

Original Research

Influence of Wind Direction on the Level of Trace Metals in Plants Collected around a Quarry Site in South Africa

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Abstract

Industrialization has resulted in the release of pollutants, especially trace metals, to the environment, which adversely affects the ecosystem. The present study investigated the influence of wind direction on the level of trace metals deposited on vegetation around the quarry site. Three plants common to the four cardinals of the quarry site, precisely 10 meters away, were collected and transported to a laboratory, where further analyses were carried out to determine the trace metal contents in the air-dried unwashed plants. The plants collected from the southwest direction, which represents the position of the stack that emits smoke from the quarry site, recording the highest trace metal concentration. The result of the plant analysis for trace metal concentration showed that *Lantana camara* among the three plants bio-accumulated most of the trace metals from the quarry site and other adjoining environment. The levels of trace metals from the plants exceeded the acceptable limits for human and livestock consumption. The study therefore concluded that wind direction and the position of the stack played a significant role in the amount of trace metals around the quarry site.

Keywords: *Datura stramonium*, *Lantana camara*, *Panicum maximum*, trace metals, wind direction

Introduction

Over the past two centuries mining has been largely responsible for the improvement of the socio-economic landscape of South Africa by growing the gross domestic product (GDP), boosting state revenue, foreign direct investment and generating employment [1, 2]. Despite the economic importance of mining to

any nation, the consequences of its activities are borne directly by the ever-increasing populations and societies around the mining areas [3].

Quarrying activity is a necessity that provides much of the materials used in traditional hard flooring, such as granite, limestone, marble, sandstone, slate and even ceramic tiles [4]. Quarrying activities such as rock breaking, grinding, and kiln operations are the primary sources of airborne pollutants (trace metals, particulate matters and other pollutants), which are often dispersed by wind to the surroundings and impact biotic and

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abiotic ecosystem functionality [5]. Blasting of rocks with explosives to extract materials for processing leads to the release of several environmental pollutants [4], including trace metals, particulate matter (PM), and compounds such as carbon monoxide (CO), nitrogen dioxide (NO₂), sulphur dioxide (SO₂), and ozone (O₃), which may threaten plant biodiversity and result in health-related problems and habitat destruction, among others [4, 6]. Quarrying activity has also been reported as the greatest suspected source of particulate matter and trace metals, which are often dispersed by wind to the surroundings and impacts on human health living within the vicinity of the quarry site [7, 8].

High concentrations of trace metals pose a great threat to human health and general ecosystems due to their persistence, inherent toxicity, consequent bioaccumulation and biomagnification in the food chain [7, 9-13]. A very high degree of respiratory morbidity is associated with the quarrying industry in humans [14], while in plants the blockage of stomata hinders photosynthesis around quarrying sites [15]. Dust and other pollutants from industrial and other sources not only deteriorate the ambient air quality, but also pose a serious health risk to people – particularly those suffering from respiratory and cardiovascular diseases [16, 17]. Studies have attributed abnormal vegetative growth, imbalanced lipid and ionic tissues composition, and increases in foliar temperature [18] on the harboring of trace metals by plants. Dust deposition may also lead to reduced photosynthesis; increased incidence of plant pest and diseases; and effects on human health through the food chain [15]. Pollutants adversely hinder plant growth by altering the photosynthesis rate, pedicle length, biochemical composition, seed germination and leaf stomata [19].

South Africa's history of plant use for food and medicine has spanned through the ages, and a large percentage of the population scavenges plants as foods and medicine available anywhere [20]. Therefore, it is necessary to study the impacts of the quarry deposits on the plants to determine their suitability for consumption by herbivores on free-ranging pasteurization and even some medicinal plants that could be scavenged for health benefits.

There are several studies globally on the distribution and concentration of airborne pollutants such as trace metals in aquatic and terrestrial ecosystems, but few studies have enunciated the impact of wind direction as a dispersal mechanism that could increase the levels of trace metals around the vicinity of quarrying sites in South Africa. There are several studies on the impacts of industrial activities through the release of toxic trace metals on vegetation and human health [7]. Human ingestion of trace metals unknowingly or indirectly from vegetables, meat and dairy consumption, and even medicinal plants poses a great risk on human health and survival [21]. The present study investigated the impact of wind direction in depositing trace metals as pollutants on plants in the environment around a quarry

site in Pretoria North, South Africa with a view to establishing its impact on trace metals accumulation in plants collected around it from four different directions, namely northeast, northwest, southeast and southwest of the quarry site.

