. It can be concluded that high metal content in crops is attributed to the accumulation of Fe and Mn, which are major ores extracted from the mining operations in the study area. Therefore, mining activities have a direct impact on the accumulation of heavy metals in soil and crops. There was no obvious heavy metal contamination in the soil and irrigation water, therefore the soils and irrigation water in the study area are not the main source of contamination of the vegetable crops. The results suggest that heavy metals may be introduced into vegetables through air deposition of contaminants from the surrounding mine activities. Heavy metals are deposited on the parts of the crops exposed to the air and then absorbed by the crops. The environmental and health risk of Fe and Mn was highest and should be of great concern. Regular monitoring of heavy metal contamination in soils and crops is necessary to avoid health risks to humans. Except for Fe and Mn, the daily intake of metals and health risk estimates indicate that heavy metal exposure through crops was unlikely and that most of the crops are safe for consumption. Post-mining sites have the potential to support a great diversity of activities, such as agriculture. However, without proper monitoring, mine sites can be potentially harmful to soils, streams, crops and general biota. As a result, there is a potential health risk to the local inhabitants in the areas around the mines.

Acknowledgement

This paper is funded by the University of Mpumalanga (UMP), South Africa. The authors are grateful for the support given by UMP.

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