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Seasonal Behaviours and Weekdays/Weekends Differences in Elemental Composition of Atmospheric Aerosols in Cairo, Egypt

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ABSTRACT

The aim of the present study was to investigate the seasonal distributions and weekdays/weekends differences in ambient aerosols and their elemental contents in the atmosphere of the 15 May City, Egypt. Aerosol samples were collected from March 2009 to February 2010. The concentrations of 14 elements including Na, Mg, Ca, K, Al, Fe, Mn, Co, Cu, Zn, Ni, Cd, Pb and Cr were measured by Atomic Absorption Spectrophotometry (AAS). The mean aerosols concentrations were 290 μg/m^3 (spring), 250 μg/m^3 (summer), 330 μg/m^3 (autumn) and 400 μg/m^3 (winter). The measured elements showed a strong seasonal variation; with the highest concentrations in winter and the lowest in summer. Na, Mg, Ca, K, Al and Fe were the dominant elements, followed by Mn, Cu, Zn, Ni and Pb. The minimum concentrations were noted for Co, Cd and Cr. The dominant elements in aerosol represented 94%, 94.51%, 94.61% and 94.28% from the total measured elements and 5.08%, 5.74%, 6.11% and 5.44% from aerosol mass during winter, spring, summer and autumn, respectively. The aerosols concentrations on weekends were reduced by 31.25% in the winter and 15.2% in the summer. The concentrations of the measured elements were higher on weekdays than weekends. The weekday/weekend concentration ratios were 1.69 and 1.38 for total measured elements during winter and summer, respectively. The mean Ni and Cd levels were higher than the proposed WHO, USEPA and the European Community standards. Significant positive correlations were found between the concentrations of aerosols, Mg, Ca, K, Al, Fe, Mn, Co, Zn and Cr. The enrichment factors (EFs) and the non-crustal fractions of all elements indicated that Na, Mg, Ca, K, Fe and Mn originate mainly from soil sources, whereas Co, Cu, Zn, Ni, Cd, Pb and Cr are mostly emitted in the atmosphere of 15 May City from anthropogenic sources.

Keywords: Aerosol; Elements; Seasonal variations; Weekdays/Weekends; Enrichment factors; Cairo; Egypt.

INTRODUCTION

Urbanization, industrialization and associated increase of energy demands have resulted in deterioration of urban air quality. In urban regions, anthropogenic activities linked with socioeconomics have significant bearing on aerosol scenarios and their trans-boundary implications (Mitra and Sharma, 2002). Ambient aerosols (suspended particulate matter, SPM) represent the most important air pollutant group, since it plays a serious adverse role in the atmosphere. It causes loss in visibility and cloud formation (Sloane *et al.*, 1991; Lee and Sequerira, 2002), and acidification of precipitation and also affect climate (Dockery and Pope, 1994; IPCC, 2007). Aerosols may carry of acidic or toxic species and may have detrimental effects on human health and ecosystems (Cheng *et al.*, 1996). Human health endpoints associated with exposure to aerosols include increased mortality and pulmonary and cardiovascular diseases (Lee *et al.*, 2006; Perrone *et al.*, 2010; Gualtieri *et al.*, 2012).

Aerosols vary in size, shape, surface area, chemical composition, solubility and origin (Pope and Dockery, 2006; Zhang *et al.*, 2009; Tai *et al.*, 2010). They are complex mixture of anthropogenic and natural origin and may be emitted directly or formed in the atmosphere (Samura *et al.*, 2003; Gualtieri *et al.*, 2010). Industrial activities, energy production, construction, wastetreatment and vehicle exhausts are the main anthropogenic sources of aerosols in the atmosphere (Sabbak, 1995; Bilos *et al.*, 2001). In urban environments, fine particles arise from anthropogenic sources, such as combustion processes and gas-to-particle conversions, whereas coarse ones originate mainly from natural processes, such as wind action on land and sea spray (Reichhardt, 1995; Jonathan *et al.*, 1997).

Atmospheric aerosols are an analytically matrix that

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contains water-soluble inorganic compounds, organic carbons, elemental carbon and metals. Among these components, trace elements are of great concern in urban air pollution problems; as they can have severe toxic and carcinogenic effects on humans. Trace elements are released into the atmosphere both from natural and anthropogenic sources. Resuspended surface dust makes a large contribution to the natural emissions, whereas the combustion of fossil fuels, automobile and industrial emissions are the principal anthropogenic sources of most toxic elements (Hao *et al.*, 2007; Yatkin and Bayram, 2008). Short-term differences of atmospheric metal concentration has been observed in a day-to-day or even hour-to-hour (Gharaibeh *et al.*, 2010). The distribution of trace elements in airborne particulates shows significant variations with the meteorological conditions in different parts of the world (Jonsson *et al.*, 2004; Shaheen *et al.*, 2005).

Metals associated with ambient aerosols catalyze oxidative stress (Muránszky *et al.*, 2011), and may be responsible for production and release of inflammatory mediators by the respiratory tract epithelium, which contribute to the toxic effects of particulate air pollutants reported in epidemiological studies (Carter *et al.*, 1997). Lead (Pb) can induce severe neurological and hematological effects, especially to children (Jedrychowski *et al.*, 2005; Heinrich and Slama, 2007). Compounds of nickel (Ni), cadmium (Cd) and chromium (Cr) are susceptible for inducing carcinogenic effects in human (IARC, 1993). Exposure to high levels of manganese (Mn) can lead to neurotoxical impairments (Heinrich and Slama, 2007).

