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The Effect of Aircraft Traffic Emissions on the Soil Surface Contamination Analysis around the International Airport in Delhi, India

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ABSTRACT

To investigate the effect of aircraft traffic emissions on soil pollution, metal levels were analyzed for 8 metals (Fe, Cr, Pb, Zn, Cu, Ni, Mn and Cd) from the vicinity of the Indira Gandhi International (IGI) airport in Delhi, India. The texture of the airport soil was observed to be sandy. Among the metals, Cd showed minimum concentration (2.07 $\mu g\ g^{-1}$), while Fe showed maximum concentration (4379 $\mu g\ g^{-1}$). The highest metal accumulation was observed at the landing site. Significant correlations were observed between metals and different textures (sand, silt, and clay) as well as with organic carbon (OC). The results indicate that grain size play a major role in OC retention in soil and subsequently helps in adsorption of metals in soil. Müller's geoaccumulation index (I-geo) showed that airport soil was contaminated due to Cd and Pb with the pollution class 2 and 1, respectively. Pollution load index of the airport site was 1.34-3 times higher than the background site. The results of factor analysis suggested that source of the soil metal is mainly from natural weathering of soil, aircraft exhaust, and automobile exhaust from near by area. With respect to Dutch target values, the airport soils showed ~3 times higher Cd concentration. The study highlighted the future risk of enhanced metal pollution with respect to Cd and Pb due to aircraft trafficking.

Key words: Airport, Metals, Soil, Delhi, Geoaccumulation index, Pollution load index, Source apportionment

1. INTRODUCTION

Soil metal contamination due to various emission sources has gained an increased attention due to the high degrees of their toxicity and stability (Adriano, 2001; Malawska and Wilkomirski, 2001). Metals are one of the major causes of concern, as they are potentially toxic elements (PTE) that remains persistently in soil (Grandjean and Landrigan, 2006) and are often present at high concentration in urban areas. Among the trace metals, Cd adversely affects the bones (osteomalacia) and kidneys; Pb inhibits the synthesis of hemoglobin with an adverse effect on the central and peripheral nervous system and kidneys (Manahan, 1994). Some of the bio-elements such as Cu and Zn are toxic to plants, when present in high amounts in soil (Kabata-Pendias and Pendias, 1992). High emissions of those pollutants are reflected in the contamination status of soils because soils are important sinks of atmospheric pollutants. As such, the soil system is considered to be a steady indicator of the environmental pollution state (Kannan *et al.*, 2003).

Accumulation and distribution of metals in soil is often explained in relation to the intensity of urbanization (Kannan *et al.*, 2005; Mielke *et al.*, 2000). The increasing trends in air travel worldwide promote the construction of new airports and/or expansion of existing airports to handle the large volume of air travelers. In turn it raises the concern about the exposure to toxic combustion products of jet fuel in the nearby residents (Tesseraux, 2004). The primary aviation fuels are kerosene-range distillates (White, 1999). Combustion of aircraft fuels results in CO_2, H_2O, CO, C, NO_X, SO_X, soot, metal particles, hydrocarbons and a great number of other compounds (Topal *et al.*, 2004).

Many studies have demonstrated the potential heavy metal pollution load of airfields such as high Pb concentration in mosses and lichens in the Helsinki-Vantaa Airport area, Finland (Mäkinen *et al.*, 1980), elevated Pb concentration in the air at Heathrow Airport, London, U.K. (Nichols *et al.*, 1981), high Cd content in feral pigeons living in the Heathrow Airport area (Hutton and Goodman, 1980), 2-5-fold higher Cd concentration in mushrooms of the Prague Airport area in Cerny Val, Czech Republic than in non-polluted forests (Sova *et al.*, 1991) and significantly higher Cd content in feathers, heart, liver and muscles of herring gulls living in the John F. Kennedy Airport area, New York (Gochfeld *et al.*, 1996). However, there are very few published reports on heavy metal contamination of airports.

