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Original Research

Characteristics and Risk Assessment of Heavy Metals in Airborne PM_{10} from a Residential Area of Northern Jeddah City, Saudi Arabia

Mansour A. Alghamdi

Department of Environmental Sciences, Faculty of Meteorology, Environment and Arid Land Agriculture, King Abdulaziz University, Jeddah, Saudi Arabia

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Abstract

This study was carried out in order to investigate the seasonal distribution of PM_{10} and its heavy metals contents in the atmosphere of a residential area of northern Jeddah during 2011-12. Potential health risk assessment for heavy metals exposure was assessed. The concentrations of 15 elements, including Al, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ga, As, Sr, Cd, and Pb in PM_{10} were determined using x-ray fluorescence. The annual average concentration of PM_{10} (65 μg/m^3) was much higher than the WHO standard for PM_{10} (20 μg/m^3). Concerning the frequency distribution of 24-h concentration of PM_{10}, about 29%, 20%, 86%, 71%, and 54% of the mean 24-h concentration of PM_{10} during summer, autumn, winter, spring, and the whole year, respectively, exceeded the WHO air quality standards for maximum 24-h concentration. Dust storm events are the main reason for the highest PM_{10} concentrations in winter and spring. The sum of metal concentrations in PM_{10} was 4,327 ng/m^3, representing 6.66% from particulate mass during the period of study. Fe and Al were the dominant metals, followed by Ti, Mn, Cd, Zn, Sr, V, Cu, Pb, Ni, Co, Cr, As, and Ga. The sum of metal concentrations was found to be higher in winter followed by spring, summer, and autumn. The annual Ni and Cd levels in PM_{10} were higher than the proposed WHO, U.S. EPA, and the European Community standards. The enrichment factors (EFs) values and non-crustal fractions indicate that Cd, As, Pb, Zn, Co, V, and Cu are mainly emitted in the atmosphere of the study area from anthropogenic sources. Based on the average values of As, Cd, Cr, and Ni in PM_{10}, Cd was found to have the highest excess cancer risk. Total ECR resulting from exposure of these carcinogenic metals through inhalation pathways was 108.77. These results indicate that 108.77 people out of 1 million are at risk of developing cancer after exposure to the carcinogenic trace metals in ambient airborne PM_{10} from a residential area of northern Jeddah.

Keywords: PM_{10}, heavy metals, enrichment factor, risk assessment, Jeddah

*e-mail: mghamdi2@kau.edu.sa

Introduction

Airborne particulate matter represents the most important ambient air pollutant group, since it plays a major role in acidification of precipitation, earth's radiation balance, climatic change, human health, agricultural, ecosystems, material, and cultural heritage [1-10]. It can also cause coughing, wheezing, shortness of breath, acute respiratory infections, chronic respiratory, aggravated asthma, lung damage, and cancer and cardiovascular diseases, leading to increased mortality [11-16]. PM_{10} (particulate matter ≤ 10 μm in aerodynamic diameter) is of particular concern to human health as it is in the inhalable size range**.**

The impact of particulate matter may not only be due to its mass levels, but also to its chemical composition [17]. Among chemical species of particulate matter, trace metals have gained special concern. Some metals of particulate matter are harmless at low concentrations, whereas others are toxic and initiators or promoters of many diseases and cancer at even extremely low concentrations [18-27]. Increased metals concentrations in airborne particulate may have a serious impact on respiratory disease, lung cancer, heart disease, and damage to other organs [23, 25, 28]. Hence with rapid urbanization, population growth, and accelerated development of the social economy, it becomes important to know the characterization, sources, and risk assessment of heavy metals in airborne PM_{10}.

Airborne particulate matter represents a complex mixture of chemicals directly released from natural and anthropogenic sources, or formed from gases into secondary aerosols via chemical reactions [29-31]. Their chemical and physical characteristics can vary depending on their emission sources and the subsequent chemical reactions that take place in the atmosphere [32, 33]. Regarding chemical composition, heavy metals are considered to be the most important group. Their sources in ambient air are natural emissions, traffic emissions, incineration, industrial emissions, and industrial metallurgical processes [34-38]. Vehicle exhausts, industrial processes, coal combustion, and oil burning are the major sources of Cr, Pb, Cu, Zn, Cd, Sb, Br, Fe, Ba, Mn, K, Ni, and V [24, 39-41]. Zn is emitted from tire wear [42], and Cu from abrasion of asbestos-free brake linings [43, 44]. Metals of anthropogenic origin are mainly distributed in fine particles [45, 46], whereas metals from natural sources are usually found in coarse particles [47].

