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TRACE ELEMENT ANALYSIS OF AEROSOL SAMPLES USING PIXE TECHNIQUE

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The present study was carried out with the aim to determine the level of $_{82}$Pb in the environment by analyzing the aerosol samples. In our experiment, the aerosol samples were collected from Chandigarh city which is also named as "The City Beautiful". Particle induced X-ray emission (PIXE) technique developed at CCCM, Hyderabad has been used for the detection of trace elements in the aerosol samples

Keywords: PIXE; aerosol; particulate matter (PM); principal component analysis (PCA).

1. Introduction

Apart from trace gases, the atmosphere contains a variety of liquids and solids that exist as dispersed phases in the air. They are collectively called aerosols. Aerosols result from both natural and anthropogenic sources. Natural sources include soil particles from ground surfaces, gases from volcanoes, forest fires, biological respiration, whereas anthropogenic sources are actually man made sources and include gases from industries, automobiles, coal thermal plants, refuse burning, etc. Aerosols constitute a tiny fraction of the total atmosphere, generally below 0.1 ppm by mass; yet, they play a large and even dominant role in many atmospheric processes. They catalyze many chemical reactions, enhance erosion processes, influence cloud properties and formation, and modify atmosphere optical properties; reducing visibility and producing important effects on the terrestrial radiative balance (radiative forcing). Radiative forcing connected with changing in global terrestrial climate is particularly a very important effect. Since aerosols carry most of the toxic metals, acids and nitrates of the atmosphere, dry or wet aerosol deposition may produce soil and water contamination and damages to buildings and vegetation. In addition, aerosol inhalation by human beings and animals may produce deleterious health effects. Air pollution in India is a result of economic expansion, population growth, industrialization and increase in number of automobiles (traffic). Air pollution problems are combined effects of gaseous air pollutants and particulate matter (PM). In many Indian cities, environmental crisis is increasing due to severe air pollution, and relevant data is scarce. Particulates with aerodynamic diameter 2.5 to 10 μm are referred as coarse particles (PM_{10}) and the particles less than 2.5 μm as fine particles ($PM_{2.5}$). These particulates are generated due to industrial and vehicular activities and responsible for respiratory and cardiovascular problems as these particles can reach deeply into our lungs and also to the alveolar region. It is required to study the pollutant elemental levels and identification of their sources for understanding their effects on human health. The importance of aerosol study is then obvious, both for air quality assessment and source identification in urban and industrial areas, and as a tool in the investigation of general atmospheric phenomena. Several factors are important for the selection of analytical methods used for the air quality monitoring: rapidness of analysis, reliability, good precision, accuracy (better than 10%), low detection limits for trace elements determination and low cost. The determination of heavy and toxic elements permits the study of their distributions, the pollution level as well as the risk assessment in the investigated ecosystems. Undoubtedly the most popular methods for this purpose at present are atomic absorption spectrometry (AAS) and inductively coupled plasma atomic emission spectrometry (ICP-AES). But the need for the exhaustive and time consuming sample preparation for these techniques, has led to increasing interest toward X-ray emission based techniques, viz., particle induced X-ray emission (PIXE)[1] and energy dispersive X-ray fluorescence (EDXRF)[2] for the environmental sample investigations.[3] Both these techniques are well-established analytical techniques for rapid multi-element nondestructive analyses and enable simultaneous detection of many elements in a solid or liquid with high-detection sensitivities, even in those cases where only small sample amounts are available. The elements are identified by the wavelengths (qualitative) of the emitted X-rays while the concentration of the elements present in the sample is determined by the intensity of the X-rays (quantitative). The rate of increase in air pollutant concentrations in developing countries such as India is higher than those in developed countries.[4,5] Indian megacities are among the most polluted cities in the world. Air concentrations of a number of air pollutants are much higher than the levels recommended by the World Health Organization (WHO) as well as the National Ambient Air Quality Standards (NAAQS), India.[6] A part of the air quality guidelines stipulated by WHO and NAAQS are presented in Table 1. In India, major sources of urban air pollution include coal

Table 1. Air quality particulate matter standards stipulated by WHO and India.