A few studies have focused on metal pollution and their associated toxicity in urban and suburban soils of Delhi (Singh and Kumar, 2006; Kaur and Rani, 2006). To the best of our knowledge, a detailed study on metal contamination has not been evaluated in the airport soil of Delhi or in any other airport soils in India. Hence, this present study aims to assess the provenance and potential mobility of metals in these soils. Further, we wanted to study the potential risks it poses based on various geochemical toxicity indices. The database generated from this study will be of immense importance in characterizing aircraft-driven pollution with respect to soil metals in India. In addition, the study may also be helpful in land-use planning of urban regions.

Thus objectives of the study were: 1) to determine the concentrations and spatial distribution of metals in airport soils, 2) to determine the associations of metals with other parameters (e.g., OC and grain sizes) 3) to assess the metal contamination in the airport soils and 4) to identify the possible sources of these metals in the soil around the airport.

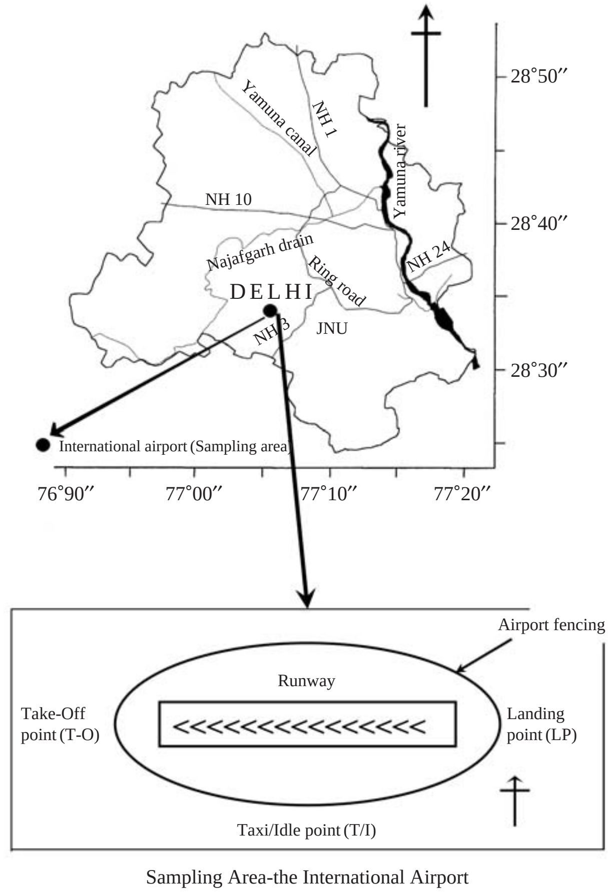

Fig. 1. Map of Delhi, India showing location of sampling area-the International Airport.

2. MATERIALS AND METHODS

2. 1 Sampling Locations

Delhi, the capital of India is situated with an altitude of 216 meters above sea level (latitude of 28°24′17″N to 28°53′N and the longitude of 76°20′37″E to 77°20′ 37″E). The study area, Indira Gandhi International (IGI) airport is one of the busiest airports in South Asia. It is located 23 km south of Delhi (Fig. 1). Delhi has a single 40 km long corridor, which is oriented in the east - west direction for both incoming and outgoing flights. The number of flights operating per day is about 700 (Indian Express, 2011). The IGI airport is surrounded by major residential areas of Pahladpur and Palam in the north, Dwarka in the north-west, Vasant Vihar in the east, Mahipalpur and Vasant Kunj in the south east and Brijwasan is situated south of the IGI airport.

There are no large industries and heavy traffic roads in the vicinity of the IGI airport. However, it is served by subsidiary road emerging from National highway (NH-8) at a distance of 4-5 km from the airport. Thus, the direct impact of vehicular emission from the highway is minimal on the sampling locations. Three sampling locations were selected in the area surrounding the airport and one background location was chosen in a remote area. Site (LP) was selected near the landing point of the airport, site (T/I) was located near the taxi/idle point (south of the runway), while site (T-O) was situated near the take-off point of the airport. The background (BG) sampling location was located at a remote area at a distance of 10 km from the airport.