Studies on elemental concentrations in ambient particulates can give useful information on pollution sources, transportation of aerosols and their effects on human health (Qin and Oduyemi, 2003; Garcia *et al.*, 2004). Thus, the use of elemental signatures to apportion aerosols into major regional sources requires an understanding of the behaviour of aerosols bearing element during different seasons. Industrial outputs are not generally seasonally dependent, whereas airborne concentrations of crustal material are seasonally affected. The aim of the present study was to: (1) investigate the seasonal variations and distribution of some atmospheric elements (Ca, Na, Fe, K, Zn, Mg, Cu, Pb, Mn, Co, Ni, Cr, Cd and Al), (2) evaluate the contribution of anthropogenic sources on the levels of these elements, and (3) study the differences in aerosols concentration levels and their elemental contents between weekdays and weekends during the winter and summer seasons.

MATERIALS AND METHODS

Site Description

Cairo is characterized by the presence of Mokattam hills to the east and southeast, besides the Shoubra-El Kheima and Helwan industrial areas in the north and south, respectively (Fig. 1). Industrial activities, heavy traffic density, as well as, the surrounding hills and desert are the main sources of air pollution in Cairo. About 52% of the industries and about 40% of electrical power stations in Egypt are found in Greater Cairo, besides more than 2 million

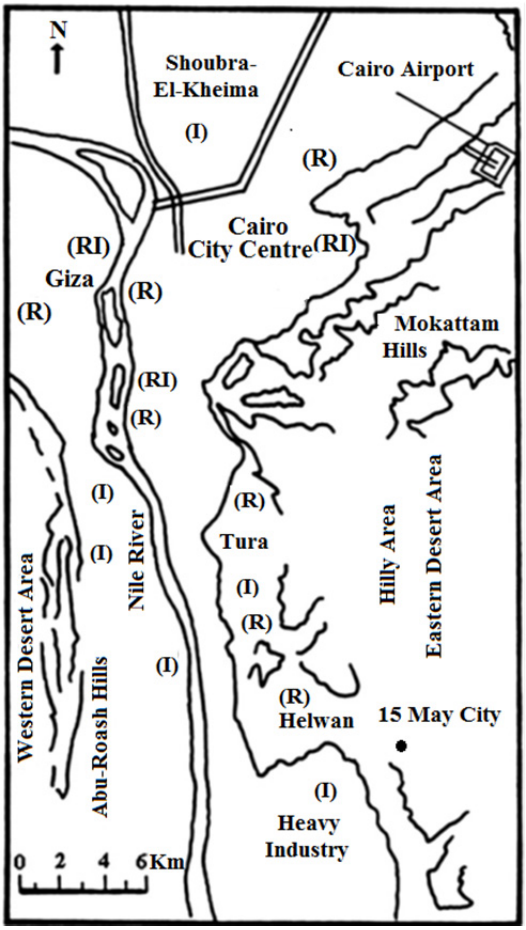

Fig. 1. Map of the greater Cairo areas showing districts of residential (R), industrial (I), residential industrial (RI) activities and the sampling site (•).

vehicles are running in the streets of the Greater city, about 60% of which are over 10 years old and therefore lack modern emission cutting features like catalytic converters (Shakour *et al.*, 2011; Hassan and Khoder, 2012). The high rate of emission coupled with low wind speeds and the frequent inversions in the area resulted in high local pollution load. Vehicle fuels used in Greater Cairo are mainly unleaded gasoline and diesel, and some vehicles are using compressed natural gas (Hassan and Khoder, 2012). The general climate of Cairo city is cold, moist and rainy in winter, and high temperature, high solar radiation, clear sky and rainless in summer. During the period of the present study, the daily temperature ranged from 17.4°C to 27.5°C (with an average of 22.3°C) in spring, 26.1°C to 35.4°C (with an average of 31.3°C) in summer, 20.5°C to 30.6°C (with an average of 25.5°C) in autumn and 10.7°C to 17.9°C (with an average of 15.5°C) in winter. The daily relative humidity ranged from 15.9% to 62.2% (with a mean value of 48.6%) during spring, 31.9% to 73.6% (with a mean value of 61.9%) during summer, 29.9% to 76.2% (with a mean value of 58.6%) during autumn and 50.9% to 76.2% (with a mean value of 67.6%) during winter. The dominant wind directions were north, north east and northwest during the four seasons. The average wind speeds were 13.1 km/h

in spring, 13.20 km/h in summer, 11.2 km/h in autumn and 8.95 km/h in winter. The mean values of global solar radiation were 11.35 MJ/m^2 in winter and 25.54 MJ/m^2 in summer. The sampling site (15 May City) is located in the southeast of Cairo, ~35 km from the centre of Cairo. It is characterized by relatively high traffic density, nearest to Autostrad high way. The main source of air pollutant emissions in 15 May City arises from traffic activities.

Sample Collection

Aerosols samples were collected using a low volume air sampler. The samples were collected using a calibrated vacuum pump (Gast, USA) to draw 15 L/min, for 24 hours.. The air was drawn through the filter holder containing a pre-weighed cellulose nitrate membrane filters (pore size 0.45 μm, diameter, 25 mm). The flow rate of a calibrated vacume pump was meaured before and after sampling time. The differences were found to be very small, so, it is considered that no overload of filter media occurred for the sampling condition. Sampling was conducted from the roof of a ~12 meter height building. Samples were collected during the period from March 2009 to February 2010. They were collected twice per week (every weekend (Friday), i.e., 12 samples and in any of the weekdays chosen between Saturday through Thursday, i.e., 12 samples) during summer and winter, and once per week during autumn and spring seasons.