S. No.	Pollutant	Time weighted average	Concentration in ambient air
[a]WHO air quality guide line			
1	$PM_{2.5}$	Annual	$10\ \mu g\,m^{-3}$
		24 h	$25\ \mu g\,m^{-3}$
2	PM_{10}	Annual	$20\ \mu g\,m^{-3}$
		24 h	$50\ \mu g\,m^{-3}$
[b]National Ambient Air Quality Standards, India			
1	$PM_{2.5}$	Annual	$60\ \mu g\,m^{-3}$
		24 h	$100\ \mu g\,m^{-3}$

[a]World Health Organization air quality guideline, 2005.
[b]National Ambient Air Quality Standards for residential area, central pollution control board, 1998.

combustion, oil refineries and industrial manufacturing facilities.[7,8] The most polluted metropolitan cities are Mumbai, Kolkata and Delhi. The mass concentration levels of particulate matter (PM) in the Indian mega cities were discussed by Gupta and Kumar.[9] A few reports[3,10] are available on the measurement of elemental concentrations of various pollutants present in the ambient air. Negi *et al.*[3] have reported the urban aerosol composition for both major and trace elements in four cities of India, namely, Bombay, Bangalore, Nagpur and Jaipur. Bandhu *et al.*[4] have reported the elemental composition of air pollution in Chandigarh city of Northern India in the year 2000. In the present work, the elemental composition of aerosol samples has been done from the city Chandigarh, India. The elemental composition of aerosol samples has been determined using PIXE technique. These results were further confirmed by analyzing some of the samples using EDXRF technique. The data derived from the study has been utilized for statistical analysis using principal component analysis (PCA) based receptor model technique to identify the possible sources contributing to the PM concentration in the study area.

2. Experimental Details

2.1. *Sample collection*

Twenty two aerosol samples were collected from three different sites of Chandigarh city (76°54′E and 30°42′N), India, during December 2008–January 2009. December and January are the coldest months in this region, temperature ranging from 7°C to 25°C. Table 2 gives an overview of sampling. Samples were collected from three different sites: Physics Department, Panjab University (low traffic intensity, and a relatively cleaner zone); Gate No. 1, Panjab University (PU); Inter State Bus Terminus (ISBT) in sector 43. In Physics Department, Panjab University, sampler was placed on the roof of Cyclotron building, second site chosen was the entrance of

Table 2. The present aerosol sampling program in Chandigarh City, India.

	Site 1 Physics Dept.	Site 2 Gate No. 1, PU	Site 3 ISBT-43
N (No. of samples)	6	8	8
Sampling period	Nov. 08 – Jan. 09	Dec. 08 – Jan. 09	Jan. 09 – Feb. 09
Collection time (h)	6–7	6–7	6–7

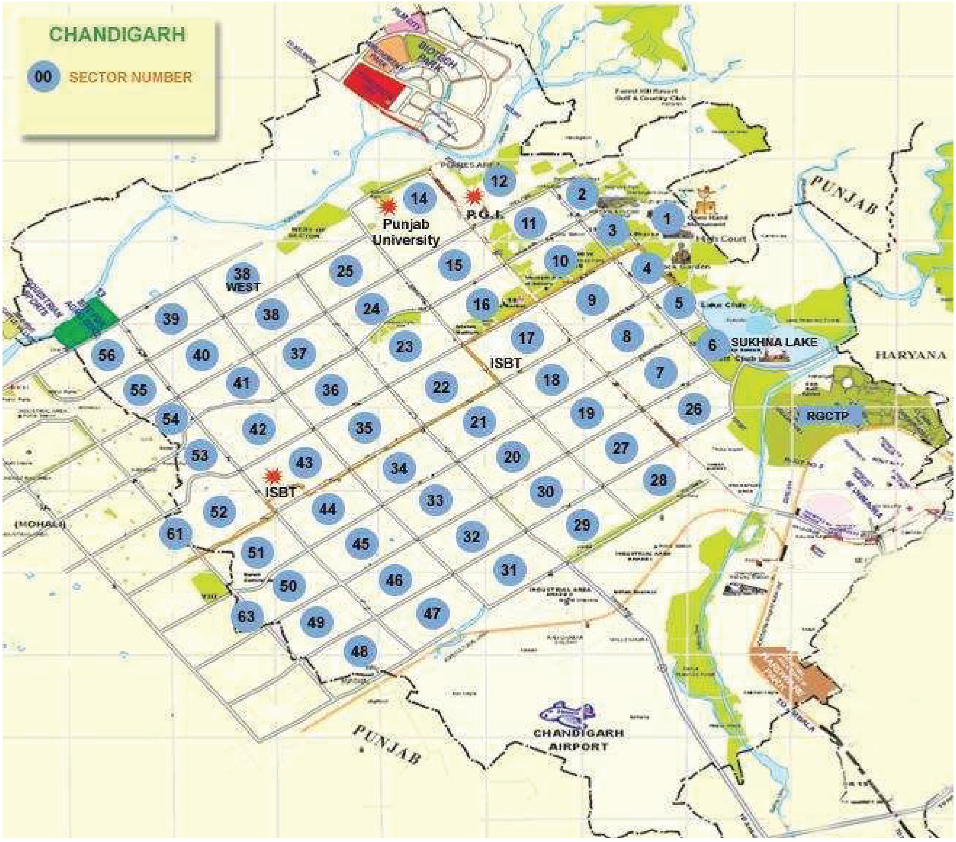

Fig. 1. Site map of the Chandigarh city with the sampling sites marked with ∗.

