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Heavy metals in atmospheric dust deposited in leaves of *Acacia farnesiana (Fabaceae)* and *Prosopis laevigata (Fabaceae)*

Metales pesados en polvo atmosférico depositado en hojas de *Acacia farnesiana (Fabaceae) y Prosopis laevigata (Fabaceae)*

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Abstract

Atmospheric dust establishes an element of study to know the distribution of pollutant particles such as heavy metals and their effects on ecological systems. The objective was to determine the elemental composition of particles deposited in two species of trees as an indicator of environmental impact in San Luis Potosí, México. The distribution of *Acacia farnesiana* and *Prosopis laevigata* trees was taken into account in five soil uses to collect leaf material and extract atmospheric dust during the spring and summer seasons, determining the concentration of heavy metals using the ICP-MS technique. The results indicated the presence of Al> Cu> Zn> Pb> V> As> Ni> Cd> Ti> Cr> Co. Correlations with values of r^2> 0.90 were presented between V-Ti, Ni-V, Ni-Ti, Al-Ti and Cr-V. The species factor conditioned the concentrations of Al, Ti, V, Cr, Ni and Zn mainly in the particles deposited in *Prosopis* leaves. Particles of nine elements were conditioned by the activities of the five land uses, where the use of mineral soil affected by the presence of Al, Cd, Co, Pb, Cu and Zn. Concentrations of Cd were 6.2 times higher in the use of mining soil than in the agricultural sector; 5.9 and 5.4 times the concentrations of Co and Pb in the use of mining soil with respect to the trade and service respectively. The season had only significant effects on Cr and Pb particles. This study indicates the existence of pollutants that can affect ecological systems so it falls within the context of continued evaluation of environmental impacts.

Keywords
pollution • arborean plants • land uses • environmental impact

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Resumen

El polvo atmosférico se establece como elemento de estudio para conocer la distribución de partículas contaminantes, como son los metales pesados y sus efectos sobre los sistemas ecológicos. El objetivo fue determinar la composición elemental de las partículas depositadas en dos especies de árboles como un indicador de impacto ambiental en San Luis Potosí, México. La distribución de los árboles de *Acacia farnesiana* y *Prosopis laevigata* se tomó en cuenta en cinco usos del suelo para recolectar material foliar y extraer el polvo atmosférico durante la primavera y el verano, determinando la concentración de metales pesados utilizando la técnica ICP-MS. Los resultados indicaron la presencia de Al> Cu> Zn> Pb> V> As> Ni> Cd> Ti> Cr> Co. Se presentaron correlaciones con valores de r^2> 0,90 entre V-Ti, Ni-V, Ni-Ti, Al-Ti y Cr-V. El factor especie condicionó las concentraciones de Al, Ti, V, Cr, Ni y Zn principalmente en las partículas depositadas en las hojas de Prosopis. Las partículas de nueve elementos fueron condicionadas por las actividades de los cinco usos de la tierra, donde el uso del suelo mineral se vio afectado por la presencia de Al, Cd, Co, Pb, Cu y Zn. Las concentraciones de Cd fueron 6,2 veces más altas en el uso de suelo minero que en el sector agrícola; 5,9 y 5,4 veces las concentraciones de Co y Pb en el uso del suelo minero con respecto al comercio y al servicio, respectivamente. La temporada solo tuvo efectos significativos sobre las partículas de Cr y Pb. Este estudio indica la existencia de contaminantes que pueden afectar los sistemas ecológicos, por lo que entran en el contexto de la evaluación de los impactos ambientales.

Palabras clave
contaminación• vegetación arbórea • usos de suelo • impacto ambiental

Introduction

The atmospheric dust or particulate material constitutes an element of study to investigate the distribution of heavy metals and their effects on ecological systems and environmental health. Some authors state that they are solid or liquid particles suspended in the air, with a diverse chemical composition and a size that varies between 0.005 to 100 μm of aerodynamic diameter (27, 31). Its presence in the environment is associated with anthropogenic sources such as fossil fuels, vehicular and industrial emissions, energy production, among others (14). Studies on atmospheric dust have been limited due to the high cost of instrumental monitoring methods and also due to sampling difficulties, which has led to the use of organisms that act as bioaccumulators (19). Several species of plants have been studied to evaluate the behavior of atmospheric dust such as: *Platanus orientalis, Alstonia scholaris, Ficus bengalensis, Polyalthia longifolia, Azadirachta indica, Nerium oleander, Lantana camara; Alstonia scholaris, Ficus bengalensis, Morus alba, Polyalthia longifolia* among others (19, 20, 26, 28).