Monitoring of atmospheric airborne particulate matter levels alone may be insufficient for identification of specific pollution sources and their respective impacts on air quality and health. Thus knowledge of the chemical composition of particulate matter can be used to evaluate the impacts of the various pollution sources on air quality. To achieve the abatement of particulate matter pollution it is also necessary to identify their pollution sources for which control measures may be possible. In recent years, dramatic economic rise, rapid industrial development, population growth, construction and demolition projects, and the critical increase in traffic flow in Jeddah city have affected the atmospheric environment, especially to contamination of atmospheric particulate matter and their metallic composition. There is a lack of information on the seasonal behavior of PM_{10} and its heavy metals characterization and their risk assessment, especially in the residential area of Jeddah. Therefore, the aim of the present study is to:

1. Investigate the seasonal variations of PM_{10}.
2. Study the distribution and levels of atmospheric heavy metals in PM_{10}.
3. Evaluate the contribution of anthropogenic sources on the levels of these metals.
4. Evaluate the potential health risk for residents.

Materials and Methods

Study Area

Jeddah is located on the Red Sea coast in the western part of Saudi Arabia and is surrounded by mountains on the northeastern, eastern, and southeastern sides. It is considered the most significant commercial centre as well as the crossroads between East and West to Asia, Africa, and Europe, with more than 3.4 million inhabitants. Unfortunately, due to lack of awareness and proper regulations, rapid growth and industrialization of the city over the past 30 years has led to an increase in the rate of air quality deterioration, raising concerns about the potential health implications of increased air pollution levels. Like almost everywhere else in the world, Jeddah's environment and its population's health are affected by both mobile and stationary sources. The mobile source is traffic, with more than 1.40 million vehicles fueled mainly by unleaded gasoline and diesel. The main stationary sources in Jeddah include an oil refinery, a major seaport, a desalination plant, a power generation plant, and several manufacturing industries. The general climate of Jeddah is warm and humid or moderate in winter, whereas it is characterized by high temperature, humidity, and solar radiation in summer. Rainfall is generally sparse. During the period of the present study, the daily temperature ranged from 21 to 35ºC (with an average of 28ºC) in spring, 29 to 37ºC (with an average of 32.6ºC) in summer, 21 to 35ºC (with an average of 29.1ºC) in autumn, and 19 to 28ºC (with an average of 24.5ºC) in winter. The daily relative humidity ranged from 17 to 73% (with a mean value of 52.9%) during spring, 28 to 71% (with a mean value of 52%) during summer, 38 to 77% (with a mean value of 58.7%) during autumn, and 32 to 79% (with a mean value of 58.5%) during winter.

Sample Collection and Analysis

The sampling site was located in northern Jeddah, Al Basateen district (Fig. 1). Most air pollutant emissions, which are major contributors of airborne particulate matter and its metallic composition near the measurement site, arise from traffic activities. Sampling was carried out at a

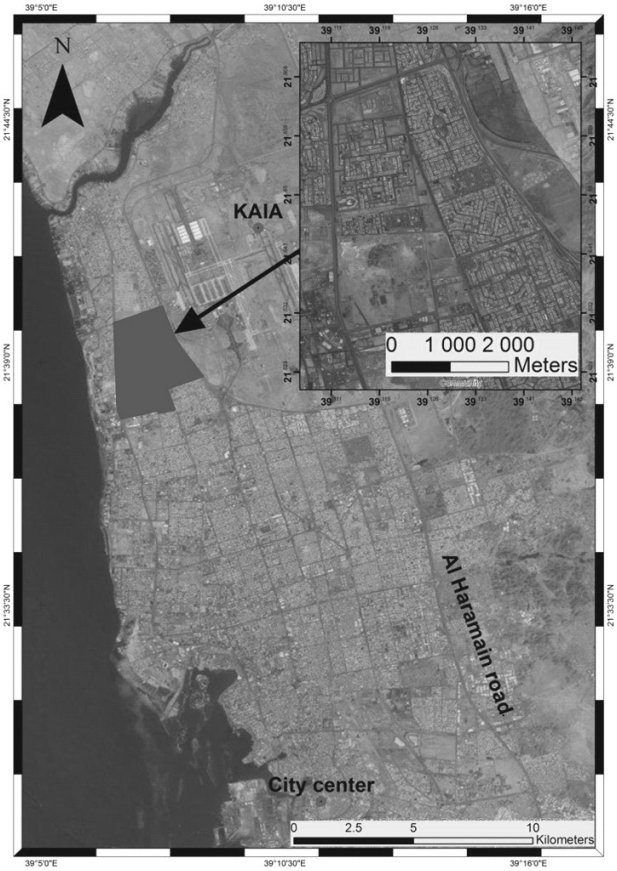

Fig. 1. Jeddah map with sampling site.

height of 9 m above ground level. A PM_{10} sampler with a calibrated vacuum pump to draw air at rate of 10 L/ min was used to collect the particulate samples. Daily 24-hr samples were collected on Teflon filters (Gelman Teflo, 37 mm, 0.2 μm pore-size) from midnight to midnight. The flow rate of the vacuum pump was calibrated before and after each sampling session. Samples were collected from summer 2011 to summer 2012. Filter masses were measured on a microbalance. Samples were then analyzed for 15 heavy metals by nondestructive XRF. Concentrations of heavy metals above detection limits were defined as 3 times the uncertainty of the measurements (3σ).

