



## Elemental characterization of PM<sub>2.5</sub> and PM<sub>1</sub> in dense traffic area in Istanbul, Turkey

Burcu Onat<sup>1</sup>, Ulku Alver Sahin<sup>1</sup>, Tanil Akyuz<sup>2</sup>

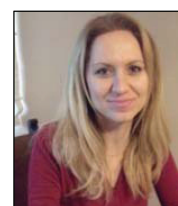
<sup>1</sup> Engineering Faculty, Department of Environmental Engineering, Istanbul University, Avcilar, Istanbul, 34320, Turkey

<sup>2</sup> Department of Physics, Istanbul Kultur University, Yenibosna, Istanbul, 34156, Turkey

### ABSTRACT

An aerosol monitoring study was conducted to measure the fine particulate matter (PM<sub>2.5</sub> and PM<sub>1</sub>) concentrations and composition in the urban area of Istanbul, the most populated city in the north–west of Turkey. The sampling station was located near the D–100 highway. The PARTISOL particulate matter sampler was used during the campaign and operated from 24 April 2009 to 24 May 2009 for PM<sub>2.5</sub> and from 11 December 2009 to 9 April 2010 for PM<sub>1</sub>. Nineteen PM<sub>2.5</sub> samples and 17 PM<sub>1</sub> samples were collected. The glass fiber filters were weighed before and after sampling to obtain mass concentrations. Then X-ray fluorescence was used to measure the concentration of 23 elements (Na, Mg, Al, Si, P, S, Cl, K, Ca, Ti, V, Cr, Mn, Fe, Co, Cu, Zn, As, Rb, Sr, Y, Mo, Ba). PM<sub>2.5</sub> concentration ranged between 23.8 µg/m<sup>3</sup> and 81.5 µg/m<sup>3</sup> and PM<sub>1</sub> concentrations were between 7.6 µg/m<sup>3</sup> and 30.2 µg/m<sup>3</sup>. As a result of the principal components analysis (PCA), PM<sub>2.5</sub> metal emissions were dominated by significant anthropogenic sources, as expressed by high factor loadings in S, Cr, Zn, Cu and K. Crustal elements were likely related to first component (high loadings in Mg, Al, Ba and Si) for PM<sub>2.5</sub> and third component for PM<sub>1</sub>.

**Keywords:** PM<sub>2.5</sub>, PM<sub>1</sub>, XRF, heavy metals, traffic



**Corresponding Author:**

*Burcu Onat*

☎ : +90-212-4737070

☎ : +90-212-4717380

✉ : bonat@istanbul.edu.tr

### Article History:

Received: 15 August 2012

Revised: 11 November 2012

Accepted: 12 November 2012

doi: 10.5094/APR.2013.010

### 1. Introduction

The chemical and physical characteristics of airborne particles are variable depending on the source of the particles. It is essentially important to know their chemical composition to evaluate and reduce the health and environmental effects of the particles. Exposure to inhalable particulate matter emissions from roadways has been implied as injurious to human health and increased risk of respiratory illnesses (Tsai et al., 2000; Lin et al., 2002). Heavy metals pollution is one of the environmental problems of particular concern to the cities which have dense residential and industrial areas and heavy traffic. The emissions of on–road motor vehicles are considered as exhaust and non–exhaust emissions. The emission of brake wear, tire wear and re–suspended road dust from roadways are non–exhaust emissions and also related to motor vehicle activity (Lough et al., 2005). Although the regulatory efforts focus on exhaust emissions, all these emissions are needed to be considered in assessing the impact of motor vehicles on human health and the environment. The observed studies about the health effects with roadway exposure may be more closely related to specific chemical components than to total mass concentrations of inhalable particles (Gavett and Koren, 2001; Claiborn et al., 2002). Metals are suspected to be linked to health impacts and therefore there is a great need to better characterize the metal emissions from motor vehicle roadways (Schaumann et al., 2004).

Most of the trace elements are determined by solution based specimen methods, such as AAS, ICP–OES and ICP–MS etc. X–ray fluorescence spectrometry (XRF) has the advantage that it can measure the solid specimen with very simple sample preparation. Recently, XRF method has been preferred to determine the chemical composition of airborne particulate matter (Carvalho et al., 2004; Lough et al., 2005; Calzolari et al., 2008; Canepari et al., 2009; Niu et al., 2010; Richard et al., 2010; Weckwerth, 2010; Apeagyei et al., 2011; Lopez et al., 2011; Indresand and Dillner, 2012). In this work, PM<sub>2.5</sub> and PM<sub>1</sub> sampling was conducted near a highway in Istanbul. PM<sub>2.5</sub> and PM<sub>1</sub> concentration levels were measured and their chemical composition was determined by a non–destructive method, XRF.

