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Metal Levels in Airborne Particulate Matter in Urban Islamabad, Pakistan

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Trace metals in airborne particulate matter present serious health hazard since they can be absorbed into human lung tissues during breathing. Frequently, anthropogenic emissions raise the levels of metals in suspended particles well above natural background levels (Pitts and Finlayson-Pitts 2000). Geological and construction materials as well as soil dusts are predominantly found in the coarse particle size range, constituting about 50% of total suspended particulate matter (TSP) in the form of metal oxides, depending of course on the nature of the geological area and the industrial activities pursued (Chow and Watson 1992).

Earlier studies evidenced that TSP and metal concentrations followed, in general, a similar distribution pattern (Bilos et al. 2001; Ragosta et al. 2002). However, inhalable particulate matter (PM_{10}) analysed in various urban areas of the world (Sweet et al. 1993) showed considerable variation in relation to some toxic metals. Beceiro-Gonzalez et al. (1997) found that TSP and PM_{10} metal distribution patterns were different in that Fe and Mn were related to coarse particles while Cd and Zn to PM_{10}. Also, the particulate metal levels were reported to depend on climatic variables such as temperature, relative humidity, wind speed and rain fall (Ragosta et al. 2002; Zimos et al. 1995). These findings necessitated that the particulate matter should be monitored on a regular basis to characterize and identify the sources and the variations in the distribution pattern.

The main objective of this work is to evaluate the total PM and airborne particulate trace metals (Fe, Na, Zn, K, Pb, Mn, Cr, Ni, Co and Cd) in the urban area of the capital city of Islamabad, Pakistan. The area registers high levels of air and water pollution as a consequence of contaminated fumes and effluents from local industries and traffic emissions (Shah et al. 2004; Shujah and Jaffar 1999). Despite reported risks to the health of local population, no viable study has been carried out to identify the main sources of PM and metals in the local atmosphere. In that sense, this work could be used as an incentive to perform other studies in order to develop strategies that would control and diminish the problem. It is anticipated that the study would help to develop futuristic control strategies towards creating a pollution free environment.

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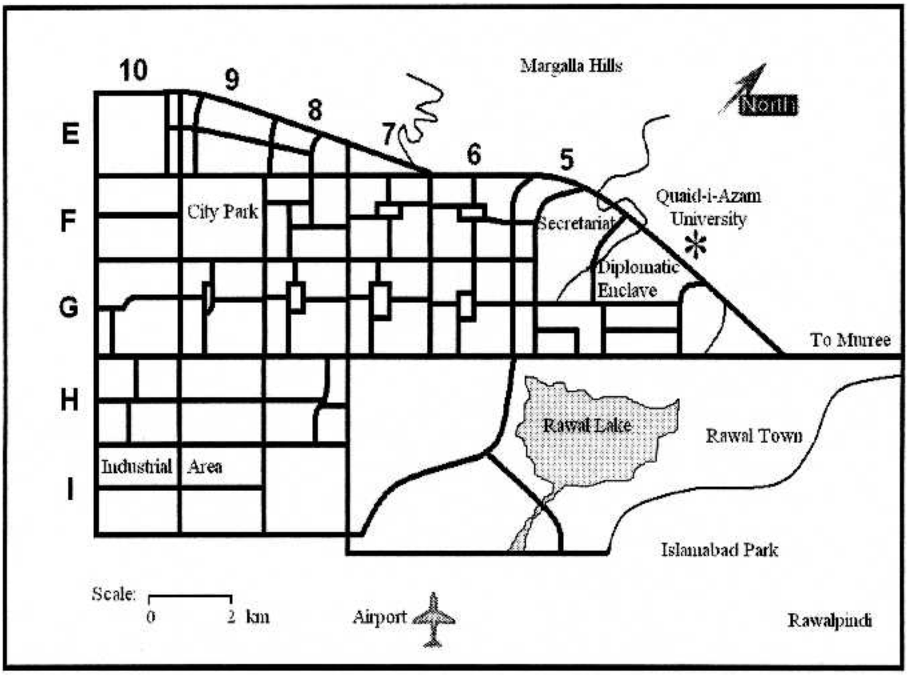

Figure 1. Location of sampling site (*) and residential sectors in Islamabad.

