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Original Research

Trace Metals in Soil and Plants around a Cement Factory in Pretoria, South Africa

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Abstract

Rapid economic development across South Africa in recent decades has necessitated massive construction and building works, resulting in an increased demand for cement production. This has set cement factories all over South Africa to operate at maximum capacity in a bid to meet market demands. The present study investigated the concentrations of trace metals in soil and plants around a cement factory (PPC) in Pretoria, South Africa. Soil sampling was carried out around the cement factory during winter and summer periods, while plant sampling was only carried out during the summer period. Thirty soil samples were collected in different directions – southwest (SW), southeast (SE), and northeast (NE) – of the sites. Plant samples were also collected from these different directions. The result showed that soil pH was in the acidic medium and ranged from 5.12±0.21- 5.67±0.23. There was a significant difference in the concentrations of trace metals from the different directions ($p<0.05$).

The pollution index (PI) revealed that the soil has been moderately polluted with elements such as Pb, Ni, Cr, Zn, Cd, and Cu. Strong positive correlations were recorded for most of these elements, suggesting a common source for them. The result of the plant analysis showed that *Panicum maximum* bio-accumulated most of the trace metals from the soil. *L. camara* showed a prospect as a bio-accumulator of heavy metals from these plants. The levels of trace metals from the plants exceeded the acceptable limits for human and livestock consumption. The study revealed that the source of the trace metals as pollutants cannot be attributed to the cement factory only but also to vehicular emissions.

Keywords: trace metals, *Lantana camara*, pollution, cement factory, soil

Introduction

Metal pollution of soil dust and agricultural soils arising from industrial activities, vehicular emissions, and waste disposal sites are well documented [1-3]. The cement industry forms part of the industries that are well known to be problematic as regards the introduction of heavy metals from the dust emanating from their operations [1-3]. The deposition of these trace metals occurred at various distances around the cement factories and are influenced by wind velocity, particle size, and stack fumes [4]. Typical raw cement is made up of 25 mg/kg Cr, 21 mg/kg Cu, 20 mg/kg Pb, and 53 mg/kg Zn [5]. Further to this elemental composition, it was also reported that about 0.07 kg of dust is generated into the atmosphere when 1 kg of cement is manufactured [2].

Soil contamination by heavy metals can cause long-term problems on the biogeochemical cycle, which may affect soil functioning systems, leading to changes in soil fauna [6].

From previous studies in other countries, it has been established that dust containing elevated amounts of trace

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metals emanating from the vicinity of cement factories may adversely affect humans, plants, and soil composition within the vicinity [7]. Most cement factories have been noted as potential sources of metals such as Hg, Zn, Pb, Cr, and Cd [8-11]. The effects and concentrations of the dust containing trace metals as pollutants vary and depend largely on technology employed from the cement industries to ameliorate environmental degradation. In humans, trace metals such as Pb may affect the brain and cause retarded growth, especially in children [12]. In plants, excessive [Pb] alters normal metabolic pathways by disrupting specific cellular enzymes and may also inhibit the photosynthetic ability of plants [13]. On a general note, excessive levels of heavy metals may result in the induction of oxidation stress, damage to DNA, and disturbances in the biosynthetic pathways [14].

Quality of the environment is vital for sustainable development, especially in the face of rapid developmental programs from developing countries. The rapid economic developments in South Africa over the past few years have resulted in an increased demand for cement production [15], which stood at 14.9 million tons in 2012 and is expected to reach 18.1 million tons in 2018 owing to the emergence of new cement manufacturing plants in South Africa and neighbouring countries such as Lesotho, Botswana, and Swaziland [15]. Although several studies have noted the impact of the cement industry on the environment from developed countries, few studies have been conducted in South Africa [1, 5, 6, 10].

The present study was carried out to investigate the concentrations of heavy metals from soils and plants collected around the Hercules cement factory in Pretoria. The study also assessed the level of heavy metal contamination in the topsoil based on pollution index (PI).