### 2. Material and Method

#### 2.1. Study area

Istanbul is the most densely populated city in Turkey, located in the coastal area and separated into two parts by Istanbul Bosphorus. With an approximate population of 13 million, the metropolitan city has 11 143 industrial establishments and 2 500 000 registered motor vehicles. The study area is located in the vicinity of TEM (Trans European Motorway) and D–100 highways and the airport highway crossroad. Filter samples were collected near the D–100 highway (at the Kultur University Campus), the distance from the highway was about 25 m (Figure 1). Ataturk Airport is about 2 km away from the sampling station.

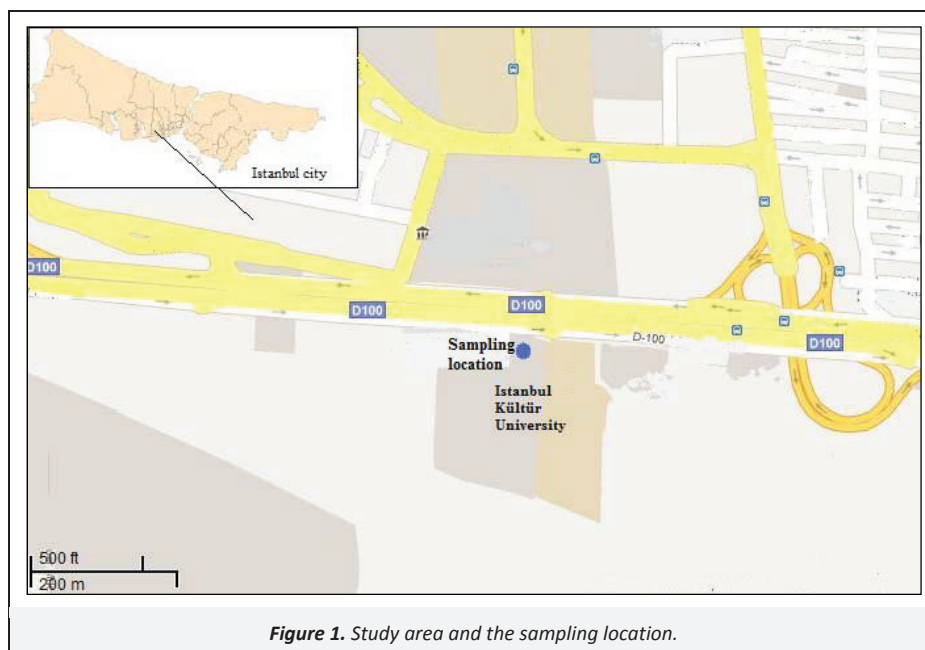


Figure 1. Study area and the sampling location.

## 2.2. Sampling procedure

PM<sub>2.5</sub> and PM<sub>1</sub> sampling was carried out using PARTISOL–FRM MODEL 2000 AIRSAMPLER (US EPA RFPS–048–117–reference method) with PM<sub>2.5</sub> and PM<sub>1</sub> inlets. Particles were collected on 47 mm glass fiber filters (Whatman, glass microfiber, GF/A) at a flow rate of 16.7 L/min. The sampling time was 24 hours. PM<sub>1</sub> sampling was performed randomly and 3–4 samples per month collected between 11 December 2009 and 09 April 2010. PM<sub>2.5</sub> sampling was done continuously during 28 April–23 May 2010. During PM<sub>1</sub> and PM<sub>2.5</sub> sampling period, the temperature was ranged between 4.1 °C and 12.4 °C; 12.0 °C and 20.0 °C, the relative humidity ranged between 67–94% and 59–91%, respectively. The filters were conditioned at a temperature of 20±1 °C and at 50±5% relative humidity for 48 h before and after field sampling and weighed on an electronic balance (RADWAG, sensitivity: 0.01 mg) to determine the mass concentrations.