2. 2 Soil Sampling

Sampling was done from December 2005 to February 2006, from the immediate periphery of the airport, using a stainless steel auger upto a depth of 5 cm. Soil samples were spread out and air-dried in dark, homogenized and then they were sieved through 2 mm diameter sieve. Representative samples were obtained after quartering and coning. Approximately 15 to 20 soil samples were collected from different spots from each sampling location (LP, T/I and T-O) in order to make one composite sample. Soil sampling was done twice monthly and per site 6 samples were collected for a period of 3 months. Thus, in the 3 month sampling period 24 samples were analyzed for 4 sites. Results are reported as an average of 6 samples per site.

2. 3 Analysis

2. 3. 1 Determination of pH, EC, OC, and Soil Texture

1 : 2.5 soil solution prepared in double distilled water was used to measure soil pH and electrical conductivity (EC) of all the soil samples. The organic carbon (OC) content in soil was determined following Walkey and Black method using potassium dichromate oxidation procedure (Walkey and Black, 1934). Soil texture was determined by pipette method using sodium hexametaphosphate solution.

2. 3. 2 Determination of Metals

Soil samples were digested for metal analysis by following the method of Agemian and Chau (1976). In this method, 0.5 grams of soil was digested in concentrated nitric acid (HNO_3), perchloric acid ($HClO_4$), and hydrofluoric acid (HF) at 150°C in Teflon bomb for 5 hours. The digested sample was subsequently dissolved in boric acid solution, and the final volume was made up 50 mL. Finally, all the samples were analyzed on an atomic absorption spectrophotometer (Shimadzu AA 6800) for 8 metals (Fe, Cr, Pb, Zn, Cu, Ni, Mn and Cd). The detection limits ($\mu g\ g^{-1}$) for these metals were 8.65, 0.21, 0.78, 1.11, 1.48, 0.28, 11.3, and 0.01, respectively.

2. 3. 3 Analytical Quality Control

Analytical methods were checked for the precision and accuracy. All the samples were analyzed in duplicate. Replicate analyses gave an error between $\pm$10% and $\pm$15%. Procedural blanks were performed periodically to prevent contamination.

2. 3. 4 Statistics

Data were analyzed using SPSS 10.0 (SPSS Inc, Chicago, IL, USA). Pearson correlation analyses were applied to determine the correlations between the metals, OC, and different grain sizes. Source apportionment of metals was done using Principal Component Analysis (PCA) to elucidate the plausible sources of metals in the present study.

3. RESULTS AND DISCUSSION

3. 1 Physico-chemical Properties

Soil texture analysis showed sand as the predominant component (greater than 50%) of the airport soil. The range of organic carbon (OC) (Table 1) in the investigated soil samples was 0.92-1.33%. The pH values of soil were in the sub-alkaline range (7.73-7.94). The concentrations of the metals investigated in the airport and background soils are presented in Table 2.

3. 2 Concentration and Distribution of Metals

Concentration of 8 metals (Cd, Fe, Cr, Pb, Zn, Cu, Ni and Mn) was determined in airport soils (sites LP, T/I, and T-O) and background soil (BG) in the $<$2 mm fraction. The concentrations of metals measured in soil samples of the airport and background sites are presented in Table 2. The overall concentration of the airport was considered by averaging the values of LP, T/I and T-O sites. Results of two-way Anova illustrated that there were significant differences between all the four sampling sites with respect to the metal concentration ($p \leq 0.05$). On an average, for most of the metals (except for Fe and Mn), the airport sites were observed to have ~1.5 times higher concentration than BG.

Landing location (LP) showed relatively high concentration for most of the metals (Fig. 2). Hence, emissions from aircraft during landing and take-off may be responsible for such enrichment at LP relative to T-O. This may be due to the fact that particulate emissions are strongly dependent on the power settings of the engine (Kalivoda and Feller, 1995). Particulate emissions are higher at low engine powers because combustion efficiency is low. During landing operations, engine is set at low power settings at which

Table 1. Physico-chemical parameters at different sampling locations.