The foliar surface of plants is continuously exposed to atmospheric patterns and is the main dust receptor affecting the reflectance spectra and growth factors of plants, so it can be used to determine the level of contamination, as well as the capacity of interception and mitigation of each species (15, 21, 24, 29).

The urban zone of San Luis Potosí - Soledad de Graciano Sánchez is characterized by the growth of the industrial population and large areas of crops under irrigation. Among the associated environmental problems are overexploitation and contamination of aquifers, erosion, salinization and loss of soil fertility and inadequate disposal of domestic and industrial waste. Emphasis is placed on the need to generate actions that address the problems related to air pollution and improve the green infrastructure (9, 15, 23).

In the urban and industrial area of the city of San Luis Potosí have been found to have levels of solid particles in suspension, with an annual average of 438 g/m^3 value that is above the threshold of 90 μg/m^3 marked by the WHO (World Health Organization), with the presence of elements such as Pb, Ni, Cu, Cd, As (10). Likewise, in this area, more than 20 species of trees are considered more abundant and of common use as part of the urban and regulated green infrastructure within afforestation and reforestation programs (16, 25).

In addition, several studies have been conducted that indicate the presence of heavy metals in soil, leaves and bark of tree species associated with the dynamics of agricultural, urban, industrial, commercial and service land uses.

On the other hand, the capacity of retention of atmospheric dust in species like *Shinus molle, Prosopis laevigata* and *Acacia farnesiana* has been studied, which has indicated differences between the seasons, species and uses of finding that the greater accumulation of atmospheric dust in leaves, occurred in the winter-spring season and the lowest in the summer, while, in the bark, the largest amount was recorded in winter and the lowest in spring (5, 6, 7, 8, 9, 13).

As a follow-up to the study of the environmental impact of land uses, the atmospheric dust deposited in the foliar material of *Acacia farnesiana* and *Prosopis laevigata* was considered to determine the presence of heavy metals and associate it with the potential use of efficient green infrastructure in the mitigation of environmental problems such as the atmospheric contamination and the use for protection of agricultural areas.

Materials and methods

The study area was located in the state of San Luis Potosí, within the rural-urban area between the municipalities of "Soledad de Graciano Sánchez" and "San Luis Potosí".

The municipality of "Soledad de Graciano Sánchez", is located geographically at 22°11" North latitude and 100°56" West Longitude with altitude of 1,850 meters above sea level, while the municipality of "San Luis Potosí", at coordinates 22°09'04" North latitude and 100°58'34" West.

The climate is mainly characterized by being temperate dry with warm summer, BSOkw11 (e) g. This climate registers 400 mm annual rainfall, concentrated in summer and part of autumn, particularly between the months of May to October, although it should be noted that in half of this season there is a season in which precipitation decreases.

The 6 dominant soil types are lithosol, xerosol, pheozem, chestnut tree and fluvisol (22). In a journey formed by an ecological corridor of approximately 35.5 km, it allowed locating 30 sites considering the alternation in the presence of the species *Prosopis laevigata* (Fabaceae) and *Acacia farnesinana* (Fabaceae).

The sites were located on paths fragmented by five types of dominant land use: agriculture, rural residential, commerce and services, urban and mining residential (figure 1, page 176).

