The Nucleus **50**, No. 3 (2013) 241-251

The Nucleus
A Quarterly Scientific Journal of Pakistan Atomic Energy Commission
NCLEAM, ISSN 0029-5698

POLLUTION LEVEL ASSESSMENT OF ROAD DUST FROM ISLAMABAD EXPRESSWAY

Y. FAIZ, *N. SIDDIQUE and M. TUFAIL[1]

Chemistry Division, Directorate of Science, PINSTECH, Nilore, Islamabad, Pakistan

[1]Pakistan Institute of Engineering and Applied Sciences (PIEAS), Nilore, Islamabad, Pakistan

(Received July 29, 2013 and accepted in revised form September 06, 2013

Thirteen road dust and four soil samples were analyzed using Instrumental Neutron Activation Analysis (INAA) and Flame Atomic Absorption Spectroscopy (FAAS) to determine the elemental composition of road dust collected from Islamabad Expressway. Pollution parameters and indicators such as Enrichment Factors (EFs), Pollution Load Index (PLI), Geoaccumulation Index (I_{geo}), Pollution Index (PI) and Integrated Pollution Index (IPI) were calculated and showed that the area around Islamabad Expressway is low to moderately polluted especially by elements such as Mg and Sb. The IPI of the elements was found to vary in the order; Mg>Sb>Cu>Sr≈Pb>Ga>Na >Sn≈Zn>Yb>Se>Hf. The 5 samples collected around the busy intersections of Faizabad and Zero Point have higher amounts of most of the elements determined. Moreover the pollution indices for these samples indicate that these sites are more contaminated than the remaining 8 sampling sites.

Keywords: Islamabad expressway, Neutron activation analysis (NAA), Pollution indices (PI), Enrichment factors (EFs), Pollution load index (PLI), Geoaccumulation index (I_{geo}), Pollution index (PI), Integrated pollution index (IPI)

1. Introduction

A major source of environmental pollution is the transport sector. With the increase in global population the number of on-road vehicles is also increasing. Therefore, numerous studies have been carried out to analyze vehicular exhaust as well as the soil and road dust around major highways and roads [1-3]. In such studies focus has been on the elemental concentrations of heavy metals as well as gaseous pollutants such as CO, CO_2, NO_x and SO_x [4-7]. In these studies, heavy metals in road dust have been frequently found to originate from non-soil derived sources; i.e. vehicular emissions and industrial sources [8-10].

A study was undertaken to analyze the road dust from Islamabad Expressway. Islamabad Expressway is the busiest route of entry into Islamabad. This road is a 10-lane highway starting in Islamabad at Zero Point and joins the small town of Rawat at the Grand Trunk (GT) Road, in the Punjab province. It is a 25 km road which starts at the coordinates 34°41'25" N and 73°03'57" E and ends at 33°30'38" N and 73°10'49" E. As shown in Table 1 two very busy intersections on this highway are at Zero Point and Faizabad. Moreover 3 industrial estates are located around this road; 1) between Zero Point and Faizabad, 2) near Kahuta Chowk while 3) is near Rawat. Numerous brick kilns are operational on the eastern side of this road. The area surrounding this highway is a rapidly developing residential and business area with a few high-rise buildings under construction.

The elemental composition of the road dust and soil samples were obtained using the complementary techniques of instrumental neutron activation analysis (INAA) and flame atomic absorption spectroscopy (FAAS). Therefore, the elements Al, As, Ba, Br, Ce, Co, Cr, Cs, Eu, Fe, Ga, Hf, K, La, Lu, Mg, Mn, Mo, Na, Nd, Rb, Sb, Sc, Se, Sm, Sn, Ta, Tb, Th, Ti, Yb and Zr were determined using INAA while Cd, Cu, Ni, Pb and Zn were determined using FAAS. The elemental results obtained using FAAS and INAA have been published in our earlier publications [11-12]. Here the data obtained has been used to calculate frequently used parameters and pollution indicators such as Enrichment Factors (EFs), Pollution Load Index (PLI), Geoaccumulation Index (I_{geo}), Pollution Index (PI) and Integrated Pollution Index (IPI). Studies have shown the usefulness of these parameters in obtaining an estimate of the pollution status of a site [13]. The results of these calculations are presented and discussed in this paper.

* Corresponding author : nailasiddique@yahoo.ca

2. Materials and Methods

2.1. Dust and Soil Sampling

Thirteen road dust samples were collected from six sites along Islamabad Expressway. A brief description of the sampling sites is given in Table 1. Four soil samples were also obtained from four undisturbed or green areas. The dust samples were collected using a battery operated vacuum dust collector, whereas soil samples were collected at a depth of 10 cm by scraper plate method. Approximately 0.5 kg each of dust and soil sample was collected and brought to the Analytical Laboratory at the Pakistan Institute of Engineering and Applied Sciences (PIEAS) for preparation. The samples were dried at 100 °C for 5 h in an electric oven and sieved through a 0.125-mm (120 meshes ASTM) stainless steel sieve to obtain particle size of < 125 µm. The particulars of the FAAS and NAA analysis are given in the papers by Faiz et al. [11-12] and are described briefly below.