Locations	pH	EC ($S\ m^{-1}$)	OC (%)	Sand (%)	Clay (%)	Silt (%)
LP	7.93	0.14	1.33	50.1	22.8	27.1
T/I	7.94	0.13	0.92	55.4	15.3	29.3
T-O	7.73	0.08	1.00	56.7	8.54	34.8
BG	8.15	0.09	1.89	48.9	33.7	17.4

Table 2. Metal concentration ($\mu g\ g^{-1}$) at different sampling locations.

Site	LP	SD*	T/I	SD*	T-O	SD*	BG	SD*
Cd	2.07	1.21	2.35	1.35	2.35	1.44	0.08	0.001
Cr	120	46.1	114	33.8	147	64.0	62	21.2
Pb	42.9	13.9	28.6	4.31	40.8	5.26	20	2.78
Zn	142	56.9	70.6	22.2	77.4	23.9	51	6.51
Cu	28.1	6.11	14.4	2.68	21.3	7.76	13	3.79
Ni	42.9	5.43	45.3	19.5	44.3	11.8	28	4.57
Mn	429	95.0	346	40.3	397	120	350	59.2
Fe	4441	113	4318	98.7	4376	72.2	4168	47.6

(*SD denotes Standard deviation)

emissions are maximized due to incomplete combustion (Kesgin, 2006). Hence, the highest concentration at LP site should be due to its location near the landing point. Emissions tend to decrease as power setting increases, i.e. during take-off, which supported the minimum metal concentration at the sampling site near take-off point. In addition, LP is located downwind of the runway, receiving more depositional load, while T-O is in the upwind direction. Hence, lesser metal concentration at T-O site should be justified. Among the metals studied in the airport soils, Cd was found to have the minimum concentration (2.07-2.35 $\mu g\ g^{-1}$) (Table 2), while Fe had maximum concentration (4318-4441 $\mu g\ g^{-1}$). The average concentration loadings of the airport soil was Cd < Cu < Pb < Ni < Zn < Cr < Mn < Fe. The content of metals in soil is strongly correlated with grain size, if metal input remains constant (Sharma *et al.*, 1999). In soils, Fe-oxides are the main absorbers of heavy metals (Xia *et al.*, 2007). High values of Fe concentration observed in the study area are suspected to be associated with the Fe accumulation because of desilification. Other studies have also reported that high Fe concentrations are in soil due to natural geochemical processes (Salonen *et al.*, 2007; Micó *et al.*, 2006). High Mn concentration should be attributed to the geology of the area, due to the occurrence of Mn rich sedimentary rocks throughout the south western part of Delhi. This observation is in agreement with studies of Kaur and Rani (2006). The pH values in the airport soils were in the sub-alkaline range of 7.73-7.94. Thus, the metals are expected to remain largely immobile after deposition. The metals will be specifically adsorbed to Fe-oxides and clay minerals which become deprotonated due to high pH-values and tend to form stable hydroxo-metal complexes with metals under such conditions (Gocht *et al.*, 2001).

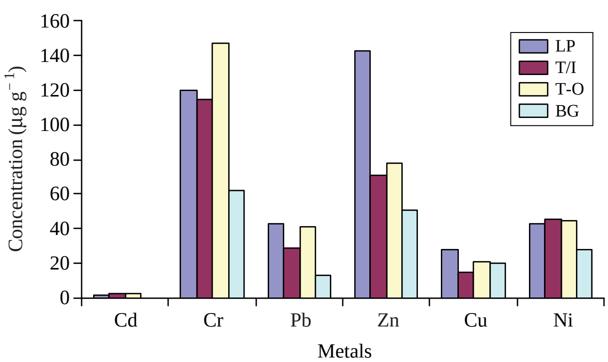

Fig. 2. Variation of metal concentration levels in different sampling sites (except Fe & Mn).

