Roadside dust contamination with toxic metals along industrial area in Islamabad, Pakistan post-print

Authors: Waheed Akram, Morgan Madhuku, Kashif Shahzad, Ali Awais, Ishfaq Ahmad, Muhammad Arif, Ishaq Ahmad

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Abstract

An investigation has been carried out to understand the contamination characteristics of roadside dust in the industrial area of Islamabad, Pakistan. The amounts of Si, S, Cl, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Pb, Zn, Ga, As, Se and Cd were determined from 95 roadside dust samples collected along the Islamabad industrial area using Proton Induced X-ray Emission (PIXE). The results indicated that concentrations of all elements, except Cd, in the roadside dust were significant. The results of the enrichment factor show that the elementary composition of the roadside dust could be categorized as soil elements from the crust of the earth and elements from anthropogenic pollution. The high enrichment factors imply that elements such Cr, Cu, Pb, Zn, As, Se, Cd, Ni, Co and S came from anthropogenic activities. The source of metal contamination was identified using multivariate statistical analysis. It has been concluded that Ca, Sc, Ti, V, Mn and Fe mainly originate from crustal sources; Cr, Cu, Ni, Pb, Zn and Ga are associated with point-sources from industrial pollution/traffic; and S, Cl, K, As and Se are mainly related to oil/coal combustion.

Full Text

Preamble

Roadside Dust Contamination with Toxic Metals Along Industrial Area in Islamabad, Pakistan

Waheed Akram[1,*], Morgan Madhuku[1,2], Kashif Shahzad[1], Ali Awais[1], Ishfaq Ahmad[1], Muhammad Arif[1], and Ishaq Ahmad[1,†]

[1]National Center for Physics, Islamabad, Pakistan
[2]iThemba LABS, Private Bag X11, Wits 2050, Johannesburg, South Africa

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An investigation has been carried out to understand the contamination characteristics of roadside dust in the industrial area of Islamabad, Pakistan. The amounts of Si, S, Cl, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Pb, Zn, Ga, As, Se and Cd were determined from 95 roadside dust samples collected along the Islamabad industrial area using Proton Induced X-ray Emission (PIXE). The results indicated that concentrations of all elements, except Cd, in the roadside dust were significant. The enrichment factor results show that the elementary composition of the roadside dust could be categorized as soil elements from the earth' s crust and elements from anthropogenic pollution. The high enrichment factors imply that elements such as Cr, Cu, Pb, Zn, As, Se, Cd, Ni, Co and S came from anthropogenic activities. The source of metal contamination was identified using multivariate statistical analysis. It has been concluded that Ca, Sc, Ti, V, Mn and Fe mainly originate from crustal sources; Cr, Cu, Ni, Pb, Zn and Ga are associated with point-sources from industrial pollution/traffic; and S, Cl, K, As and Se are mainly related to oil/coal combustion.

Keywords: PIXE, Roadside dust, Toxic metals
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Introduction

Solid matter comprising soil, metallic elements from anthropogenic activities, and natural biogenic matter is referred to as dust [1]. Soil is composed of inorganic matter, humus, living organisms, air, and water. Anthropogenic materials include particles from vehicle exhaust, tire wear, weathered street surfaces, brake lining wear, and residues from oil lubrication, while natural biogenic matter consists of vegetation crushed by moving vehicles [2–4]. Dust particles originating from the atmosphere and collecting along the sides of a road are called roadside dust [5, 6]. Displaced soil and atmospheric aerosols constitute the two main sources of roadside dust and the heavy metals found within it [1].

Furthermore, vehicle emissions, construction industry activities, corrosion of metallic support systems, heating systems, and sinking particulate matter all contribute to roadside dust [3, 6]. This roadside dust does not remain deposited for long, as it can easily be re-suspended into the atmosphere and contributes significantly to trace elements. The dust may also enter dams or other water bodies as dissolved solids after being washed away by rainfall in street runoff [1].

Consequently, the composition of roadside dust in urban areas is affected to a great extent by human activities. Both anthropogenic and natural biogenic materials that can be crushed by moving vehicles contribute directly to roadside dust [7]. Soil and roadside dust can supply particulate matter and pollutants to the hydrosphere and atmosphere during runoff, re-suspension, leaching, and weathering. Rapid industrialization and urbanization have resulted in almost half of the world' s population moving into urban areas where human activities are increasing the amount of contaminants discharged into the urban environment. Hence, various environmental problems have arisen, with pollution from toxic metals being a major issue, especially in urban soils and roadside dust [8, 9].