2.2. Flame Atomic Absorption Spectroscopy (FAAS)

The road dust and soil samples were digested using the Leeds Public Analyst Method for FAAS analysis [14]. Therefore, 1 gram of each sieved sample was ashed for 30 min. at 350 °C to remove the carbon present in these samples and the ash was refluxed for 15 min with 25 ml of 25% HNO_3. The solution of each sample was cooled and filtered on Wattman prewashed filter paper. The filtrates were diluted to 100 ml with distilled water prior to FAAS analysis. For quality assurance purposes, reference materials (RMs) IAEA-S-7 (soil) and IAEA-SL-1 (lake sediment) were used. The solutions for the RMs were also prepared in the same manner as for the dust and soil samples. Blank solution of double distilled water was prepared in the same way as employed for all samples without the addition of any sample. Chemicals and solvents used were of analytical reagent grade and were obtained from Merck, Darmstadt, Germany. The operating parameters for Cd, Cu, Ni, Pb and Zn metals were set as per recommendations given in the instrument operation manual. The analysis was carried out with a Varian SpectrAA 300 AAS spectrometer. An air/acetylene flame was used for the excitation of the metal atoms. Specific hollow cathode lamps of characteristic wavelengths and slit width were used for estimation of each element.

2.3. Instrumental Neutron Activation Analysis (INAA)

Spec-pure elemental salts were taken in appropriate amounts and dissolved in supra-pure aqua-regia acid mixture to prepare multi-element synthetic standard solution as described in the paper by Waheed et al. [15]. Approximately 100 mg each of the dust sample in triplicate alongwith the synthetic standard and two RMs (IAEA S–7 and IAEA SL–1) were packed and sealed in polyethylene capsules. Multiple batches of these 17 samples were then packed and sealed in polyethylene rabbits for irradiation. The sealed targets were irradiated for periods of 30 seconds to 5 hours in the periphery of the reactor core at the Pakistan Atomic Research Reactor 2 (PARR-2), which is a 27 kW, Miniature Neutron Source Reactor (MNSR) with a thermal neutron flux of $1x10^{12}$ cm^{-2} s^{-1}. After irradiation, the targets were left for the desired cooling period depending on the half-life of the isotopes being studied. The irradiated samples were then transferred to pre-cleaned, pre-weighed polyethylene capsules for counting. The optimized irradiation schemes have been devised taking into account the nuclear properties of the elements being quantified. For example isotopes of ^{28}Al, ^{52}V, ^{49}Ca and ^{27}Mg were counted for 100 seconds after irradiation of 30 seconds and a cooling period of 2 minutes, short-lived isotopes, such as ^{155}Sm, ^{165}Dy and ^{56}Mn, were determined after 5 minutes irradiation, 1 hour cooling and 600 seconds counting times, medium lived isotopes of ^{42}K, ^{72}Ga, ^{24}Na, ^{76}As, ^{166}Ho, ^{82}Br, ^{140}La, ^{153}Sm, ^{99}Mo, U(^{239}Np), ^{122}Sb and ^{175}Yb were measured after 1 hour irradiation and cooling times of 1-2 days and long lived isotopes; ^{177}Lu, ^{147}Nd, ^{131}Ba, ^{117m}Sn, ^{86}Rb, ^{233}Th, ^{51}Cr, ^{141}Ce, ^{181}Hf, ^{59}Fe, ^{203}Hg, ^{95}Zr, ^{85}Sr, ^{160}Tb, ^{46}Sc, ^{182}Ta, ^{75}Se, ^{65}Zn, ^{134}Cs, ^{60}Co and ^{152}Eu were quantified after irradiation for 5 hours and cooling time of 2-3 weeks. Details of the irradiation protocols are available in Waheed et al [16]. U was determined through ^{239}Np as reported in an earlier work [17]. Sm was determined using both short and medium irradiation/ cooling times. The possibility of spectral interferences is low as the thermal-to-fast flux ratio at PARR-2 is 5.2. However, the few that were observed were corrected for [18-19].

The gamma spectrometry system consists of a high purity germanium (HPGe) detector (Canberra Model AL-30) connected to PC-based Intertechnique Multichannel Analyser (MCA). The resolution of the system for the 1332.5 keV ^{60}Co peak is 1.9 keV with peak-to-Compton ratio of

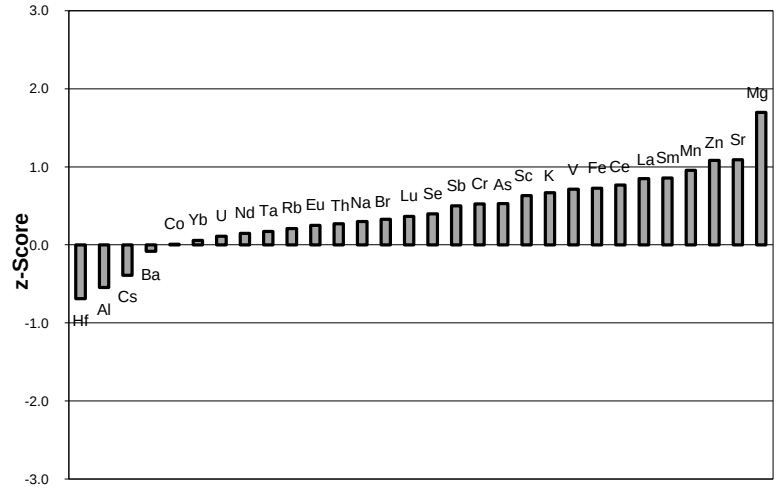

Figure 1. QA plot for IAEA-S7 (Soil).

