THE RELATIONSHIP BETWEEN HEAVY METALS CONCENTRATIONS IN SOIL AND PLANT (*Senna auriculata* (L.) Roxb.) OF THE HILLS AND ROADSIDES IN TIRUCHIRAPPALLI, INDIA

S.P. Anand and R. Nagalakshmi[*]

PG and Research Department of Botany, National College, Bharathidasan University, Tiruchirappalli, Tamil Nadu, India

ABSTRACT

The relationship between heavy metal concentrations of soil and plant (*Senna auriculata*) in the hills and roadsides was studied. Atomic absorption spectroscopy was used for determination of metals such as lead (Pb), chromium (Cr), cadmium (Cd), zinc (Zn), copper (Cu), and iron (Fe) in the soil and plant (leaves and flowers) samples. The results showed that heavy metal concentrations in roadside soil and plant samples were much greater than that in hills. It is evident that concentration of a heavy metal in soil samples are considerably higher (p<0.05) than that in plant samples. Pearson correlation analysis shows that Pb in leaves and flowers correlated well with that in soil, r>0.93. Strong positive relationship exists between soil and plant for Cr content, (r≥0.97). Cadmium and Zn contents in leaves and flowers correlated significantly with Cd, and Zn in soil, all r>0.97. The Cu concentration of leaves and flowers shows a positive correlation with Cu content in soil, all r≥0.93. The Fe concentration of both plant leaves and flowers is found significantly and positively correlated with soil Fe, r=0.99. Overall results reveal that all the heavy metals are significantly and positively associated with soil and plant, implying that increasing concentration of heavy metals in soil is likely to increase their concentrations in *S. auriculata* plant.

Keywords: Heavy metals, Hills, Roadsides, *Senna auriculata*, Soil

INTRODUCTION

Heavy metals are the elements that have metallic characteristics and comparatively high density. Heavy metals in soils or plants cannot be destroyed or degraded. Further, with the growth of industrialization, heavy metals' presence has rapidly increased. Heavy metals are of two types – the one group consists of micronutrients

---

[*] Corresponding author: nagalakshmi.93botany@gmail.com

that plants essentially take a small amount for normal growth of plants, the elements are iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), molybdenum (Mo), and nickel (Ni), while the other metals such as cadmium (Cd), chromium (Cr), lead (Pb), arsenic (As) and cobalt (Co) are toxic heavy metals (Emamverdian et al., 2015). Plants absorb heavy metals that are present in soil solution. Because of the variability in soil qualities and plant growth characteristics, there is frequently no direct connection between total metal concentrations in soils and plants (Obrador et al., 2007). One of the reasons for the lack of a good correlation between metal concentrations in soils and plants is that it might, be influenced by soil contamination sources.

Heavy metal phytoavailability in soil may be measured by establishing a relationship between metal concentration in soil and accumulation in plant tissues (Chen et al., 2014). Heavy metal concentrations in various ecosystems are currently increasing in comparison to natural background levels due to rapid growth in industrial, agricultural, and urban activities. Roadside soils, plants, and organisms are absorbing significant quantities of toxic metals, primarily from automobile emissions and toxic substances transported. The principal metallic contaminants of roadside soil include lead, cadmium, copper, zinc, nickel, iron, and chromium, among other heavy metals (Silva et al., 2005). Lead and cadmium are toxic even in low quantities. As a result, the focus of this research is on Pb, Cd, Cr, Zn, Fe and Cu. Heavy-metal (e.g. Pb) emissions from automobiles are caused by fuel combustion, lubricating oil consumption, tyre wear, brake wear, road abrasion, and other factors (Weckwerth, 2001). The Cd emissions are mostly caused by lubricant oil use as well as tyre wear. Zinc emission arises due to tyre wear and galvanized components such as gasoline tanks. The most significant source of Cu emission is brake wear. Heavy metals can be transferred from roadside soils to plant uptake by atmospheric deposit or vehicle runoff (Viard et al., 2004; Nabulo et al., 2006).