Methodology

Study Area and Sample Collection

The study was carried out in Pretoria North, South Africa between March and July, 2017. Reconnaissance visit was done around the quarry site to identify three different plants with economic and domestic importance common to the four cardinals of the quarry site. The coordinates of the study site are 25.6776°S, 28.1766°E. Three common plants (*Lantana camara*, *Panicum maximum*, and *Datura stramonium*) were identified, and five cuttings of the three plants (*Lantana camara*, *Panicum maximum*, and *Datura stramonium*) were collected randomly from four different cardinals, namely northeast (NE), northwest (NW), southeast (SE) and southwest (SW) of the quarry site. Each direction is about 10 m from the stack that emits smoke from the quarry site where major crushing activities take place. Samples were collected using secateurs in separate polyethylene bags and transported to the laboratory, where they were correctly identified by a Botanist in the Department of Biology of Sefako Makgatho Health Sciences University, South Africa. After proper identification, the plants were air-dried and bulked.

Sample Digestion

The collected plants were air-dried until all moisture was completely eliminated. Bulked air-dried unwashed plant samples were ground mechanically using a mortar and a pestle to produce fine powder. Then 0.5 g of sample was weighed into a beaker. A mixture of 3 ml concentrated HNO₃, 5 ml HClO₄ and 4 ml H₂O₂ was added to the sample, and it was placed on a hot plate for about 7 minutes until a clear solution was obtained. The digested sample was allowed to cool and then filtered into a 50 ml flask using Whatman filter paper. Distilled water was added to make volume.

A blank was prepared similarly but without the ground plant sample for the purpose of quality assurance and quality control. Spiked samples were also prepared. The resulting solutions were then analyzed for trace metals contents in five replicates using ICP-OES in order to determine the concentrations of trace metals in the digested unwashed plant samples.

Certified reference material by the National Institute of Standard and Technology (NIST 1515 Apple Leaves) was also used to validate the method for the purpose of quality assurance.

The data obtained for the trace metals were all subjected to analysis of variance (ANOVA) using SPSS

23.0 for windows. Means were separated using Duncan's multiple range tests at $p < 0.05$.

Results

The concentration of Mercury (Hg) in all three plants ranged from 60.3 ± 4.11 mg/kg d.m. to 158.7 ± 37.29 mg/kg d.m. (Table 1), and the highest concentration of Hg was recorded in *Datura stramonium* 158.7 ± 37.29 mg/kg d.m. in the southwest direction of the site (Table 1). Mercury recorded the lowest concentration of 60.3 ± 4.11 mg/kg d.m. in the northwest direction of *Lantana camara* (Table 1).

At the southwest direction of the study site, the concentrations of trace metals, including Ni, Cu, Zn, Cd, Cr, Hg, Fe, and Mn, were significantly higher (232.3 mg/kg d.m., 148.3 mg/kg d.m., 134.3 mg/kg d.m., 2925 mg/kg d.m., 158.7 mg/kg d.m., 283 mg/kg d.m., 136.7 mg/kg d.m.) in *D. stramonium*. The higher concentration of Copper (Cu) was recorded in *P. maximum* northwest of the site (Table 1).

The concentration of Cu ranged from 67.5 mg/kg d.m. in *L. camara* at the northwest direction to 1045 mg/kg d.m. in *P. maximum* at the northwest direction (Table 1). In the southwest direction, *D. stramonium* has the higher concentration of Cu (153.3 mg/kg d.m.).

The concentrations of Cd and Mn were highest in all three plants to the southwest, with the exception of *P. maximum*, where it was highest at 123. At the southwest direction of the study site, the concentrations of the trace metals including Ni, Cu, Zn, Cd, Cr, Hg, Fe, and Mn were significantly higher (232.3 mg/kg d.m., 148.3 mg/kg d.m., 134.3 mg/kg d.m., 2925 mg/kg d.m., 158.7 mg/kg d.m., 283 mg/kg d.m., 136.7 mg/kg d.m.) in *D. stramonium*.

Higher concentrations of Cu and Mn were recorded in *P. maximum* to the northwest (1045 mg/kg d.m.) and northeast (178.51 mg/kg d.m.) of the site, respectively (Table 1).