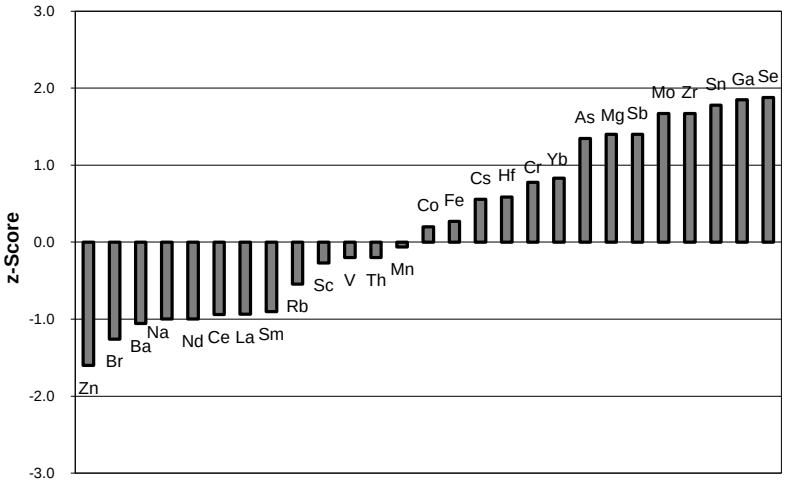

Figure 2. QA plot for IAEA-SL1 (Lake sediment).

40:1. "Intergamma, version 5.03" software was used for data acquisition. The data files, containing information on peak energy, peak area, etc. alongwith our indigenously developed computer program were used to obtain elemental concentrations [20]. All necessary corrections (background subtraction etc) were applied and the final results obtained on dry weight basis.

3. Results and Discussion

Various procedures are employed to check the reliability and accuracy of analytical results. These include use of 2 or more techniques as well as the use of reference materials (RM). In this study validation of results was performed using RMs as discussed below:

3.1. Quality Assurance (QA)

Two RMs, IAEA-S7 [21] and IAEA SL1 [22] were used for QA purposes. In order to compare the experimental results with the certified data, Z-scores were obtained as given by the expression

$$Z-score = \frac{(Value_{Analyst} - Value_{Cetified})}{\sigma_{Certified}} \quad (1)$$

where $\sigma_{Certified}$= the uncertainty at 1σ level provided on the RM certificate [23].

If $|z\text{-}_{score}| \leq 2$ satisfactory performance

$2 < |z\text{-}_{score}| < 3$ questionable performance

and $|z\text{-}_{score}| \geq 3$ unsatisfactory performance

The Z-scores for IAEA-S7 and IAEA-SL1 have been plotted in Figures 1 and 2. From these plots it can be seen that all of the elements determined have $|z\text{-}_{score}| < 3$ implying that none of the results are unsatisfactory. Furthermore, the data also fulfills the criteria $|z\text{-}_{score}| \leq 2$ meaning that the results are in very good agreement with the

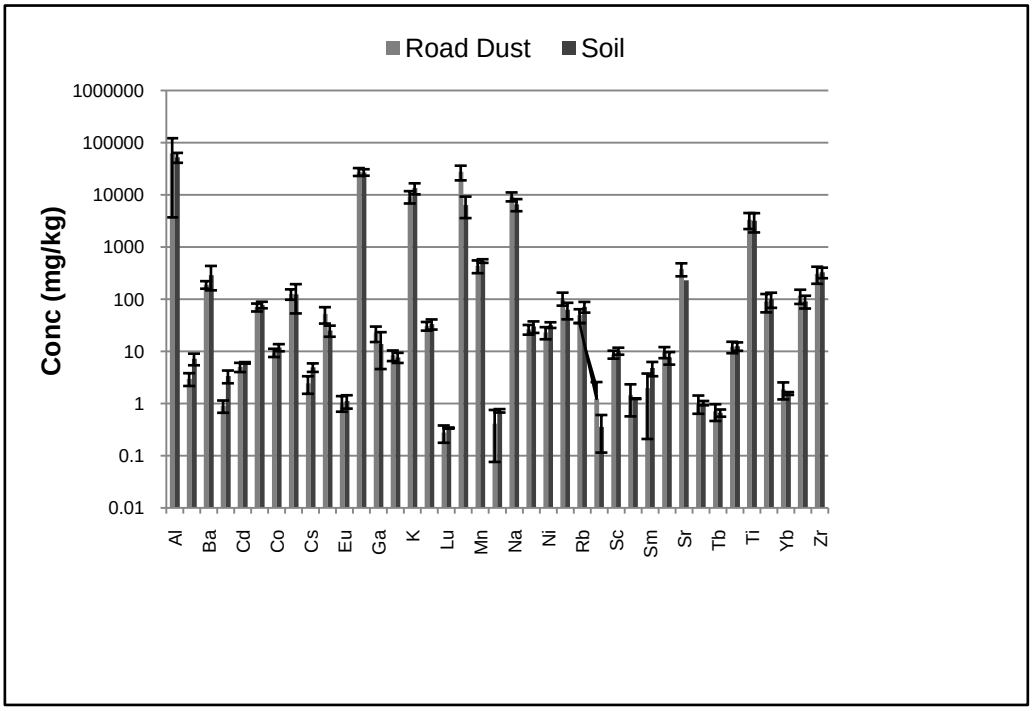

Figure 3. Comparison of average elemental composition of road dust samples with soil samples.

certified data; as only the results for U in IAEA-S7 and Se in IAEA-SL1 are close to 2. These plots show that the experimental procedures used provide reliable results.