Gravimetric and Chemical Analysis

Cellulose nitrate membrane filter was carefully equilibrated in desiccator before and after sampling to eliminate the effect of humidity, which can affect weight. The mass of particulate collected on each filter was determined by the difference in weight before and after sampling, then, particulate concentration was calculated from the volume of air filtered. Field blanks were collected through putting another set of cellulose nitrate membrane filters in the sampling site for the same duration with the same steps without operating the air sampler. After weighing, each filter was extracted by nitric acid (Merk Suprapure 65%) and hydrochloric acid (Merk Suprapure 37%) mixture on a hot plate to estimate the selected elements (Method IO-3.1, 1999). The extracted solution was filtered with washing by double distilled water (Gonzalez *et al.*, 1997). The filtered solution was diluted to 50 mL with Double-distilled water in a volumetric flask and refrigerated in pre-cleaned strong polyethylene bottle until analysis was conducted. Selected elements were determined by an Atomic Absorption Spectrophotometer (Varian 220 Spectr A A). All glassware and plastic vessels were treated by dilute (1:1) nitric acid and rinsed with double distilled water before use. Double-distilled water was used for preparing the stock solutions of target elements and all dilutions. Calibration curves for each target elements were obtained by using suitable standard solutions prepared from the stock solutions. In order to determine the precision of the analytical process, sample from one season was analyzed four times. The relative standard deviation (RSD) for this sample was found to be 2.5%. Laboratory blanks were prepared by adding the same volume of a 1:3 mixture of concentrated hydrochloric and nitric acids to a conical flask containing none of the samples being investigated. This consisted of all components added to the matrix during digestion. Blank samples were analyzed for total element concentrations. Field and laboratory blanks were used to evaluate external elemental contamination introduced by sample handling and analytical procedures.

Meteorological Parameters

The temperature and relative humidity during every sampling were measured using a Sigma-II thermohygrograph (no. 7210), SK Sato Keiryoki MFG-Co., Ltd., Japan. Wind speed and direction, and solar radiation data were obtained from Egyptian Meteorological Organization.

Statistical Analysis

Data were analyzed using SPSS version 17 (SPSS, Chicago, Illinois, USA). The mean and standard deviation were used as summary statistics. Pearson correlation coefficient was used to test the correlation between two variables (Norman and Steriner, 2000).

RESULTS AND DISCUSSION

The average aerosols concentrations (± SD) on seasonal basis are shown in Table 1. The maximum levels were found in winter and the low levels in summer and spring seasons. This is consistent with the results reported by Cong *et al.* (2011) and Kulshrestha *et al.* (2009). The lowest average aerosols concentration in the present study was recorded in summer, at 250 μg/m^3, and the highest 400 μg/m^3 in winter (Table 1). The winter/summer concentration ratio of aerosols was 1.60. The highest concentration of aerosols in winter may be attributed to lower dispersion rate of pollutants and low level ground based inversions during winter (Shridhar *et al.*, 2010). Increasing mixing layer heights and consequent better dispersion conditions are the probable cause for lower concentrations during summer season (Almeida *et al.*, 2006; Srimuruganandam and Nagendra, 2011) .

In the present study, aerosols mean levels exceeded the WHO primary (80 μg/m^3) and secondary (60 μg/m^3) standards during the four seasons (WHO, 2000). They also exceeded the annual average of the Egyptian Ambient Air Quality Standard (90 μg/m^3, EEAA, 1995). The daily concentrations of aerosols in winter exceeded the Egyptian Ambient Air Quality Standard (230 μg/m^3) for 24-h during 100% of the investigated days. Therefore, from these results, it is assumed that 15 May City is heavily polluted by particulate matter.

Table 1 also shows the summary of mean seasonal variations in elemental levels during the study period. Based on the average concentration, Na, Mg, Ca, K, Al and Fe were the dominant elements; the sum of which was 20330 ng/m^3 in winter, 16655 ng/m^3 in spring, 15275 ng/m^3 in summer and 17940 ng/m^3 in autumn, followed by Mn, Cu, Zn, Ni and Pb; the sum of which was 1173 ng/m^3 in winter, 879 ng/m^3 in spring, 797 ng/m^3 in summer and 990 ng/m^3 in autumn. The minimum concentrations were

Table 1. Seasonal variations in atmospheric aerosols (μg/m^3) and their related elemental contents levels (ng/m^3) during the period of study.

Element	Spring	Summer	Autumn	Winter
SPM	290 ± 75	250 ± 68	330 ± 86	400 ± 95
Na	2300 ± 629	2000 ± 500	2650 ± 650	2880 ± 776
Mg	1500 ± 440	1350 ± 480	1450 ± 420	1600 ± 370
Ca	5200 ± 1320	5000 ± 1500	5400 ± 1380	6200 ± 1400
K	955 ± 290	875 ± 238	990 ± 300	1150 ± 430
Al	3300 ± 799	3050 ± 762	3800 ± 810	4100 ± 920
Fe	3400 ± 782	3000 ± 750	3650 ± 801	4400 ± 980
Mn	153 ± 42	140 ± 37	165 ± 49	204 ± 61
Co	30 ± 8	21 ± 6	26 ± 7	35 ± 10
Cu	55 ± 17	51 ± 14	63 ± 22	84 ± 37
Zn	123 ± 39	115 ± 28	135 ± 45	167 ± 63
Ni	49 ± 15	41 ± 11	57 ± 19	68 ± 23
Cd	31 ± 9	26 ± 6	37 ± 11	43 ± 12
Pb	499 ± 134	450 ± 120	570 ± 185	650 ± 230
Cr	28 ± 8	25 ± 7	35 ± 10	46 ± 13