The highest concentration of Fe was recorded to the southwest for all three plants; it ranged from 989 mg/kg d.m. northeast of *Lantana camara* to 2925 mg/kg d.m. southwest of *Datura stramonium* (Table 1).

The concentration of Zinc (Zn) was highest in the southwest for all the plants except in *Lantana camara*, where the highest was recorded at 186 ± 54.37 mg/kg d.m. to the northeast (Table 1).

Generally, the concentrations of trace metals from this study are in the order $Fe < Cu < Mn < Zn < Hg < Cr < Ni < Cd$ (Table 1). From the three plants collected from the study sites, the concentrations of all trace metals exceeded the acceptable limit set by the World Health Organization (WHO). The permissible limit set by WHO for Cd in plants is 0.03 mg/l, Cr – 0.05 mg/kg d.m., Zn – 3.00 mg/kg d.m., Hg – 0.5 mg/kg d.m., Mn – 0.50 mg/kg d.m., Ni – 0.02 mg/kg d.m., Fe – 63.55 mg/kg d.m. and Cu – 1.89 mg/kg d.m. [22].

Iron (Fe)

There is a significant difference ($p < 0.05$) in Fe content between *L. camara* and *D. stramonium* in all wind directions of the site (Fig. 1). There is significant difference ($p < 0.05$) among the three plants in the northwest and southeast directions (Fig. 1). *Datura stramonium*, however, is significantly different ($p < 0.05$) from the other two plants in all the directions (northeast, northwest, southeast and southwest).

Cadmium (Cd)

There is no significant difference between *L. camara* and *P. maximum* in the northeast, northwest and southwest direction for Cd concentrations (Fig. 2). *Datura stramonium*, however, is significantly different ($p < 0.05$) from the other two plants (*P. maximum* and *L. camara*) in the northeast (Fig. 2). The concentration of Cd in *P. maximum* is significantly different ($p < 0.05$) from the other two plants in the southeast (Fig. 2). There is no significant difference in Cd concentration in all three plants to the northwest and southwest direction of the study sites (Fig. 2).

Chromium (Cr)

There is no significant difference in Cr concentration between *L. camara* and *P. maximum* at the northeast and the southwest direction of the study site. However, there is significant difference ($p < 0.05$) between *P. maximum* and the other two plants at the southeast direction of the study site (Fig. 3). No significant difference is observed in Cr concentration among the three plants in the northwest direction of the study sites (Fig. 3).

Copper (Cu)

There is a significant difference ($p < 0.05$) in Cu concentration between *P. maximum* and the other two plants (*L. camara* and *D. stramonium*) in the northwest direction of the study site (Fig. 4). There is no significant difference in the concentration of Cu among the plants in the southwest direction of the study site (Fig. 4). Furthermore, there is no significant difference between *L. camara* and *P. maximum* for Cu concentration in the northeast, southeast and southwest directions of the study site (Fig. 4). In the southeast direction there is a significant difference ($p < 0.05$) in Cu concentration between *D. stramonium* and the other two plants (*L. camara* and *P. maximum*).

Zinc (Zn)

There is no significant difference in the concentration of Zn among the three plants at the northeast and southwest direction of the study site (Fig. 5). A significant difference ($p < 0.05$) was observed in Zn concentration among all three plants

Table 1. Trace metal concentrations in plants collected from the quarry site.