Gate No. 1 and the sampler was placed on the roof of security post. This site is on the main road, facing Post Graduate Institute for Medical Education and Research (PGIMER) entrance. At the third site, i.e., ISBT-43 sampler was placed at the exit of bus stand from where all buses leave and stop for some time. Figure 1 shows the site map of Chandigarh city showing the location of all the three sites. At all the sites, sampler was placed at a height of about 8 to 9 feet from the ground level. The sampling period for all these samples was related to be the most acute one, viz., 10:00 hrs to 17:00 hrs.

The flow rate of air was chosen as 3–4 L/min. The flow rate was monitored periodically for each sample and no cases of reduction of flow rate due to filter clogging were experienced during the sampling. Samples were collected on 37 mm ϕ nucleopore polycarbonate filter paper with the help of model 200 Personal Environmental Monitor PEM (SKC Inc. USA). It hasa single stage impactor with an after filter. The impactor stage removes particles of aerodynamics diameter greater than 10 μm so that the particles of aerodynamics diameter less than 10 μm (PM_{10}) are collected on the after filter. The particles on the impactor are discarded and the particles on the after filter are analyzed. Particulate matter (PM) is calculated using the relation

$$\mathrm{PM}_{10\,(\mu\mathrm{g/m^3})} = \frac{\text{wt. of loaded filter}(g) - \text{wt. of blank filter}(g)}{\text{Flow rate } (\mathrm{m^3/min}) \times \text{Sampling time (min)}}\,. \tag{1}$$

2.2. *Elemental analysis using PIXE*

All of the samples collected from Chandigarh city were analyzed using PIXE technique. The PIXE measurement was performed at the Surface and Profile Measurement Laboratory at the National Centre for Compositional Characterization of Materials (NCCCM), BARC, Hyderabad, using the 3 MV Tandetron accelerator.

A well collimated 2.3 MeV proton beam of diameter 5 mm and current 5–7 nA was incident on the targets. Targets were placed at an angle 15° w.r.t the beam axis inside the scattering chamber. The X-rays were detected by a planar high purity germanium (HPGe) detector (Eurisys measures type EGX100-01, Be window thickness 40 μm, FWHM of 150 eV at 5.9 keV) placed at 45° to the beam axis. A 40 μm Mylar foil served as the X-ray exit window. Schematic diagram is shown in Fig. 2. The vacuum in the scattering chamber, pumped by a turbo molecular pump, was about 2×10^6 Torr. The data were recorded on a PC-based MCA. The

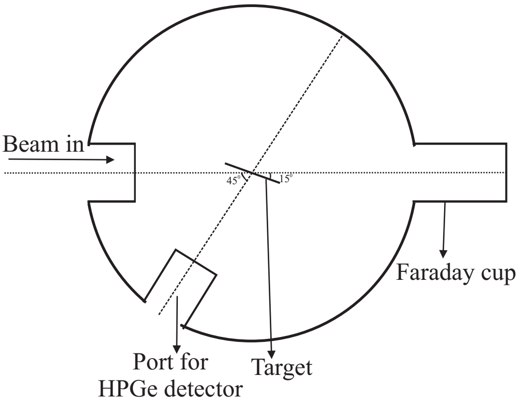

Fig. 2. Schematic diagram of PIXE setup at NCCCM, Hyderabad.

standards were run just before and immediately after running the samples in the same experimental conditions in order to check the accuracy of the results.

2.3. *Elemental analysis using EDXRF*

The elemental analysis of aerosol samples was carried out using EDXRF setup available at Department of Physics, Panjab University, Chandigarh. The reflection mode experimental setup shown in Fig. 3 was used in the present measurements. It consists of water cooled single window $_{42}$Mo anode glass X-ray tube, (PW 1316/92) along with the 4 kW X-ray generator, (PW 3830) procured from Pan Analytic, the Netherland. The X-ray tube has a $_{4}$Be window (diameter 14 mm, thickness 300 μm). The tube emits $_{42}$Mo K X-rays along with the continuous radiations (Bremsstrahlung) ranging up to the maximum applied tube operational voltage. The detection system consisted of LEGe solid state detector (100 mm$^2 \times 10$ mm, 8 μm Be window, Canberra, US) in horizontal configuration and having an energy resolution of 150 eV for the $_{25}$Mn Kα X-rays. The detector was equipped with $_{50}$Sn collimator of diameter 4 mm and was also shielded using Sn shield in order to reduce the background. The X-ray tube was equipped with $_{50}$Sn collimator of diameter 3 mm. The X-ray tube was operated at 29 kV and 10 mA. The X-rays from the tube were made to fall on a $_{42}$Mo secondary excitor and the