noted for Co, Cd and Cr; the sum of which was 124 ng/m^3 in winter, 89 ng/m^3 in spring, 72 ng/m^3 in summer and 98 ng/m^3 in autumn. The seasonal relative contribution of the individual element to total element concentrations in aerosol are presented graphically in Fig. 2 .The distribution and relative concentration of the individual measured elements were found to follow the following pattern: Ca (28.67%) > Fe (20.34%) > Al (18.96%) > Na (13.31%) > Mg (7.40%) > K (5.32%) > Pb (3.00%) > Mn (0.94%) > Zn (0.77%) > Cu (0.39%) > Ni (0.31%) > > Cr (0.21%) > Cd (0.20%) > and Co (0.16%) in winter, Ca (29.51%) > Fe (19.29%) > Al (18.73%) > Na (13.05%) > Mg (8.51%) > K (5.42%) > Pb (2.83%) > Mn (0.87%) > Zn (0.70%) > Cu (0.31%) > Ni (0.28%) > Cd(0.18%) > Co (0.17%) and Cr (0.16%) in spring, Ca (30.97%) > Al (18.89%) > Fe (18.58%) > Na (12.39%) > Mg (8.36%) > K (5.42%) > Pb (2.79%) > Mn (0.87%) > Zn (0.71%) > Cu (0.32%) > Ni (0.25%) > Cd (0.16%) > Cr (0.15%) > and Co (0.13%) in summer. However in autumn, the distribution patterns were Ca (28.38%) > Al (19.97%) > Fe (19.18%) > Na (13.93%) > Mg (7.62%) > K (5.20%) > Pb (3.00%) > Mn (0.87%) > Zn (0.71%) > Cu (0.33%) > Ni (0.30%) > Cd (0.19%) > Cr (0.18%) and Co (0.14%). These results indicate that crustal elements were the most abundant constituents in aresols of the study area. This is because of re-suspension of road dust and wearproducts of Asphalt pavement (Lindgren, 1996). Soil dust is a source for Na and K (Rahn, 1999). Mn, Ni and Cr in aerosol mass reflect the bulk matrix of road dust. The presence of Zn, Cu , Mn, Fe, Co, Ni, Cd, and Pb in aerosols mass can be linked emissions from brake and tire wear (Legret and Pagotto, 1999; Adachi and Tainosho, 2004). Ca and Mg come from combustion of motor oil additives and Fe and Cr are linked to emissions from the brake lining materials (Garg *et al.*, 2000), automobile rusts (Hopke *et al.*, 1980) and motor car exhausts (Weber *et al.*, 2000). Another emission source of Mn and Ni are automobile exhaust fitted with catalytic convertor (Young *et al.*, 2002). Pb also comes from fuel and motor oil combustion and re-suspension road dust (Young *et al.*, 2002; Tüzen, 2003).

The highest average levels of Ca, Mg, Na, K, Al, Fe, Mn, Co, Cu, Zn, Ni, Cd, Pb and Cr were recorded during winter, whereas the lowest levels were found in summer (Table 1). The sum of element concentrations were 21627, 17623, 16144 and 19028 ng/m^3 in winter, spring, summer and autumn, respectively, representing 5.41%, 6.07%, 6.46% and 5.77% from aerosols mass during the corresponding seasons, respectively. The winter/summer concentration ratios were 1.44, 1.18, 1.24, 1.31, 1.34, 1.47, 1.46, 1.67, 1.65, 1.45, 1.66, 1.65, 1.44 and 1.84 for Na, Mg, Ca, K, Al, Fe, Mn, Co, Cu, Zn, Ni, Cd, Pb and Cr, respectively. These results agree with Srimuruganandam and Nagendra (2012) who found that the average elemental concentrations in particulate matter were found to be higher in winter season followed by monsoon and summer seasons.

The correlation coefficients matrix between aerosols mass and their elements content during the period of study are presented in Table 2. Statistically significant correlation coefficients ($p < 0.001$) are highlighted in bold. Significant correlations between different pairs were found, some of which were common in the four seasons. Significant positive correlations were found between the concentrations of aerosols, Mg, Ca, K, Al, Fe, Mn, Co, Zn and Cr. This may be attributed to the natural input of trace element and aerosols in the local atmosphere, as most of these metals are well known for their crustal abundance (Hien *et al.*, 2001; Loyola *et al.*, 2006).

The average concentrations of atmospheric aerosols and their related airborne elements in the present study in comparison with those reported from other regions around the world are shown in Table 3. From this table, it can be concluded that, the mean values of atmospheric aerosols and their related element in the atmosphere of the study area were lower/higher or similar to those detected in other cities of the world. Generally, this variations among the different locations of the world was presumably due to the difference in the traffic density, industrial activities, and intensity of human activities, land use patterns and the frequency of rainfall prior to sample collection.

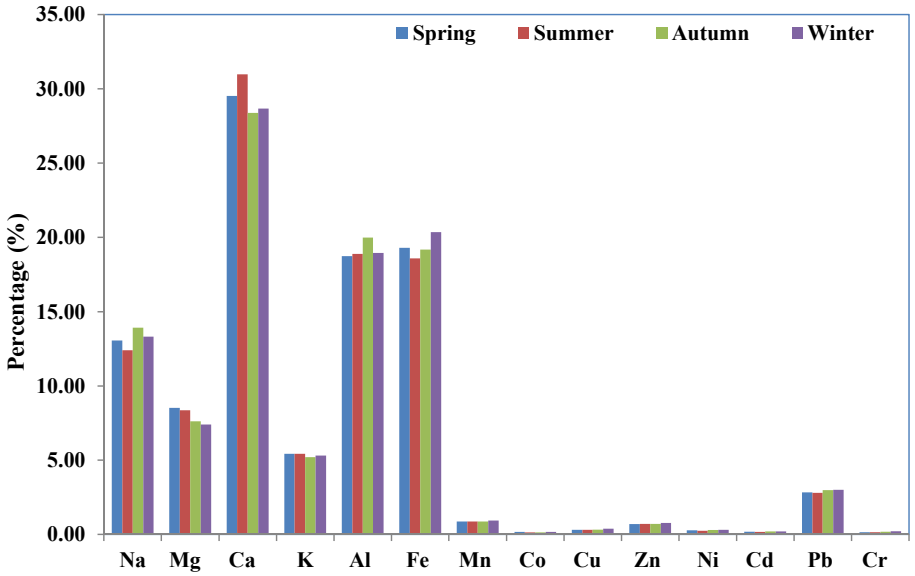

Fig. 2. Seasonal variations of the contribution of each element to total elements mass concentrations of the atmospheric aerosols.