Plants	Sites	Trace Metal Concentrations (mg/kg d.m.)									
		Cu	Zn	Cr	Cd	Fe	Hg	Mn	Ni		
<i>Lantana camara</i>	NE	136.3±2.31	186±54.37	128±2.65	123.3±0.58	989±171.1	126.7±3.51	149.2±51.5	126±1.73		
	NW	67.5±14.04	129±1.41	57.1±3.39	55.2±1.33	1165±21.21	60.3±4.11	146.5±0.71	55.4±2.82		
	SE	147.3±15.54	113±5.66	58.5±4.43	54.8±2.05	1300±14.14	69.6±4.46	138±8.49	56.1±3.40		
	SW	147.3±19.5	182.7±39.58	128.3±3.06	124±0	1585±7.07**	111±5.57	185.5±2.12	127±2.65		
<i>Panicum maximum</i>	NE	137.7±12.86	173.3±44.50	138±11.27	123±1.0	1080±0	117±6.0	178.5±0.71	127±3.46		
	NW	1045±7.07	105.8±24.65	67.1±5.47	55.1±0.89	1045±7.07	71.47±4.76	101.9±29.68	55.47±2.80		
	SE	196.5±64.34	166±40.45	143±11.14	120±1.0	196.5±64.34	116.7±6.68	123±33.15	127±2.65		
	SW	148.7±14.01	195±64.12	130.7±4.16	122.3±1.53	1575±106.1**	112±5.0	153.7±36.95	129±4.36		
<i>Datura stramonium</i>	NE	68.6±12.68	162±1.41	56.57±3.02	54.7±1.93	1923.3±20.82	63.73±7.75	148.5±0.71	56.5±3.55		
	NW	69.47±17.25	176±8.49	56.37±2.42	55.1±1.53	1895±21.2	64.1±5.67	133.5±4.95	56.1±3.29		
	SE	69.57±17.43	156.5±2.12	57.9±3.18	54.1±2.15	2480±14.14	68.3±7.62	171.5±2.12	55.87±3.81		
	SW	153.3±23.67	232.3±97.35	148.3±15.01	134.3±14.57	2925±7.07**	158.7±37.29	283±2.83	136.7±13.32		

Values in asterik (**) indicates the trace metals concentrations with the highest concentration across the plants (Southwest wind direction). NE represents Northeast direction, NW represents Northwest direction; SE represents Southeast direction; SW represents Southwest direction.

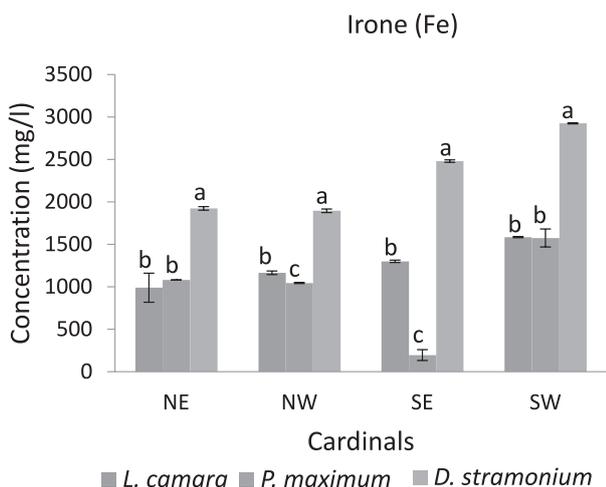


Fig. 1. Iron concentrations in plants collected from across the directions.

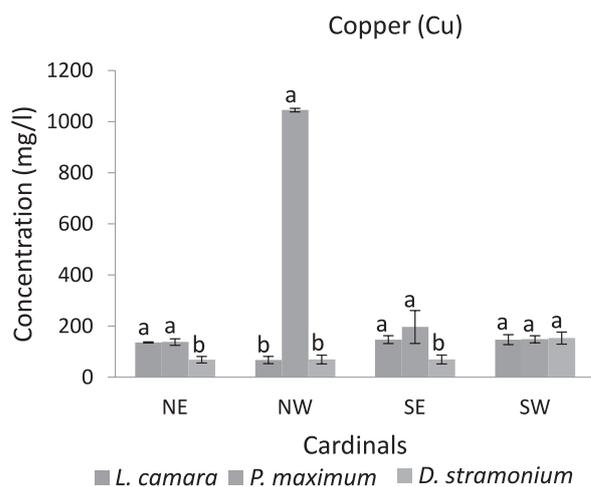


Fig. 4. Copper concentrations in plants collected from across the directions.

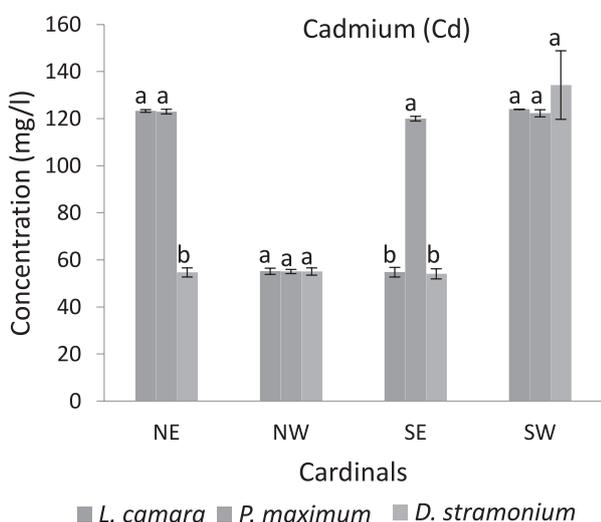


Fig. 2. Cadmium concentrations in plants collected from across the directions.