Metal pollution from aircraft may rise through emissions from combustion of fuel additives (WHO, 2005). Pb, Mn, Fe, Zn, and Cu are commonly used as additives in aviation fuels (Collins *et al.*, 2002) to boost the octane number, improve combustion, suppress smoke, and reduce NO_X emissions. Ni and Zn emissions may increase due to Ni-Zn alkaline storage batteries (Dell, 1996). High Cr concentration may be due to abrasion of primers applied to aircraft surfaces to prevent corrosion (a human carcinogen) (Carlton, 2003; Dell, 1996). Currently, aviation gasoline is the one of the fuels containing lead additive, which is used to boost the octane of aviation gasoline (US EPA, 2008).

The metal concentrations observed in this study were compared with these of literature in many other airport soils (Table 3). High Cd concentrations found in the present study have also been reported around Zagreb airport, Croatia; Tribhuban airport, Kathmandu and Thessaloniki airport, Greece; and Queen Alia International airport, Jordan. High Cd concentration

Table 3. Concentration of metals in airport soils from different countries (in $\mu g\ g^{-1}$).

Sampling sites	Cd	Pb	Zn	Cu	Ni	Mn	Fe	Cr	Reference
IGI airport, Delhi, India	2.26	37.5	97	21.3	44.2	391	4379	127	This study
Queen Alia Int. airport, Jordan	6.55	60.2	51.4	3.02	–	–	–	17.3	Al-Khashman and Shawabkeh, 2009
Storm Runoff, Int. airport, Genoa, Italy	–	10.2	82-134	10.2-18.2	–	–	–	–	Gnecco *et al.*, 2008
Zagreb airport, Croatia	3.85	–	277	–	49.5	–	–	–	Romic and Romic, 2003
Santa Barbara Regional airport, USA	–	60	75	23	–	–	–	–	Boyle, 1996
Los Angelos airport, USA	–	24	47	14	–	–	–	–	Boyle, 1996
Saudi Arabia airport, Giza	–	26	32	10	–	–	–	–	Falih, 1997
Soviet military air field, Tartu-Raadi, Estonia	0.31	28	–	–	–	–	–	–	Mander *et al.*, 2004
Tribhuban airport, Kathmandu (Lichens)	2.72	13.2	–	–	–	–	–	1.25	Chettri *et al.*, 2002
Taichung airport, Taiwan ($\mu g\ m^{-2} day^{-1}$) (Dry deposition)	–	50.1	59.4	52	–	27.7	615	28.1	Fang *et al.*, 2007
Thessaloniki airport, Greece (sediments)	2.40	1.77	153	56.9	165	604	–	252	Catsiki *et al.*, 2003

Table 4. Correlation matrix of metals, OC, and grain sizes ($p \leq 0.05$).

	Cd	Cr	Pb	Zn	Cu	Ni	Mn	Fe	OC	Sand	Silt	Clay
Cd	**1**											
Cr	0.35	**1**										
Pb	−0.62	**0.52**	**1**									
Zn	−1.00	−0.27	**0.68**	**1**								
Cu	−0.86	0.17	**0.93**	**0.90**	**1**							
Ni	**0.90**	−0.10	−0.90	−0.93	−1.00	**1**						
Mn	−0.80	0.29	**0.97**	**0.84**	**0.99**	−0.98	**1**					
Fe	−0.89	0.13	**0.91**	**0.92**	**0.98**	−1.00	**0.99**	**1**				
OC	−0.98	−0.17	**0.75**	**0.98**	**0.94**	−0.96	**0.89**	**0.96**	**1**			
Sand	**0.98**	**0.52**	−0.46	−0.96	−0.76	**0.80**	−0.67	−0.78	−0.93	**1**		
Silt	**0.72**	**0.90**	0.10	−0.66	−0.28	0.34	−0.16	−0.32	−0.59	**0.84**	**1**	
Clay	−0.88	−0.75	0.17	**0.84**	**0.52**	−0.58	0.41	**0.56**	**0.78**	−0.95	−0.96	1

could arise due to wear and tear of aircraft wheels and brakes (Czarnowska, 1999; de Miguel *et al.*, 1997). Moreover, from Ni-Cd alkaline storage batteries are used as an emergency flight power source (Dell, 1996).

