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Original Research

Investigating the Concentrations of Different Elements in Soil and Plant Composition from a Mining Area

Joshua O. Olowoyo[1]*, Anthony I. Odiwe[2], Nquobile M. Mkolo[1], Linda Macheka[1]

[1]Department of Biology, University of Limpopo, P.O.Box 139, Medunsa, Pretoria, South Africa
[2]Department of Botany, Obafemi Awolowo University, Ile-Ife, Nigeria

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Abstract

Contamination of soils around mines by heavy metals has not yet received the serious attention that it deserves in South Africa. The current study evaluated the concentrations and levels of pollution by trace metals in soils around a Ferro-chromium mine in South Africa. Soil samples were collected from 20 locations in four different directions, namely southwest, southeast, northwest, and northeast of the mine. The soils were analyzed for trace metals concentrations using ICP-MS. The result revealed that soil pH was in the acidic medium with a very low level of soil organic matter. The concentrations of elements from the soil followed the order Al > Fe > Ca > Mg > Cr > Na > Mn > Ni > Zn > V > Cu > Pb > As > Cd. Higher concentrations for all the elements were recorded from the topsoil and also from the southwestern direction, and the differences in the concentrations were significant ($p > 0.05$). A highly significant positive correlation of Fe and Cr with Ni and with each other ($0.42 \leq r \geq 0.82$) were recorded. The P_i (pollution index) and I-geo (geoaccumulation index) indicated that the soils around the mine were severely contaminated with Cr and Ni. The concentrations of Fe, Cr, and Ni from the soil samples were high enough to cause serious health problems for people living in the area.

Keywords: pollution, trace metals, mining, chromium, lead and arsenic

Introduction

Mining is one of the major sectors that is currently supporting various developmental projects and boosting the economy of South Africa [1]. The mining sector in South Africa has contributed greatly not only to the country's gross domestic product, but also provides jobs, generates coal for the energy sectors, and contributes to capital inflows into the economy, among other factors.

But mining operations rely on pollution-prone technologies, and controls on the discharge of pollutants from African mines and smelters are lax or non-existent [2]. Over the years, mining activities have been identified from different areas to increase the introduction and levels of trace metals in soil and plants around its vicinity if unchecked and uncontrolled [3]. For instance, in China, production from mining activities boosted the economy initially for decades but has led to indirect loss of about $4.4 billion annually in recent years due to environmental pollution. The most prominent effect of mining activities in the environment is soil pollution, consisting of high levels of toxic trace metals and metalloids [4]. In most cases, soil structure is often left exposed and degraded, and in some instances with many heaps of excavated soil. The heaps of soil formed may be transported to different areas around the mining environment via wind, depending on climatic and hydrological conditions.

The continuous introduction and loading of pollutants in the environment by mining activities has led to negative changes in natural ecosystems, bringing about a loss of biodiversity (fauna and flora). Exposure to heavy metal

*e-mail: woleolowoyo@yahoo.com

toxicity from mine waste may be directly or indirectly linked to many diseases in plants, animals, and humans [5]. Exposure to cadmium from mining industries in Belgium was associated with renal dysfunction, increased calciuria, and osteoporosis [6]. Severe and often deadly pathological changes are associated with excessive intake of chromium hexavalent compounds [7]. It was reported that occupational exposure to hexavalent chromium compounds may lead to a variety of clinical problems; this is due to the inhalation and retention of Cr (VI)-containing materials, which also increases the incidence of bronchogenic carcinoma [8].

The quality of life of communities around the mining area may put the population at higher risk of exposure to heavy metals. Therefore, the quality of life in such communities may thus to some extent depend on the status of soil and plants around the area. Accumulation of metallic elements in the soil and other physico-chemical factors such as soil pH, redox potential, and organic matter content of the soil may lead to transfer of metals from soil to the liquid soil phase, causing variations in the availability and toxicity of these elements [9]. Therefore, environmental pollution from mines can become an important source of soil and plant contamination that may cause diseases in humans via the food chain [10]. It is therefore important to continuously monitor the status of soil and plants around the mining environment in order to prevent adverse effects on humans. Over the past decades, several studies have been conducted on the impact of different mining areas on the surrounding soils, with little or no attention on the Fe-Cr mining industries.

This study focuses on the level and nature of trace metals composition in soils around a ferro-chromium mining area in South Africa. To the best of our knowledge this study will be the first study conducted in South Africa that examines the impact of a ferro-chromium mine on the surrounding soils.