## 2.3. XRF analysis

The quantitative analyses of Na, Mg, Al, Si, P, S, Cl, K, Ca, Ti, V, Cr, Mn, Fe, Co, Cu, Zn, As, Rb, Sr, Y, Mo and Ba were performed. The post weighed filter samples were analyzed using spectro IQ–2 model Energy Dispersive X–Ray Fluorescence (ED–XRF) spectrometer. The accuracy of the analytical procedures was checked against the standard reference materials. SRM 1648a (Urban particulate matter standard), IAEA–SL, IAEA–SOIL–7, BCR–176 (city waste incineration ash) and GBW 7109 standards were used. The tablets of 31 mm with 0.50 g standard and 7.95 g cellulose powders were prepared under pressure (25 tones) with dry method. The standard curves were obtained. For filter samples, 8.0 g cellulose powder tablets were prepared. Blank filter and dust filters were cut at the diameter of 31 mm and the measurements were performed. SRM 1648 standard was used for QA/QC. SRM measurement was done every 10 samples and the observed recovery was between 95% and 105%.

The SPECTRO IQ–II is equipped with an air cooled 50 W end window X–ray tube. The primary tube spectrum is monochromatized and polarized by doubly curved HOPG crystal. Two different excitation modes were chosen: Mode1 [tube voltage; 48 kV, typical power, 25 W, elements analyzed: Co–Ce (K–lines) and Hf–U (L–lines)] and Mode2 [tube voltage; 25 kV, typical power, 25 W, elements analyzed: Na–Fe (K–lines)]. A Silicon Drift Detector (SDD) was used to collect the fluorescence radiation from the sample. The resolution of the SDD was better than 175 eV for Mn K $\alpha$  at an

input count rate of 10 000 cps. During the measurement, the sample chamber was flushed with He. All measurement parameters are controlled by a PC connected to the system.

## 3. Results and Discussion

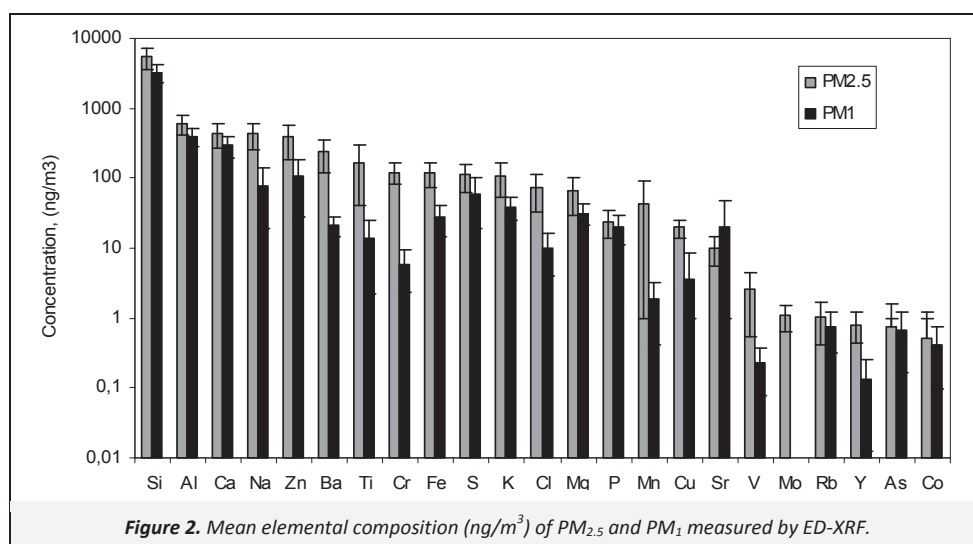
Sampling campaign was performed between 24 April 2009 and 24 May 2009 for PM<sub>2.5</sub> and between 11 December 2009 and 9 April 2010 for PM<sub>1</sub>. The number of collected filters for PM<sub>2.5</sub> and PM<sub>1</sub> were 19 and 17, respectively. The mass concentrations and elemental composition of PM<sub>2.5</sub> and PM<sub>1</sub> are given in Table 1. The daily PM<sub>2.5</sub> concentrations varied from 23.8  $\mu\text{g}/\text{m}^3$  to 81.5  $\mu\text{g}/\text{m}^3$ , and the mean PM<sub>2.5</sub> concentration and standard deviation was 40.5±13.7  $\mu\text{g}/\text{m}^3$ . The daily PM<sub>1</sub> concentrations varied from 7.6  $\mu\text{g}/\text{m}^3$  to 30.2  $\mu\text{g}/\text{m}^3$ , the mean PM<sub>1</sub> concentration and standard deviation was 22.1±6.4  $\mu\text{g}/\text{m}^3$ . Most of daily concentrations (about 60% of total data) were higher than the ambient air PM<sub>2.5</sub> standard declared by United States Environmental Protection Agency (US EPA), given as 35  $\mu\text{g}/\text{m}^3$  for 24 h mean. PM<sub>1</sub> levels were higher than that measured at a background station in Finland (4.3±3.8  $\mu\text{g}/\text{m}^3$ ), similar to the value at the urban station of Italy (22±6  $\mu\text{g}/\text{m}^3$ ), but lower than at the roadside station in Hong Kong (44.0±19.4  $\mu\text{g}/\text{m}^3$ ) and at the urban site in China (127.3±62.1  $\mu\text{g}/\text{m}^3$ ) (Ariola et al., 2006; Makkonen et al., 2010; Shen et al., 2010; Cheng et al., 2011). The value of PM<sub>1</sub>/PM<sub>2.5</sub> ratio was calculated as approximately 0.55 (Table 1). The PM<sub>2.5</sub> and PM<sub>1</sub> concentrations measured in this study were two to ten times higher than those observed at the urban and background sites of Istanbul during a recent study (Sahin et al., 2012).