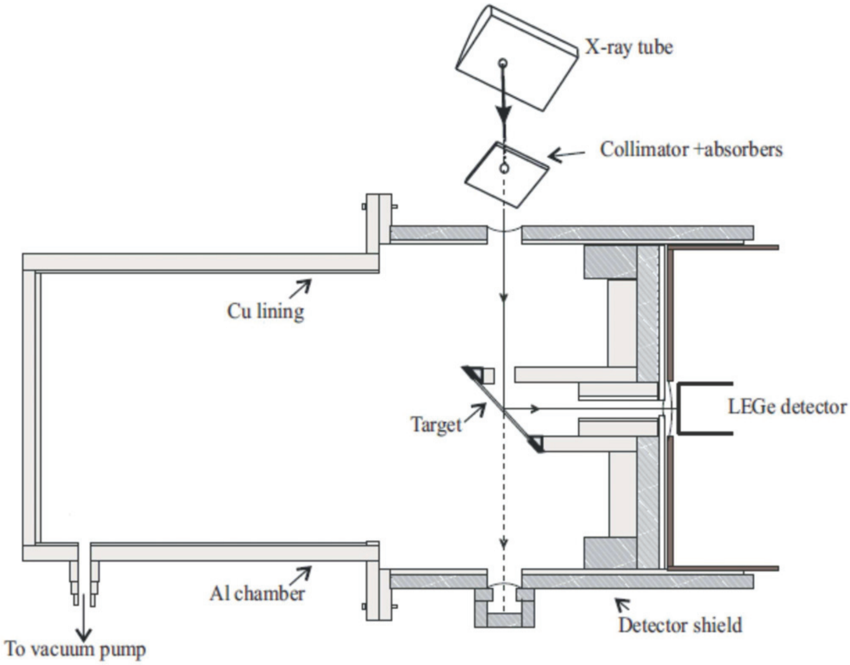

Fig. 3. Schematic of EDXRF setup.

characteristic K X-rays of $_{42}$Mo (17.8 keV, the weighted average energy of the Mo Kα and Kβ lines) were in turn used to excite the characteristic X-rays of the elements present in aerosol samples. The X-ray spectra were collected using a PC-based multichannel analyzer (Multiport II, Canberra, US). The $_{13}$Al chamber was evacuated (10^{-2} Torr) to avoid attenuation of low energy X-rays in air and to eliminate the K X-ray ($E_{Kx} = 2.975$ keV) peak due to argon gas present in the air. The chamber was equipped with a 4 mm collimator and a 2 μm Mylar window. The target was mounted in vertical plane making an angle of 45° with the detector axis and the X-ray tube axis. The X-ray tube and detector were kept outside the chamber. The $_{13}$Al chamber containing the target was mounted on the detector head. The $_{13}$Al chamber in and exit collimators, X-ray tube collimator and the target center were aligned using laser beam.

3. Data Analysis

Qualitative and quantitative analysis of PIXE spectra was done using the GUPIX code. GUPIX code uses H-value standardization method for the calibration of experimental setup. This H parameter is used to calibrate the system. For the calibration of setup, some standard foils of $_{28}$Ni, $_{47}$Ag, $_{57}$La and $_{66}$Dy of thickness 340, 32.5, 57.3 and 60 μg/cm^2 respectively were used. X-ray spectrum was obtained from these foils using the proton beam. Figure 4 shows some of the spectrum from standard foils. Figure 4(a) is spectrum from Dy foil showing L X-rays and 4(b) is from Ni foil showing Ni K X-rays. These spectrums were used in the GUPIX and H-value of $4.508 \times 10^{-3} \pm 2.59 \times 10^{-4}$ was obtained for the setup. The H-value is used in the GUPIX program, which convert measured X-ray yield to concentration for all the elements fitted. The conversion equation is

$$C_Z = \frac{Y(Z,M)}{Y_{It}(Z,M)HQ\varepsilon\beta}\,, \tag{2}$$

where $Y(Z,M)$ is the X-ray intensity or yield (principal X-ray line) for an element Z in a matrix $M, Y_{It}(Z,M)$ is the theoretical intensity or yield per micro-Coulomb of charge per unit concentration per steradian, C_Z is the actual concentration of Z in M in g/cm^2, Q is the measured beam charge in micro-Coulombs, ε is the intrinsic efficiency of the detector; (close to 1.0 between 5 and 20 keV), and β is the correction factor for the transmission through any filters or absorbers between target and detector. Elemental concentration in g/cm^2 is converted to g/m^3 using relation

$$\text{Conc. in g/m}^3 = \frac{\text{Conc. on filter (g/cm}^2) \times \text{Area of the filter (cm}^2)}{\text{Flow rate (m}^3\text{/min)} \times \text{Sampling time (min)}}\,. \tag{3}$$