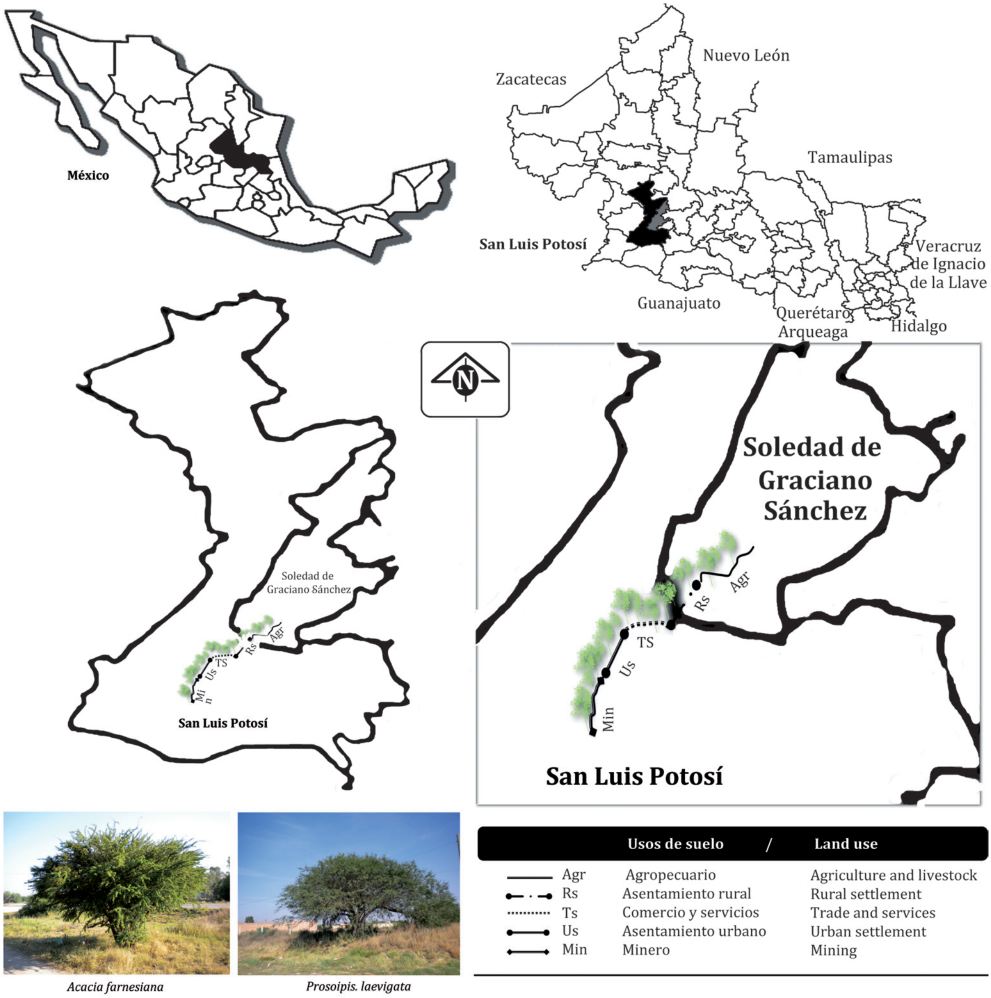

Figure 1. Location of the study area of atmospheric dust in tree species.
Figura 1. Ubicación del área de estudio de polvo atmosférico en especies arbóreas.

For each species, 30 to 40 g of foliar material were taken from branches of individuals with a height greater than 1.60 m. It was considered that the trees were located in the alignment of the road section, alternating their presence in left and right side, as well as their exposure to sources of pollution and air currents. So that there was no effect of the flowering season of these species, the samples were taken in the same individuals during the summer and autumn seasons, as well as in winter and spring, corresponding 115 samples during the four seasons. For the determination of metal concentrations, weighed between 10 to 15 g of foliar material that was washed and filtered in a 100 ml volumetric flask using a No. 42 (previously tared) Whaltman filter paper, then dried in an oven at 60°C and heavy with the powder extracted from the washing of leaves.

Finally, the paper was weighed with atmospheric dust and together with filter paper used as white, in a muffle at 450°C, performing a dry digestion until incineration. The resulting ashes were augmented to 25 ml in volumetric flask with 1% HNO_3; for the analysis of Al, As, Co, Cu, Ni, Cd, Cr, Pb, Ti, V and Zn using the ICP-MS technique. The concentrations of the metals in mg kg^{-1} were reported. For the analysis (ANOVA), it was designed in Minitab setting an $\alpha \leq 0.05$, testing the interactions between the factors land use, species and season with respect to the concentrations of heavy metals. A correlation analysis (Pearson's correlation coefficients) was carried out, as well as a principal component analysis (PCA).

Results and discussion

The analyses carried out indicate the presence of eleven (11) metallic elements in atmospheric dust retained from a total of 115 samples of the species evaluated. The average tendency oscillated with Al> Cu> Zn> Pb> V> As> Ni> Cd> Ti> Cr> Co (figure 2).