Methodology

Study Site

The mining industry is located in the North West Province of South Africa (25.39.38 S and 27.50.42 E). The area normally receives about 540 mm of rain per year, with most rainfall occurring mid-summer. It receives the lowest rainfall (0 mm) in June and the highest (105 mm) in January. Average temperature ranges from 19.8ºC (June) - 29.3ºC (January), with the coldest period during July (2.1ºC) on average during the night. The mine operates 2 chrome ore mines of about 1.2 Mt per annum and 4 furnaces with a capacity of about 412 kt per annum. The mine operates using a closed open furnace in order to reduce particulate emissions.

Soil and Plant Sample Collection

Soil sampling and plant identification was carried out at a distance of about 1 km around the mining area in each direction. The area around the mining industry was divided into four different directions: northeastern (S1) – this area is predominantly noted for heaps of mine waste, with scattered tree shrubs; northwestern (S2) – this is an area with grasses; southeastern (S3) – an area with small farming activities and also surrounded by houses, though scattered; and southwestern (S4) – an informal settlement housing the mine workers and their family members living directly opposite the mine. From each direction, five different stations were selected and soil samples were collected from two depths (0-15 cm and 15-30 cm) using a soil auger of 2.5 cm diameter. The soil samples were taken from 2 m ×2 m square comprising 5 samples from each station and 5 samples from each direction. Soil was dried at room temperature, ground, sieved to pass through a 2 mm sieve, and used for chemical analysis. Plant samples were collected around the mining industry from the different directions as in the case with the soil samples and identified. Five transects 500 m long were laid out in each direction and within each transect five nested quadrates were established and all plant species present were identified to species level wherever possible in the field. Those that could not be identified were preserved for identification in the Department of Biology using different reference materials. The plants were later oven dried at 80ºC for 48 hours, ground, passed through a sieve of 2 mm, and used for chemical analysis.

Chemical Analysis of Samples

With the soil samples the digestion was carried out using the micro wave oven digestion system with 4 acid solutions. 1 g of the soil samples were added with 2 ml of HCl, 2 ml of $HClO_4$, 2 ml of HF, and 8 ml of HNO_3. The resulting solution were then analyzed for trace metals contents using ICP-MS. The plant samples also were digested using the microwave oven digestion system, but with 2 acid which were 7 ml of HNO_3 and 2 ml of H_2O_2. Soil organic matter was determined by loss-on-ignition at 550ºC. Soil pH was determined in 0.01 M $CaCl_2$ (1:2 soil-solution ratio) and in distilled water using a pH meter fitted with a glass electrode (Jenwal Model 3015 digital).

Quality Assurance

For the purpose of quality assurance, the analyses were carried out in triplicate while some of the samples were spiked. Analysis of certified reference material NCS DC 73309 (GSD-11 soil) that contains metals purchased were digested the same way with the samples. Precision was around 6-7% for most of the elements determined, and the overall recovery rate ranged from 87-115%.

Pollution Assessment

Pollution assessment of the soil was calculated using the pollution index (P_i) method and the geo-accumulation index (I-geo). The pollution index was calculated using the formula:

Table 1. Mean concentrations of some elements in soils collected around the mining area mg/g.

	Trace metals									
	Na	Mg	Al	Ca	V	Cr	Mn	Fe	Ni	Zn
Northeast										
Topsoil	3.05±0.12	21.97±1.23	85.15±3.25	28.40±2.11	0.16±0.01	9.06±0.23	1.44±0.21	46.11±1.23	0.20±0.02	0.13±0.04
Subsoil	2.93±0.35	21.45±2.14	79.92±2.54	24.07±1.47	0.16±0.05	8.97±0.24	1.37±0.14	44.54±3.56	0.19±0.09	0.09±0.01
Northwest										
Topsoil	3.58±0.68	26.73±0.35	89.84±2.65	30.41±1.01	0.20±0.08	13.96±1.54	1.55±0.24	52.04±3.58	0.24±0.01	0.14±0.23
Subsoil	3.06±0.54	23.39±1.47	87.34±2.68	30.28±0.69	0.16±0.06	8.92±1.36	1.53±0.17	47.89±3.69	0.22±0.01	0.13±0.11
Southwest										
Topsoil	3.59±0.14	15.65±0.38	114.41±3.58	46.30±0.22	0.10±0.01	0.94±0.22	1.33±0.25	40.09±4.52	0.17±0.07	0.71±0.14
Subsoil	3.23±0.15	13.54±0.65	92.63±2.68	43.52±0.47	0.11±0.08	0.92±0.38	1.28±0.11	40.05±4.04	0.19±0.02	0.69±0.58
Southeast										
Topsoil	6.97±0.36	14.80±1.47	85.38±3.22	49.97±0.77	0.11±0.04	0.91±0.58	1.24±0.35	40.51±2.57	0.12±0.05	0.52±0.10
Subsoil	13.07±0.78	43.29±1.22	120.1±0.32	121.4±0.25	0.09±0.01	0.28±0.44	1.13±1.00	46.12±5.87	0.25±0.04	0.47±0.05