Senna auriculata (L.) Roxb., a member of the Fabaceae family and often known as aavaram, was chosen as an important medicinal plant for this research. The leaves of these plants are therapeutic; they are eaten, boiled individually or with tea, or used in wound healing. *Senna auriculata* is an excellent choice for roadside landscaping. As a result, monitoring metal concentrations in these plant leaves are important, especially in industrially polluted and road side areas. Metal mobility between soil and plants is a critical topic in determining the environmental impact of metals (Anoliefo et al., 2006). Therefore, in the current study, a correlation analysis was performed to investigate the relationship of the concentrations of six heavy metals, namely Pb, Cr, Cd, Zn, Cu, and Fe in the leaves and flowers of *S. auriculata* with their concentrations in soils in the hills and roadsides.

MATERIALS AND METHODS

Collection and identification

Soil and plant samples were collected from hills (sites 1 and 2) and roadside near industrial regions (sites 3 and 4) in July 2021. Site 1 is Pachaimalai Hills, Site 2 is Kolli Hills, Site 3 is Avur Road, and Site 4 is Samayapuram Road. Botanical Survey of India (BSI/SRC/5/23/2021/Tech-166), Southern Regional Centre, Coimbatore recognized and authenticated the collected plant species.

Analytical procedure

Each soil sample was homogenized and oven-dried at 105°C. After sieving, the material was poured into a 300 ml beaker and heated at 230°C with15ml of nitric acid (HNO_3, 69%) and 25 ml of perchloric acid ($HClO_4$, 58%). After being turned to ash, the digested solution was filtered using Whatman No. 42 filter paper, and the volume was increased to 50ml in a volumetric flask. The metal concentration is determined using an atomic absorption spectrophotometer (Mehmet, 2008). The plant samples were air-dried at room temperature for 5-7 days before being ground into a fine powder. According to Uddin et al. (2016), the wet digestion process was the most efficient for plant materials. A sample weighing 2 g was taken into a conical flask. After that, a 9 ml mixture of nitric-hydrochloric acids HNO_3 (65%) and HCl (37%), in a 1:3 ratio, was added to the conical flask. The mixture was then gently heated at 95°C water bath for 4–5 hours, or for a period until the sample was dissolved. The digest was allowed to cool before being filtered through a Whatman No. 42 filter paper and diluted with deionized water to a final volume of 50 ml. The Stock 1000 ppm standard solutions for all of the heavy metals under test were made in deionized water (Urmila, 2016). Atomic Absorption Spectroscopy (THERMO SCIENTIFIC-ice 3000) was used to detect the heavy metal concentrations in soil and plant samples at National College Instrumentation Facility, National College Tiruchirappalli. All samples and standard solutions were measured in triplicate.

Calculation

The metal concentration which we get from AAS is in mg/L of the solution. This can be converted into mg per kg of the dry weight of soil and plant by the following formula:

$$\text{Concentration of the metal in sample} = \frac{\text{Measured concentration in AAS (mg) x Volume (L)}}{\text{Weight of the sample (kg)}}$$

Statistical analysis

The mean and standard deviation of the heavy metal values from three replicates were calculated using Microsoft Excel. ANOVA was used to determine whether there was a significant difference between the mean concentrations of heavy metals in plant and soil samples collected from hills and roadsides. To assess the magnitude of the relationship between heavy metal concentrations in soil and plant samples, Pearson's correlation test was performed. The significance level was fixed at $p < 0.05$.