MATERIALS AND METHODS

Islamabad is situated at an elevation of about 500 m above sea level (Latitude 33°49′N; Longitude 72°24′N) and covers an area of 906 km^2 with about 1.2 million inhabitants. The climate is tropical with two distinct seasons, viz., winter and summer, with average temperatures of about 14 °C and 35 °C respectively. The average rainfall in this area is about 250 mm per annum, mainly due to the monsoon period in summer, while there is only scanty precipitation during winter. The industrial areas, I-9/10 (Figure 1) have high vehicular traffic density which is the main source of city's air pollution.

Sampling of TSP was carried out using high volume air sampler (Model GMWL-2000H, USA) installed at the top-roof of one of the buildings of the Department of Chemistry, Quaid-i-Azam University (Figure 1). The sampling was performed on regular daily basis (8-12 hours, daytime), during the period June 2002 – September 2002 and a total of 92 TSP samples were collected on glass fibre filter papers (20 cm × 25 cm) for trace metal analysis.

The TSP mass on a filter was determined after drying and weighing the filter to a constant weight. Each filter containing particulate matter was then digested in 4:1 (v/v) $HNO_3/HClO_4$ mixture (NIOSH Method-7300, 1984). The selected metal levels were estimated by the Atomic Absorption Spectrophotometric method using optimum analytical conditions maintained on Shimadzu AAS system, AA-670, Japan. Blanks were simultaneously prepared as a routine check for each metal in the acids and blank filters. The blank levels were approximately <10 % of the estimated metal concentrations. All reagents used were of AAS grade (certified purity >99.99 %) procured from E-Merck. The metal stock solutions (1000 ppm) were used to prepare working standards. The accuracy of the method was evaluated using a Standard Reference Material (OL-96), obtained from the National Institute of Health, Islamabad, where inter-laboratory comparison of the data was also conducted. Normally, the two results agreed within ± 2.0 % for triplicate runs of the sub-samples.

Climatic data were obtained from the Pakistan Agriculture Research Council (PARC) on a daily basis. Statistical analysis of the data was performed with STATISTICA software (StatSoft Inc. 1999). Multivariate statistical methods (Factor Analysis and Cluster Analysis) were used for source identification of metals and particulate matter (Jobson 1991).

RESULTS AND DISCUSSION

Data, along with range and standard deviation (SD) on mean metal and TSP levels pertaining to the present study period are shown in Table 1 that also lists the corresponding data from other urban sites and background levels. The TSP levels vary from 18.5 to 218.6 μg m^{-3} with an average value of 150.5 μg m^{-3}, which is higher than WHO guideline of 120 μg m^{-3} (WHO 1997), thus manifesting the particulate pollution in the local atmosphere. In comparison with other urban sites, the recorded TSP levels are lower than those found in Lahore and Karachi but higher than those reported for Mumbai, India.

Table 1. Selected metal and TSP levels (μg m^{-3}) in airborne particulate matter from Islamabad (n=92) compared with other urban and background levels.

	Range	Mean	SD	Lahore	Karachi	Mumbai	Dhaka	Background
TSP	18.5-218.6	150.5	29.1	607	244	130	-	-
Fe	0.954-3.510	2.467	0.473	9.930	4.20	2.95	24.8	3.950
Na	0.108-1.761	0.763	0.383	2.740	8.70	5.87	1.27	-
Zn	0.015-3.279	1.033	0.713	27.70	0.10	0.21	0.801	0.122
K	0.532-1.164	0.808	0.139	3.300	-	1.27	1.550	3.980
Pb	0.012-0.481	0.146	0.101	3.920	0.07	0.55	0.279	0.069
Mn	0.011-0.108	0.082	0.015	0.350	0.08	0.40	-	0.0964
Cr	0.008-0.056	0.024	0.013	0.113	0.03	0.04	-	0.015
Ni	0.005-0.045	0.029	0.006	0.080	0.02	0.04	-	-
Co	0.007-0.048	0.015	0.006	-	-	-	-	0.0017
Cd	0.001-0.017	0.005	0.004	0.040	-	0.04	0.0025	0.0005
Ref.	1	1		2	3	4	5	6

Ref.: 1) This study; 2) Harrison et al. 1997; 3) Parekh et al. 1987; 4) Sharma & Patil 1992; 5) Salam et al. 2003; 6) Ghauri et al. 2001