3.2. Results

The average results for the 13 road dust and 4 soil samples using INAA and FAAS have been plotted in Figure 3. In this figure the average elemental concentrations alongwith their standard deviations have been plotted [24]. The elemental concentrations were obtained on dry weight basis and at a confidence interval of 95%. In the road dust and soil samples upto 39 elements were determined using INAA and FAAS [11,12]. Al, Fe, K, Mg, Na and Ti were found in higher amounts with lower amounts of Ba, Ce, Cr, Cu, Ga, La, Mn, Nd, Ni, Pb, Rb, Sr, V, Zn and Zr and the remaining elements (As, Br, Cd, Co, Cs, Eu, Hf, Lu, Mo, Sb, Sc, Se, Sm, Sn, Ta, Tb, Th and Yb) in trace amounts. It should be noted that the concentrations of trace elements are closer to their detection limits and have therefore higher uncertainties.

From Figure 3 it can be seen that the elemental composition of road dust and soil samples is comparable with slightly elevated amounts of Cu, Ga, Mg, Na, Pb, Sb, Sr and Zn in road dust samples. It was found that slightly higher concentrations of most elements were measured at the Faizabad sites (D-4 and D-5) followed by the Zero Point sites (D2 and D-3) and Kahuta Chowk (D-10) to a lesser extent. Moreover the lowest concentrations occur around the Rawat More (D-12 to D-13) and the Khanna Bridge (D-6) sites. This trend reflects the traffic volumes at these crossing as there is much heavier traffic around Faizabad and Zero Point which are busy traffic intersections. Kahuta Chowk also has heavy traffic but much less as compared to the Faizabad and Zero Point sites. The lower concentrations at Khanna Bridge and Rawat More can be attributed to the lower population density and hence fewer residential activities in these areas. A closer inspection of Figure 3 shows that most elements do not have large ranges or standard deviations [25]. These show that the samples probably have a local origin which is dependent upon the geochemical composition of the local soil and the activities carried out within the area.

3.3. Pollution Level Assessment

Pollution level can be estimated through different calculation models and indicators such as enrichment factor (EF), pollution load index (PLI), geo-accumulation index (I_{geo}), pollution index (PI) and integrated pollution index (IPI). These are discussed below:

Table 1. Description of road dust and soil samples collected from Islamabad Expressway.

Sampling location	Sample ID	Description of the sampling location
Road dust samples		
Zero Point	D-1	Residential area, unpaved roads, small industrial units
	D-2	Construction activities, commercial area, heavy traffic
	D-3	Automobile workshops, residential area, private offices
Faizabad	D-4	Traffic burden due to flyover and bus stands
	D-5	Residential area, construction activities, heavy traffic
Khanna Bridge	D-6	Brick kilns, heavy traffic, residential area
	D-7	Heavy traffic, residential and commercial area
Kraal Chowk	D-8	Near Islamabad Airport; brick kilns, heavy traffic, residential area
	D-9	Construction activities, heavy traffic, residential area
Kahuta Chowk	D-10	Green land, brick kilns, traffic burden
	D-11	Green land, traffic load, small industrial units
Rawat More	D-12	Rural residential area, heavy traffic, industrial area
	D-13	Residential area, traffic load, building construction
Soil samples		
Shakkar Parian	S-1	Green park area, near Zero Point
Near Krall Chowk	S-2	Rural area, near Kraal Chowk
G-11 Sector	S-3	Grassy area in a developed residential sector of Islamabad
E-11 Sector	S-4	Grassy area in a developing residential sector of Islamabad

3.3.1. Enrichment Factor (EF)

EF of an element is based on standardization of a measured element against a reference element. EF is defined as "ratio of relative frequency of a certain isotope in an isotope mixture to the relative frequency of this isotope in natural isotope mixture". EF is calculated as expressed below:

$$EF = \frac{|C_i/C_r|_S}{|C_i/C_r|_B} \quad (2)$$

where, S and B stand for sample and background respectively; C_i is the concentration of the element i, and C_r is the concentration of reference element for normalization. A reference element is one characterized by low occurrence variability, such as Al, Fe or Mn etc. [26]. The magnitudes of EF values obtained are categorized as follows:

EF $\leq$ 2 deficiency to minimal enrichment implies predominant source is the earth crust

2 < EF $\leq$ 5 moderate enrichment, contributions from non-crustal sources; i.e. due to human activities

5 < EF $\leq$ 20 significant enrichment

20 < EF $\leq$ 40 very high enrichment

40 < EF extremely high enrichment

Al was used as reference material to calculate EF values due to its high abundance in soil and least probability of its originating in soil from other environmental sources [27]. EF values were calculated and are given in Table 2 where values between 2 and 5 have been underlined, above 5 and between 20 are in bold and above 20 are underlined and in bold. From this table it can be seen that most EF values are below 2. Only the EFs for Sb and Se are above 20 while the EFs for Sn are between 5 and 20 at 10 of the 13 sites with EFs around 5 for 2 more sites. The EFs for Hf are also around 5 for most sites. Most of these elements were measured in trace amounts with high uncertainties and near their detection limits. Moreover Se was detected at 4 sites only. Therefore, based on these results it cannot be concluded that these elements are being enriched in road dust and further work is required to confirm these findings. From Table 2 it can be seen that the elements which may be enriched are Ce, Cr, Mg and Th. For these elements the higher EFs are also obtained from sites D-1 to D-10 with lower EFs for the remaining sites. These results indicate

Table 2. Enrichment factors (EF) for sites along Islamabad Expressway.