RESULTS AND DISCUSSION

Heavy metal concentrations in soil samples

Table 1 shows the mean concentrations of heavy metals in soil samples of four study sites. The findings demonstrate that heavy metal concentrations in roadside samples are greater than in hill sources. The majority of the heavy metal levels in the soil samples studied were below the WHO limit values (2007). However, several soil samples had Cd and Zn levels that were higher than the recommended limits of 0.8 mg/kg and 100 mg/kg, respectively. Cd levels above the standard in roadside soil samples such as site-3 (9.65 mg/kg) and site-4 (6.74 mg/kg). The Zn content in the site-3 soil sample (115.84 mg/kg) exceeded the standard limits. The elevated Cd and Zn values of the roadside samples are due to fuel combustion from automobiles plus discharge of the paint, chemical, and electronic industries, as well as certain cement companies located within 300 m of the sample collection site. The disposal of industrial wastes or the release of pollutants into the atmosphere enhances the overall content of Cd in soils (Weggler et al., 2004). Anthropogenic Cd accumulations in the environment are a source of concern in industrialized nations, and it is classified as a potentially dangerous element in terms of soil biological activity, plant metabolism, and human and ecosystem health (Kabata-Pendias and Pendias, 2001). Zinc exists naturally in soil (approximately 70 mg kg^{-1} in crustal rocks), but Zn concentrations are rising unnaturally due to anthropogenic influences. The majority of Zn is released to the environment via industrial operations such as mining, coal and waste incineration, and steel manufacture. Large quantities of heavy metals are "absorbed" by roadside soils from several sources, including automobile emissions, coal-burning waste, and other activities (Jose et al., 2009, Saeedi et al., 2009). Heavy metals are found in fuels, fuel tank walls, engines and other vehicle components, catalytic converters, tyres, and brake pads, and road surface materials (Zehetner et al., 2009).

Table 1. Mean concentration of heavy metals in soil samples

Metals	Concentrations (Mean ± SD) (mg/kg)			
	Site - 1	Site - 2	Site - 3	Site- 4
Pb	3.09±0.28	0.07±0.21	27.44±0.02	23.95±0.30
Cr	0.97±0.02	2.73±0.04	15.82±0.07	27.69±0.15
Cd	0.28±0.37	0.04±0.02	9.65±3.21	6.74±0.02
Zn	10.6±0.01	9.02±2.37	115.84±0.25	89.35±0.29
Cu	8.02±0.62	9.76±0.01	25.89±0.03	13.32±0.03
Fe	10.23±0.03	17.8±0.21	54.03±0.74	98.46±0.42

Site 1: Pachaimalai hill, Site 2: Kolli hill, Site 3: Avur road, Site 4: Samayapuram road.

Heavy metal concentrations of *Senna auriculata* plants

The mean concentrations of heavy metals in leaves and flowers of *Senna auriculata* are presented in Table 2. Lead values in leaf and flower samples from the study sites ranged from 0.01 to 13.46 mg/kg and 1.02 to 12.78 mg/kg, respectively, compared to the WHO-recommended permissible limit of 10 mg/kg for plants. This criterion was satisfied by the determined The Pb levels in plant samples from hills are within the limit. However, the Pb concentration in the sample of site-3 (roadsides) was much greater than the permissible limits. The Cr concentration of leaves ranged from 0.63 to 3.84 mg/kg and in flowers the concentration varied from 0.42 to 3.06 mg/kg. The maximum Cr concentration of leaves and flowers (3.84 mg/kg and 3.06 mg/kg) was detected in site 4 sample (3.84 mg/kg and 3.06 mg/kg), which was much above the permissible limit (2 mg/kg). The Cd level in leaves was 0.05 to 0.32 mg/kg. The Cr values in flowers varied from 0.03 to 0.27 mg/kg. According to the WHO, the maximum permissible concentration of Cd in plants is 0.3 mg/kg. Thus, all the leaf and flower samples from hills and roadsides were found to have Cd concentrations below the acceptable limit, except for the flower sample from a roadside (site 3), which had a Cd content slightly higher than the permissible limit of 0.32 mg/kg.