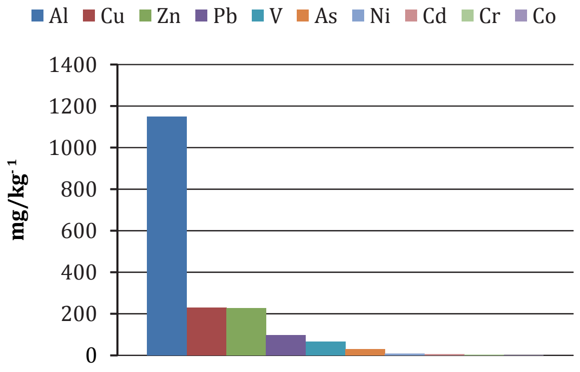

Figure 2. Average concentrations of heavy metals in sedimentable particulate matter.

Figura 2. Concentraciones promedio de metales pesados en material particulado sedimentable.

Regarding the correlation analysis, 11 significant associations were found with the presence of these elements and with values $r^2 > 0.80$ (table 1, page 179).

Among these are the relationship between V-Ti ($r^2 = 0.947$, $p = 0.000$), Ni-V ($r^2 = 0.937$, $p = 0.000$), Ni-Ti ($r^2 = 0.930$, $p = 0.000$), Al-Ti ($r^2 = 0.910$, $p = 0.000$) and Cr-V ($r^2 = 0.902$, $p = 0.000$). This observation indicates that dust contamination by metals they can come mainly from common (11).

Relationship atmospheric dust-tree species

According to the effect of the tree species factor, six of the eleven elements analysed in the sedimentary particulate material present significant differences in the concentrations of heavy metals deposited in *A. farnesiana* and *P. laevigata* (table 2, page 179). These elements were: Al ($p = 0.001$), Ti ($p = 0.000$), V ($p = 0.000$), Cr ($p = 0.000$), Ni ($p = 0.000$) and Zn ($p = 0.023$). It is distinguished that, of these six elements found in the atmospheric dust, their highest concentrations were present in the particles deposited in *Prosopis* leaves. He emphasizes that the concentrations are twice the amount of deposited particles of Ti, V, Cr, Ni and Zn in *Prosopis l.* with respect to *Acacia f.*

This result is associated with studies conducted in the area where the presence of heavy metals is determined by anthropogenic sources and the efficiency of these species to retain atmospheric dust in leaves and bark (5, 6, 7, 8).

The deposition of atmospheric dust with metallic contents implies processes such as sedimentation, impact and interception (20). Not only the diameter and shape of the particles have impacts (17).

In diverse investigations it is indicated that the dust deposition capacity of the plants can depend on its geometrical surface, phyllotaxis and external characteristics of the leaves as it is the presence or absence of pilosity, cuticle, length of the petiole, height of the canopy and crown. Other aspects are the condition of humidity, direction and wind speed (11, 12, 18, 24). The mobilization and transport of atmospheric dust is related to variations in vegetation growth conditions, density and vegetation (2, 18, 30).

Relationship atmospheric dust-land use

The significant effect of the use of soil on the concentrations of heavy metals in atmospheric dust, was presented in nine of the 11 elements analysed, these being: Al ($p = 0.058$), Ti ($p = 0.046$), V ($p = 0.023$), Co ($p = 0.000$), Ni ($p = 0.022$), Cu ($p = 0.000$), Zn ($p = 0.000$), Cd ($p = 0.000$) and Pb ($p = 0.000$). It is distinguished that in the use of mining soil the presence of a greater quantity of particles with contents of Al, Cd, Co, Pb, Cu and Zn was evidenced (table 3, page 180).

On the other hand, particles with contents of Ni, Ti and V were concentrated in greater quantity in the use of agricultural land. It is distinguished that the concentrations of Cd were 6.2 times higher in the use of mining land than in the agricultural one; 5.95 and 5.4 times the concentrations of Co and Pb in the use of mining land with respect to trade and service, respectively. Another comparison is the one that occurred with the Zn, where they were 6.8 times their concentration in particles of the use of mining land in relation to trade and service.

The presence of these heavy metals in this area has been associated with the diversification of land uses (7, 8). Similar results regarding the effect of land uses on concentrations of heavy metals in atmospheric dust have been reported (1).