$$P_i = C_i / S_i$$

...where C_i represents the concentration of heavy metal i in soil while S_i indicates the relevant standard value for this metal. The S_i values for the metals calculated were: 3 mg/kg (Cd), 350 µg/g (Cr), 150 µg/g (Ni), 100 µg/g (Pb), and 200 µg/g (Zn) [11]. The geo-accumulation index was determined using the model [12]:

$$\text{I-geo} = \log_2 (C_i / 1.5B_i)$$

B_i is the soil background concentration of heavy metal i in South African soils [11] and 1.5 is the correction factor.

Soil contamination levels using P_i were classified into four grades: $P_i < 1$ unpolluted, $1 \leq P_i < 2$ slight pollution, $2 \leq P_i < 3$ medium pollution, and $P_i \geq 3$ heavy pollution. With the geo-accumulation index, the I-geo was classified into seven grades: I-geo ≤ 0 uncontaminated, $0 <$ I-geo ≤ 1 slightly moderately contaminated, $1 <$ I-geo ≤ 2 moderately contaminated, $2 <$ I-geo ≤ 3 moderately severely contaminated, $3 <$ I-geo ≤ 4 severely contaminated, $4 <$ I-geo ≤ 5 severly extremely contaminated, and I-geo > 5 extremely contaminated [12, 13].

Results

Soil pH from all the areas was in the range 4.85±0.16 – 5.34±0.11. Levels of soil pH recorded from the southwestern and southeastern directions were more acidic than those recorded for the other areas. The average mean concentration of soil organic matter (SOM) from the study sites was in the range 6.83±0.54%-18.67±0.45%, with the highest soil organic matter occurring at the northwestern direction of the mining site. Particle size analysis (USDA classification system) indicated that soils of the southwestern, southeastern, and (to a lesser extent) northeastern areas have sandy loam texture, while that of the northwestern area has loam or silt loam texture.

The concentrations of trace elements in soil samples examined are presented in Tables 1-3. From Table 1, aluminium exhibited the highest mean concentration for all the elements examined. The concentration for Al ranged between 79.92±1.13 mg/g – 120.11±2.23 mg/g from all the sites (Table 1). The highest mean concentration for this element was recorded from the subsoil from the southeastern part of the mining area with the lowest mean concentration from the sub soil of the northeastern part. Elevated levels were recorded for Cr from all the sites with the highest mean value from the northwestern direction. The values recorded for Cr were in the range 0.28±0.07 mg/g – 13.96±1.45 mg/g. Fe concentration was in the range 40.05±1.12 mg/g – 52. 04±2.13 mg/g. The highest mean value for this element was recorded from the topsoil collected from the northwestern direction of the mining industry and the lowest recorded from the subsoil in the southwestern direction of the mining industry. In all, elevated concentrations were recorded for elements such as Al, Fe, Ca, Mg, Cr, Na, Ni, and V.

The concentrations recorded for elements such as Cu, Cd, Pb, and As were low when compared with elements such as Al, Fe, Ca, Mg, Cr, Na, Ni, and V (Table 1). Concentrations of Pb ranged between 2.29±0.01 µg/g – 13.63±1.12 µg/g. The highest concentration for Pb was recorded from the northwestern direction in the subsoil, while the lowest concentration was recorded from the subsoil in the southeastern direction of the mining industry (Table 3). Basically, heavy metal concentrations followed the order Al > Fe > Ca > Mg > Cr > Na > Mn > Ni > Zn > V > Cu > Pb > As > Cd from the soil samples (Tables 1 and 2).

Table 2. Concentrations of trace metals in μg/g from the soils around the mining area.