Table 2. Mean concentration of heavy metals in *Senna auriculata*

Metals	Plant parts	Concentrations (Mean ± SD) (mg/kg)			
		Site 1	Site 2	Site 3	Site 4
Pb	Leaves	1.86±0.03	0.01±0.01	13.46±0.02	7.43±0.26
	Flowers	1.02±0.01	ND	12.78±0.03	7.38±0.37
Cr	Leaves	0.63±0.01	1.07±0.03	1.89±0.01	3.84±0.01
	Flowers	0.42±0.01	0.91±0.26	1.65±0.04	3.06±0.02
Cd	Leaves	0.05±0.03	ND	0.32±0.01	0.21±0.02
	Flowers	0.03±0.01	ND	0.27±0.03	0.19±0.02
Zn	Leaves	2.63±0.02	1.56±0.01	59.05±0.12	39.24±0.01
	Flowers	0.87±0.02	1.38±0.04	56.12±0.65	38.96±0.03
Cu	Leaves	1.98±0.01	3.48±0.02	9.52±0.03	6.02±0.01
	Flowers	1.46±0.02	3.35±0.01	9.46 ±0.02	5.73±0.01
Fe	Leaves	4.87±0.27	5.48±0.03	11.92±0.01	19.28±0.22
	Flowers	3.84±0.43	5.07±0.02	10.72±0.01	18.02±0.24

ND – not detected, *P<0.05

The Zn concentrations in leaves and flowers ranged from 1.56 to 59.05 mg/kg and 0.87 to 56.12 mg/kg, respectively. The greatest Zn level of leaves and flowers was observed in the site 3 sample, which was above the permissible limit (50 mg/kg). The Cu concentrations in *S. auriculata* leaves and flowers ranged from 1.98 to 9.52

mg/kg and 1.46 to 9.46 mg/kg, respectively, both of which were lower than the WHO permissible limit of 10 mg/kg. The Fe values in leaves varied from 4.87 to 19.28 mg/kg and that in flowers was from 3.84 to 18.02 mg/kg. According to the WHO, the maximum allowable level of Fe in plants is 15 mg/kg. The sample from site 4 contains higher concentrations of Fe than the other sites.

Except for cadmium, analytical results demonstrate that samples from site 1and2 (hills) showed heavy metal concentrations below the permissible limits. Cadmium was not detectable in the site 2 sample. Except for Cd and Cu, the heavy metal concentration of the roadside samples was greater than the acceptable limit. The Pb and Zn levels in the site 3 sample as well as Fe and Cr levels in the site 4 sample, of both leaves and flower extract are above the permissible limit. Therefore, the results indicate that the plant samples from the roadside had higher heavy metal contents than the ones from the hills. This is also true for heavy metal concentrations in soil samples from sites 3 and 4 (both roadsides) than in the hills sources (Table 2).

Table 3. Pearson correlation coefficient(r) between heavy metal concentrations in soil and *S. auriculata* leaves

	Pb soil	Cr soil	Cd soil	Zn soil	Cu soil	Fe soil	Pb leaves	Cr leaves	Cd leaves	Zn leaves	Cu leaves	Fe leaves
Pb soil	1											
Cr soil	0.818	1										
Cd soil	0.983	0.700	1									
Zn soil	0.992	0.741	0.998	1								
Cu soil	0.753	0.237	0.859	0.828	1							
Fe soil	0.765	0.996	0.635	0.680	0.152	1						
Pb leaves	0.940[*]	0.574	0.986[*]	0.975[*]	0.931[*]	0.500	1					
Cr leaves	0.643	0.966[*]	0.493	0.544	-0.019	0.985[*]	0.344	1				
Cd leaves	0.974[*]	0.667	0.998[*]	0.994[*]	0.882	0.599	0.992	0.453	1			
Zn leaves	0.973[*]	0.666	0.998[*]	0.994[*]	0.882	0.599	0.993	0.452	0.981	1		
Cu leaves	0.878	0.444	0.950[*]	0.930[*]	0.975[*]	0.364	0.988	0.199	0.963	0.964	1	
Fe leaves	0.777	0.997[*]	0.651	0.694	0.172	0.999[*]	0.518	0.981	0.615	0.615	0.383	1