Methodology

The study was carried out at about 50 m from a cement factory in Pretoria. The cement factory is situated just next to a very busy road (GPS: 25º43'21 S, 28º10'15 E). The area falls on the western part of Pretoria. There are two major seasons in the area (winter and summer), although the city usually witnesses a short period of spring and autumn. Sampling was done during the two major seasons. Sampling was carried out in the northeastern (NE), northwestern (NW), and southwestern (SW) areas of the cement company. Soil and plant samples were collected from these directions around the area: 30 soil samples from the topsoil (0-15 cm) and 30 soil samples from the sub soil (15-30 cm). Plants samples were collected from each of the directions where soil samples were collected and were identified up to the species.

The soil samples were ground in the laboratory and air-dried. From the ground soil samples, 0.5 g of the soil were added with 2.0 ml of HCl, 2.0 ml of $HClO_4$, 2.0 ml of HF, and 8 ml of HNO_3. The resulting solutions were then analyzed for trace metals contents using ICP-MS in order to determine the concentrations of trace metals from the soil samples. The plant samples were partitioned into three parts, namely for analyses: root, stem, and leaves. From these parts, 0.2 g of each of the different parts were acid-digested using 2 ml HCl, 1 ml $HClO_4$, 2 ml of HF, and 5 ml of HNO_3, and the resulting solutions were then analysed for trace metal contents using ICP-MS. Quality assurance was done using Certified Reference Materials for both soil and plant samples and the analysis was also carried out in triplicate.

The ability of plants to uptake trace metals from the soil was determined using the transfer factor model [16]. The transfer factor is calculated as the concentration of heavy metals in plant parts to the concentration present in the soil. This is an index of soil-plant transfer. Values >1 indicate that plants are enriched in elements from soil (accumulator), ratios around 1 indicate that plants are not influenced by elements (indicator), and values <1 show that plants exclude the element from soil (excluder).

Pollution Assessment

Pollution assessment of the soil was calculated using the pollution index (*Pi*) method and the geo-accumulation index (I_{geo}). The pollution index was calculated using the formula:

$$Pi = Ci/Si$$

...where *Ci* represents the concentration of heavy metal *i* in soil while *Si* indicates the relevant standard value for this metal [11, 17]. Soil contamination level, using *Pi*, was classified into four grades: $Pi < 1$ unpolluted, $1 \leq Pi < 2$ is regarded as slight pollution, $2 \leq Pi < 3$ regarded as medium pollution, and $Pi \geq 3$ regarded as heavy pollution [18].

Statistical Analysis

The data obtained for the trace metals were all subjected to analysis of variance followed by Duncan's multiple range test so as to separate the significant means. Pearson correlation was used to determine if there was a common source and relationship between the trace metals.

Results

Different plants were identified from the sites. *Celtis dustralis* was collected from the SW direction of the study sites, *Lantana camara*, *Bidens bipinnata*, *Ergrostis tenella*, and *Panicum maximum* were collected from the NW direction, while *Datura stramonium*, *Sida cordifolia*, and *P. maxium* were collected from the SE. There was no plant that was common in all the different directions where sampling was done, hence different plant species were collected from different sites and were analysed for trace metal contents as shown in Table 1.

The highest concentrations for all the trace metals were recorded from *Panicum maximum* collected from the SE direction of the study site (Table 1). From the plant, the

Table 1. Concentrations of trace metals from plants collected from the study sites in µg/g and mg/g.*