Table 2. Correlation coefficients[a] between the element concentrations in the atmospheric aerosols of 15 May City during the period of study.

	SPM	Na	Mg	Ca	K	Al	Fe	Mn	Co	Cu	Zn	Ni	Cd	Pb	Cr
Na	0.35	1													
Mg	**0.89**	0.41	1												
Ca	**0.85**	0.45	**0.79**	1											
K	**0.81**	0.35	**0.75**	**0.80**	1										
Al	**0.91**	0.44	**0.90**	**0.76**	**0.84**	1									
Fe	**0.90**	0.48	**0.89**	**0.78**	**0.86**	**0.85**	1								
Mn	**0.92**	0.38	**0.88**	**0.87**	**0.88**	**0.88**	**0.94**	1							
Co	**0.73**	0.39	**0.72**	**0.65**	**0.70**	**0.86**	**0.80**	**0.79**	1						
Cu	0.20	0.25	0.25	0.20	0.19	0.18	0.21	0.20	0.18	1					
Zn	**0.62**	0.38	**0.65**	**0.54**	**0.53**	**0.55**	**0.52**	**0.53**	**0.52**	0.15	1				
Ni	0.19	0.18	0.19	0.25	0.15	0.18	0.19	0.21	0.18	0.16	0.19	1			
Cd	0.41	0.20	0.35	0.43	0.39	0.43	0.42	0.44	0.45	0.21	0.25	0.24	1		
Pb	0.39	0.33	0.38	0.32	0.30	0.45	**0.53**	0.36	0.48	0.25	0.37	0.30	0.33	1	
Cr	**0.78**	0.32	**0.74**	**0.71**	**0.75**	**0.77**	**0.76**	**0.83**	**0.82**	0.26	**0.54**	0.18	0.45	0.25	1

[a] Significant ($p < 0.001$).

The average element concentrations in the atmospheric aerosols of the 15 May City can be compared with the safe limits proposed by international agencies. WHO and USEPA standards for atmospheric Pb, Mn, Cr, Ni and Cd are 500, 150, 1100, 0.38 and 5 ng/m^3, and 1500, 500, 100, 0.24 and 6 ng/m^3, respectively (WHO, 2000; ATSDR, 2002). In the present study, the average concentrations of Cr were lower than the WHO and USEPA standards. However, Ni and Cd levels were many times higher than the proposed WHO and USEPA standards. Likewise, average concentrations of Cd and Ni were also higher than those recommended by the European Community (EC, 2000). Similarly, the mean concentration of Cd in the atmosphere of 15 May City was much higher than the safe limit range of the metal (0.24–0.55 ng/m^3) for cancer (EC, 2000). The mean concentrations of Pb and Mn were lower than the USEPA standard and relatively higher than the WHO standard in winter and autumn seasons.

Enrichment factors (EFs) can give an insight into differentiating an anthropogenic source from a natural origin, and hence, can also assist in the determination of the degree of contamination (Yongming *et al.*, 2006). To obtain preliminary information about the sources of elements in the aerosols of the study area, the enrichment factors (EFs) for each element were calculated. The enrichment factor for a generic element X with respect to a reference crustal element Y is defined as EFX = (X/Y)air/(X/Y)crust, where the ratio (X/Y) is the concentration ratio of X and Y in either aerosol sample or earth crust. In the present study, Al was used as the reference element Y, and the earth crust chemical composition was taken from Taylor (1964) and Taylor and McLennan (1985). Our calculation of EFs was

Table 3. Comparison of average aerosols (μg/m^3) and their elemental levels (ng/m^3) in the atmosphere of the study area with the counterpart data reported from other regions around the world.