Enrichment Factor Calculation

Enrichment factors (EFs) can give insight into preliminary information about the contributions of non-crustal sources of heavy metals in the airborne particulate matter of the study area. So the enrichment factor (EF) for each metal in atmospheric PM_{10} of the study area was calculated. The enrichment factor for a generic element X with respect to a reference crustal element Y is defined as $EF_X = (X/Y)_{air}/(X/Y)_{crust}$, where the ratio (X/Y) is the concentration ratio of X and Y in either airborne particulate matter 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 [48] and Taylor and McLennan [49]. EF calculation was done assuming that contributions of synthetic 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 fraction of heavy metals in airborne particulate matter of the study area coming from non-crustal sources [$(C_x)^*$] were also calculated by the following formula [50]:

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

…where $(C_x)_{air}$ is the concentration of an element x in the air, $(C_{Al})_{air}$ is the concentration of Al in the air, $(Cx)_{crust}$ is the concentration of an element x in the crust, and $(C_{Al})_{crust}$ is the concentration of Al in the crust.

Determining Excess Cancer Risk

For the health risk assessment, excess cancer risks (ECRs) for the concentrations of heavy metal in airborne particulate matter (PM_{10}) were calculated by using the equation:

Excess cancer risk (inhalation) = unit risk factor (URF) (μg/m^3) × ambient exposure concentration of pollutant (μg/m^3)

URF is the toxicity value used for carcinogens. It can be used to estimate the increased risk of getting cancer. The required unit risks of the metals in the present study were taken from the risk assessment data performed by the U.S. EPA integrated risk information system (IRIS) [51]. The U.S. EPA [52] has classified Cr(VI) as a Group A carcinogenic metal through inhalation route of exposure. The measured concentration of Cr was assumed to be a mixture of carcinogenic Cr (VI) and non-carcinogenic Cr(III) in 1:6 concentration ratio in ambient air [53]. So the concentration of Cr(VI) in the present study used for carcinogenic risk assessment was calculated as one seventh of the total concentration of measured Cr [53-56]. Although Pb is classified as B2 (a probable human carcinogen), its ECR in the present study was not calculated because its unit risk is currently under amendment by the U.S. EPA due to inadequate human evidence.

Results and Discussion

PM_{10} Mass Concentration

The seasonal variations of PM_{10} concentrations during the period of study are presented in Fig. 2. As shown in this figure, the highest PM_{10} concentrations were found in winter and spring and the lowest values in summer and autumn. The average values were 43, 44, 100, and 67 μg/m^3 in summer, autumn, winter, and spring, respectively. Local pollutant emissions alone in Jeddah cannot explain the highest levels of PM_{10} concentrations appearing in winter and spring seasons, because the city is exposed to many bouts of sand-dust events during the

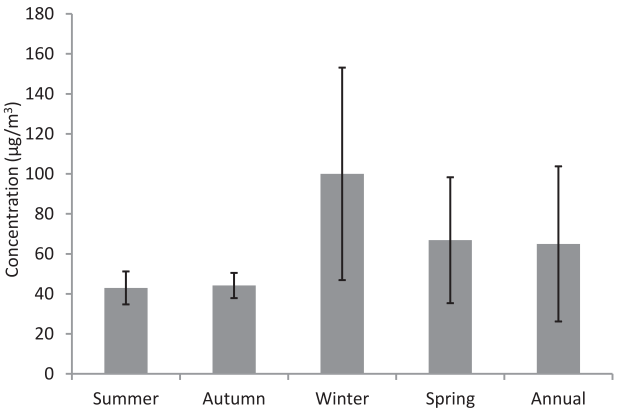

Fig. 2. Seasonal and annual variations of PM_{10} concentrations during the period of study.