The emissions of particles are related to traffic as a result of fuel combustion, vehicular component wear, road degradation and roadway maintenance (Slezakova et al., 2007). The traffic related PM contains metallic elements with anthropogenic origin such as V, Cr, Fe, Ni, Cu, Zn, Pb (Sansalone and Buchberger, 1997). In some studies, Pb, Zn and Cu were indicated as marker elements of traffic emissions. The road dust include Fe, Cu, Cr, Ag, Mn, Pb, Ni, Cd, Zn (Yongming et al., 2006) and the vehicle exhaust emission include Cu, Zn, Pb, Br, Fe, Ca and Ba (Huang et al., 1994; Cadle et al., 1997). Slezakova et al. (2007) observed that the elements S, Mn, Zn, Pb, P, K and Cr originated mostly from anthropogenic activities and they were predominantly present in the fine fraction while Mg, Al, Si and Ca mostly originated from crustal sources and were predominantly present in the coarse fraction.

**Table 1.** Statistical summary of  $PM_{2.5}$  and  $PM_1$  elemental compositions ( $ng/m^3$ ) at the roadside sampling station

	$PM_{2.5}$ (N=19)		$PM_1$ (N=17)		$PM_1/PM_{2.5}$
	Mean	SD	Mean	SD	
Mass ( $\mu g/m^3$ )	40.50	13.70	22.1	6.4	0.55
Silicon (Si)	5 441	1 901	3 245	966.5	0.60
Aluminum (Al)	602.1	191.5	393.3	113.7	0.65
Calcium (Ca)	437.5	172.7	293.7	97.2	0.67
Sodium (Na)	429.5	173.8	79.8	60.9	0.19
Zinc (Zn)	384.7	197.6	108.2	80.5	0.28
Barium (Ba)	241.9	119.4	21.1	6.3	0.09
Titanium (Ti)	167.5	126.6	13.9	11.7	0.08
Chromium (Cr)	121.7	40.7	5.87	3.48	0.05
Iron (Fe)	117.3	43.8	27.5	13.2	0.23
Sulfur (S)	110.5	49.4	60.0	41.4	0.54
Potassium (K)	107.4	54.3	39.0	13.7	0.36
Chlorine (Cl)	73.5	39.9	10.2	6.11	0.14
Magnesium (Mg)	66.3	36.5	31.5	10.4	0.47
Phosphorus (P)	24.0	10.2	20.2	9.31	0.84
Manganese (Mn)	42.1	51.2	1.85	1.44	0.04
Copper (Cu)	19.6	5.66	3.66	4.78	0.19
Strontium (Sr)	10.0	4.50	10.8	3.80	1.08
Vanadium (V)	2.54	2.00	0.22	0.15	0.09
Molybdenum (Mo)	1.08	0.44	0.09	0.10	0.09
Rubidium (Rb)	1.05	0.62	0.75	0.43	0.72
Yttrium (Y)	0.81	0.38	0.13	0.12	0.16
Arsenic (As)	0.75	0.86	0.69	0.52	0.91
Cobalt (Co)	0.52	0.68	0.41	0.32	0.79