* $P<0.05$

Table 4. Pearson correlation coefficient(r) between heavy metal concentrations in soil and *S. auriculata* flowers

	Pb soil	Cr soil	Cd soil	Zn soil	Cu soil	Fe soil	Pb flower	Cr flower	Cd flower	Zn flower	Cu flower	Fe flower
Pb soil	1											
Cr soil	0.818	1										
Cd soil	0.983	0.700	1									
Zn soil	0.992	0.741	0.998	1								
Cu soil	0.753	0.237	0.859	0.828	1							
Fe soil	0.765	0.996	0.635	0.680	0.152	1						
Pb flower	0.950*	0.598	0.991*	0.981*	0.920*	0.526	1					
Cr flower	0.682	0.978*	0.539	0.588	0.033	0.992*	0.421	1				
Cd flower	0.984*	0.705	0.999*	0.998*	0.856	0.641	0.989	0.545	1			
Zn flower	0.981*	0.691	0.999*	0.997*	0.865	0.626	0.992	0.529	0.999	1		
Cu flower	0.861	0.412	0.939*	0.917*	0.982*	0.331	0.976	0.216	0.936	0.943	1	
Fe flower	0.755	0.994*	0.624	0.669	0.137	0.999*	0.513	0.994	0.629	0.614	0.317	1

* $P<0.05$

Correlation between soil and *S. auriculata* for heavy metal concentrations

Correlation analysis was done to see the relationship of the concentrations of Pb, Cr, Cd, Zn, Cu and Fe in the leaves and flowers of *S. auriculata* with their concentrations in soils which shows a significant positive correlation (Tables 3 and 4).

The heavy metal levels in plant leaves correlated significantly ($p<0.05$) with its level in soils showing r = 0.94 for Pb, r = 0.99 for Cd, r = 0.97 for Cr, r = 0.97 for Zn, r = 0.93 for Cu and r = 0.98 for Fe, and in flowers the 'r' values for Pb, Cr, Cd, Zn, Cu and Fe are 0.95, 0.98, 0.99, 0.98, 0.92 and 0.99, respectively.

The correlation analysis reveals that increasing concentrations of heavy metals in the soil causes their increasing concentrations in *S. auriculata* (Fig. 1). Essien and Douglass (2012) found that Pb, Zn, Cu, Ni, Mn, and V in soils all had a significant influence on increasing selected metals (Pb, Zn, Cd) in plants at various coefficients. According to Gregor (2004), metal uptake by both roots and leaves increases as the available metal concentration in the external medium increases. Thus, in the present study, the plants grown in the roadside had a greater concentration of metals than the plants grown in the hills. This is consistent with the findings of Velikovic et al. (2016), who found that the concentration of heavy metals in the soil influences the concentration of heavy metals in vegetable crops produced on contaminated soil. Onder et al. (2007) also reported significant positive relationship between soil and plant heavy metal content. Furthermore, the presence of a positive interaction in the majority of the correlations implies that the absorption of one heavy metal in a plant