Metals are helpful indicators of environmental pollution as they are typical contaminants in urban environments. Heavy metals in soil come from two main sources: (i) natural background, representing heavy metals obtained from parent rocks; and (ii) anthropogenic contamination, including farming and agriculture-related activities and sewage sludge. There are generally more heavy metals in soils from anthropogenic than from natural sources.

The condition of urban soils and heavy metal contamination in Pakistan has hitherto not been adequately addressed, and attempts to conduct extensive surveys using systematic sampling strategies have been limited. There is a need to understand changes in soil characteristics and their spatial variation to combine traditionally based soil survey approaches and associated soil interpretations [10–12]. Focus along these lines in terms of soil condition is limited. It is therefore critical to analyze the effects of land use on metal levels in soils to develop legislation aimed at reducing metal inputs and preserving soil functions.

Therefore, this study attempted to (1) determine average concentrations of Cu, Zn, Ni, Pb, Cr and Cd; (2) define the natural and/or anthropogenic sources of these metals using enrichment factor; (3) establish the local or exotic sources causing contamination in soils; and (4) expand the trace metal database for roadside dust in Islamabad. The results of this research may be useful for the municipality, as there is a lack of information regarding heavy metals in roadside dust in Islamabad and its relationship with environmental factors. This information may also be useful in alleviating metal contamination in pursuit of Islamabad' s development as an international megapolitan.

Materials and Methods

A. Study Area

The city of Islamabad is located near the Margallah Hills at the northern edge of the Potohar Plateau, supporting natural terraces and meadows across the whole area. Streams flow down from Margallah Hills and ranges of the Murree Hills, converging with numerous small streams like Soan and Kurang tributaries passing through the city. Urban growth is occurring at a high pace, leading to deterioration of vegetation in the area. Islamabad is situated at latitude 33.72°N and longitude 73.07°E, at altitudes of 457-610 m (asl). The area is in a semi-arid region with mild summers and winters and rugged topography varying in elevation, mainly comprising steep slopes and gullies.

The natural soils of the area derive from wind and water-laid deposits and sedimentary rocks. Soils from wind deposits vary from dark brown to yellowish brown in color, and the subsoil is usually calcified or calcareous silt loam [13]. Due to recent accelerated urbanization and developmental activities, adverse effects from discharging untreated sewage wastes and dumping of solid waste on the soil have been observed [14].

B. Sampling

For this study, sector I-9, the industrial area of Islamabad, was selected to determine the extent of contamination by toxic metals in roadside dust that might affect the health of inhabitants. A total of 95 sampling sites were selected from sector I-9. Due to rapid changes in soil use in the urban area, the identified sites were not further divided into different categories. Dust samples were collected from both sides of the road using a spatula and small brush, then mixed thoroughly to obtain a representative sample for each site. All collected samples were kept in sealed polyethylene (PE) bags to avoid contamination, after which the samples were taken to the laboratory for preservation.

C. Sample Preparation

The dust samples were dried at room temperature and sieved using a 2-mm sieve to remove unwanted particles like stones and debris. The dried samples were then mixed thoroughly, and about 1 g of the homogenized sample was ground into powder. From each homogenized sample, approximately 180 mg was pelletized using a press and a 13 mm die to obtain 1 mm thick pellets.

D. PIXE Analysis

The pelletized samples were irradiated with a 3.0 MeV proton beam from the 5 MV Pelletron Tandem accelerator installed at the Experimental Physics Lab, National Centre for Physics, Islamabad. The calibration and standardization of the newly installed PIXE chamber for both thick (TiV/Fe alloy) and thin (SRM 2783) targets was carried out using NIST standard reference materials. The diameter of the collimated proton beam was 2 mm. A 100 μm thick Mylar "funny" filter was used during the measurements, which reduced the count-rate to ensure a dead time of less than 10% at beam currents of 2–5 nA. Observation of the samples after irradiation showed no apparent damage. The emitted X-rays were detected using a 30 mm^2 Si(Li) detector with an energy resolution of 138 eV (FWHM) at 5.9 keV of Mn. The PIXE data was analyzed using the computer code GUPIXWIN.