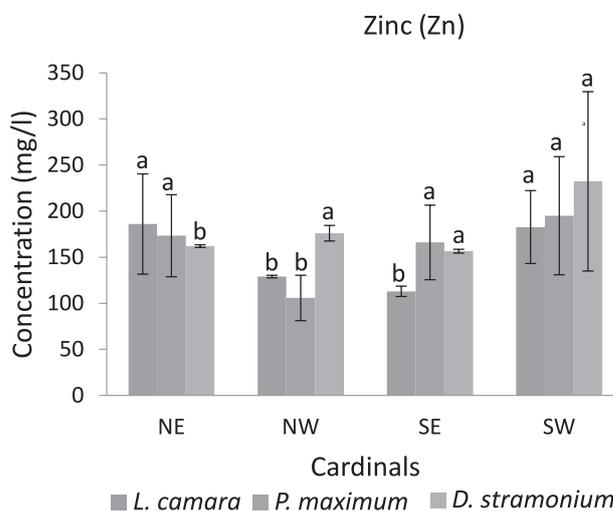


Fig. 5. Zinc concentrations in plants collected from across the directions.

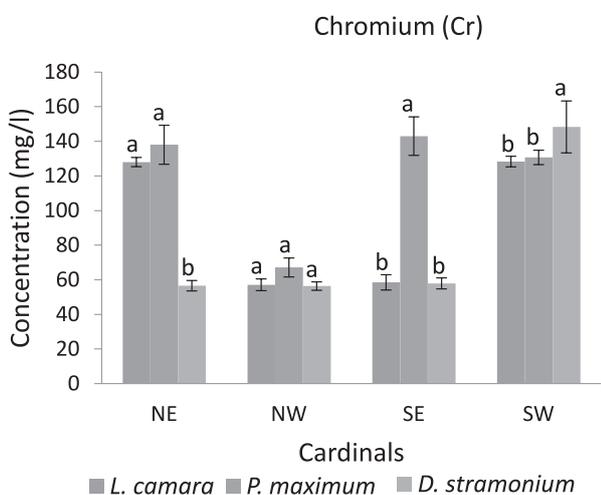


Fig. 3. Chromium concentrations in plants collected from across the directions.

in the southeast direction of the study site (Fig. 5). In addition, there is a significant difference ($p < 0.05$) in the concentration of Zn between *D. stramonium* and the other two plants (*L. camara* and *P. maximum*) in the northwest direction of the site (Fig. 5).

Mercury (Hg)

The concentration of Hg is significantly different ($p < 0.05$) between *D. stramonium* and the other two plants (*L. camara* and *P. maximum*) at the northeast and the southwest directions of the site (Fig. 6). In the southeast direction of the study site, there is significant difference ($p < 0.05$) in the concentration of Hg between *P. maximum* and the other two plants (*L. camara* and *D. stramonium*) (Fig. 6). There is no significant difference in the concentration of Hg between *D. stramonium* and *P. maximum* in the northwest direction of the study site (Fig. 6).

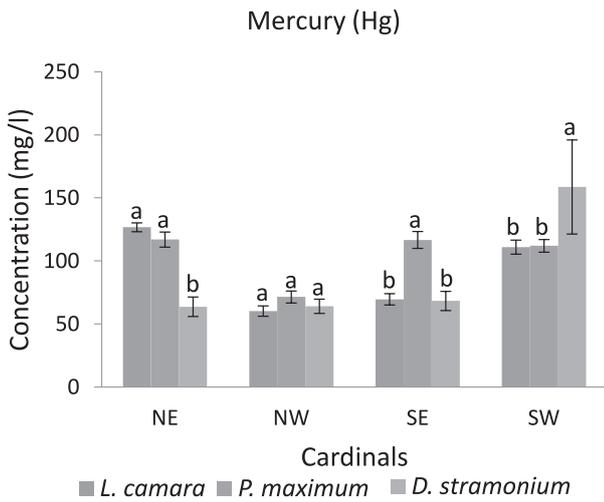


Fig. 6. Mercury concentrations in plants collected from across the directions.