	Trace metals				Soil pH	Soil OM %
	Cu	Cd	Pb	As		
Northeast						
Topsoil	30.15±0.21	0.08±0.11	11.06±0.28	2.89±0.01	5.21±0.14	13.21±0.07
Subsoil	25.95±1.23	0.09±0.02	8.45±0.14	2.58±0.12	5.34±0.11	14.23±0.56
Northwest						
Topsoil	27.64±3.25	0.09±0.01	10.66±0.45	3.46±0.08	5.11±0.23	15.32±0.21
Subsoil	33.97±2.56	0.10±0.01	13.63±0.74	3.51±0.03	5.32±0.08	18.67±0.45
Southwest						
Topsoil	35.61±2.45	0.09±0.03	9.38±0.58	4.91±0.25	4.85±0.16	6.83±0.54
Subsoil	34.25±1.22	0.08±0.04	8.95±0.14	4.58±0.22	4.92±0.12	9.23±0.65
Southeast						
Topsoil	24.13±3.98	0.07±0.01	6.97±0.25	3.43±0.14	4.91±0.22	8.32±0.01
Subsoil	24.33±0.65	0.03±0.00	2.29±0.11	3.37±0.27	5.01±0.22	10.11±0.05

The results of pollution assessment with P_i and I-geo are presented in Tables 3 and 4, respectively. The results of the Pi indicate that the soils around the mining area were not polluted with Cd, Pb, and Cu. There was medium pollution with Zn from the southwestern and southeastern parts of the mining area (Table 3). There was heavy pollution for Cr and Ni and Zn in the soils of the mining area. The I-geo revealed a moderately contaminated soil for Ni and Zn, and an extremely contaminated soil with Cr. There were no levels of contamination recorded for Cd, Pb, and Cu from the sites.

Only *Cymbopogon excavatus* grass was noticed as a dominant and common grass from the study sites. However, there was the presence of other shrubs such as *Acacia karoo*, *Saersia lancea* (*Rhus lancea*), *Rhus leptodictya*, *Acacia caffra*, *Dodoneae augustifolia,* and farm-growm wheat toward the northeastern part of the mining area. The elemental concentration in the grass followed the order Mn > Fe > Cr > Zn > Cu > V > Pb > As (Table 5). A significantly different concentration for the elements in the grass was noticed from all directions ($p > 0.05$). The highest mean concentration for all the elements in the grass was recorded for Mn from the roots of the grass at the southeastern part of the mining area. For elements such as Cr and Pb the concentrations of these elements in the roots of the grass were more than those recorded for the leaves, and the differences in the concentrations were significant ($p > 0.05$).

Discussion

In general, the level of soil pH recorded for all the soil samples were in the acidic medium. The values of soil pH showed significant differences between the soils around the Ferro-chromium mining ($p< 0.05$). The mobility of trace metals in soil is highly favored by acidic condition of the soil, the trace element cations become more soluble and mobile when soil pH is acidic [14]. A similar report of soil becoming acidic around a mining and smelting industry was reported in a study conducted in Spain [15]. However, the increase in soil pH witnessed with depth from the soil around the mining area will restrict trace element mobility at the topsoil. The mobility of trace metals would then be mainly restricted at the soil surface, hence mixing with dust and thus polluting the area. This finding agrees with the other studies in metal mining areas where the pH was acidic [16]. The SOM also affects the mobility of trace elements in the soil by providing sorption sites [17, 18]. Organic matters from the study were low in most of the sites, with the exception of the northwestern site, which was an area noted for farming activities. The level of SOM in the surface soils indicated that most of the soils are deficient in organic matter, thereby inducing fewer sorption sites and hence favoring the mobility of the trace metals [16].

The concentrations of the mean major elements (Al, Fe, Mg, Ca, Na, Mn, and K) from the soils were higher than those of the mean upper crust reported by Wedepohl [19]. Extremely high levels for these elements were recorded in both surface and subsurface layers of the soil. For example, the acceptable mean concentration for Fe in agricultural soils ranged between 21,000 μg/g – 26,000 μg/g [20]. Our results showed values clearly above this limit. Also, the soil around the mining area could be said to be highly contaminated with Mn, though as of the time of writing of this paper, the maximum allowable limit in South Africa has not yet been set. But considering results and allowable limit from other countries, the maximum allowable limit for Mn is 900 mg/kg [21], and our results clearly indicated that all the soils collected around the mining area have values above the recommended limit. Higher concentrations of

Table 3. Pollution Index for soils collected around the mining area.