N: Number of samples, SD: Standard deviation



In this work, XRF provided the elemental composition of the measured  $PM_{2.5}$  and  $PM_1$  mass and 23 metals were determined. The comparison of metal concentration for  $PM_{2.5}$  and  $PM_1$  are illustrated in Figure 2. The contribution of the measured elements in  $PM_{2.5}$  and  $PM_1$  were ranged from 19.0% to 23.1% and from 18.1% to 20.9%, respectively. The most observed crustal element was Si, about 13.4% of  $PM_{2.5}$  and 14.7% of  $PM_1$ . On average, 3.9% of  $PM_{2.5}$  and 3.6% of  $PM_1$  consisted of Al, Na, Ca and Mg. In a recent study in Istanbul (Sahin et al., 2010) it was observed that the V and Cu concentrations were between  $2.0 ng/m^3$ – $3.6 ng/m^3$  and  $4.6 ng/m^3$ – $23.6 ng/m^3$ , respectively at a sampling station close to the traffic. These results were very similar with the results found

in this study (Table 1). However, in the present study Cr and Mn concentrations of  $PM_{2.5}$  were about ten times higher ( $62.0 ng/m^3$ – $220.0 ng/m^3$  and  $13.4 ng/m^3$ – $235.6 ng/m^3$ ) than those in the previous study ( $6.4 ng/m^3$ – $8.7 ng/m^3$  and  $11.8 ng/m^3$ – $24.3 ng/m^3$ ). In another study conducted in an urban area of Istanbul, the mean Cr concentrations in TSP (Total Suspended Particle) were observed as  $279.8 ng/m^3$  at a sampling station near highway and  $62.2 ng/m^3$  at a sampling station close to the traffic (Onat et al., 2012). In the same study, the mean V and Cu concentrations were  $47.9 ng/m^3$ – $51.9 ng/m^3$  and  $49.2 ng/m^3$ – $109.7 ng/m^3$ , respectively. The location of the station, traffic load and airport were probably the reasons for these high levels.

**Table 2.** Results of principal component analysis (PCA) in PM<sub>2.5</sub> and PM<sub>1</sub> fractions

Metals	PM <sub>2.5</sub>				PM <sub>1</sub>		
	Factor 1	Factor 2	Factor 3	Factor 4	Factor 1	Factor 2	Factor 3
Na	<b>0.94</b>	-0.07	-0.09	-0.16	<b>0.81</b>	0.27	0.28
Mg	<b>0.85</b>	-0.16	0.20	0.04	<b>0.86</b>	0.04	0.48
Al	<b>0.87</b>	0.20	0.32	-0.06	0.44	0.53	<b>0.70</b>
Si	<b>0.92</b>	0.09	0.29	0.14	0.50	0.49	<b>0.70</b>
P	<b>0.82</b>	0.34	0.04	-0.11	0.04	0.53	<b>0.82</b>
S	<b>0.93</b>	-0.08	-0.05	-0.16	0.33	0.02	<b>0.73</b>
Cl	<b>0.65</b>	0.14	0.47	0.39	<b>0.77</b>	0.56	0.22
K	<b>0.90</b>	-0.06	0.25	0.12	0.60	<b>0.62</b>	0.47
Ca	-0.16	<b>0.82</b>	0.18	0.00	<b>0.68</b>	0.48	0.53
Ti	<b>0.90</b>	-0.02	-0.08	0.34	<b>0.74</b>	0.61	0.16
V	0.24	0.10	<b>0.68</b>	-0.52	<b>0.96</b>	0.22	0.13
Cr	0.87	0.27	0.11	0.16	<b>0.84</b>	0.51	0.10
Mn	0.06	-0.13	-0.04	<b>0.86</b>	<b>0.96</b>	0.18	0.10
Fe	<b>0.79</b>	0.14	0.35	-0.03	<b>0.88</b>	0.37	0.22
Co	0.39	0.36	<b>0.55</b>	0.02	0.02	<b>0.86</b>	0.26
Cu	<b>0.81</b>	0.22	<b>0.46</b>	0.11	<b>0.69</b>	0.55	0.11
Zn	<b>0.75</b>	0.02	0.15	-0.43	<b>0.85</b>	0.10	0.40
As	0.07	<b>0.82</b>	-0.17	-0.32	0.13	<b>0.71</b>	0.42
Rb	0.11	<b>0.87</b>	0.41	-0.08	0.38	<b>0.75</b>	0.47
Sr	0.87	-0.08	0.41	-0.04	-0.02	0.26	<b>0.91</b>
Y	0.33	0.87	0.07	0.22	<b>0.64</b>	0.70	0.11
Mo	<b>0.81</b>	-0.06	0.38	0.09	<b>0.94</b>	0.33	0.08
Ba	<b>0.56</b>	-0.60	0.17	0.23	<b>0.89</b>	-0.36	0.11
Total	11.5	3.8	2.3	1.8	10.7	5.6	4.7
% of Variance	50	16.4	9.8	7.9	46.4	24.3	20.2
Cumulative %	50	66.3	76.1	84	46.4	70.6	90.9
Source	Road dust and exhaust	Oil combustion	Oil combustion	Exhaust	Exhaust	Combustion	Crustal