Maximum concentration levels are shown by Fe at 2.467 μg m^{-3}, followed by Zn, K and Na at 1.033, 0.808 and 0.763 μg m^{-3}, respectively. Relatively lower levels are recorded for Pb, Mn, Cr, Ni, Co and Cd. Large spread around mean metal levels are associated with Zn, Fe, Na, K and Pb, as shown by the respective SD values. In comparison with other urban sites around this part of the world, the estimated metal levels are found to be lower in general than those noted for Lahore, Mumbai and Dhaka. The mean concentrations of Mn, Cr and Ni are comparable with those reported for Karachi; levels of Pb and Zn are higher and those of Na and Fe lower than those of Karachi. In comparison with the background site (Ghauri et al. 2001), which is 70 km north of Islamabad, the levels of Zn, Pb, Cr, Co and Cd are much higher in the urban atmosphere. This shows that local atmosphere is enriched with toxic metals most likely arising from the anthropogenic sources such as automobile and industrial emissions.

Dependence of metal and TSP levels on climatic variables was also investigated. During the present study the average temperature varied between 19.0 and 46.0 °C. The relative humidity (RH) varied from 28.0 to 100 % with a mean value of 70.2 %. Average wind speed remained 0.75 m s^{-1} with a maximum of 2.93 and a minimum of 0.12 m s^{-1}. The rainfall is recorded at a mean value of 6.56 mm day^{-1}. The correlation coefficient matrix for TSP and metal levels vs. observed climatic variables is given in Table 2. It brings out two categories of metals: those showing positive correlation with temperature but negative with RH, such as K, Pb, Cr, Ni and Co, and those showing positive correlation with RH and negative with temperature, such as Fe, Na, Zn, Mn, and Cd. Wind speed is positively correlated with K, Cr and Co, but negatively with the rest of the metals. Generally the wind speed has a dilution effect on metal levels near their sources. However, in the present case, the wind was responsible for carrying air masses from the industrial sector to the central locations of the city under the prevailing north-east wind direction (Figure 1) thus resulting in increased metal levels in the urban area. Rainfall is found to show significant negative correlations with all metals, mainly due to its washing effect. Maximum temperature favours the re-suspension of particulate matter in air as manifested by its positive correlation with TSP while other climatic variables showed inverse behaviour with TSP.

The correlation statistics (Table 3) reveal strong positive correlations between Fe-TSP (0.655), Mn-TSP (0.860), Fe-Mn (0.508), Zn-Cd (0.766), Mn-Ni (0.580), and Cr-Co (0.542). In addition, other dominant correlations are noted between K-Cr, Pb-Ni, Fe-Na, Fe-Ni, Fe-Cd, Na-Zn, K-Mn, Pb-TSP, Ni-TSP and Pb-Cr, with $r > 0.319$, suggesting the presence of some common sources which would be verified by using multivariate analysis.

Source identification of airborne metals and TSP has been carried out by using factor analysis and cluster analysis (Hopke 1992; Ragosta et al. 2002; Quiterio et al. 2004). Factor analysis with varimax normalized rotation (Table 4) yields 3 factors, constituting more than 75 % of total variance.

Table 2. Correlation coefficient (r) matrix for TSP and airborne metals with climatic variables (n=92).

	TSP	Fe	Na	Zn	K	Pb	Mn	Cr	Ni	Co	Cd
Max. T	0.411	-0.149	-0.156	-0.492	0.772	0.187	0.389	0.618	0.241	0.204	-0.580
Min. T	-0.198	0.036	-0.177	-0.019	0.372	0.044	-0.015	-0.195	0.042	0.040	-0.066
RH (8:00)	-0.292	0.304	0.135	0.536	-0.872	-0.537	0.479	-0.709	-0.269	-0.222	0.603
RH (14:00)	-0.493	0.213	0.172	0.571	-0.633	-0.352	0.549	-0.751	-0.272	-0.296	0.531
Wind Speed	-0.429	-0.824	-0.398	-0.242	0.596	0.017	-0.194	0.724	-0.111	0.595	-0.319
Rain Fall	-0.704	-0.489	0.057	-0.287	-0.028	-0.218	-0.794	-0.163	-0.570	-0.393	-0.068

Values of r >0.319 or <-0.319 are significant at p<0.001

Table 3. Correlation coefficient (r) matrix for TSP and airborne metals in Islamabad (n=92).