Sites		Trace Metals					
		Cd	Cr	Ni	Pb	Zn	Cu
Northeast	Topsoil	0.03	25.88	10.00	0.11	0.65	0.25
	Subsoil	0.03	25.62	9.50	0.09	0.45	0.22
Northwest	Topsoil	0.03	39.88	12.00	0.11	0.70	0.23
	Subsoil	0.03	25.49	11.00	0.14	0.65	0.28
Southwest	Topsoil	0.03	2.69	8.50	0.09	3.55	0.30
	Subsoil	0.02	2.63	9.50	0.09	3.45	0.29
Southeast	Topsoil	0.02	2.60	6.00	0.07	2.60	0.20
	Subsoil	0.01	0.80	12.50	0.02	2.35	0.20

Table 4. Geo-accumulation Index for the sites.

Sites		Trace Metals					
		Cd	Cr	Ni	Pb	Zn	Cu
Northeast	Topsoil	-5.22	6.25	1.41	0.00	-1.12	-2.31
	Subsoil	- 5.05	6.21	1.34	-3.32	-1.64	-2.53
Northwest	Topsoil	- 5.05	6.86	1.68	-2.98	-1.00	-2.44
	Subsoil	- 5.06	6.22	1.55	-2.64	1.33	-2.15
Southwest	Topsoil	- 5.05	2.97	1.18	-3.16	1.29	-2.07
	Subsoil	-5.22	2.94	1.33	-3.24	1.30	-2.13
Southeast	Topsoil	- 5.44	2.92	0.68	-3.61	0.89	-2.64
	Subsoil	- 6.65	1.22	1.74	-5.21	0.75	-2.62

Mn in Guangxi (2,772 mg/kg) and Morroco (3,637 mg/kg) were reported, respectively [22, 23]. The high concentration of Mn may pose a serious health threat for communities around the mine, because previous research has shown that Mn could be linked to the initial symptoms of Parkinson's disease [24].

The concentrations for trace elements such Cu, Cd, Pb, and As were low when compared with the acceptable limits in soil for agricultural purposes. These values were lower when compared to previously reported values for the soils in mining areas; elevated levels of Cd, Cu, and Pb, in the range of 0.80-2.20, 13.6-60.00, and 33.0-708 $mg \cdot kg^{-1}$ for forest soil around a Au-Ag-Pb-Zn mine area in Korea [25]. Arsenic in surface soils of about 424 mg of a mineralized area in southwest England also has been reported [26].

The correlation analysis form the data obtained from this study showed a highly significant positive correlation of Fe and Cr with Ni and with each other ($0.42 \leq r \geq 0.82$). This suggested the presence of the former two elements from a common source. Also, a highly significant positive correlation was observed for Fe and Cr with Mn ($0.63 \leq r \geq 0.88$). The pollution index and the I-geo clearly indicate that the soils were severely contaminated with Cr and Ni in the northeastern and northwestern directions, while a moderate pollution level for these trace elements was recorded from the southeastern and southwestern directions of the mining area with a slightly contaminated level of Zn (Tables 3 and 4). Cr pollution is known to affect lungs, causing lung cancer and death. In some cases skin rashes, upset stomachs and ulcers, respiratory problems, weakened immune systems, kidney and liver damage, and alteration of genetic material are common symptoms associated with inhalation or ingestion of substances high in Cr [27]. Ni, on the other hand, is needed by the human body to produce red blood cells. However, in excessive amounts it can become mildly toxic. Long-term exposure can cause lung fibrosis, cardiovascular and kidney diseases. The most serious concerns relate to nickel's carcinogenic activity [28]. Exposure to high concentrations of Fe in dust like the values observed in this study can produce mucus irritation, and persistent exposure can cause siderosis [29].

The relationship between uptakes of metals from soil by leaves was investigated through the use of concentration

Table 5. Mean concentrations of some elements in μg/g from grass of *Cymbopogon excavatus* collected around the mining area.