Element	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	D13
As						3.08	4.49	3.98	3.66	2.19	2.93	3.04	1.30
Ba					0.72	1.04	1.25	1.12	0.95	0.79	0.49	0.66	0.60
Br											0.34	0.58	0.66
Ce	1.92	1.83	1.70	0.33	2.64	2.50	2.38	1.82	3.33	2.87	1.31	1.93	1.54
Co	0.69	0.65	0.59	0.12	0.73	0.84	0.79	0.87	0.83	0.92	0.36	0.59	0.40
Cr	1.75	2.64	1.40	0.34	2.27	2.28	3.94	2.46	2.78	1.79	1.43	2.74	2.24
Cs	1.66	1.39	1.90	0.23	1.31	1.35	1.43	1.17	1.37	2.77	0.74	1.18	1.13
Eu		0.51			1.64	1.31	1.97		2.93	1.97	0.98	1.80	1.39
Fe	1.03	1.12	0.78	0.23	1.17	1.13	1.11	1.19	1.25	1.03	0.59	0.74	0.64
Ga						1.62		2.90	3.73	3.74			
Hf	4.59	**5.15**	3.15	0.63	**7.41**	**5.80**	**8.31**	**5.18**	**8.57**	4.02	2.50	**5.11**	4.21
K	0.72	0.58	0.70	0.10	0.51	0.57	0.75	0.66	0.86	1.07	0.32	0.61	0.49
La	1.51	1.91	1.81	0.31	2.06	1.64	2.91	1.92	2.63	2.18	1.10	1.78	1.05
Lu	1.44	1.30	0.79	0.24	1.24	1.49	1.08	1.37	0.44	0.88	0.36	0.60	0.69
Mg	2.85	2.67	1.82	0.52	3.60						1.45	1.23	1.07
Mn	0.62	0.70	0.48	0.12	0.72	0.88	0.96	0.78	1.77	1.20	0.64	0.68	0.74
Mo	0.78	1.21	0.93	0.13	0.28	0.34	0.46	0.21	0.27	0.11	0.19	0.22	0.38
Na	0.78	0.58	0.48	0.11	0.52	0.66	0.77	0.89	0.84	0.57	0.30	0.46	0.37
Nd	2.53	1.90	1.63	0.34	2.13	1.89	2.11	1.58	1.63	1.53	0.95	1.27	1.08
Rb	1.21	0.95	1.30	0.19	1.09	1.03	0.98	1.04	0.98	1.33	0.44	0.75	0.61
Sb	**23.1**	**31.6**	**5.78**	3.39	**7.49**	2.98	**5.39**	**30.98**	2.11		0.95	0.98	2.25
Sc	0.80	0.73	0.61	0.13	0.77	0.81	0.79	0.98	0.94	0.88	0.38	0.55	0.45
Se									**39.2**		**72.8**	**34.8**	**30.9**
Sm			0.71	0.35	0.19	0.23	0.20	0.27	0.75	0.50	0.39	0.48	0.52
Sn	4.68	**7.45**	4.80	1.51	**13.1**	**10.7**	**13.4**	**9.52**	**12.6**	**9.36**	**8.50**	**6.31**	**6.38**
Sr	2.57	1.74	0.87	0.49	1.68	1.86	2.18	1.69					
Ta	0.69	0.58	0.73	0.22	0.72	1.14	0.67	0.89	1.00	1.07	1.37	0.72	0.80
Tb	1.15	1.22	1.23	0.19	2.56	2.42	2.32	1.97	1.86	0.95	0.81	0.87	0.66
Th	3.48	3.19	2.60	0.76	4.10	3.16	3.27	3.32	4.31	3.72	1.33	1.89	1.70
Ti	2.18	1.64	1.06	0.28	1.73						0.58	0.73	0.71
V	0.97	0.56	0.46	0.14	0.78	1.59	2.15	1.69	1.80	1.96	1.39	0.83	1.10
Yb	1.29	1.43	1.05	0.18	0.70	0.56	0.92	1.20	1.55	1.19	0.33	0.98	0.61
Zr	2.50	3.03			4.50	2.62	3.62	3.12	**6.72**		1.16	3.92	3.61
PLI	**0.98**	**1.16**	**1.11**	**1.20**	**0.91**	**0.80**	**0.70**	**0.93**	**0.83**	**0.89**	**0.69**	**0.78**	**0.76**

that these sites are slightly contaminated by Ce, Cr and Mg which may become suspended after the passage of vehicles and can be ingested by humans through the air. The sources of these elements are probably exposed soil, industry and vegetation respectively [28].