In India, as soil standards are not available for metals, the values in this study were compared with Dutch target values (Table 5). All the metal concentrations were below the guidance values, except Cd, Cr and Ni. Cd concentration in this study area was ~3 times higher than the Dutch standards.

3. 3 Correlation Analysis

Pearson correlation test was made to assess the relationship between 8 metals, OC, and grain sizes. The results of this analysis are reported in Table 4. OC did not show significant correlation with Cd, Cr, and Ni. This suggests that aerial deposition patterns (rather than an equilibrium situation between organic matter and other phases) probably have influenced these metal concentrations. Therefore, it supports the hypothesis that the metal burden of Cd, Cr and Ni the airport soils result from atmospheric concentration (Stalikas *et al.*, 1997). This could be ascribed to the absence of metal accumulation in humic material and the occurrence of airborne carbonaceous particles formed by combustion (Mielke *et al.*, 2004).

Significant correlation of OC with clay fraction suggests that grain size influences OC content. Thus, the lower the grain size, the higher the OC content. Significant correlation of OC with Fe, Mn, and Zn implies that soil properties influence these metal concentration and that these metals are probably derived from natural weathering. Zinc tends to form complexes with organic matter and mostly associates with organic matter through adsorption and/ incorporation into the biologically resistant humic component in soils (Achterberg *et al.*, 1997). In addition, the strong positive correlation with Fe and Mn indicates the probable adsorption of these metals on to the oxyhydroxides of Fe and Mn (Stalikas *et al.*, 1997). The correlation of these metals suggests that these metals may have the same partitioning to the soil and mineralogical background. Nevertheless, good correlation among Cu, Pb and Zn suggests that significant part of these metals also contributed from automobiles and airplane exhaust. Likewise, there is a good correlation between for Pb and Cu with OC (Table 4), suggesting the high affinity of these metals for organic ligands (Balasoiu, 2001).

Table 5. Geoaccumulation index (I_{geo}) values of metals in sampling sites and their corresponding Dutch target values.

Metals	LP	T/I	T-O	Airport	BG	Dutch standard ($\mu g\ g^{-1}$)
Cd	**2.20**	**2.38**	**2.38**	**2.32**	−2.49	0.8
Fe	−3.99	−4.04	−4.02	−4.02	−4.09	−
Cr	−0.17	−0.24	**0.12**	−0.09	−1.12	100
Pb	**0.52**	−0.07	**0.44**	**0.30**	−1.21	85
Zn	0.00	−1.01	−0.88	−0.63	−1.48	140
Cu	−1.27	−2.22	−1.66	−1.72	−1.75	36
Ni	−1.25	−1.17	−1.20	−1.21	−1.87	35
Mn	−1.57	−1.88	−1.68	−1.71	−1.87	−

3. 4 Geoaccumulation Index (I_{geo}) and Pollution Load Index

To assess the origin of metals and their potential link to anthropogenic activities, geoaccumulation index (I-geo) was calculated. It is a quantitative measure to evaluate metal pollution of the soil matrix. It was originally defined by Müller (1979) in order to determine contamination in sediments and soils by comparing current concentrations with pre-industrial levels. It can be calculated by the following equation:

$$I_{geo} = \log_2 (C_n / 1.5 B_n)$$

where Cn is the measured concentration of the metal (n) in the <2 mm fraction of soil, Bn is the geochemical background value in average shale (Turekian and

Wedepohl, 1961) of metal n, and 1.5 is the background matrix correction factor due to lithogenic effects. Müller distinguished seven classes of I-geo (class 0 to 6) (Müller, 1981) where the highest class (class 6) reflects 100-fold enrichment above the background values.

The results of I_{geo} values determined in this study are shown in Table 5. The I-geo values of Pb and Cd were 0.30 and 2.32, respectively (Table 5). It thus indicates contamination in the airport soil. According to the Müller classification, airport soils of Delhi belonged to the pollution class 1 and 2 with respect to Pb and Cd, respectively. Thus, the study area showed high Cd contamination.