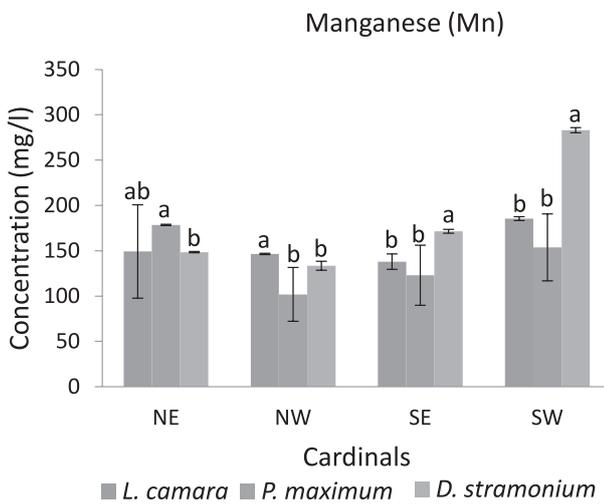


Fig. 7. Manganese concentrations in plants collected from across the directions.

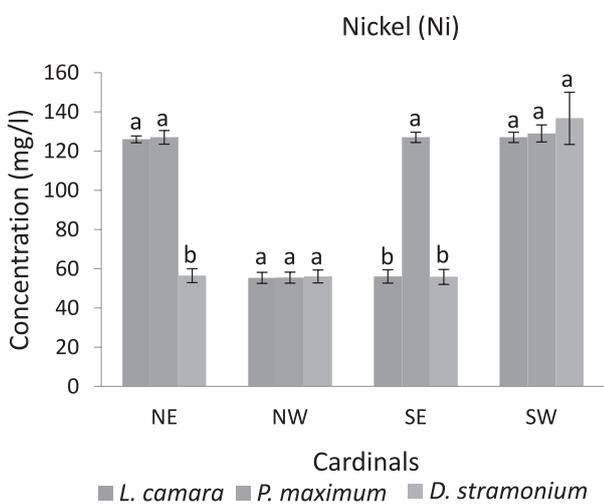


Fig. 8. Nickel concentrations in plants collected from across the directions.

Manganese (Mn)

There is significant difference ($p < 0.05$) in the concentration of Mn between *D. stramonium* and the other two plants (*L. camara* and *P. maximum*) at the southeast and southwest directions of the study site (Fig. 7). In the northwest direction there is significant difference ($p < 0.05$) between *L. camara* and the other two plants (*P. maximum* and *D. stramonium*). There is significant difference ($p < 0.05$) in Mn concentration between *D. stramonium* and *P. maximum* in the northeast direction of the study site.

Nickel (Ni)

In the northwest and the southwest direction of the study site there is no significant difference in the concentration of Ni among the three plants (Fig. 8). There is significant difference ($p < 0.05$) in the concentration of Ni between *P. maximum* and the other two plants (*L. camara* and *D. stramonium*) in the southeast direction of the study site (Fig. 8). The concentration of Ni is significantly different ($p < 0.05$) between *D. stramonium* and the other two plants (*L. camara* and *P. maximum*) in the northeast direction of the study site (Fig. 8).

Discussion

The negative impacts of elevated trace metals on vegetation and human health abounds in literature [5, 7]. Trace metals contamination and persistence in the environment and subsequent transfer through food-chain magnification is hazardous and results in grave consequences in plants and humans [21]. Several studies have reported that the extent of damage and absorption of these trace metals in plants differs and depend on factors such as sizes and shapes of the leaves, the nature of the leaves and stomata abundance of the leaves [23, 24]. For instance, Cr, Cd and Pb at high concentrations are toxic to plants by altering the seedling germination process and hindering growth and development [25-27].

Trace metals such as Cu, Ni and Zn are classified as essential elements for proper growth, morphology, and physiological well-being of plants; however, these trace metals are toxic at higher concentrations in plants [22]. Although Ni and Zn are essential elements at low concentration, increased Ni and Zn concentrations from different sources such as atmospheric deposition have hazardous effects on biota of plants throughout terrestrial food chains [28-30]. High Cr concentration causes a decrease in plant biomass and secondary metabolites such as sugars, chlorophyll, and carotenoids [31]. A similar development was found in *Phyllanthus amarus* and *Brassica juncea* for increased concentration of Cd [32].