	Plant parts	Trace metals								
		V	Cr	Mn	Fe	Cu	Zn	Cd	Pb	As
Northeast	Leaves	13.54±0.11	86.23±0.12	156.2±0.12	98.36±1.11	19.52±2.35	54.56±0.01	0.07±0.01	8.36±0.21	3.25±0.08
	Roots	10.23±0.01	125.3±0.21	168.2±0.25	102.6±1.25	30.26±2.03	68.32±1.17	0.09±0.00	12.32±0.11	5.23±0.21
Northwest	Leaves	12.54±0.02	95.23±0.05	165.3±0.45	108.4±2.36	22.38±0.14	58.23±0.25	0.08±0.01	8.37±0.02	2.32±1.11
	Roots	13.56±0.03	134.3±0.01	160.2±1.23	110.2±1.47	29.35±1.04	60.53±1.04	0.07±0.02	11.32±0.05	3.22±0.54
Southwest	Leaves	13.57±0.04	99.23±0.08	172.3±1.25	118.3±1.45	28.92±1.05	59.23±1.11	0.09±0.01	10.25±0.58	4.52±0.69
	Roots	14.56±0.05	125.6±0.09	175.3±0.24	114.4±0.58	30.23±0.12	65.14±0.35	0.08±0.02	11.32±0.17	6.25±0.25
Southeast	Leaves	12.32±0.05	96.31±0.035	186.3±0.14	100.1±0.11	32.21±1.12	59.38±0.32	0.09±0.01	12.32±1.25	2.35±1.47
	Roots	15.23±0.08	142.3±0.07	202.3±0.25	125.1±0.23	36.52±0.45	65.78±1.02	0.09±0.01	15.25±1.65	8.32±1.04

Table 6. Transfer ratio for elements in soil and *Cymbopogon excavatus.*

	Plant parts	Trace metals								
		Pb	As	Cu	Fe	Mn	Zn	Cd	V	Cr
Northeast	Leaves	0.76	1.12	0.65	0.02	0.10	0.42	0.88	0.09	0.01
	Roots	1.11	1.81	1.00	0.02	0.11	0.53	1.13	0.06	0.02
Northwest	Leaves	0.79	0.67	0.81	0.02	0.11	0.42	0.89	0.06	0.01
	Roots	1.06	0.93	1.06	0.01	0.03	0.43	0.78	0.09	0.01
Southwest	Leaves	1.09	0.92	0.81	0.02	0.05	0.08	1.00	0.14	0.11
	Roots	1.21	1.27	0.85	0.03	0.05	0.09	0.89	0.15	0.14
Southeast	Leaves	1.77	0.69	1.33	0.02	0.05	0.11	1.29	0.11	0.11
	Roots	2.18	2.42	1.51	0.02	0.06	0.13	1.29	0.14	0.16

factor (CF). This is an index of soil-plant transfer that favors the understanding of plant uptake characteristics. It is the ratio of the metal concentration in the plant $\{M\}_{plant}$ to the total metal concentration in the soil $\{M\}_{soil}$. Ratios > 1 indicate that plants are enriched in elements (accumulator), ratios around 1 indicate that plants are not influenced by elements (indicator), and ratios < 1 show that plants exclude the elements from uptake (excluder). The result showed that elements such as Pb, As, Cu, and Cd may have been accumulated largely from soil though aerial deposition and trace metals entrance via the leaf stomata may also account for the levels of trace metals in the plant (Table 6). Values obtained from the transfer factor indicated a high translocation from soil to plant parts, so it may be concluded that the grass *Cymbopogon excavatus* accumulated some elements from the soil. The result of this study was in agreement with the findings of [30] that Cd, Pb, and Cu may be translocated by plants via the roots, though Cd tends to be more available to plants than other heavy metals. The result further pointed out that Cd is readily translocated to plant shoots after root absorption, even if in various plant species.

Conclusion

The present study evaluated concentrations of some elements around ferro-chromium mining areas in South Africa. The evaluation was based on the determination of the total concentrations of the elements in the soil. The results of this study indicate that the concentrations of Al, Fe, Ca, Mg, Cr, Na, Ni, Mn, and V were far above the critical values of these elements reported by various environmental protection agencies. The positive correlations exhibited by Fe, Cr, Ni, and Mn pointed to a common source, and in this instance could be traced to the ferro-chromium mining industry around the area. The high levels of trace metals found in the southwestern direction of the mining area also suggested the effect of wind in transporting these metals into a different areas or becoming more localized at a particular region. However, possible contamination from fertilization processes and transport activities also be should taken into account. Further studies are needed in order to ascertain the mobility and possible translocation of trace metals by plants in the vicinity of the mine.

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