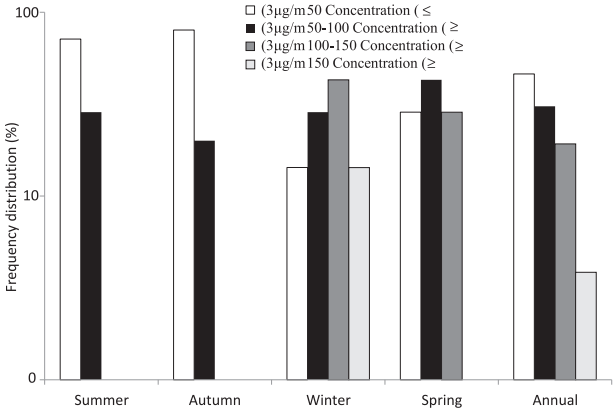

Fig. 4. Frequency percentage distribution of daily PM_{10} concentrations during the period of study.

year (especially during winter and spring seasons), which lead to increasing the levels of dust concentration in the atmosphere. Therefore, a large input of dust from the upstream regions during sand-dust events might be the main reason for the highest PM_{10} concentration in winter and spring in this study. This finding is consistent with those of previous investigators, who found that the seasonal differences in particulate matter are mainly driven by the influence of dust storm events common in the region. Engelbrecht et al. [33] measured air pollution levels in multiple locations, including Djibouti, Afghanistan, Qatar, United Arab Emirates, Iraq, and Kuwait, and found high levels of soil- and dust-related elements. Occurrences of dust events were largely responsible for exceeding PM annual standards. In Saudi Arabia, the seasonal variation of PM_{10} concentrations was found to be mainly related to the dust episode season, with relatively higher concentrations during February-April [57].

Annual PM_{10} levels in the study area were relatively higher when compared with those reported for Barcelona [58], Finokalia [59], Milan [60], and Zonguldak [61]. When compared to Cairo [62], Beirut [63], Cordoba [64], Baoshan [65], Mumbai [66], and Qatar [33], the study area has a lower level of PM_{10} (Fig. 3)

The annual average concentration of PM_{10} in the present study (Fig. 2) was clearly much higher than the

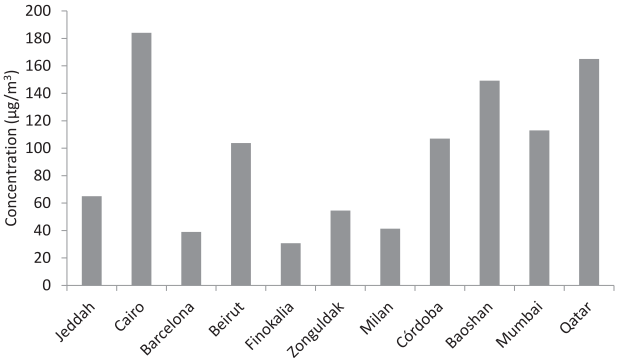

Fig. 3. PM_{10} levels in selected cities.

World Health Organization (WHO) PM_{10} annual average (20 µg/m³) [67]. The frequency percentage distribution of the 24-h average PM_{10} concentrations is graphically presented in Fig. 4. The WHO air quality standard for 24-h PM_{10} is 50 µg/m³. With respect to the frequency distribution of 24-h concentrations of PM_{10}, about 28.6%, 20%, 85.71%, 71.43%, and 54% of the mean 24-h concentrations of PM_{10} during summer, autumn, winter, spring, and the whole year, respectively, (Fig. 4), exceeded the WHO air quality standards for maximum 24-h concentration.

Heavy Metal Concentrations

Table 1 also shows the summary of mean seasonal variations in heavy metal levels during the study period. Based on the average concentration, Al and Fe were the dominant metals; the sum of which were 1,672 ng/m³ in summer, 1,386 ng/m³ in autumn, 6,385 ng/m³ in winter, and 3,702 ng/m³ in spring, followed by Ti, Mn, Cd, Zn, V, Sr, Pb, Ni, and Co – the sum of which were 204 ng/m³ in summer, 205 ng/m³ in autumn, 478 ng/m³ in winter, and 293 ng/m³ in spring. The minimum concentrations were noted for Cu, As, Ga, and Cr; the sum of which were 8.38 ng/m³ in summer, 11.87 ng/m³ in autumn, 22.14 ng/m³ in winter, and 16.87 ng/m³ in spring. The highest average levels of measured heavy metals were recorded during winter (Table 1). The sum of metal concentrations were 1,885, 1,602, 6,945, and 4,012 ng/m³ in summer, autumn, winter, and spring, respectively, representing 4.39%, 3.64%, 6.95%, and 5.99% from PM_{10} mass during the corresponding seasons, respectively. These results agree with those of Srimuruganandam and Nagendra [68], who found that the average elemental concentrations in particulate matter were found to be higher in winter. In the present study, the sum of heavy metals concentrations in PM_{10} was 4,327ng/m³, representing 6.66% from PM10 mass during the period of study. The seasonal relative contribution of the individual element to total element concentrations in PM_{10} are presented graphically in Fig. 5. The distribution

Table 1. Seasonal variations of heavy metal concentrations (ng/m^3) in atmospheric PM_{10} aerosol of the study area during the period of study.