The annual average limit value for As in respirable particles (PM<sub>10</sub>) is stated as 6 ng/m<sup>3</sup> in EU directive (EU–Directive 99/30/EC). As and Cr are identified as carcinogenic elements and the unit risk factors are described as 0.0015 µg/m<sup>3</sup> for As and 1 µg/m<sup>3</sup> for Cr by The World Health Organization (WHO) and the Environmental Protection Agency (EPA). However, V and Mn are classified as non-carcinogenic and toxic substances with health risks. Carcinogenic substance As (0.8±0.9 ng/m<sup>3</sup> in PM<sub>2.5</sub> and 0.7±0.5 ng/m<sup>3</sup> in PM<sub>1</sub>) and toxic substance Cr (19.6±5.7 ng/m<sup>3</sup> in PM<sub>2.5</sub> and 3.7±4.8 ng/m<sup>3</sup> in PM<sub>1</sub>) concentrations are lower than the limit values. The average V (2.5±2.0 ng/m<sup>3</sup> in PM<sub>2.5</sub> and 0.2±0.1 ng/m<sup>3</sup> in PM<sub>1</sub>) and Mn (42.2±51.1 ng/m<sup>3</sup> in PM<sub>2.5</sub> and 1.9±1.4 ng/m<sup>3</sup> in PM<sub>1</sub>) concentrations are much lower than WHO guideline values of 1 and 0.15 µg/m<sup>3</sup>.

The principal component analysis (PCA) was used for the source identification using independent variables. The PCA results are given in Table 2 and the possible pollutant sources were examined. Bold characters correspond to statistically significant variables for each factor. At the sampling site, the first component (factor 1) was extracted explaining 50% and 46.4% in PM<sub>2.5</sub> and PM<sub>1</sub> of the total variance, respectively. Factor 1 was related to anthropogenic sources, as expressed by high factor loadings in S, Cr, Zn, Cu and K. Additionally, crustal elements (Al and Si) were possibly related to first component in PM<sub>2.5</sub>, but also related to third component in PM<sub>1</sub>. Factor 1 is likely related to re-suspended road dust and exhaust emissions for PM<sub>2.5</sub>, only vehicle exhaust emission for PM<sub>1</sub>. Factor 2 explained 16.4% in PM<sub>2.5</sub> and 24.3% in PM<sub>1</sub>, factor 3 39.8% in PM<sub>2.5</sub> and 20.2% in PM<sub>1</sub> and factor 4 7.9% in PM<sub>2.5</sub> of the total variance. Factors 2 and 3 for PM<sub>2.5</sub> are probably

associated with oil combustion (high loading in As, medium loadings in V and Co). Also, the same was observed for factor 2 for PM<sub>1</sub>. Factor 3 for PM<sub>1</sub>, enriched with Al, Si, P, S and Sr, is best explained by crustal materials or road dust. Factor 4 for PM<sub>2.5</sub> is related to direct exhaust emissions (high loading in Mn). Also high loadings in Na, Mg, Cl (factor 1) and Ca (factor 2) can be explained by sea salt spray.