Plants	Trace metals									
	Pb	Cr	Cu	Zn	Mn	Cd	As	U	Ni	Sb
Celtis dustralis L.	5.77±0.11	7.35±0.56	12.8±0.21	19.5±0.01	85.9±0.99	0.06±0.01	0.29±0.06	0.06±0.01	5.97±0.27	0.17±0.02
Celtis dustralis S.	2.86±0.10	4.36±0.03	22.1±0.70	36.0±1.69	74.4±3.74	0.03±0.01	0.06±0.01	0.01±0.00	1.30±0.02	0.06±0.01
Lantana camara L.	39.34±1.04	17.40±0.18	33.31±0.42	95.7±0.28	237.9±2.19	0.06±0.01	0.52±0.03	0.09±0.01	9.65±0.23	0.34±0.01
Lantana camara S.	63.70±2.71	31.93±0.24	101.7±1.41	176.2±1.06	368.7±6.71	0.11±0.01	0.78±0.06	0.14±0.01	11.26±0.01	0.63±0.01
Bidens bipinnata L.	52.38±1.32	80.25±5.65	278.4±6.36	152.3±1.77	394.7±7.85	0.46±0.01	1.99±0.08	0.26±0.02	23.19±1.24	0.08±0.01
Bidens bipinnata S.	7.67±0.52	18.67±0.41	93.9±2.43	59.3±3.88	64.9±0.70	0.22±0.01	0.33±0.03	0.03±0.00	3.52±0.11	0.14±0.01
Datura stramonium L.	7.94±0.19	3.80±0.14	113.7±1.69	89.7±2.19	85.40±3.11	0.10±0.01	0.44±0.04	0.03±0.00	3.71±0.49	0.15±0.00
Datura stramonium S.	6.48±0.82	10.23±1.15	149.7±2.35	77.4±3.13	77.7±2.32	0.06±0.01	0.69±0.13	0.04±0.00	5.84±1.34	0.19±0.02
Sida cardifolia L.	0.03±0.01	9.60±1.23	99.3±1.11	59.2±1.01	108.3±3.12	1.19±0.32	1.03±0.11	0.06±0.01	7.26±1.23	1.93±0.24
Sida cardifolia S.	5.97±0.01	28.61±7.32	138.97±4.40	334.38±1.45	142.28±1.32	0.57±0.03	0.70±0.17	0.04±0.00	15.67±0.25	0.21±0.00
Panicum maximum L.	226.87±2.86	258.75±6.64	2.93±0.38*	1.89±0.12*	3.82±2.32*	0.73±0.14	7.12±1.89	0.61±0.13	168.05±1.86	2.80±0.20

*Values recorded in mg/g due to high values.

Table 2. Mean concentrations of trace metals from soil in summer.

Site	Depth	Trace metals									
		Pb	Cr	Cu	Zn	Mn	Cd	As	U	Ni	Sb
Southwest	0-15	53.01±1.81	257.85±1.89	82.56±3.00	135.45±7.99	106.10±4.53	0.12±0.00	5.23±0.22	0.71±0.25	109.50±5.94	0.02±0.01
	15-30	38.14±1.31	216.10±6.64	77.32±1.31	80.37±3.26	146.55±0.35	0.14±0.01	4.21±0.14	1.02±0.07	83.80±1.98	0.03±0.00
Northwest	0-15	121.55±1.63	171.10±1.67	57.49±3.25	116.90±0.99	161.75±3.32	0.20±0.01	8.35±0.39	0.82±0.05	49.77±4.71	0.09±0.02
	15-30	94.09±0.16	185±7.49	50.72±0.12	104.75±1.34	150.95±1.77	0.18±0.01	8.84±0.06	0.88±0.02	52.14±2.05	0.07±0.02
Northeast	0-15	38.18±2.25	101.98±3.57	52.43±1.02	137.00±0.99	230.45±2.19	0.19±0.01	5.01±0.02	1.80±0.07	38.25±0.89	0.11±0.03
	15-30	47.14±1.86	85.79±6.59	228.95±0.32	339.20±19.23	244.10±4.10	0.74±0.04	3.43±0.15	2.17±0.106	30.05±1.11	3.51±0.15