Heavy metal	Summer		Autumn		Winter		Spring	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Al	903	401	717	220	3002	1608	1677	892
Ti	74.32	30.68	62.73	15.46	273.37	154.08	149.13	88.66
V	16.55	9.81	15.88	4.07	21.37	11.81	16.15	3.79
Cr	1.96	0.76	2.03	0.68	6.68	4.48	4.61	2.98
Mn	26	11	25	4	82	42	41	24
Fe	770	211	668	158	3383	2230	2025	1306
Co	5.44	2.48	5.70	1.88	7.93	5.12	2.34	1.15
Ni	5.14	3.03	5.21	1.14	6.82	4.09	4.98	1.63
Cu	3.76	1.40	6.06	2.45	10.26	4.68	8.77	3.47
Zn	15.83	7.19	20.10	3.04	28.63	14.67	17.91	7.50
Ga	1.04	0.79	1.32	0.75	1.82	1.20	0.84	0.32
As	1.62	0.83	2.46	1.84	3.08	4.05	2.56	3.85
Sr	9.71	3.44	10.62	2.91	34.29	25.80	23.64	16.24
Cd	46.04	35.96	49.00	13.67	70.54	52.40	33.69	14.28
Pb	5.14	2.40	10.57	3.41	13.05	4.53	4.76	3.29

and relative concentrations of the individual measured elements were found to follow the following pattern: Al > Fe > Ti > Cd > Mn > V > Zn > Sr > Co > Ni > Pb > Cu > Cr >As, and Ga in summer; Al >Fe > Ti > Cd > Mn > Zn > V > Pb > Sr > Cu > Co > Ni > As > Cr > and Ga in autumn; Fe > Al > Ti > Mn > Cd > Sr > Zn > V > Pb > Cu > Co > Ni > Cr > As, and Ga in winter; and Fe > Al > Ti > Mn > Cd > Sr > Zn > V > Cu > Pb > Ni > Cr > Co > As, and Ga in spring. However, during the period of study the distribution patterns were Fe > Al > Ti > Mn > Cd > Zn > Sr > V > Cu > Pb > Ni > Co > Cr > As, and Ga. These results indicate that Al and Fe, representative of crustal metals in PM10, were the most abundant metals during the period of study. Both elements have a crustal origin, and the association of crustal elements with coarse soil particles was found [61, 69]. However, Mn, Cr, Cu, and Ni metals are normally known to be emitted from mixed sources [70]. Anthropogenic activities are the main sources of Mn, Zn, Pb, and Cr [71]. The presence of Zn, Cu , Mn, Fe, Co, Ni, Cd, and Pb in particulate mass can be linked to emissions from brake and tire wear [72, 73]. Another emission source of Mn and Ni is automobile exhaust fitted with a catalytic convertor [74]. Pb also comes from fuel and motor oil combustion and re-suspension road dust [74, 75]. Although Pb has been banned in petrol for several years in Saudi Arabia, its presence in atmospheric

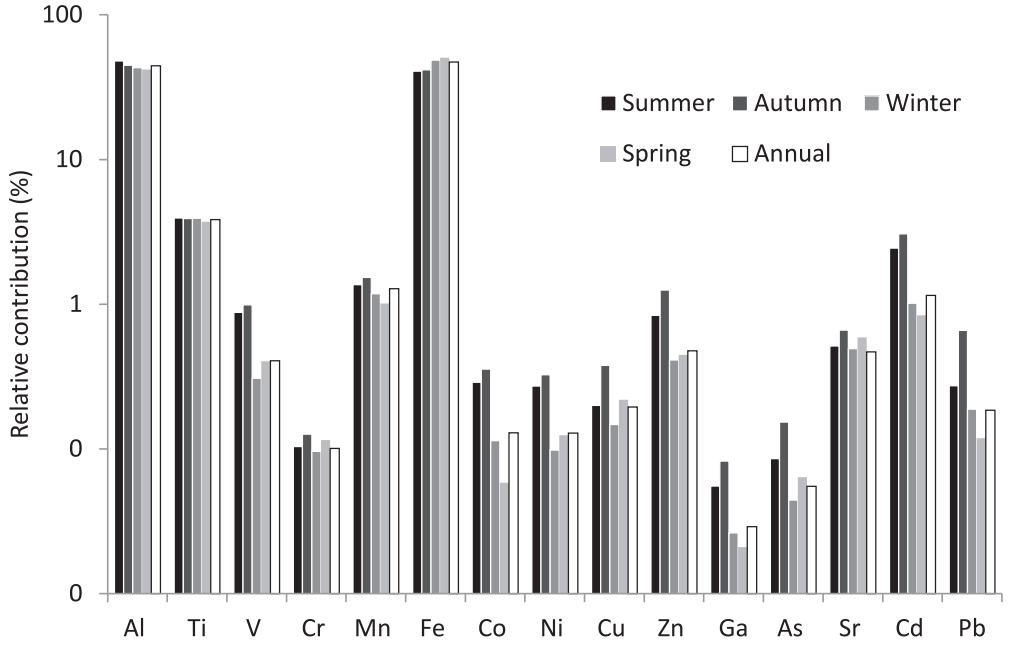

Fig. 5. Seasonal and annual variations of the contribution of each metal to total metal mass concentrations of atmospheric PM_{10}.