Table 1. Results of the Pearson correlation coefficient test on sedimentable particulate matter.

Tabla 1. Resultados de la prueba del coeficiente de correlación de Pearson en material particulado sedimentable.

Elemento	Al	Ti	V	Cr	Co	Ni	Cu	Zn	As	Cd
Ti	**0.910**									
	0.000									
V	**0.887**	**0.947**								
	0.000	0.000								
Cr	**0.860**	**0.889**	**0.902**							
	0.000	0.000	0.000							
Co	**0.418**	**0.423**	**0.368**	**0.416**						
	0.000	0.000	0.000	0.000						
Ni	**0.847**	**0.930**	**0.937**	**0.878**	**0.436**					
	0.000	0.000	0.000	0.000	0.000					
Cu	**0.462**	**0.451**	**0.395**	**0.434**	**0.554**	**0.473**				
	0.000	0.000	0.000	0.000	0.000	0.000				
Zn	**0.472**	**0.494**	**0.376**	**0.397**	**0.476**	**0.385**	**0.612**			
	0.000	0.000	0.000	0.000	0.000	0.000	0.000			
As	**0.260**	**0.245**	**0.193**	**0.257**	**0.269**	**0.281**	**0.700**	**0.404**		
	0.005	0.008	0.039	0.006	0.004	0.002	0.000	0.000		
Cd	**0.301**	**0.296**	**0.263**	**0.292**	**0.548**	**0.341**	**0.860**	**0.467**	**0.674**	
	0.001	0.015	0.048	0.010	0.000	0.002	0.000	0.000	0.000	
Pb	**0.440**	**0.446**	**0.362**	**0.484**	**0.523**	**0.456**	**0.672**	**0.574**	**0.498**	**0.588**
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 2. Ratio of heavy metal concentrations to deposited particulate matter according to species (N = 115, p≤0.05).

Tabla 2. Relación de las concentraciones de metales pesados en material particulado sedimentable depositado de acuerdo con la especie (N=115, p≤0,05).

Especie	***Al (mg kg^{-1})***		***Ti (mg kg^{-1})***		***V (mg kg^{-1})***	
	Media	E.E.	Media	E.E.	Media	E.E.
A. farnesiana	815.62	133.43	15.12	2.83	35.77	7.99
P. laevigata	1447.77	125.46	32.30	2.66	95.38	7.61

Especie	***Cr (mg kg^{-1})***		***Ni (mg kg^{-1})***		***Zn (mg kg^{-1})***	
	Media	E.E.	Media	E.E.	Media	E.E.
A. farnesiana	2.43	0.44	4.52	0.89	255.66	92.19
P. laevigata	4.91	0.42	10.33	0.85	549.90	87.78

Table 3. Ratio of concentrations of heavy metals deposited in atmospheric dust according to land uses (N = 115, $p \leq 0.05$).
Tabla 3. Relación de las concentraciones de metales pesados en polvo atmosférico depositado de acuerdo con el uso de suelo (N=115, $p \leq 0,05$).

Elements	Land use									
	Agriculture and livestock		Rural settlement		Trade and service		Urban settlement		Mining	
	(mg kg^{-1})		(mg kg^{-1})		(mg kg^{-1})		(mg kg^{-1})		(mg kg^{-1})	
	Average	±E.E.	Average	±E.E.	Average	±E.E.	Average	±E.E.	Average	±E.E.
Al	1355.25	197.09	1290.12	197.09	777.52	197.09	810.12	211.53	1418.98	206.20
Cd	2.37	1.77	2.61	1.77	2.46	1.77	4.63	1.90	14.70	1.85
Co	1.33	0.78	1.52	0.78	0.96	0.78	1.18	0.83	5.72	0.81
Ni	10.12	1.36	7.80	1.36	4.56	1.36	5.46	1.45	9.19	1.41
Pb	50.80	21.87	56.38	21.87	48.92	21.87	83.92	25.93	268.52	25.28
Cu	121.66	98.04	91.40	98.04	56.52	98.04	102.61	106.11	807.85	10.343
Ti	29.79	4.12	26.65	4.12	14.98	4.12	18.43	4.42	28.88	4.31
V	86.31	12.04	78.59	12.04	38.39	12.04	47.99	12.92	76.16	12.59
Zn	217.11	138.79	236.06	138.79	156.17	138.79	331.91	148.96	1072.65	145.20

Presence of Zn and Cu has been associated with traffic activities and industry and Ni with contaminated soils (19). Presence of this element is associated with vulcanization activities in tires, abrasion of car tires increases and lubricating oils (28).