highest concentration for all the trace metals was recorded for MN, with a value of 3.82±2.32 mg/g, followed by Cu (2.93±0.38 mg/g) and Zn (1.89±0.12 mg/g). The concentrations of trace metals from *Panicum maximum* was in the order Mn > Cu > Zn > Cr > Pb > Ni > As > Sb > Cd > U. From all the plants collected from the study sites, the values of Pb exceeded the acceptable limit of 2.00 mg/kg set by WHO in plants except for the values recorded for *Sida cordifolia* leaves collected from the SE (Table 1). Similar observations were noticed for Cr, Cu, Mn, and Ni from all plants. The concentrations of Cd from *Sida cordifolia*, *Bidens bipinnata*, and *Panicum maximum* also exceeded the limit of 0.02 mg/kg set for plants by the World Health Organization (Table 1). From all the plants examined, the levels of trace metals in the leaves were higher from the stems (except for *Sida cordifolia*), and the difference in all were significant ($p > 0.05$).

The transfer factor (TF) showed that some of the plants did take up most of the metals directly from the soil. The TF showed that the concentration of most of the trace metals in *Panicum maximum* were greater than 1, which shows that the plant was enriched from elements from the soil. Similar observation was also noticed for *Lantana camara* and *Datura stramonium* – especially with trace elements such as Cu and Sb, which might have been taken up by plants from the soil though interference from the anthropogenic sources that could not be eliminated totally. The result from the plants further revealed that most of the trace metals present in the plants might have been the result of anthropogenic emissions coming from the cement factory and other pollutants around the area.

The soil pH ranged from 5.12±0.21-5.67±0.23. The soils were all in the acidic medium. The concentrations of trace metals from the soil are reported in Table 3. The results showed differences in the concentrations of trace metals during the sampling periods and the differences obtained were significant ($p<0.05$). The concentrations of most of the trace metals determined from the soil samples were evidently above the acceptable limit recommended for agricultural purposes. During the sampling periods, the concentrations of Pb ranged from 37.66±3.89-121.55±1.63 µg/g, and the differences obtained were significant ($p<0.05$). The highest concentration for Pb was recorded from the NW, which was not far from the busy road (Tables 2 and 3). The concentra-

Table 3. Mean concentrations of trace metals from soil during winter.

Site	Depth	Trace metals									
		Pb	Cr	Cu	Zn	Mn	Cd	As	U	Ni	Sb
Southwest	0-15	107.25±0.35	225.7±10.32	531.75±0.07	170.45±3.04	124.2±1.41	0.21±0.01	2.52±0.05	0.46±0.01	129.7±3.39	0.11±0.01
	15-30	104.65±1.91	148.1±13.01	248.5±10.04	143.35±0.35	148.75±2.76	0.22±0.01	3.33±0.001	0.46±0.001	78.82±2.51	0.11±0.02
Northwest	0-15	48.01±2.82	236±5.49	94.84±4.15	137.85±2.19	83.5±2.12	0.23±0.04	2.27±0.12	0.49±0.017	54.28±3.86	0.29±0.04
	15-30	558.65±1.06	220.7±10.47	321.8±5.65	537.35±13.65	267.85±4.59	0.86±0.12	10.58±0.32	0.85±0.002	216.85±7.57	0.66±0.05
Northeast	0-15	89.28±7.142	61.82±1.58	58.47±5.16	175.35±8.69	188.45±4.59	0.50±0.00	4.18±0.69	1.29±0.023	29.9±0.04	0.34±0.04
	15-30	37.66±3.89	76.45±7.62	88.41±4.07	96.03±0.55	185.75±0.35	0.11±0.02	2.91±0.24	1.56±0.025	28.57±0.69	0.08±0.01

Table 4. Pollution index for soil collected during summer.