3.3.2. Pollution Load Index (PLI)

PLI is used to compare the pollution level of various sites and is calculated using the following relation [29]:

$$PLI = \sqrt[N]{\sum_{i=1}^{N} C_i / C_{iu}} \quad (3)$$

where C_i is the concentration of i^{th} element in road dust samples under study and C_{iu} is the concentration of the same element in uncontaminated soil. PLI≤1 indicates that the site is "uncontaminated", 1<PLI≤2 shows that the site is "slightly contaminated" while PLI>2 implies "contaminated" site. PLI values for each site were calculated and are also given in Table 2. It can be seen that the PLI values vary from 0.70 to 1.20. Based on these values sampling sites are slightly contaminated in the following order D4>D2>D3, whereas the sites (D1, D5, D8) and (D6, D7, D9-D13) show negligible pollution loads with PLI values close to or below 1.

3.3.3. Geoaccumulation Index (I_{geo})

I_{geo} is defined by the following relation [30]:

$$I_{geo} = \log_2 \left[\frac{C_n}{1.5 B_n} \right] \quad (4)$$

where C_n represents the measured concentration of element n and B_n is the geochemical background value of the element in fossil argillaceous sediment (average shale). In this study, B_n is the background content of element n in soil. The values of I_{geo} are categorized as follows:

I_{geo}≤0 unpolluted environment

0<I_{geo}≤1 unpolluted to moderately polluted

1<I_{geo}≤2 moderately polluted

2<I_{geo}≤3 moderately to strongly polluted

3<I_{geo}≤4 strongly polluted

4<I_{geo}≤5 strongly to extremely polluted, and

I_{geo} >5 extremely polluted.

I_{geo} values were obtained for all the samples studied and are given in Table 3. I_{geo} values between 1 and 2 have been underlined while values above 2 are in bold. From this data it can be seen that generally the values of I_{geo} are below or very close to zero for most of the elements at all 13 sites. The only elements which have I_{geo} values greater than 1 are Mg and Sb. As mentioned earlier the concentrations of Sb measured are near their detection limits. However the higher I_{geo} values for Mg especially at site D-5 (Faizabad) is understandable as there are many fruit vendors at this site [28]. Average I_{geo} values for the 13 sites have also been obtained and listed in Table 3. It can be seen that the elements Cu, Ga, Mg, Pb, Sb have average I_{geo} above zero. Once again the only element which has an average I_{geo} value > 1 is Mg while the other 4 elements have values closer to zero. These calculations show that the road dust along Islamabad Expressway is moderately polluted by Cu, Ga, Mg, Pb and Sb while the Faizabad site is moderately to strongly polluted by Mg.

3.3.4. Pollution Index (PI)

PI was calculated for elements determined in road dust samples using the expression [31]:

$$PI = \frac{C_n}{B_n} \quad (5)$$

where C_n and B_n are the measured and the background concentrations of element n respectively in dust and soil. PI is classified in the following way:

PI≤1 low level of pollution

1<PI≤3 middle level of pollution

PI>3 high level of pollution

PI values were obtained for the road dust samples and are given in Table 4. PI values between 1 to 3 are underlined while the values above 3 are given in bold. From this table it can be seen that most of the PI data lies below 1. The PI values for Cr, Fe, Ga, Hf, Na, Pb, Se, Sn, Sr, Ta, Tb, Ti, Yb and Zn are generally above 1 while for Cu and (Mg and Sb) are above 2 and 3 respectively. The elements Hf, Sb, Se, Sn, Ta, Tb, Ti and Yb are measured near their detection limits and have large measurement uncertainties. However the higher PI values for Cr, Cu, Fe, Pb and Zn suggest traffic and industry sources. Once again Mg lies in the high pollution category.

Table 3. Geo-accumulation index data for sites along Islamabad Expressway.