		SPM	Ca	Na	Fe	K	Zn	Mg	Cu	Pb	Mn	Co	Ni	Cr	Cd	Reference
15 May Ciry, Cairo	Summer	250	5000	2000	3000	875	115	1350	51	450	140	21	41	25	20	Present study
	Autumn	330	5400	2650	3650	990	135	1450	63	570	165	26	57	35	37	
	Winter	400	6200	2880	4400	1150	167	1600	84	650	204	35	68	46	48	
	Spring	290	5200	2300	3400	955	123	1500	55	499	153	30	49	28	31	
Islamabad, Pakistan	Summer	148	3984	2860	2482	1480	1255	1012	159	68	71	41	27	16	3	Shah and Shaheen (2010)
	Autumn	198	7611	3815	3705	2582	2032	1360	174	118	81	38	26	34	6	
	Winter	138	6184	5473	1493	2986	1108	927	254	124	48	18	22	29	6	
	Spring	190	6650	3402	2559	1784	1145	1442	149	122	107	16	31	32	5	
Qingdao, China	Summer	-	-	-	1541	-	204	-	14.2	63.9	44.4	-	6.3	-	1.3	Hao *et al.* (2007)
	Autumn	-	-	-	2997	-	200	-	25	166	72	-	10.1	-	1.7	
	Winter	-	-	-	3788	-	452	-	38.2	315	134	-	8.6	-	5.1	
	Spring	-	-	-	2880	-	205	-	27.2	101	65.8	-	8.1	-	3.2	
Izmir, Turkey	Summer	-	4268	1144	949	384	285	314	36.6	115	31.8	-	14.5	26.9	1.5	Yatkin and Bayram (2007)
	Autumn	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
	Winter	-	4346	904	874	694	294	228	58	184	24.8	-	18.1	25.5	1.6	
	Spring	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Al-Hashimya, Jordan	Summer	-	17612	1237	1351	529	215	1409	7.74	81.8	52.3	11.7	11.5	14.2	4.71	Al-Momani *et al.* (2005)
	Autumn	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
	Winter	-	16969	602	1896	484	209	1306	13.5	97.1	48.3	10.3	6.49	4.1	2.89	
	Spring	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Chillan, Chile	Summer	-	3650	-	4750	510	230	410	240	10	30	-	20	-	-	Celis *et al.* (2004)
	Autumn	-	420	-	950	4210	380	260	150	30	40	-	10	-	-	
	Winter	-	230	-	290	1980	510	120	110	30	80	-	10	-	-	
	Spring	-	2140	-	2450	980	80	370	220	10	20	-	10	-	-	
Erdemli, Turkey	Summer	-	-	-	568	-	20.8	-	11.1	27.6	12	-	-	5.7	0.2	Kocak *et al.* (2004)
	Autumn	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
	Winter	-	-	-	377	-	17.6	-	8.8	30.3	7.6	-	-	4.2	0.2	
	Spring	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Won Ju City, Korea	Summer	-	-	-	1820	-	-	-	551	76.2	33.9	-	14.3	10.7	1.3	Kim (2003)
	Autumn	-	-	-	1866	-	-	-	508	166	35.7	-	10.7	7.1	2.2	
	Winter	-	-	-	2240	-	-	-	448	211	60.8	-	33.3	5.1	4.2	
	Spring	-	-	-	1957	-	-	-	374	149	48.7	-	14.5	11.1	1.6	
Madrid, Spain	Summer	-	834	-	666	226	54	325	60.2	124	19	-	26.8	14.3	-	Roman *et al.* (2003)
	Autumn	-	1445	-	917	200	114	313	104	203	24.6	-	29.8	17.4	-	
	Winter	-	1434	-	1367	204	383	482	1	196	30.8	-	31.7	25.7	-	
	Spring	-	590	-	1056	210	-	424	35	120	23.4	-	28.1	9.8	-	
Bursa, Turkey	Summer	-	10800	11400	41400	8510	311	15800	805	53	992	-	32	92	1.8	Samura *et al.* (2003)
	Autumn	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
	Winter	-	12800	904	3390	613	251	1330	109	80	66	-	128	78	5.3	
	Spring	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Shiraz, Iran	Summer	-	15305	-	3252	-	72	-	-	410	65	-	-	15	-	Hadad *et al.* (2003)
	Autumn	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
	Winter	-	11274	-	1891	-	100	-	-	669	38	-	-	15	-	
	Spring	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Lodz City, Poland	Summer	-	1200	-	353	-	28.3	-	-	34.8	7.24	0.18	10.4	4.32	-	Bem *et al.* (2003)
	Autumn	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
	Winter	-	481	-	677	-	71.7	-	-	41.2	16.7	0.31	0.59	4.11	3.52	
	Spring	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Taejon City, Korea	Summer	-	-	-	1024	-	129	-	31.6	204	25.3	0.99	33.6	13.2	4.19	Kim *et al.* (2002)
	Autumn	-	-	-	1626	-	273	-	47.8	262	61.1	1.54	37.2	35.9	2.68	
	Winter	-	-	-	1782	-	298	-	56.6	251	75.9	1.46	42.6	30.8	3.39	
	Spring	-	-	-	2171	-	208	-	33.2	251	55.7	2.02	39.7	18.3	2.78	
Cartagena, Spain	Summer	97.5	-	-	-	-	1470	-	40	240	-	-	-	-	5.85	Grau *et al.* (2000)
	Autumn	84.3	-	-	-	-	1470	-	30	220	-	-	-	-	4.6	
	Winter	86.8	-	-	-	-	1690	-	30	300	-	-	-	-	6.05	
	Spring	85	-	-	-	-	1530	-	30	260	-	-	-	-	5.44	

done assuming that contributions of man-made sources to Al are insignificant in the study area. The use of average crust values provides meaningful comparison to many other studies that commonly use this technique. The average local soil profiles are not available and will be investigated in the follow up study. The mean EF values of the elements measured in aerosols are summarized in Fig. 3. Since trace element EFs include some degree of uncertainty related to the natural variations of the earth crust composition, only elements with EFs greater than 5 can be regarded as enriched in atmospheric aerosols and associated with sources other than the local soil (Hien *et al.*, 2001). Generally, EFs close to unity point to a crustal origin while those greater than 10 are considered to have a predominantly non-crustal source. In aerosols samples from the study area, EF values lower than 5 were found for Na, Mg, Ca, K, Fe and Mn during the four seasons. The similarities between EF values in different seasons suggest that the main sources of these elements are of a crustal type (e.g., soil and re-suspended dust), while anthropogenic sources have a lesser contribution (Hien *et al.*, 2001; Hao *et al.*, 2007). The moderately higher EFs for Na, Mn and Ca than Mg, K, and Fe denote that part of Na, Mn and Ca are derived from anthropogenic sources and human activities such as construction, wind-blown road dust, cement factories and building material manufacturing facilities. The EFs of Cr is relatively higher than the aforementioned elements which means that anthropogenic sources have a somewhat higher contribution to this element (Hao *et al.*, 2007). The atmospheric aerosols in the study area were found to be extremely enriched by Co, Cu, Zn, Ni, Cd, Pb and Cr during the different seasons. The high EF values for these elements indicate that they are present in atmospheric aerosols in concentrations too high to be explained in terms of normal crustal weathering processes. Consequently, these elements are immensely originating from the anthropogenic sources (Loyola *et al.*, 2006; Yongming *et al.*, 2006). In urban environments, the anthropogenic sources of the majority of the enriched elements are the emissions of combustion from mobile sources (vehicle-exhaust emissions) and industrial activities (Lough *et al.*, 2005; Birmili *et al.*, 2006).