Results and Discussion

A. Total Contents of Metals

The concentration levels of elements found in roadside dust in Islamabad are shown in Fig. 1 [Figure 1: see original paper]. The concentrations with respect to sampling locations for Zn and Cu are shown in Fig. 2 [Figure 2: see original paper]. It is evident that the concentration of metals varies with distance from the source.

The elements determined include Si, S, Cl, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Pb, Zn, Ga, As, Se and Cd, and elemental levels in the dust samples were ranked as Fe > Ca > Co > Sc > K > Ti > Mn > Zn > Pb > Cu > Ni > Cr > V > Si > S > As > Ga > Cl > Se > Cd. The soil background values of Islamabad were used as references [15]. The mean concentration of measured heavy metals, except Cd, greatly exceeded the reference values. The levels of Cu, Ni, Pb and Zn were over three times greater than the reference values.

Worldwide concentrations of these elements in road dust as found in literature are given in Table 1 . Comparatively, metal concentrations for different studies show different metal diversity and variable magnitude of concentration. In this study, the extent of pollution is significant for several metals at different sites based on absolute metal content. Compared with metal contents in other cities such as Ottawa (Canada) (Table 1), the mean values of Cd, Cu, Ni, Pb and Zn in the analyzed roadside dust are much higher.

B. Assessment of Pollution

Atmospheric particles mainly come from low-temperature crustal weathering, soil remobilization (crustal source), and various anthropogenic sources at high temperatures. Enrichment factors (EF) are used to determine the chemical nature and principal sources of trace elements in aerosols by incorporating reference elements, and to evaluate the strength of crustal and non-crustal sources using Eq. (1), based on crustal materials. However, since crustal material types and soils originate from different areas, and little is known about uncertainties of fractionation during weathering, the EF values are better resolvable within 10 or slightly larger for crustal materials (Fig. 3 [Figure 3: see original paper]).

The EF of elements such as Cl, V, Mn, Fe, Ca, and K are close to unity or less than 10, suggesting they are attributable mainly to crustal sources. The high enrichment values for Cr, Cu, Pb, Zn, As, Se, Cd, Ni, Co and S suggest their dominant sources are non-crustal and various pollutant emissions may contribute to their loading. Higher EF values of elements indicate heavy metal contamination levels in roadside dust. This enrichment analysis confirms that trace elements come from a mixture of crustal particles and anthropogenic sources in the roadside dust of Islamabad. The EF values of Cu, Pb and Ni were 60.22, 84.2 and 22.4, respectively.

Copper is an essential trace element widely distributed in the environment, occurring naturally in elemental form and as a component of many minerals. It is present in flora and fauna and in various foods and beverages, including drinking water. Severe inhalation exposure to Cu dust or fumes at concentrations of 0.075-0.12 mg/m^3 may cause metal fume fever with symptoms such as cough, chills and muscle ache [30]. The recommended safe and adequate dietary intake for Cu is 1.5-3.0 mg per day for adults, 0.7-2.5 mg per day for children and adolescents, and 0.4–0.7 mg per day for infants [30]. In this study, the average concentration of Cu in roadside dust samples from Islamabad I-9 sector was 100.2 µg/g (Table 1), which is greater than the 25 µg/g average concentration in soil. The variation in Cu concentration with sampling location is shown in Fig. 2. The global concentration of Cu varies from 25 µg/g to 1075 µg/g (Table 1). Of the 19 places listed, 8 have higher and 11 have lower Cu concentrations than those found in Islamabad.

Nickel is found in the earth’ s crust in combination with other elements. It is present in all soils and in the environment where it combines with oxygen or sulfur as oxides or sulfides. Nickel is also released into the atmosphere through burning coal and oil in power generator plants. Health hazards from Ni exposure in the occupational environment are due primarily to inhalation. About 10% of women and 2% of men in the world are extremely sensitive to Ni exposure. The most common reaction to Ni exposure is skin rash called nickel dermatitis through direct contact with Ni [31]. In the present study, the concentration of Ni was 58.3 µg/g (Table 1), while the average concentration in soil samples was 32 µg/g. The highest Ni concentration, 347.6 µg/g, was found in sample No. 55. These results suggest a higher Ni contribution from sediments and soils in roadside dust and also from traffic emissions. The amount of Ni measured at all sampling points along Islamabad I-9 sector was two times higher than the reference value [15]. The concentration of Ni measured at various places around the world varies from 4.2 µg/g to 177 µg/g (Table 1). There are 4 places where Ni levels are greater and 13 places where they are lower than that found in Islamabad.