#### 4. Conclusion

In this study, the elemental characterization of PM<sub>1</sub> and PM<sub>2.5</sub> collected at an urban station at the vicinity of the highway were determined by ED–XRF. The mean PM<sub>2.5</sub> and PM<sub>1</sub> concentrations were 40.5±13.7 µg/m<sup>3</sup> and 22.1±6.4 µg/m<sup>3</sup>, respectively. These results were about ten times higher than those observed in the previous studies at the background stations in Istanbul. The fine particle exposure can be greater at the traffic microenvironments. About 20% of the PM<sub>2.5</sub> and PM<sub>1</sub> mass was constituted by 23 elements considered in this study. Carcinogenic and toxic elements concentrations (As, Cr, V and Mn) were observed at lower concentrations than the limit values of WHO and EPA. The ratios of As and Co concentrations in PM<sub>1</sub> and PM<sub>2.5</sub> as follows: As in PM<sub>1</sub>/As in PM<sub>2.5</sub> was 0.91 and Co in PM<sub>1</sub>/Co in PM<sub>2.5</sub> was 0.79. The PCA showed that the elements predominantly present in PM<sub>2.5</sub> and PM<sub>1</sub> originated mostly from anthropogenic activities especially traffic (exhaust and non-exhaust) emissions. The crustal elements (especially Al and Si) were dominantly present in factor 1 for PM<sub>2.5</sub> and in factor 3 for PM<sub>1</sub>. In Turkey, only PM<sub>10</sub> limits are defined in the national standards. Therefore, the determination of PM<sub>2.5</sub> and

PM<sub>1</sub> concentrations is very important to establish the national limits.

## Acknowledgement

This study was supported by the Research Fund of the University of Istanbul: Project Number: 547.