The fraction of elements coming from non-crustal sources [$(C_x)^*$] can be calculated by the following formula (Mason, 1966):

$$(C_x)^* = \{(C_x)_{air} - (C_{Al})air.(C_x/C_{Al})_{crust}\}/(Cx)_{air} \quad (1)$$

where:

$(C_x)_{air}$: the concentration of an element x in the air

$(C_{Al})_{air}$: the concentration of Al in the air

$(Cx)_{crust}$: the concentration of an element x in the crust

$(C_{Al})_{crust}$: the concentration of Al in the crust.

The percentage of crustal and non-crustal fractions of the detected elements during the four seasons are shown in Table 4. According to the results, a substantial part of Na, Mg, Ca, K, Fe and Mn entered to the air from the Earth' crust, while Co, Cu, Zn, Ni,Cd, Pb and Cr are mostly emitted by anthropogenic sources in all seasons.

Weekday and weekend aerosols mass concentrations and their related elements concentrations are shown in Table 5. The average aerosols concentrations were higher during weekdays than weekends in the summer and winter seasons. The aerosols averaged 400 and 250 μg/m^3 on weekdays and 275 and 212 μg/m^3 on weekends, during the winter and summer seasons, respectively. The weekdays/weekends aerosols concentration ratios were 1.45 on winter and 1.18 on summer. The aerosols concentrations on the weekends compared with weekdays were reduced by 31.25% in winter and 15.2% in summer. This reduction could be attributed to the decrease of traffic density due to the official days-off of government institutions, schools and colleges. The effect of decreasing traffic density during weekends did not only cause low exhaust particulate emission, but also reduce emissions generated from tyre wears and re-suspension of street dust. In addition, the reduced emissions of nitrogen oxides (NO_x) from the traffic sources on weekends lead to a decrease in the formation of secondary aerosol. This is consistent with the observations of other investigators who have attributed the decrease in aerosols concentration on weekend days to the decrease in traffic density (Latha and

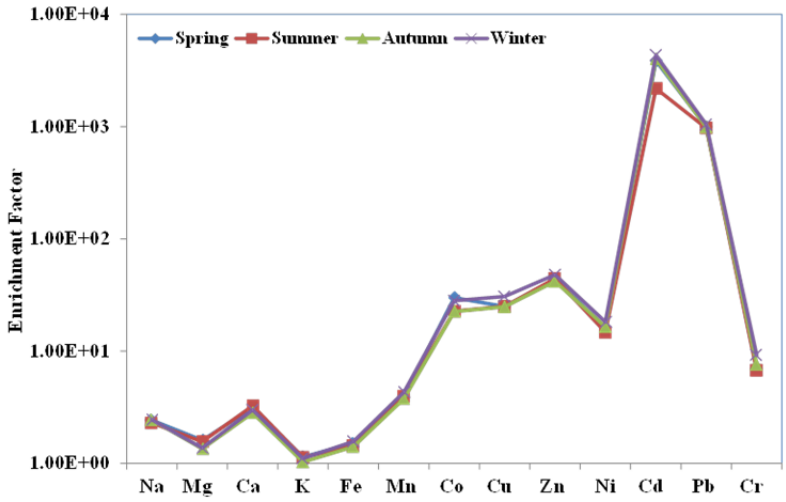

Fig. 3. Seasonal variations of the enrichment factors of atmospheric elements.

Table 4. Crustal and non-crustal fractions (%) in atmospheric aerosols of the study area during the four seasons.

Element	Spring		Summer		Autumn		Winter	
	Crustal	Non-crustal	Crustal	Non-crustal	Crustal	Non-crustal	Crustal	Non-crustal
Na	41.14	58.86	43.73	56.27	41.12	58.88	40.82	59.18
Mg	62.28	37.72	63.96	36.04	74.19	25.81	72.55	27.45
Ca	32.00	68.00	30.76	69.24	35.48	64.52	33.35	66.65
K	87.75	12.25	88.52	11.48	97.48	2.52	90.54	9.46
Fe	66.40	33.60	69.55	30.45	71.22	28.78	63.74	36.26
Mn	24.90	75.10	25.15	74.85	26.58	73.42	23.20	76.80
Co	3.34	96.66	4.41	95.59	4.44	95.56	3.56	96.44
Cu	4.01	95.99	4.00	96.00	4.03	95.97	3.26	96.74
Zn	2.28	97.72	2.26	97.74	2.39	97.61	2.09	97.91
Ni	6.14	93.86	6.78	93.22	6.08	93.92	5.49	94.51
Cd	0.03	99.97	0.04	99.96	0.02	99.98	0.02	99.98
Pb	0.10	99.90	0.10	99.90	0.10	99.90	0.10	99.90
Cr	14.32	85.68	14.82	85.18	13.19	86.81	10.83	89.17

Table 5. Weekday and weekend mass concentrations ($\mu g/m^3$) of aerosols and their related elemental contents levels (ng/m^3) during the summer and winter seasons.