Zinc is an essential trace element present in soil. It can cause deficiency symptoms and can be toxic when intake and exposures exceed physiological needs. The primary source of Zn exposure for people is food, though oral exposure can become excessive through non-dietary sources. Certain occupational exposures can be hazardous. High Zn levels may disrupt the homeostasis of other essential elements. In this study, the average Zn concentration found in roadside dust samples was 162.6 µg/g, which is higher than the average Zn concentration (91 µg/g) in soil (Table 1). The global concentration of Zn ranges from 16.6–840 µg/g (Table 1). In the compiled data, there are 13 places where Zn concentration is greater and 5 places where it is lower than the 162 µg/g found in roadside dust of Islamabad.

Lead is ubiquitous in industrialized societies, and evidence of its negative effects on humans has been noted for centuries. Lead poses a unique threat to the developing minds and learning capacities of young children, who can be exposed from eating Pb-based paint chips or playing in contaminated soils. Pb can also damage the nervous system, kidneys, and reproductive system. In this study, the average Pb concentration was 128 µg/g in roadside dust samples and 62.5 µg/g in soil samples (Table 1). The highest Pb concentration in dust samples was about twice the average Pb concentration found in soil [15]. The high Pb concentration could be due to traffic burden, brick kilns, and usage of leaded gasoline, which was phased out in Pakistan in 2005. Furthermore, most light vehicles on this highway use CNG (compressed natural gas), therefore the concentration of Pb is somewhat under control and should decrease with time. From the compiled data in Table 1, there is substantial variation in Pb concentration from city to city, ranging from 11.2 µg/g to 1927 µg/g. There are 7 places where Pb concentration is greater, 10 places where it is lower, and one place (Beijing, China) where the concentration is comparable to that in dust from Islamabad' s industrial area.

C. Correlation of Metal Levels in Roadside Dust Samples

To establish inter-elemental relationships in roadside dust samples, principal component analysis was applied to the complete elemental concentration dataset. Principal component analysis is an important method for qualitative source distribution in aerosol studies [32]. Its purpose is to establish the minimum factors that can explain the main variance of the system. Statistical analysis software SPSS 10.0 was used for rotated component matrix factor analysis of element mass concentration in dust samples (Table 2).

The first, second and third factors account for 80.8%, 10.2% and 1.5% of variance, respectively. Retaining three factors is sufficient to explain 92.5% of total variance. The first factor has high loading for Ca, Sc, Ti, V, Mn and Fe, suggesting these elements come from geological resources [33]. The second factor is related to Cr, Cu, Ni, Pb, Zn and Ga, indicating an industrial or traffic source probably comprising different emissions from industrial activities [15, 34], while the third factor shows high loading of S, Cl, K, As and Se, suggesting they may have originated from oil/coal combustion [35].

Conclusion

Road dust is an increasing problem for developed and developing countries and is a source of various diseases. Roadside dust samples collected in sector I-9 of Islamabad were investigated for the presence of Si, S, Cl, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Pb, Zn, Ga, As, Se and Cd using PIXE. The concentration levels of these elements were generally higher compared with values currently available in literature. The relationships between different elements showed that Co, Ni, Cu, Pb and Zn are contaminants that may have originated from industrial pollution and vehicles.

The numbers of industries and vehicles in sector I-9 of Islamabad have grown rapidly in recent years. Due to rapid industrialization and urbanization of Islamabad, the population of sector I-9 in particular, and Islamabad as a whole, is expected to increase even more in coming years. Preventive measures such as using public transport, converting liquid fossil fuels to gaseous form, and establishing more green areas can be employed to address this problem. We recommend that besides periodic heavy metal monitoring in road dust on highways, regular air sampling should be carried out to observe seasonal pollution patterns in this area.

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Note: Figure translations are in progress. See original paper for figures.