	TSP	Fe	Na	Zn	K	Pb	Mn	Cr	Ni	Co
Fe	0.655									
Na	0.191	0.353								
Zn	-0.373	0.154	0.360							
K	0.068	-0.351	0.143	-0.328						
Pb	0.319	0.112	-0.150	-0.332	0.235					
Mn	0.860	0.508	0.153	-0.402	0.369	0.208				
Cr	0.066	-0.570	-0.452	-0.467	0.444	0.305	0.149			
Ni	0.476	0.343	-0.416	-0.355	-0.050	0.436	0.580	0.245		
Co	-0.350	-0.564	-0.482	-0.101	0.057	0.165	-0.535	0.542	-0.317	
Cd	-0.245	0.336	0.074	0.766	-0.620	-0.094	-0.389	-0.372	-0.027	0.041

Values of r >0.319 or <-0.319 are significant at p<0.001

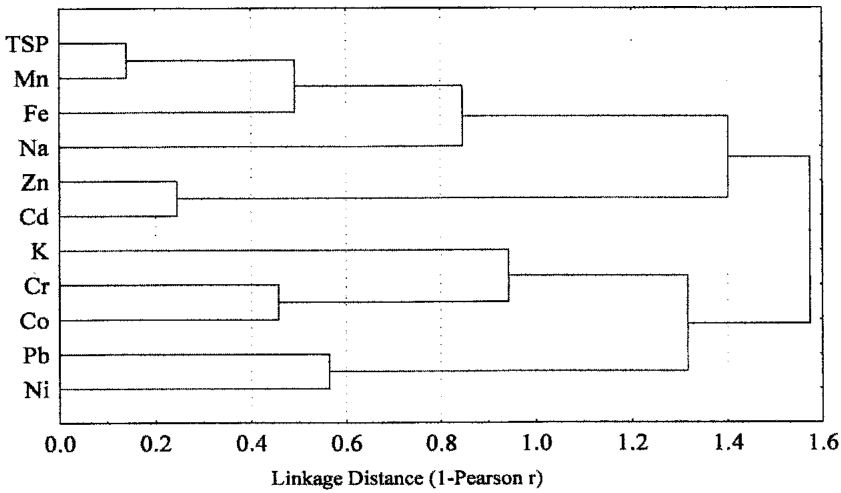

Figure 2. Dendrogram of metals showing the clustering pattern using complete linkage method.

First factor with maximum variance (31.4 %) showed higher factor loadings for TSP, Fe, Na and Mn with significant contribution from Co and Cr. This factor is contributed by natural wind blown soil mainly originating from excavation activities along the Margalla Hills (Figure 1). Factor 2, with higher factor loadings of Zn, K, Cr, Co and Cd, at 28.6 % of total variance, shows the contribution from the industries and metallurgical units housed in sector I-9/10 of the city. Factor 3 is associated with 15.6 % of total variance, having higher factor loadings for Pb and Ni with significant contributions from Mn and Na. This factor is believed to originate from automobile emissions and traffic-induced road dust.

Table 4. Varimax normalized rotated factor loadings of metals and TSP in airborne particulate samples.

Factor	1	2	3
Eigen values	3.6	3.1	1.6
% total Variance	31.4	28.6	15.6
Cumulative % Variance	31.4	60.0	75.6
TSP	0.816	0.208	-0.316
Fe	0.848	-0.418	0.005
Na	0.639	0.065	0.550
Zn	0.103	0.664	-0.419
K	-0.012	0.838	0.054
Pb	-0.149	-0.114	0.718
Mn	0.822	-0.259	0.410
Cr	0.368	0.588	-0.121
Ni	-0.481	0.071	0.763
Co	0.589	0.615	-0.057
Cd	0.066	0.891	-0.028

The corresponding cluster analysis in the form of dendrogram is shown in figure 2, which is in agreement with the above observation and it confirms the results of factor analysis. The source identification study is also found to be in good agreement with other studies reported for other parts of the world (Quiterio et al. 2004; Ragosta et al. 2002; Bilos et al. 2001; Beceiro-Gonzalez et al. 1997; Parekh et al. 1987).

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