Table 2. Correlation coefficients between the measured heavy metal concentrations in the atmospheric PM_{10} of the study area during the period of study.

	Al	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	As	Sr	Cd	Pb
Al	1.00	**0.99**	**0.68**	**0.95**	**0.97**	**0.96**	0.17	**0.67**	**0.75**	**0.74**	0.15	-0.18	**0.90**	0.37	0.45
Ti		1.00	**0.69**	**0.97**	**0.96**	**0.99**	0.11	**0.64**	**0.73**	**0.69**	0.20	-0.18	**0.94**	0.36	0.42
V			1.00	**0.72**	**0.69**	**0.67**	0.16	**0.91**	0.41	**0.70**	0.03	-0.31	**0.68**	0.28	0.36
Cr				1.00	**0.91**	**0.98**	-0.03	**0.65**	**0.73**	**0.67**	0.15	-0.19	**0.95**	0.12	0.36
Mn					1.00	**0.93**	0.25	**0.72**	**0.74**	**0.81**	0.13	-0.19	**0.84**	0.51	0.54
Fe						1.00	-0.02	0.59	**0.71**	**0.62**	0.20	-0.16	**0.96**	0.15	0.35
Co							1.00	0.37	-0.03	0.48	0.07	0.03	-0.06	**0.89**	0.58
Ni								1.00	0.51	**0.85**	-0.15	-0.38	0.55	0.43	0.53
Cu									1.00	**0.70**	-0.02	-0.22	**0.62**	0.24	0.52
Zn										1.00	-0.05	-0.22	0.56	**0.65**	**0.72**
Ga											1.00	0.66	0.25	0.09	0.22
As												1.00	-0.13	0.20	-0.03
Sr													1.00	0.20	0.25
Cd														1.00	0.42
Pb															1.00
[a]Significant ($p < 0.001$)															

particulate of the study area reflects the significant degree of historical Pb contamination and its long half-life. In the present study, the correlation coefficients matrix between the measured heavy metal concentrations in atmospheric PM_{10} during the period of study is presented in Table 2. Statistically significant correlations ($p < 0.001$) are highlighted in bold. Significant positive correlations were found between V, Cr, Mn, Fe, Ni, Cu, and Zn. These correlations indicate that these metals originated from common anthropogenic sources such as motor vehicles and industrial activity [76, 77]. Zn, Ni, Cu, and Cr can be derived from tire and brake wear while Fe can originate from motor exhaust emissions and brake wear [78].

The degree of heavy metal contamination in atmospheric PM_{10} of the study area can be assessed by comparing their measured concentrations with regulatory standards. Such an approach, however, cannot be adopted in this study because standards are not available for the measured metals. An alternative approach would be to compare the heavy metal concentrations in the study area with the safe limits proposed by international agencies. WHO and U.S. EPA standards for atmospheric Pb, Mn, Cr, Ni, and Cd are 500, 150, 1,100, 0.38, and 5 ng/m^3, and 1,500, 500, 100, 0.24, and 6 ng/m^3, respectively [79, 80]. In the present study, the average concentrations of Pb, Cr, and Mn in PM_{10} were lower than the WHO and U.S. EPA standards. However, Ni and Cd levels in PM10 were many times higher than the proposed WHO and U.S. EPA standards. Likewise, the mean concentration of Cd in the atmosphere of Jeddah City was much higher (91 folds) than the safe limit range of the metal (0.24-0.55 ng/m^3) for cancer [81].

The annual average concentrations of atmospheric airborne heavy metals 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 heavy metals in the atmosphere of the study area were in the range of those reported in other cities of the world. The variations among the different locations of the world was presumably due to the difference in the traffic density, industrial activities, intensity of human activities, land use patterns, and the frequency of rainfall prior to sample collection.

Enrichment Factor Analysis

The presence of individual metals in atmospheric particulate matter can be attributed to natural emission, marine sources, and anthropogenic activities. Enrichment

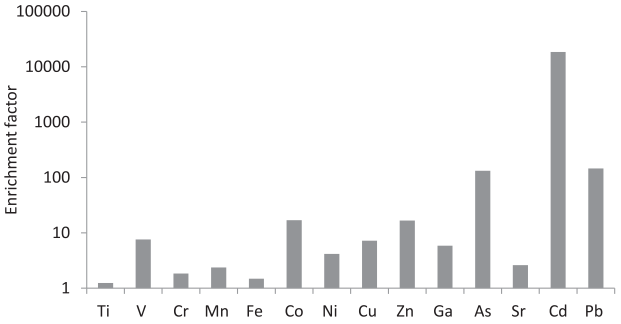

Fig. 6. Enrichment factor of heavy metals in atmospheric PM_{10} of the study area.