Atmospheric dust ratio-season

With regard to the effect of the season, it is indicated that only Cr and Pb had significant effects for this factor ($p \leq 0.05$, figure 3). In this sense, the Cr concentrations ranged from 4.81 to 5.89 mg/kg^{-1} and in Pb from 77.54 to 125.88 mg/kg^{-1}, in both cases, in summer the highest concentration of particles of these elements.

The Cr is associated with the manufacturing industry, use or disposal of chromium products can be found in air, soil and water. This does not remain in the atmosphere, but is deposited in the soil and water (4).

As for the GDP, a large part comes from human activities such as the burning of fossil fuels, mining and manufacturing. When the lead is released into the air, it can travel long distances before being deposited on the ground (3). Presence of Pb particles has been associated with heavy vehicular traffic and industrial dusts (1).

In scenarios where the period of dry weather, the moisture content of the soil is below the vegetation cover is poor, there is more mobilization of particles that may contain heavy metals (11, 28, 30). In the study area, it has been associated to the influence of the directions of the prevailing winds of the city vary during the course of the year in relation to particles of industrial and anthropic sources coming from the E and ENW and the influence of winds from WSW and N (10).

Principal component analysis and similarity

Respectively, the first two components (PC1 and PC2) presented a variance of 6.55 and 1.91 of the total variance, which represented 59.6% and 17.5%.

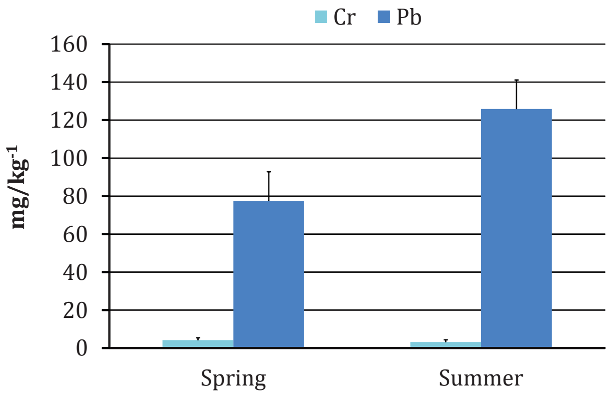

Figure 3. Relationship of concentrations of Cr and Pb in atmospheric dust according to the season.

Figura 3. Relación de concentraciones de Cr y Pb en polvo atmosférico de acuerdo con la temporada.

For PC1 the highest values of the coefficients are related to Al, Ti, V, Cr and Ni. With respect to PC2 positive coefficients were presented with respect to Co, Cu, As, Cd and Pb, and negative with Al, Ti, V, Cr, Ni and Zn. Together, the first two and the first three components represent 76.9% and 83.5%, respectively, of the total variability (figure 4). It was distinguished a group of thirteen samples distant from the axis related to the use of mining soil and with the highest averages of heavy metals found in atmospheric dust with respect to the rest, being these: 22, 24, 25, 49, 52, 53, 54, 55, 111, 112, 113, 114 and 115.

Another important group of 24 samples removed from the axis stands out at the species level and most of them belonged to *Prosopis.* The behaviour of groups and the incidence of heavy metal localities can be attributed to anthropogenic activities derived from land uses, soil or geological composition, dust derived from vehicular traffic and streets (7, 8, 11, 26).

With respect to the similarity analysis, associations were found between the elements analysed with atmospheric dust (figure 5, page 183).

The relationship between Al, Ti, V, Ni and Cr is distinguished with values ranging from 95.08 to 96.87.

On the other hand, a group consisting of Cu, Cd, As and Pb presented values between 90.98 and 83.62 of association.