## References

- Apeagyei, E., Bank, M.S., Spengler, J.D., 2011. Distribution of heavy metals in road dust along an urban-rural gradient in Massachusetts. *Atmospheric Environment* 45, 2310-2323.
- Ariola, V., D'Alessandro, A., Lucarelli, F., Marazzan, G., Mazzei, F., Nava, S., Garcia-Orellana, I., Prati, P., Valli, G., Vecchi, R., Zucchiatti, A., 2006. Elemental characterization of PM<sub>10</sub>, PM<sub>2.5</sub> and PM<sub>1</sub> in the town of Genoa (Italy). *Chemosphere* 62, 226-232.
- Cadle, S.H., Mulawa, P.A., Ball, J., Donase, C., Weibel, A., Sagebiel, J.C., Knapp, K.T., Snow, R., 1997. Particulate emission rates from in use high emitting vehicles recruited in Orange County, California. *Environmental Science and Technology* 31, 3405-3412.
- Calzolai, G., Chiari, M., Lucarelli, F., Mazzei, F., Nava, S., Prati, P., Valli, G., Vecchi, R., 2008. PIXE and XRF analysis of particulate matter samples: an inter-laboratory comparison. *Nuclear Instruments and Methods in Physics Research Section B-Beam Interactions with Materials and Atoms* 266, 2401-2404.
- Canepari, S., Perrino, C., Astolfi, M.L., Catrambone, M., Perret, D., 2009. Determination of soluble ions and elements in ambient air suspended particulate matter: inter-technique comparison of XRF, IC and ICP for sample-by-sample quality control. *Talanta* 77, 1821-1829.
- Carvacho, O.F., Trzepla-Nabaglo, K., Ashbaugh, L.L., Flocchini, R.G., Melin, P., Celis, J., 2004. Elemental composition of springtime aerosol in Chillan, Chile. *Atmospheric Environment* 38, 5349-5352.
- Cheng, Y., Zou, S.C., Lee, S.C., Chow, J.C., Ho, K.F., Watson, J.G., Han, Y.M., Zhang, R.J., Zhang, F., Yau, P.S., Huang, Y., Bai, Y., Wu, W.J., 2011. Characteristics and source apportionment of PM<sub>1</sub> emissions at a roadside station. *Journal of Hazardous Materials* 195, 82-91.
- Claiborn, C.S., Larson, T., Sheppard, L., 2002. Testing the metals hypothesis in Spokane, Washington. *Environmental Health Perspectives* 110, 547-552.
- Gavett, S.H., Koren, H.S., 2001. The role of particulate matter in exacerbation of atopic asthma. *International Archives of Allergy and Immunology* 124, 109-112.
- Huang, X.D., Olmez, I., Aras, N.K., Gordon, G.E., 1994. Emissions of trace-elements from motor-vehicles - potential marker elements and source composition profile. *Atmospheric Environment* 28, 1385-1391.
- Indresand, H., Dillner, A.M., 2012. Experimental characterization of sulfur interference in IMPROVE aluminum and silicon XRF data. *Atmospheric Environment* 61, 140-147.
- Lin, S., Munsie, J.P., Hwang, S.A., Fitzgerald, E., Cayo, M.R., 2002. Childhood asthma hospitalization and residential exposure to state route traffic. *Environmental Research* 88, 73-81.
- Lopez, M.L., Ceppi, S., Palancar, G.G., Olcese, L.E., Tirao, G., Toselli, B.M., 2011. Elemental concentration and source identification of PM<sub>10</sub> and PM<sub>2.5</sub> by SR-XRF in Cordoba city, Argentina. *Atmospheric Environment* 45, 5450-5457.
- Lough, G.C., Schauer, J.J., Park, J.S., Shafer, M.M., DeMinter, J.T., Weinstein, J.P., 2005. Emissions of metals associated with motor vehicle roadways. *Environmental Science and Technology* 39, 826-836.
- Makkonen, U., Hellen, H., Anttila, P., Ferm, M., 2010. Size distribution and chemical composition of airborne particles in south-eastern Finland during different seasons and wildfire episodes in 2006. *Science of the Total Environment* 408, 644-651.
- Niu, J.J., Rasmussen, P.E., Wheeler, A., Williams, R., Chenier, M., 2010. Evaluation of airborne particulate matter and metals data in personal, indoor and outdoor environments using ED-XRF and ICP-MS and co-located duplicate samples. *Atmospheric Environment* 44, 235-245.
- Onat, B., Sahin, U.A., Bayat, C., 2012. Assessment of particulate matter in the urban atmosphere: size distribution, metal composition and source characterization using principal component analysis. *Journal of Environmental Monitoring* 14, 1400-1409.
- Richard, A., Bukowiecki, N., Lienemann, P., Furger, M., Fierz, M., Minguillon, M.C., Weideli, B., Figi, R., Flechsig, U., Appel, K., Prevot, A.S.H., Baltensperger, U., 2010. Quantitative sampling and analysis of trace elements in atmospheric aerosols: impactor characterization and Synchrotron-XRF mass calibration. *Atmospheric Measurement Techniques* 3, 1473-1485.
- Sahin, U.A., Scherbakova, K., Onat, B., 2012. Size distribution and seasonal variation of airborne particulate matter in five areas in Istanbul, Turkey. *Environmental Science and Pollution Research* 19, 1198-1209.
- Sahin, U.A., Onat, B., Guney, A., Scherbakova, K., Polat, G., 2010. Seasonal variation of size distribution and metal composition of particulate matter in Istanbul atmosphere. *Fourth National Air Pollution and its Control Symposium, 25-27 October 2010*, Ankara, 535-549 (in Turkish).
- Sansalone, J.J., Buchberger, S.G., 1997. Partitioning and first flush of metals in urban roadway storm water. *Journal of Environmental Engineering-ASCE* 123, 134-143.
- Schaumann, F., Borm, P.J.A., Herbrich, A., Knoch, J., Pitz, M., Schins, R.P.F., Luettig, B., Hohlfeld, J.M., Heinrich, J., Krug, N., 2004. Metal-rich ambient particles (particulate matter(2.5)) cause airway inflammation in healthy subjects. *American Journal of Respiratory and Critical Care Medicine* 170, 898-903.
- Shen, Z.X., Cao, J.J., Arimoto, R., Han, Y.M., Zhu, C.S., Tian, J., Liu, S.X., 2010. Chemical characteristics of fine particles (PM<sub>1</sub>) from Xi'an, China. *Aerosol Science and Technology* 44, 461-472.
- Slezakova, K., Pereira, M.C., Reis, M.A., Alvim-Ferraz, M.C., 2007. Influence of traffic emissions on the composition of atmospheric particles of different sizes - Part 1: concentrations and elemental characterization. *Journal of Atmospheric Chemistry* 58, 55-68.
- Tsai, F.C., Apte, M.G., Daisey, J.M., 2000. An exploratory analysis of the relationship between mortality and the chemical composition of airborne particulate matter. *Inhalation Toxicology* 12, 121-135.
- Weckwerth, G., 2010. Origin of fine dust in urban environmental zones - evidence from element patterns received by dichotomous collection and INAA. *Applied Radiation and Isotopes* 68, 1878-1883.
- Yongming, H., Peixuan, D., Junji, C., Posmentier, E.S., 2006. Multivariate analysis of heavy metal contamination in urban dusts of Xi'an central China. *The Science of the Total Environment* 355, 176-186.