impacts the co-absorption of other heavy metals in the same plant which shows a synergistic relationship among them.
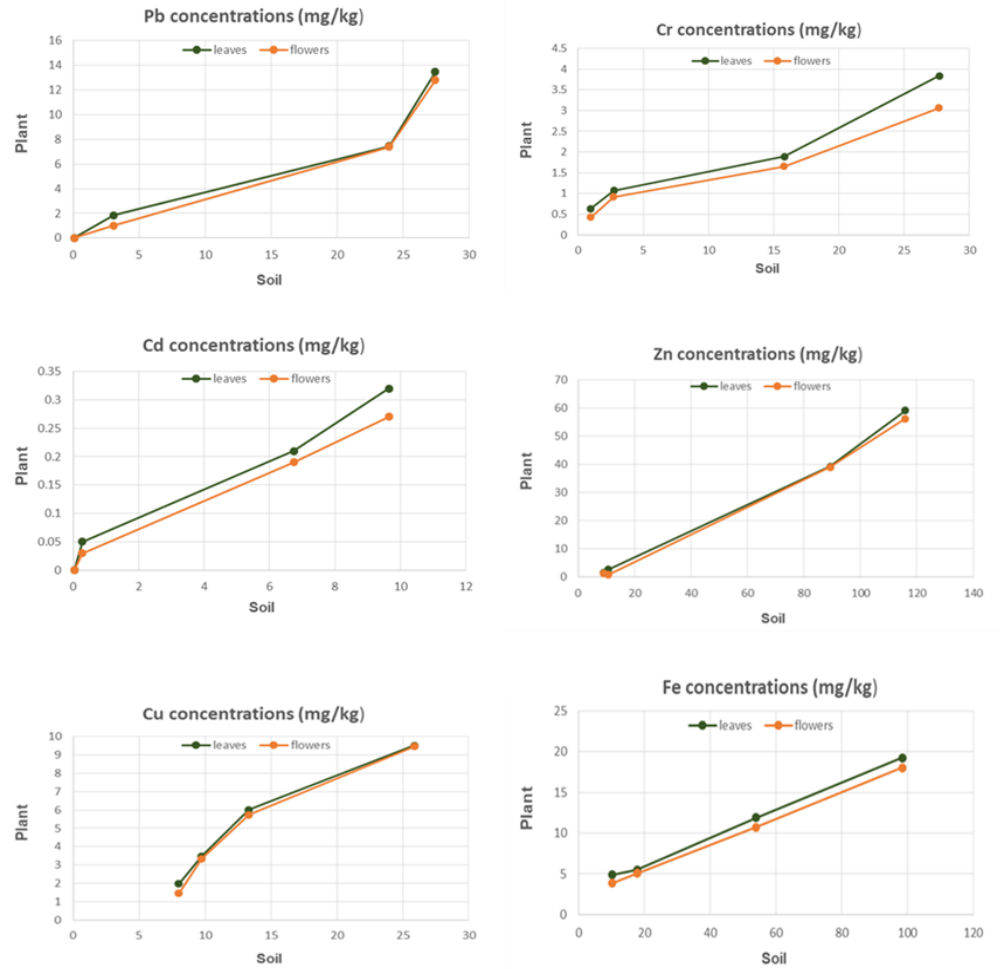

Figure 1. The relationship between soil and plant (*S. auriculata*) for heavy metal concentration

CONCLUSION

Heavy metals (Pb, Cr, Cd, Zn, Cu and Fe) are significantly and positively correlated with soil and plants implying those rising concentrations of heavy metals in soil increased concentrations of *S. auriculata*. Heavy metal concentrations in roadside soils and plants are relatively higher than that in hills.

REFERENCES

Anoliefo, G.O., Ikhajiagbe, B., Okonofhua, B.O. and Diafe, F.V. (2006). Eco-Taxonomic distribution of Plant species around motor mechanic workshops in Asaba and Benin City Nigeria: Identification of oil tolerant plant species. *African Journal of Biotechnology*, 4(19): 1757-1762.

Chen, Z., Ai, Y., Fang, C., Wang, K., Li, W., Liu, S., Li, C., Xiao, J. and Huang, Z. (2014). Distribution and phytoavailability of heavy metal chemical fractions in artifcial soil on rock cut slopes alongside railways. *Journal of Hazardous Materials*, 273: 165-173.

Emamverdian, A. Ding, Y., Mokhberdoran, F. and Xie, Y. (2015). Heavy metal stress and some mechanisms of plant defense response. *Scientific World Journal*, 2015: 1-8.

Essien, O.E. and Douglass E.E. (2012). Heavy metal transfer to vegetables from contaminated farmland adjoining sub urban animal park/market, Uyo. *African Journal of Agricultural Research*. 7(8): 1268-1275.

Gregor, M. (2004). Metal availability, uptake, transport and accumulation in plants. p. 1-27. In Prasad, M.N.V. (ed.), *Heavy metal stress in plants-from biomolecules to ecosystems*. Spinger-verlag, Berlin. Germany.