In case of EDXRF, the elemental concentrations in various samples were determined using the relation

$$m_j = \frac{N_{ij}}{I_0 G \varepsilon_{ij} \sigma_{ij} \beta_{ij}}\,, \tag{4}$$

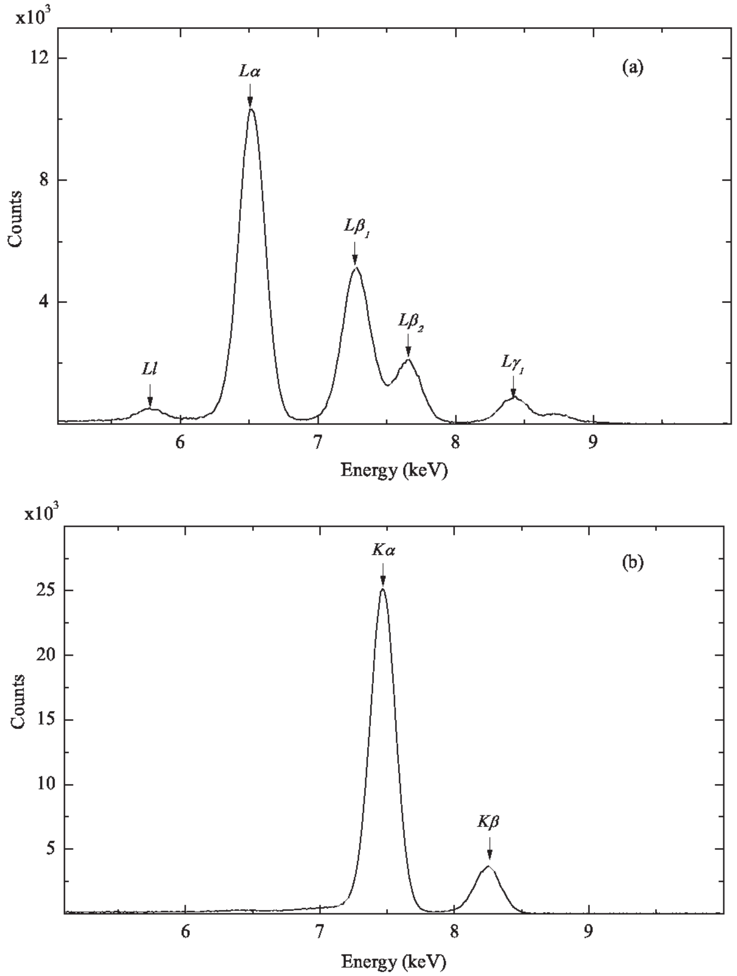

Fig. 4. (a) L X-ray spectrum of $_{66}$Dy. (b) K X-ray spectrum of $_{28}$Ni.

where N_{ij} is the number of counts/s for the ith X-ray photo peak of the jth element, I_0 is the intensity of the photons emitted by the source, G is the geometry factor, ij is the XRF cross-section of the ith X-rays of jth element in cm^2/g at the incident photon energy, ε_{ij} is the detector efficiency for the ith X-ray of the jth element and ε_{ij} is the self-absorption correction factor for absorption of incident and emitted X-rays. The factor $I_0 G \varepsilon_{ij}$ was determined over the energy region 3–16 keV by collecting K X-ray spectra from thin elemental standard foils of CaF$_2$ (133 μg/cm^2), Ti (78 μg/cm^2), Mn (156 μg/cm^2), Fe (216 μg/cm^2), Co (159 μg/cm^2), Zn (125 μg/cm^2), Sr (178 μg/cm^2), Pb (243 μg/cm^2), SiO (95 μg/cm^2), KCl (167 μg/cm^2), CuS (Cu = 71.4 μg/cm^2, S = 19.9 μg/cm^2) as explained earlier.[11]

4. Results and Discussion

Typical PIXE X-ray spectra of the aerosol samples collected from Chandigarh city are shown in Figs. 5(a) and 5(b). Figure 5(a) indicates the trace elements present in the blank filter paper while Fig. 5(b) shows the trace elements present in a typical aerosol sample from site 2. The maximum suspended particulate matter (SPM) level was found to be 766 g/m^3 at site 3. Ten elements namely $_{16}$S, $_{17}$Cl, $_{19}$K, $_{20}$Ca, $_{22}$Ti, $_{23}$V, $_{24}$Cr, $_{25}$Mn, $_{26}$Fe and $_{30}$Zn were quantified in most of the aerosol samples. The overall error in concentrations is estimated to be 13–15%. This is attributed to the errors incurred during sampling (10%) and analysis (10%). The summary statistics of elemental concentrations for all the three sampling sites are given in Tables 3–5. These include the arithmetic means, arithmetic standard deviation (σ), minimum and maximum values for elemental concentration data. No significant difference in the elemental composition from one sampling station to other is found despite the difference in the activity at each place.