Element	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	D13	Average
Al	-0.97	-0.62	-0.38	-0.28	-0.90	-0.92	-1.31	-0.87	-1.16	-0.85	-0.35	-0.58	-0.50	-0.75
As						-1.93	-1.78	-1.52	-1.92	-2.35	-1.44	-1.61	-2.76	-1.91
Ba					-1.46	-0.95	-1.08	-0.80	-1.31	-1.28	-1.46	-1.27	-1.32	-1.21
Br											-2.96	-2.43	-2.17	-2.52
Cd*														-0.72
Ce	-1.04	-0.76	-0.63	-0.91	-0.51	-0.61	-1.07	-1.02	-0.43	-0.34	-0.97	-0.64	-0.90	-0.76
Co	-1.07	-0.80	-0.70	-0.85	-0.91	-0.74	-1.21	-0.64	-0.98	-0.54	-1.40	-0.90	-1.38	-0.93
Cr	-1.10	-0.16	-0.84	-0.80	-0.66	-0.67	-0.27	-0.51	-0.62	-0.95	-0.78	-0.06	-0.28	-0.59
Cs	-1.60	-1.51	-0.81	-1.80	-1.87	-1.85	-2.15	-2.00	-2.06	-0.74	-2.14	-1.70	-1.68	-1.68
Cu*														0.38
Eu		-2.12			-0.72	-1.06	-0.86		-0.14	-0.40	-0.91	-0.26	-0.56	-0.78
Fe	-0.68	-0.20	-0.49	-0.17	-0.42	-0.49	-0.91	-0.37	-0.58	-0.56	-0.86	-0.76	-0.90	-0.57
Ga						-0.75		0.14	0.22	0.53				0.03
Hf	-0.76	-0.24	-0.72	-0.94	0.00	-0.37	-0.24	-0.49	-0.04	-0.83	-1.02	-0.21	-0.42	-0.48
K	-1.13	-1.10	-0.58	-1.34	-1.56	-1.41	-1.41	-1.15	-1.06	-0.44	-1.68	-0.97	-1.22	-1.16
La	-1.17	-0.48	-0.32	-0.79	-0.65	-1.00	-0.56	-0.73	-0.55	-0.52	-1.00	-0.54	-1.23	-0.73
Lu	-0.51	-0.31	-0.80	-0.40	-0.66	-0.41	-1.27	-0.48	-2.41	-1.11	-1.91	-1.38	-1.11	-0.98
Mg	1.61	1.87	1.55	1.82	2.01						1.26	0.79	0.66	1.45
Mn	-1.48	-0.94	-1.26	-1.14	-1.19	-0.93	-1.18	-1.04	-0.15	-0.41	-0.82	-0.95	-0.76	-0.94
Mo	-0.91	0.06	-0.07	-0.79	-2.32	-2.06	-2.02	-2.71	-2.62	-3.61	-2.33	-2.32	-1.50	-1.79
Na	0.15	0.07	0.04	-0.03	-0.37	-0.05	-0.22	0.43	0.06	-0.18	-0.62	-0.22	-0.48	-0.11
Nd	-0.36	-0.43	-0.41	-0.57	-0.54	-0.74	-0.97	-0.95	-1.19	-0.97	-1.15	-0.96	-1.12	-0.80
Ni*														-1.11
Pb*														0.10
Rb	-1.01	-1.00	-0.32	-1.02	-1.10	-1.18	-1.65	-1.12	-1.50	-0.74	-1.85	-1.29	-1.53	-1.18
Sb	2.08	2.89	0.67	1.99	0.53	-0.82	-0.35	2.61	-1.55		-1.90	-2.08	-0.81	0.27
Sc	-0.82	-0.60	-0.61	-0.80	-0.81	-0.74	-1.17	-0.43	-0.76	-0.56	-1.26	-0.96	-1.19	-0.82
Se									-1.12		0.58	-0.71	-0.81	-0.52
Sm			-0.77	0.31	-3.24	-2.96	-3.56	-2.65	-1.48	-1.76	-1.63	-1.55	-1.36	-1.88
Sn	-1.31	-0.29	-0.68	-0.27	0.25	-0.07	-0.13	-0.18	-0.06	-0.19	0.17	-0.48	-0.39	-0.28
Sr	0.47	0.26	-0.51	0.76	-0.08	0.05	-0.11	-0.04						0.10
Ta	-1.16	-1.08	-0.50	-0.15	-1.03	-0.40	-1.55	-0.70	-0.82	-0.42	0.44	-0.72	-0.48	-0.66
Tb	-0.96	-0.52	-0.27	-0.86	0.26	0.16	-0.29	-0.09	-0.45	-1.12	-0.86	-0.97	-1.29	-0.56
Th	-0.60	-0.38	-0.44	-0.13	-0.30	-0.69	-1.03	-0.58	-0.48	-0.39	-1.38	-1.09	-1.17	-0.67
Ti	-0.01	-0.07	-0.46	-0.28	-0.28						-1.31	-1.19	-1.15	-0.59
V	-1.22	-1.67	-1.70	-1.37	-1.47	-0.46	-0.41	-0.33	-0.51	-0.09	-0.08	-1.06	-0.57	-0.84
Yb	-0.10	0.39	0.18	-0.28	-0.93	-1.26	-0.94	-0.11	-0.03	-0.11	-1.45	-0.12	-0.71	-0.42
Zn*														-0.30
Zr	-1.27	-0.64			-0.35	-1.15	-1.07	-0.85	-0.03		-1.76	-0.22	-0.27	-0.76

* From Faiz et al. [11]

Table 4. Pollution Indices (PI) for sites along Islamabad Expressway.