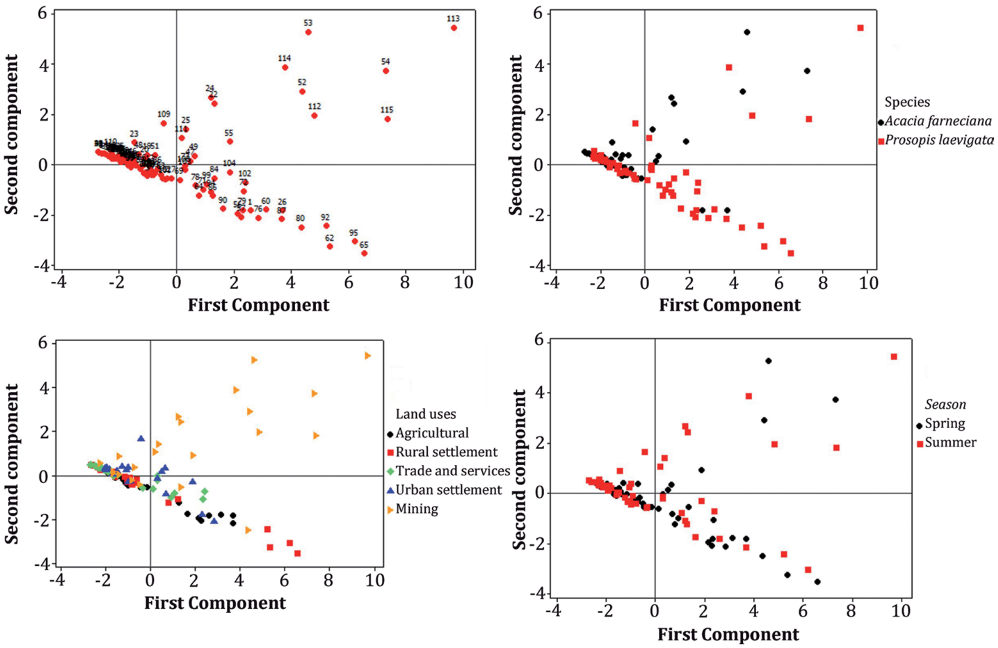

Figure 4. Dot diagram derived from the principal component analysis with atmospheric heavy metals.

Figura 4. Distribución de puntos derivado del análisis de componentes principales con metales pesados en polvo atmosférico.

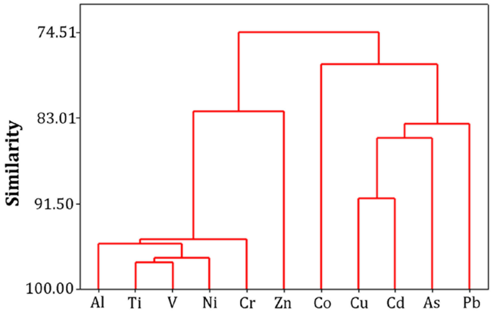

Figure 5. Dendrogram of similarity of Euclidean distance in metals studied in atmospheric dust.

Figura 5. Dendrograma de similitud de la distancia euclidiana en metales estudiados en polvo atmosférico.

This confirms a high correlation between these elements. With respect to Zn and Co, the distance found with the other elements is notorious. This indicates the association between the presence of particles and the effect of the dynamics of each of the land uses. For example, it has been associated with Pb, Cd and Cu with sources such as fossil fuel, biomass combustion and industrial emissions, vehicular traffic. Others may be associated with sources of natural contamination (18). In the study area these elements have been found in atmospheric particles and associated mainly with industrial sources such as mining activity (10).

Conclusions

The study indicated the presence of heavy metals in atmospheric dust retained in leaves of *P. laevigata* and *A. farnesiana* evidenced by concentrations that oscillated with Al> Cu> Zn> Pb> V> As> Ni> Cd> Ti> Cr> Co.

Likewise, significant correlations with values r^2> 0.90 were presented between V-Ti, Ni-V, Ni-Ti, Al-Ti and Cr-V.

The species factor conditioned the concentrations of Al, Ti, V, Cr, Ni and Zn mainly in the particles deposited in *Prosopis* leaves. Particles of nine elements were conditioned by the influence of the activities of the five evaluated land uses, where the use of mineral soil affected mainly with the presence of Al, Cd, Co, Pb, Cu and Zn. Concentrations of Cd were 6.2 times higher in the use of mining land than in agriculture; 5.95 and 5.4 times the concentrations of Co and Pb in the use of mining land with respect to trade and service, respectively.

The season only had significant effects on Cr and Pb particles. This indicates the existence of contaminating elements that can affect ecological systems and environmental health considering the need to continue with these studies in the environmental impact assessment.

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