Site	Trace metals						
	Depth	Cd	Cr	Ni	Pb	Zn	Cu
Southwest	0-15	0.04	0.74	0.73	0.53	0.68	0.69
	15-30	0.05	0.62	0.56	0.38	0.40	0.64
Northwest	0-15	0.07	0.49	0.33	1.22	0.58	0.48
	15-30	0.06	0.53	0.35	0.94	0.52	0.42
Northeast	0-15	0.06	0.29	0.26	0.38	0.69	0.44
	15-30	0.25	0.25	0.20	0.47	1.69	1.91

tions of Cr ranged between 61.82±1.58 µg/g-257.85±1.89 µg/g, with the highest concentrations occurring from the SW during the sampling periods (Tables 3 and 4). Significantly higher concentrations were recorded for Cu and Zn during the winter ($p<0.05$).

The concentrations for Cu ranged between 50.72±0.12-531.75±0.07 µg/g, while the concentrations for Zn ranged between 80.37±3.26 µg/g-537.35±13.65 µg/g. Concentrations of Mn ranged between 83.5±2.12 µg/g-267.85±4.59 µg/g. A consistently higher concentration for Mn was recorded from the NE and the differences obtained for the two seasons were significant ($p<0.05$). There was a seasonal variation in the values recorded for Cd from all the sites and the differences obtained from each of the sites during the two sampling periods were significant ($p<0.05$). The concentrations for Cd ranged from 0.12±0.01 µg/g-0.86±0.12 µg/g. With Ni, the concentrations obtained from the sites ranged between 29.9±0.04 µg/g-216.85±7.57 µg/g. The highest concentration for Sb was recorded during the summer period, with a value of 3.51±0.15 µg/g from the NE.

The pollution index calculated for some of the metals (Tables 4 and 5) revealed that the soil might have been moderately or strongly polluted in some instances going by the levels of Ni, Pb, Zn, and Cu that were recorded from the soil around the study sites.

Discussion

The abilities of plants to absorb trace metals via stomata vary and these depend on factors such as size, nature, and shapes of the leaves, and the size and abundance of stomata in the leaves [19]. It was further reported that trace metals and other particulate matters deposited on leaf surfaces may be retained by cuticular waxes [20]. From the present study, the nature and structure of the plant leaves differs greatly and this might have been responsible for the differences in the concentrations of trace metals in the foliar part – even for those collected from the same area.

Several studies have reported on the ability of *Panicum maximum* as bio-accumulators of trace metals from the soil. In a study carried out to establish the phytoremediation potentials of plants, *Panicum maximum* showed a phytoremediation potential for Pb, Cr, and Cd [21]. Similar observation was also noted in the in a separate study in Nigeria, where *Panicum maximum* was used to monitor and determine trace metals contamination of roadsides in plants very close to the roads [22]. The findings of the present study also confirmed the ability of *Panicum maximum* as bio-accumulators of trace metals from contaminated soil. Findings from this study further show that *L. camara* can be investigated for its bioaccumulation potential. This may

Table 5. Pollution index for soil collected during winter.

Site	Trace metals						
	Depth	Cd	Cr	Ni	Pb	Zn	Cu
Southwest	0-15	0.07	0.64	0.86	1.07	0.85	4.43
	15-30	0.07	0.42	0.53	1.05	0.72	2.07
Northwest	0-15	0.08	0.67	0.36	0.48	0.69	0.79
	15-30	0.29	0.63	1.45	5.59	2.69	2.68
Northeast	0-15	0.17	0.18	0.19	0.89	0.88	0.49
	15-30	0.04	0.22	0.19	0.78	0.48	0.74

Table 6. Correlation coefficient matrix of metals in soil collected during winter.