Pollution load index (PLI) for a particular site has also been evaluated following the method proposed by Tomilson *et al.* (1980). This parameter can be expressed as:

$$\mathrm{PLI} = (\mathrm{CF1} \times \mathrm{CF2} \times \mathrm{CF3} \times \cdots \times \mathrm{CFn})^{1/n}$$

where n is the number of metals (six metals were considered except Fe and Mn) and CF is the contamination factor. The contamination factor can be calculated from the following relation:

$$\mathrm{CF\ (Contamination\ factor)} = \frac{\text{Metal concentration in the sediments}}{\text{Background values of the metal}}$$

Background values were calculated using the average shale value (Turekian and Wedepohl, 1961). The PLI for the airport site was found to be 1.34, while that for BG site it was 0.48. Thus, it can be concluded that the airport site is ~3 times more contaminated than the background site.

3. 5 Source Apportionment

Principal Component Analysis (PCA) is a source apportionment tool that can be used to reduce a set of original variables and to extract a small number of latent factors (principal components, PCs) for analyzing relationships among the observed variables. By determining the PCA component loadings, communalities, and eigen values, the variables related to specific geochemical or environmental sources or processes were identified. In PCA analysis, Varimax normalized rotation was applied to the axes which maximised the variance of the components.

To obtain more insight into the data structure, PCA was performed to identify the main sources influencing the metal concentration in the soil in the immediate periphery of the airport area. Results obtained by PCA are given in Table 6. Concentrations of 8 metals were chosen as active variables. The majority of the variance (85.6%) of the scaled data was explained by four eigen vectors known as principal components. The first principal component (PC1) explained 26.7% of total variance, the second (PC2), the third (PC3), and the fourth (PC4) principal component explained 23.4%, 21.1% and 14.4% of the total variances, respectively.

Table 6. Principal component analysis (PCA) data following Varimax rotation for metals.

Variable	Component			
	1	2	3	4
Cd	0.07	0.07	0.27	**0.91**
Cr	0.40	−0.01	**0.86**	0.03
Cu	0.06	**0.91**	0.11	−0.03
Fe	**0.84**	0.33	−0.15	0.25
Mn	**0.95**	0.07	0.19	−0.05
Ni	−0.22	0.05	**0.86**	0.32
Pb	0.22	**0.75**	−0.17	0.29
Zn	**0.51**	**0.59**	0.20	−0.29
Eigen values	2.13	1.86	1.68	1.15
% variance	26.68	23.35	21.09	14.43
Cumulative %	26.68	50.04	71.14	85.57

The first component (PC1) was predominately weighted in metals; Fe, Mn and Zn. These results showed that the metals (Fe, Mn, and Zn) in the airport soils were associated with metal industry and tire wear particles (Bennett *et al.*, 2011; Councell *et al.*, 2004). The second component (PC2) had high factor loadings for metals, Cu, Pb, and Zn. All these metals are anthropogenically derived. Pb can originate from industries like battery, paint particles, and fuels with additives such as anti-knocking agent (Lovestead and Bruno, 2009). The third component (PC3) had high factor loadings of Cr and Ni. The patterns derived by PC2 and PC3 are suspected to be derived from mobile sources like aircraft and automobile emissions, respectively, although it is yet difficult to critically distinguish from each other. The fourth component is heavily weighed in Cd, probably reflecting aircraft emission (from aircraft batteries) (Kulin, 1997). Overall, it can be inferred that the primary source of metals in the soils of airport area is of anthropogenic origin such as vehicular and aircraft emissions.

4. CONCLUSIONS

This study highlights the importance of atmospheric deposition of metals from incomplete combustion of fossil fuels as the significant sources of soil pollution in the airport area. The results provide information about amounts and mixtures of metals in airport soils. Our study can thus represent a starting point for assessing possible health effects of chemical mixtures in the airport environment and in its peripheral residential areas. Further studies on the possibility of toxic effect of metals in soils are necessary, as contaminated soils contain high amounts of these pollutants. This type of spatial information is necessary for detailed chemical emissions inventory development. As such, hazardous risk assessment is of immense importance for achieving appropriate air-soil-water management plans and remediation measures.

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