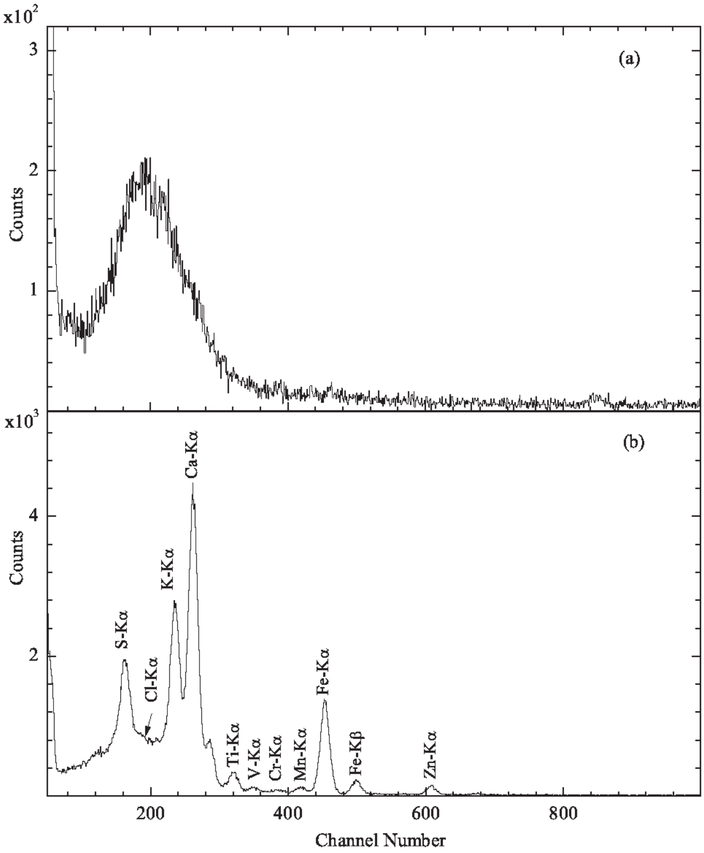

Fig. 5. PIXE spectra of (a) blank filter paper, (b) aerosol samples from Gate 1, PU (site 2).

Table 3. Summary statistics for aerosol concentration (ng m^{-3}) data from Physics Department, Panjab University, Chandigarh (site 1).

Element	Mean aerosol concentration	σ	Min	Max
$_{16}$S	4833	2121	2080	8045
$_{17}$Cl	506	252	0	818
$_{19}$K	2465	816	1317	3910
$_{20}$Ca	2896	976	1266	4247
$_{22}$Ti	403	200	224	811
$_{23}$V	16	10	0	25
$_{24}$Cr	33	14	15	55
$_{25}$Mn	66	41	0	138
$_{26}$Fe	2717	1166	1158	4932
$_{28}$Ni	6	10	0	26
$_{30}$Zn	673	283	329	1161
$_{35}$Br	112	83	0	228
PM_{10}	332	217	119	766

Table 4. Summary statistics for aerosol concentration (ng m^{-3}) data from Gate No. 1, Panjab University, Chandigarh (site 2).

Element	Mean aerosol concentration	σ	Min	Max
$_{16}$S	5201	1825	2756	7591
$_{17}$Cl	865	880	408	3179
$_{19}$K	2262	689	1304	3743
$_{20}$Ca	3450	1223	2101	6492
$_{22}$Ti	272	99	154	478
$_{23}$V	22	13	0	47
$_{24}$Cr	42	13	25	65
$_{25}$Mn	89	44	56	202
$_{26}$Fe	2586	883	1577	4651
$_{28}$Ni	4	7	0	20
$_{30}$Zn	635	164	451	970
$_{35}$Br	41	30	0	81
PM_{10}	211	109	122	476

From the concentration one can just say that the concentration levels at Gate No. 1 (PU) and ISBT are somewhat higher than those found inside the PU site, i.e., Physics Department. This observation becomes clear from Fig. 6, where a comparison of mean concentration values taken over the whole sampling period is presented.

The comparison of present results with those of measured earlier in 1994/1995[10] using a millipore diaphragmatic vacuum pump (Cat. no. xx 55 22050), collected at the height of 40–60 feet without size fractionation are shown in Table 6. In these samples the cut-off was assumed to be 10 μm based on the height of the sampler from

Table 5. Summary statistics for aerosol concentration (ng m^{-3}) data from ISBT-43, Chandigarh (site 3).