Table 3. Comparison of the heavy metal concentrations (ng/m^3) PM^{10} in the present study with those from other areas of the world.

Metal	Present study	Putuo[a]	Hangzhou[b]	Agra[c]	Zonguldak[d]	Córdoba[e]	Shanghai[f]	Beirut[g]	Vienna[h]	Vashi[i]	Lahore[j]	New Taipei[K]	Kolkata[l]	Thessaloniki[m]	Delhi[n]	Istanbul[o]
	Jeddah	China	China	India	Turkey	Argentina	China	Lebanon	Austria	India	Pakistan	Taiwan	India	Greece	India	Turkey
Al	1921.0				589.0	100.0	3115.0		570.0	2100.0	8400.0	542.6				
Ti	166.7				58.0	319.0		150.0	20.0	193.0	560.0	47.9				
V	17.6					17.0			2.1	16.3	21.0	7.8				
Cr	4.4	22.0	36.0	300.0	7.5	8.0	22.0		5.0	70.0	30.0	5.4	101.0	6.6	230.0	4.0
Mn	55.4	92.0	108.0	900.0	20.0	88.0	92.0	30.0	14.0	50.2	300.0	17.5	249.0	30.0	250.0	20.0
Fe	2040.4	2660.0	220.0	2900.0	483.0	3795.0	2660.0	1860.0	740.0	2210.0	8200.0	540.5	11242.0	615.0	11200.0	700.0
Co	5.6					2.0			0.9		3.1	0.6				
Ni	5.6	11.0	11.0	200.0	5.9	6.0	11.0	6.0	9.9	8.3	18.0	8.4	48.0	8.2	370.0	7.0
Cu	8.4	22.0	134.0	40.0	121.0	27.0	22.0	50.0	20.0	25.2	73.0	14.6	107.0	44.0	210.0	20.0
Zn	20.7	303.0	892.0	500.0	84.0	64.0	303.0	80.0	48.0	148.0	11000.0	55.3	761.0	76.0	4100.0	240.0
Ga	1.3									3.7		0.9				
As	2.4								1.2	12.5	22.0	1.2				
Sr	20.3						160.0		2.7	32.0		4.2				
Cd	49.8	2.0					2.0		0.5		77.0	0.4	8.6	13.0	19.0	1.0
Pb	8.0	71.0	288.0	1100.0	19.2	13.0	71.0	80.0	11.0	60.0	4400.0	21.6	394.0	24.0	460.0	70.0

[a] Wang et al.[65]; [b] Bao et al. [82]; [c] Kulshrestha et al. [83]; [d]Tecer et al. [61]; [e]López et al. [64]; [f]Wang et al. [65]; [g]Saliba et al. [63]; [h]Limbeck et al. [84]; [i]Kothai et al. [66]; [j]Von Schneidemesser et al. [85]; [k]Gugamsetty et al. [86]; [l]Das, et al. [87]; [m]Terzi et al. [88]; [n]Khillare and Sarkar [89]; [o]Theodosi et al. [90].

factors (EF) can provide insight into differentiating an anthropogenic source from a natural origin, and hence can also assist in the determination of the degree of contamination [91]. The mean EF values of the heavy metals measured in atmospheric PM_{10} are presented in Fig. 6. Since trace element EFs include some degree of uncertainty due to the natural variations of the earth crust composition, elements with EF values near unity are assumed to have originated from crustal erosion, which is the primary source of elements, and its geochemical cycle has not been altered by emissions from anthropogenic sources. EF values lower than 5 are indicative of crustal importance, whereas EFs greater than 5 can be regarded as enriched in atmospheric particulate and associated with sources other than the local soil [92, 93]. EF values ranging from 10-100 are considered moderately enriched and those with more than 100 are considered highly enriched. In the present study, EF values lower than 5 were found for Ti, Cr, Mn, Fe, Ni, and Sr in PM_{10} during the period of study. This indicates that the main sources of these elements are of a crustal type (e.g., soil and re-suspended dust). V, Co, Cu, Zn, and Ga metals were observed as moderately enriched by anthropogenic sources. Highly enriched metals (As, Pb, and Cd) in the atmospheric PM_{10} of the study area with EF values greater than 100 indicate that they are immensely originating from anthropogenic sources. Mobile sources (vehicle exhaust emissions) and industrial activities are the anthropogenic sources of the majority of the enriched elements in particulate of atmospheric urban environments [40, 94-96].