In this present study, the concentrations of trace metals recorded from all directions showed values that were above the recommended limit as set for

trace metals in plants [21]. The permissible limit set by the WHO for Cd in plants is 0.03 mg/kg d.m., Cr – 0.05 mg/kg d.m., Zn – 3.00 mg/kg d.m., Hg – 0.5 mg/kg d.m., Mn – 0.50 mg/kg d.m., Ni – 0.02 mg/kg d.m., Fe – 63.55 mg/kg d.m. and Cu – 1.89 mg/kg d.m [21]. The plants (*Panicum maximum*, *Lantana camara*, and *Datura stramonium*) in this study have been reported as forage plants [33] and trace metal monitoring plants, as well as phytomedicine [34, 35].

Fe has the highest concentration in all plants across all the wind directions (NE, NW, SE, and SW). This suggests other possible sources for Fe concentration aside the quarry site. A study in Pretoria reported a similar trend in the concentrations of Fe from a plant collected around a mining site that was attributed to its abundant elemental composition in plants [23, 36]. A high level of Fe in herbal/edible plants was reported from a study conducted in Pakistan and Nigeria [37, 38].

The high concentration of all trace metals in the southwest direction except in Cu could be due to the direction of the prevailing wind and position of the stack. In a study on the evaluation of the impact of limestone quarry on suspended and accumulated dust in northern Israel, mineralogical and chemical analyses of the dust samples indicated that wind direction plays a major and definite role on the amount of trace metals in dust particles analyzed as the prevailing wind direction impacted positively on the amount of dust particles which translated to an increase in trace metals [5]. Similarly, in a study in South Africa, wind direction was reported to have had a considerable impact on the presence and amount of trace metal deposition in *Amaranthus spinosus* collected around a coal-fired power plant [39]. Studies have shown that distance and prevailing wind have great effect on the deposition of trace metals and its amounts on plants around an industrialized region of South Africa [39-43].

Though the values obtained for all trace metals from all locations were not significantly different from one another, they are above the permissible limits as recommended by WHO. This might be a result of the effect of season and the time at which the samples were collected. Seasonal variations have been reported in literature to affect the deposition and levels of trace metals in plant parts [44]. The present study was carried out during the summer period and there might be a significant effect of rain in reducing the concentration of deposited trace metals in and on the leaves. The concentrations of Cu and Pb were low during the summer when compared to the winter period, and this phenomenon was attributed to the effect of rain and maturity during the summer and winter periods, respectively [44, 45].

From this study, there was a great variety in the structure and nature of the plant leaves which could have been responsible for the differences in the concentrations of trace metals in the foliage of the plants. The abilities of plants to absorb trace metals through the leaf stomata

greatly varies and it is dependent on factors such as the size, nature, and shapes of the leaves, and the size and abundance of stomata in the leaves may affect the levels of trace metals in plants [24].

Panicum maximum has simple alternate leaves and *Lantana camara* is quite rough, while *Datura stramonium* are large and angular. The findings of this study are in agreement with other studies where plants that were collected from a quarry vicinity exhibited trace metal values that were above the WHO-recommended limits [46, 47].

Conclusion

We discovered that the concentrations of all the trace metals (Cu, Cd, Mn, Hg, Zn, Fe, Cr, and Ni) were generally above the permissible limits set by WHO. Concentrations of toxic trace metals above the recommended limit in plants may be dangerous, considering the non-biodegradable nature of these toxic metals and the carcinogenic effect of some of these metals.

Though the differences obtained in the concentrations of the studied metals in leaves were not significant, the values obtained for *Datura stramonium* were higher than all other plants, and these may be due to the size of the leaves, which may favor the uptake of these metals via the leaf stomata.

Wind direction and the position of the stack might also have accounted for the presence of these trace metals from the Southwestern direction when compared with other directions where plant samples were collected in this study.

Due to high concentrations recorded for elements such as Cd, Cr, Mn, Hg, and Fe, it may be necessary to have a periodic monitoring program carried out around the quarry site in order to monitor the impact of the quarry site in releasing trace metals in the environment. Furthermore, due to the high concentrations of some toxic trace metals recorded in some plants collected around the site, prolonged consumption of these plants either by grazing animals (*Panicum maximum*) or use for medicinal purposes (*Datura stramonium*) are strongly discouraged.

It is recommended that further studies may be carried out to determine the impact of the quarry on plant diversity and its impact on human health.

Conflict of Interest

The authors declare no conflict of interest.

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