Metals	Cr	Mn	Co	Ni	Cu	Zn	As	Cd	Sb	Pb	V	U
Cr	1.00											
Mn	-0.26	1.00										
Co	0.46	**0.65**	1.00									
Ni	**0.66**	**0.51**	**0.79**	1.00								
Cu	**0.61**	0.02	0.15	**0.71**	1.00							
Zn	0.40	**0.76**	**0.95**	**0.88**	0.32	1.00						
As	0.20	**0.87**	**0.92**	**0.79**	0.17	**0.97**	1.00					
Cd	0.18	**0.77**	**0.86**	**0.69**	0.10	**0.93**	**0.94**	1.00				
Sb	0.30	**0.65**	**0.92**	**0.64**	-0.02	**0.90**	**0.89**	**0.96**	1.00			
Pb	0.39	**0.78**	**0.94**	**0.90**	0.35	**0.99**	**0.98**	**0.90**	**0.86**	1.00		
V	0.39	0.40	0.43	**0.76**	**0.64**	**0.58**	**0.55**	0.40	0.26	**0.65**	1.00	
U	-0.80	0.53	-0.04	-0.37	-0.57	-0.05	0.13	0.09	0.05	-0.05	-0.47	1.00

Bold – positive correlation

become very important because the plant has long been used as a medicinal herb for treating ailments such as cancer, skin itches, leprosy, rabies, chicken pox, measles, asthma, and ulcers [23].

The concentrations of trace metals recorded from all the plants with particular reference to Pb, Cd, Ni, Mn, Cu, and Cr showed values that were above the recommended limit as set for trace metals in plants [24]. Of importance among the plants examined were *Panicum maximum*, which is used in feeding livestock, and *Lantana camara*, which may be used for medicinal purposes. The results of our study are in agreement with other studies where plants that were collected around cement factories exhibited values that were above the WHO recommended limits [11, 25, 26]. Variations in the concentrations of trace metals in plants with the unwashed plant samples collected around a cement factory have significantly higher concentrations of trace metals such as those noted in our study [26]. The study ascribed the presence of trace metals from these plants to dust accumulation from the cement factory.

The acidic nature of the soils may influence the mobility and the bioavailability of trace metals in the soil [27]. The soil pH may sometimes be a reflection on the product of contamination, which may further explain the sources of contamination in our study [28]. The highest lead concentration recorded next to the busy road around the cement factory may be due to the resuspension of this metal in the environment, as Pb is not biodegradable. The presence of Pb could also be attributed to the process and production of cement, which requires substantial amounts of energy made possible through the burning of fossil fuel, and also traffic activity involved in bringing raw materials and finished product to and from the cement factory [25].

The source of Cr around the study site may be linked to the linings of the rotaries that contain chromium or from the vehicles that are used to supply either raw materials or to take away finished goods from the cement factory. A similar observation was noted in a separate study and the source of Cr was attributed to the lining of rotaries that contain chromium and are released as pollutants in the environment due to wear and friction [1]. The observed value for Zn and Cu around the cement factory may also suggest the effects of anthropogenic sources of these pollutants. A similar observation in the concentrations of Zn and Cu around a cement factory in Nigeria was also reported from a separate study [11] that attributed the presence of the trace metals to an anthropogenic source through dust emissions from the cement factory. Positive correlations were noticed for some of the trace metals such as Pb, Zn, Cu, Mn, Ni, Cr, and As (Table 6). This suggested that most of the trace metals were pollutants from the same source, such as the cement factory or from vehicular emissions. The high concentrations of trace metals from the soil around the cement factory in the present study may be linked to the number of years when the factory has been operational.

Conclusion

The present study examined the concentrations of trace metals in plants and soils collected around a cement factory in Pretoria. The concentrations of trace metals in the soil revealed that the soil has been enriched and polluted with trace metals such as Ni, Pb, Cu , Zn, and Cr. The concentrations of trace metals from the plants around the cement factory also showed that the plants bioaccumulated most of the trace metals either from the soil or through atmospheric deposition via the stomata. *Panicum maximum* showed greater affinity as a bioaccumulation. However, plants such as *Lantana camara* should be further investigated for its bioaccumulation potential. Generally the high concentrations of these metals around the cement factory both in the plants and soils showed that the pollutants are as a result of the different activities such as the production of the cement and vehicular movement around the cement factory. The result of the study therefore demonstrated that metal concentrations can be a useful tool in measuring and determining the effects of different activities in releasing trace metals as pollutants in the environment.

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