Element	Mean aerosol concentration	σ	Min	Max
$_{16}$S	4608	3126	2892	12725
$_{17}$Cl	1063	864	579	3301
$_{19}$K	2833	567	2087	3794
$_{20}$Ca	4115	947	2959	5834
$_{22}$Ti	350	69	242	444
$_{23}$V	17	13	0	39
$_{24}$Cr	35	12	22	61
$_{25}$Mn	73	13	58	94
$_{26}$Fe	3502	691	2641	4818
$_{28}$Ni	19	18	0	52
$_{30}$Zn	442	170	165	635
$_{35}$Br	37	53	0	150
PM_{10}	390	186	136	711

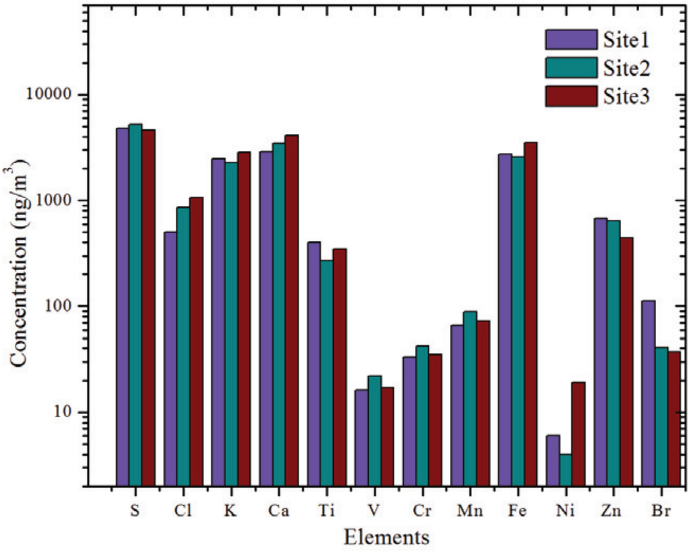

Fig. 6. Comparison plot for mean concentration of various elements measured at three sampling sites.

the ground level. Present sampler uses the single stage impactor with an after filter. The impactor stage removes particles of aerodynamics diameter greater than 10 μm so that the particles of aerodynamics diameter less than 10 μm (PM_{10}) are collected on the after filter while the earlier sampling was based only on the assumption that at a height of 40–60 feet the probable particles are less than 10 μm. During the

Table 6. Comparison of present results with measured earlier in 1994–1995 from site 3 (ISBT-43).

Element	Mean (1994–1995)	Mean (2008–2009)
$_{16}$S	9680	4608
$_{17}$Cl	1251	1063
$_{19}$K	9389	2833
$_{20}$Ca	13695	4115
$_{22}$Ti	10421	350
$_{23}$V	0	17
$_{24}$Cr	180	35
$_{25}$Mn	718	73
$_{26}$Fe	20277	3502
$_{28}$Ni	23	19
$_{30}$Zn	1209	442
$_{35}$Br	110	37
$_{37}$Rb	157	Not detected
$_{38}$Sr	183	Not detected
$_{82}$Pb	1497	Not detected

sample collection weather conditions were almost constant as this study was carried out in winter season. Present data shows that for (PM_{10}) the concentrations of all the elements are within the permissible limits of WHO and Indian standards. All the elements presented earlier are also found in all the samples. This shows that the air particulate matter has a contribution from different sources such as soil, vehicular traffic and effused burning, etc. These results are further verified by applying principle component (PC) analysis to the obtained data set.

5. Identification of Sources Using Principle Component Analysis

The pollutant concentrations do not vary independently of each other; their covariation is indicative of the extent to which it is contributed by common sources. The multivariate models, which are based on principal component analysis (PCA)[12] help to identify the contributing sources on the sampling site. These models generate a hypothesis regarding the number of sources, nature of the sources, i.e., physical or chemical and their source profiles. The results of PCA are truncated into few factors. A VARIMAX rotation is applied to the factor loading matrix. A loading close to one (+1 or −1) indicates that the pollutant is characteristic to the common source. The VARIMAX rotated PCA was applied to the multivariate dataset generated by PIXE technique for the samples from all the three sites. These results are shown in Tables 7–9.

From Table 7, it is found that, the first factor shows high loading for $_{19}$K, $_{20}$Ca, $_{22}$Ti, $_{23}$V, $_{25}$Mn, $_{26}$Fe, $_{30}$Zn and $_{35}$Br which are mainly soil related elements. The presence of $_{30}$Zn and $_{35}$Br in soil may be due to vehicular traffic and refuse burning. The second factor has high loading for $_{17}$Cl. This may be due to wood combustion

Table 7. VARIMAX rotated PC analysis for the samples from site 1.