Jose Acosta, A., Faz, A. and Martinez-Martinez, S. (2009). Identification of heavy metals sources by multivariable analysis in a typical Mediterranean city (SE Spain). *Environmental Monitoring and Assessment*, 169(1-4): 519-530.

Kabata-Pendias, A. and Pendias, H. (2001). Trace Elements in Soils and Plants, 3rd Edition, CRC Press, Boca Raton, Pp. 403

Mehmet, Y.N. (2008). Determination of lead, cadmium and copper in roadside soil and plants in Elazig, Turkey. *Environmental Monitoring and Assessment*, 136(1-3): 401-410.

Nabulo, G., Oryem-Origa, H. and Diamond, M. (2006). Assessment of lead, cadmium, and zinc contamination of roadside soils, surface films, and vegetables in Kampala City, Uganda. *Environmental Research*, 101: 42-52.

Obrador, A., Alvarez, J.M., Lopez-Valdivia L.M., Gonzalez   D., Novillo J. and Rico M.I. (2007). Relationships of soil properties with Mn and Zn distribution in acidic soils and their uptake by a barley crop. *Geoderma,* 137(3-4): 432-443.

Onder, S., Dursun, S., Gezgin, S. and Demirbas, A. (2007). Determination of heavy metal pollution in grass and soil of City Centre Green areas (Konya, Turkey). *Polish Journal of Environmental Studies*, 16(1): 145-154.

Saeedi, M., Hossein Zadeh, M., Jamshidi, A. and Pajooheshfar, S.P. (2009). Assessment of heavy metals contamination and leaching characteristics in highway side soils. Iran. *Environmental Monitoring and Assessment*, 151(1-4): 231-41.

Silva, A.L.O., Barrocas, P.R.G., Jacob, S.C. and Moreira, J.C. (2005). Dietary intake and health effects of selected toxic elements. *Brazilian Journal of Plant Physiology*, 17(1): 79-93.

Uddin, A.B.M.H., Khalid, R.S., Mohamed, A., Abdualrahman, Abdualkader, M., Kasmuri, A. and Abbas S.A. (2016). Comparative study of three digestion methods for elemental analysis in traditional medicine products using atomic absorption spectrometry. *Journal of Analytical Science and Technology,* 7(1): 1-7.

Urmila. (2016). Study of heavy metals contamination of soil and its effects on plants. Ph.D. Thesis, Maharshi Dayanand University.

Velickovic, Z., Ivankovic, N., Strikovic, V., Karkalic, R., Jovanovic, D., Bajic, Z. and Bogdanov, J. (2016). Investigation of soil properties influence on the heavy metals sorption by plants and possibilities for prediction of their bioaccumulation by response surface methodology. *Journal of the Serbian Chemical Society*, 81(8): 947-958.

Viard, B., Pihan, F., Promeyrat, S. and Pihan, J.C. (2004). Integrated assessment of heavy metal (Pb, Zn, Cd) highway pollution: Bioaccumulation in soil, Graminaceae and land snails. *Chemosphere*, 55: 1349-1359.

Weckwerth, G. (2001). Verification of traffic emitted aerosol components in the ambient air of Cologne (Germany). *Atmospheric Environment*, 35: 5525-5536.

Weggler, K., McLaughlin, M.J. and Graham, R.D. (2004). Effect of chloride in soil solution on the plant availability of bio solid-borne cadmium. *Journal of Environmental Quality*, 33(2): 496-504.

WHO. (2007). Guidelines for assessing quality of herbal medicines with reference to contaminants and residues. Geneva, Switzerland. Pp. 24-28.

Zehetner, F., Rosenffllner, U., Mentler, A. and Gerzabek, M.H. (2009). Distribution of road salt residues, heavy metals and polycyclic aromatic hydrocarbons across a highway-forest interface. *Water, Air, and Soil Pollution,* 198(1-4):125-132.