Element	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	D13	IPI
Al	0.77	0.98	1.15	1.20	0.80	0.79	0.61	0.82	0.67	0.83	1.18	1.01	1.06	0.91
As						0.39	0.44	0.52	0.40	0.29	0.55	0.49	0.22	0.41
Ba					0.54	0.77	0.71	0.86	0.60	0.62	0.55	0.62	0.60	0.65
Br											0.19	0.28	0.33	0.27
Cd*														0.92
Ce	0.73	0.89	0.97	0.80	1.05	0.98	0.71	0.74	1.11	1.18	0.77	0.96	0.80	0.90
Co	0.72	0.86	0.93	0.83	0.80	0.90	0.65	0.96	0.76	1.03	0.57	0.81	0.58	0.80
Cr	0.70	1.34	0.84	0.86	0.95	0.94	1.25	1.05	0.98	0.78	0.88	1.44	1.24	1.02
Cs	0.50	0.53	0.85	0.43	0.41	0.42	0.34	0.37	0.36	0.90	0.34	0.46	0.47	0.49
Cu*														2.06
Eu		0.35			0.91	0.72	0.82		1.36	1.13	0.80	1.26	1.02	0.93
Fe	0.94	1.30	1.07	1.33	1.12	1.07	0.80	1.16	1.00	1.02	0.83	0.88	0.80	1.03
Ga						0.89		1.65	1.74	2.16				1.61
Hf	0.89	1.27	0.91	0.78	1.50	1.16	1.27	1.07	1.45	0.84	0.74	1.30	1.12	1.10
K	0.69	0.70	1.01	0.59	0.51	0.56	0.57	0.67	0.72	1.11	0.47	0.77	0.64	0.69
La	0.67	1.07	1.20	0.87	0.95	0.75	1.02	0.91	1.02	1.05	0.75	1.03	0.64	0.92
Lu	1.05	1.21	0.86	1.14	0.95	1.13	0.62	1.07	0.28	0.70	0.40	0.58	0.70	0.82
Mg	4.59	5.47	4.40	5.30	6.05						3.59	2.59	2.38	4.30
Mn	0.54	0.78	0.63	0.68	0.66	0.79	0.66	0.73	1.35	1.13	0.85	0.78	0.89	0.80
Mo	0.80	1.57	1.43	0.87	0.30	0.36	0.37	0.23	0.24	0.12	0.30	0.30	0.53	0.57
Na	1.66	1.58	1.55	1.47	1.16	1.45	1.29	2.03	1.56	1.33	0.98	1.28	1.08	1.42
Nd	1.17	1.11	1.13	1.01	1.03	0.90	0.77	0.78	0.66	0.77	0.68	0.77	0.69	0.88
Ni*														0.72
Pb*														1.66
Rb	0.75	0.75	1.20	0.74	0.70	0.66	0.48	0.69	0.53	0.90	0.42	0.61	0.52	0.69
Sb	6.35	11.11	2.39	5.97	2.16	0.85	1.17	9.14	0.51		0.40	0.35	0.86	3.44
Sc	0.85	0.99	0.98	0.86	0.86	0.90	0.67	1.12	0.88	1.02	0.63	0.77	0.66	0.86
Se									0.69		2.24	0.92	0.86	1.17
Sm			0.88	1.86	0.16	0.19	0.13	0.24	0.54	0.44	0.48	0.51	0.58	0.55
Sn	0.61	1.23	0.93	1.25	1.78	1.43	1.37	1.32	1.44	1.32	1.69	1.07	1.14	1.28
Sr	2.08	1.79	1.06	2.54	1.42	1.56	1.39	1.46						1.66
Ta	0.67	0.71	1.06	1.35	0.73	1.14	0.51	0.92	0.85	1.12	2.04	0.91	1.07	1.01
Tb	0.77	1.04	1.24	0.83	1.80	1.68	1.23	1.41	1.10	0.69	0.83	0.77	0.61	1.08
Th	0.99	1.15	1.11	1.37	1.22	0.93	0.73	1.01	1.08	1.15	0.58	0.70	0.67	0.97
Ti	1.49	1.42	1.09	1.24	1.24						0.61	0.66	0.67	1.05
V	0.64	0.47	0.46	0.58	0.54	1.09	1.13	1.19	1.05	1.41	1.42	0.72	1.01	0.90
Yb	1.40	1.96	1.70	1.24	0.79	0.62	0.78	1.39	1.46	1.39	0.55	1.38	0.91	1.20
Zn*														1.28
Zr	0.62	0.96			1.17	0.68	0.71	0.83	1.47		0.44	1.28	1.24	0.94

* From Faiz et al. [11]

3.3.5. Integrated Pollution Index (IPI)

IPI is defined as the mean value of the pollution index (PI) of an element and is categorized as follows [32]:

IPI≤1 low level of pollution

1<IPI≤2 middle level of pollution

IPI>2 high level of pollution

The IPI values obtained are also given in Table 4 with the values above 2 in bold and the values above 1 underlined. The IPI values of Mg and Sb are the highest among elements studied and fall in the class of “high pollution level”. The elements at “middle pollution level” are Cr, Cu, Fe, Ga, Hf, Na, Pb, Se, Sn, Sr, Ta, Tb, Ti, Yb and Zn while all other elements are at “low pollution level ”. IPI of the elements were found to be in the order;

Mg>Sb>Cu>Sr≈Pb>Ga>Na >Sn≈Zn>Yb>Se>Hf with Cr, Fe, Ta, Tb, and Ti having IPI values very close to 1.

4. Conclusions

EFs, PLI, I_{geo}, PI and IPI values indicate that the area around Islamabad Expressway is low to moderately polluted especially by elements such as Mg and Sb. This is especially the case for the Faizabad and Zero Point sites which have heavier traffic loads. However more work is required to verify these findings. With the rapid increase in the population of Islamabad and the expected growth in industry and traffic these elements may become hazardous unless their amounts are closely monitored and control measures undertaken.

Acknowledgements

The authors would like to thank Dr. Shahida Waheed, DCS, CD, PINSTECH and Dr. Naseem Irfan, PE, DCME, PIEAS for their valuable suggestions and provision of laboratory facilities to accomplish this work. The authors would also like to acknowledge the assistance provided by Mr. Lal Habib, the staff at the NAA/MNSR Laboratory and the services of the Reactor Operations Group at PINSTECH.

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