Element	Component			
	Factor 1	Factor 2	Factor 3	Factor 4
$_{16}$S	−0.073	0.063	−0.960	0.003
$_{17}$Cl	0.162	**0.949**	−0.257	0.073
$_{19}$K	**0.984**	−0.132	0.095	−0.007
$_{20}$Ca	**0.930**	0.086	0.251	−0.010
$_{22}$Ti	**0.821**	−0.248	−0.003	**0.477**
$_{23}$V	**0.655**	−0.019	**0.668**	0.316
$_{24}$Cr	0.094	−0.927	−0.059	0.357
$_{25}$Mn	**0.915**	0.225	0.153	−0.155
$_{26}$Fe	**0.965**	−0.085	0.171	0.170
$_{28}$Ni	−0.049	0.138	−0.158	−0.976
$_{30}$Zn	**0.869**	0.367	0.150	0.289
$_{35}$Br	**0.516**	−0.267	**0.693**	0.368

Table 8. VARIMAX rotated PC analysis for the samples from site 2.

Element	Component		
	Factor 1	Factor 2	Factor 3
$_{16}$S	0.365	**0.881**	−0.044
$_{17}$Cl	0.130	0.281	−0.879
$_{19}$K	**0.827**	0.492	−0.009
$_{20}$Ca	**0.892**	0.290	0.324
$_{22}$Ti	**0.927**	0.278	−0.214
$_{23}$V	**0.628**	−0.224	**0.716**
$_{24}$Cr	**0.698**	−0.047	0.022
$_{25}$Mn	**0.845**	0.462	0.194
$_{26}$Fe	**0.933**	0.319	0.082
$_{28}$Ni	**0.840**	0.161	0.305
$_{30}$Zn	0.373	**0.538**	**0.643**
$_{35}$Br	−0.083	−0.917	0.291

or coal combustion. The third factor shows high loading for $_{23}$V and $_{35}$Br. These elements point toward the road dust as a source. The fourth factor has high loading for $_{22}$Ti which is again pointing toward the road dust and vehicular emission.

From Table 8, it is found that first factor is showing high loading of $_{19}$K, $_{20}$Ca, $_{22}$Ti, $_{23}$V, $_{24}$Cr, $_{25}$Mn, $_{26}$Fe and $_{28}$Ni. All these elements point to a common source of motor vehicle emission. Factor 2 shows high loading of $_{16}$S and $_{30}$Zn which is due to road dust and the factor 3 has high loading of $_{23}$V and $_{30}$Zn pointing to wood combustion and contamination of natural soil due to oil combustion. Similarly from Table 9, it is found that the first factor has high loading for Ca, Ti and Fe. The common source for these elements is mainly road dust and motor vehicular

Table 9. VARIMAX rotated PC analysis for the samples from site 3.

Element	Component			
	Factor 1	Factor 2	Factor 3	Factor 4
$_{16}$S	−0.352	**0.864**	−0.007	−0.253
$_{17}$Cl	−0.486	−0.369	0.012	**0.612**
$_{19}$K	0.485	**0.794**	−0.090	0.057
$_{20}$Ca	**0.966**	−0.193	−0.069	0.021
$_{22}$Ti	**0.973**	0.070	0.143	−0.102
$_{23}$V	0.196	0.347	0.102	**0.749**
$_{24}$Cr	0.213	0.012	**0.928**	−0.176
$_{25}$Mn	0.125	0.367	−0.844	−0.199
$_{26}$Fe	**0.960**	0.023	0.169	0.171
$_{28}$Ni	0.099	0.173	**0.840**	0.376
$_{30}$Zn	−0.016	0.261	−0.141	−0.913
$_{35}$Br	−0.067	**0.937**	−0.033	0.034

emission. The second factor is loaded with S, K and Br. For these elements source is oil combustion in motor vehicles. The third factor is showing high loading for Cr and Ni and this shows the contamination of soil due to oil combustion and the fourth factor is showing high loading of Cl and V which may be due to the wood combustion and refuse burning in the nearby areas.

6. Conclusion

PIXE analysis of aerosol samples allows measuring the concentration of all the elements with atomic number $Z \geq 11$ in a fast way and with very low minimum detection limits. In the present work, elemental analysis of aerosol samples collected from Chandigarh city have been performed. Measured concentration is also compared with the data from a previous study done in the year 1999. It is concluded that all the elements detected are within the permissible limits of World Health Organization (WHO) and Indian standards. All the elements presented earlier are found in all the samples leaving Rb, Sr and Pb. So it can be concluded that in spite of increase in the number of vehicles from 70,000 in 1999 to 8.5 lakh in 2011, lead is not detected in the present study. So it means that the use of unleaded petrol has made our environment safer to live in. Using principal component analysis, we have concluded that the main source of air pollution is mainly road dust, vehicular traffic and effused burning. Also, the difference in the elemental concentration of the three sampling sites is due to the difference in number of vehicles and their quality passing through these sites. To explore more in this area a well-planned study is required.

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