Element	Summer		Winter	
	Weekday	Weekend	Weekday	Weekend
SPM	250 ± 68	212 ± 48	400 ± 95	275 ± 52
Na	2000 ± 500	1563 ± 353	2880 ± 776	1946 ± 333
Mg	1350 ± 480	993 ± 264	1600 ± 480	1013 ± 165
Ca	5000 ± 1500	3704 ± 1020	6200 ± 1500	3690 ± 555
K	875 ± 238	700 ± 172	1150 ± 430	742 ± 120
Al	3050 ± 762	1883 ± 470	4100 ± 920	1952 ± 300
Fe	3000 ± 750	2174 ± 475	4400 ± 980	2604 ± 450
Mn	140 ± 37	100 ± 30	204 ± 61	120 ± 25
Co	21 ± 6	17 ± 5	35 ± 10	25 ± 5
Cu	51 ± 14	41 ± 12	84 ± 37	62 ± 12
Zn	115 ± 28	72 ± 18	167 ± 63	93 ± 16
Ni	41 ± 11	33 ± 9	68 ± 23	48 ± 9
Cd	26 ± 6	20 ± 5	43 ± 12	30 ± 8
Pb	450 ± 120	360 ± 95	650 ± 230	464 ± 69
Cr	25 ± 7	20 ± 6	46 ± 13	33 ± 7

Highwood, 2006; Karar *et al.*, 2006; Lonati *et al.*, 2006; Lough *et al.*, 2006). In the present study, although the aerosols mean concentrations were lower on weekend days than working days compared with other urban areas, the higher aerosols levels on weekends indicate that the emissions were not only derived from local source but a part of them are transported from other sources around the study area.

In the present study, the average concentrations of the elements in aerosols were higher during weekdays than weekends (Table 5). The weekday/weekend concentration ratios were 1.48 and 1.28 for Na, 1.58 and 1.36 for Mg, 1.68 and 1.35 for Ca, 1.55 and 1.25 for K, 2.10 and 1.62 for Al, 1.69 and 1.40 for Fe, 1.70 and 1.40 for Mn, 1.40 and 1.26 for Co, 1.35 and 1.23 for Cu, 1.80 and 1.60 for Zn, 1.40 and 1.24 for Ni, 1.41 and 1.33 for Cd, 1.40 and 1.25 for Pb, 1.39 and 1.22 for Cr, and 1.69 and 1.38 for total measured elements during the winter and summer, respectively. The higher concentrations of the measured elements on weekdays may be attributed to the higher weekday aerosols concentrations. The higher concentrations of crustal-mineral components on weekdays than weekends resulted from the influence of local and regional anthropogenic activities on the generation of crustal-mineral dust, such as re-suspension of street dust by traffic and different anthropogenic activities, such as industrial processes and building construction. The effect is especially noted during winter season, because of colder and wetter weather conditions, natural emissions of dust by the action of the wind over bare ground are at a minimum. Anthropogenic activities, such as industrial processes and building construction are possible causes for increase the crustal species on weekdays, but the most probable source of anthropogenically emitted dust is re-suspension of road dust by road traffic. The latter is an efficient emission process for dust, because the intense road traffic rapidly dries road ground, even in winter and colder weather conditions (Almeida *et al.*, 2006). This is also confirmed by higher levels of Zn at the same periods, which originates from motor oil and tire wear (Sternbeck *et al.*, 2002).

CONCLUSIONS

Seasonal distributions, weekdays/weekends differences in ambient aerosols and their elemental contents in the atmosphere of the 15 May City, Egypt during the period from March 2009 to February 2010 have been discussed in this work. The lowest average aerosols level (250 μg/m^3) was found in summer, whereas the highest average (400 μg/m^3) was detected in winter. The average aerosols concentrations exceeded the WHO and annual average of the Egyptian Ambient Air Quality Standard, indicating that the 15 May City is heavily polluted by particulate matter. The winter/summer concentration ratios were 1.44, 1.18, 1.24, 1.31, 1.34, 1.47, 1.46, 1.67, 1.65, 1.45, 1.66, 1.65, 1.44 and 1.84 for Na, Mg, Ca, K, Al, Fe, Mn, Co, Cu, Zn, Ni, Cd, Pb and Cr, respectively. Na, Mg, Ca, K, Al and Fe were the dominant elements in the atmosphere of 15 May City. The average concentrations of ambient aerosols and their elemental contents were higher during weekdays than on weekends. The weekday/weekend concentration ratios were 1.48 and 1.28 for Na, 1.58 and 1.36 for Mg, 1.68 and 1.35 for Ca, 1.55 and 1.25 for K, 2.10 and 1.62 for Al, 1.69 and 1.40 for Fe, 1.70 and 1.40 for Mn, 1.40 and 1.26 for Co, 1.35 and 1.23 for Cu, 1.80 and 1.60 for Zn, 1.40 and 1.24 for Ni, 1.41 and 1.33 for Cd, 1.40 and 1.25 for Pb, 1.39 and 1.22 for Cr, and 1.69 and 1.38 for total measured elements during the winter and summer, respectively. The mean Ni and Cd levels were higher than the proposed WHO, USEPA and the European Community standards. The correlation coefficients between the elemental concentrations of aerosols, enrichment factors (EFs) and the non-crustal fractions of all elements indicated that Na, Mg, Ca, K, Fe and Mn are mainly from soil sources, whereas Co, Cu, Zn, Ni, Cd, Pb and Cr are mostly emitted in the atmosphere of 15 May City from anthropogenic sources.

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