In the present study, the percentages of crustal and non-crustal fractions of the measured heavy metals in PM_{10} during the period of study are presented in Fig. 7. About 80.2% of Ti, 67.3% of Fe, and 54.1% of Cr in PM_{10} are entered to the air from the Earth's crust. On the other hand, nearly all (100%) of Cd, As, and Pb, 94% of Zn and Co, 86.9% of V, 86.2% of Cu, and 83% of Ga were of anthropogenic origin. Traffic emissions, combustion processes, and construction activities are the most important sources of these metals in particulate matter [94, 97-101].

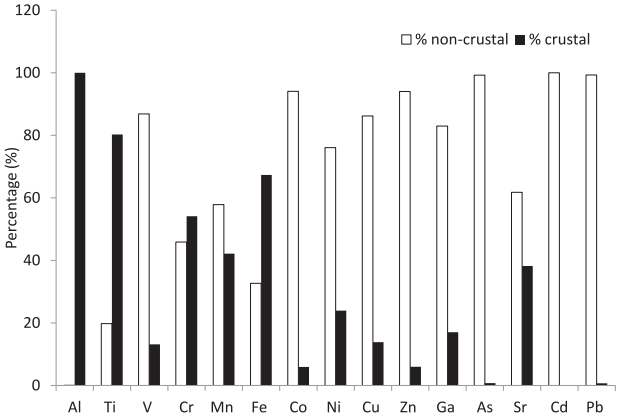

Fig. 7. Crustal and non-crustal fractions (%) of heavy metals in atmospheric PM_{10} of the study area.

Table 4. Excess cancer risk of carcinogenic heavy metals in PM_{10}.

Metal	Ambient average concentration	Inhalation Unit Risk	Excess Cancer Risk (in 1 million)
	($\mu g/m^3$)	($\mu g/m^3$)	Average
Cr(VI)	0.62×10^{-3}	1.2×10^{-2}	7.47
Ni	5.56×10^{-3}	2.4×10^{-4}	1.34
Cd	49.77×10^{-3}	1.8×10^{-3}	89.64
As	2.39×10^{-3}	4.3×10^{-3}	10.32
Total			108.77

Excess Cancer Risk Assessment

As, Cd, Cr, and Ni are the particle bound carcinogenic heavy metals used in literature for excess cancer risk assessment [87, 102, 103]. The calculated ECRs for the average value of PM_{10}-bound carcinogenic metals in the study area are listed in Table 4. The ECR is multiplied by 10^6 for comparison with one in a million standards. Cd (89.64) has the highest ECR followed by As (10.32), Cr (VI) (7.47), and Ni (1.34), respectively. Based on the average values of As, Cd, Cr, and Ni in PM_{10}, total ECR resulting from the exposure of these carcinogenic metals through inhalation pathways was 108.77. This indicates that 108.77 people out of 1 million are at risk of developing cancer after exposure to the carcinogenic heavy metals in ambient airborne PM_{10} from a residential area of northern Jeddah. The total ECR for the residents in the study area is higher than those found in Delhi city, India (43.3, Khanna et al. [103]) and northern Taiwan (79, Chen [102]), and lower than that found in Kolkata (163, Das et al. [87]).

Conclusions

The concentrations of PM_{10} and its heavy metals, including Al, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ga, As, Sr, Cd, and Pb in the atmosphere of a residential area of northern Jeddah were studied. PM_{10} concentration in winter was higher than in autumn, spring, and summer. The annual concentration of PM_{10} was much higher than the WHO standard. Concerning the frequency distribution of 24-h concentration of PM_{10}, about 29%, 20%, 86%, 71%, and 54% of the mean 24-h concentration of PM_{10} during summer, autumn, winter, spring, and the whole year, respectively, exceeded the WHO air quality standards for maximum 24-h concentration. The sum of metal concentrations was found to be higher in winter, followed by spring, summer, and autumn. Fe and Al were the dominant metals, followed by Ti, Mn, Cd, Zn, Sr, V, Cu, Pb, Ni, Co, Cr, As, and Ga by decreasing proportion by concentration. Based on EF values and non-crustal fractions, Cd, As, Pb, Zn, Co, V, and Cu are mainly emitted in the atmosphere of the study area from anthropogenic sources. The concentrations of PM_{10} and its heavy metals in this study are within those found in other cities. The annual Ni and Cd levels in PM_{10} were higher than the proposed WHO, U.S. EPA, and European Community standards. Excess cancer risk was found to be in the order Cd >As > Cr > Ni. According to health risk assessment, 108.77 people out of 1 million could get cancer after exposure to the heavy metals in PM_{10} from a residential area of northern Jeddah.

References

1. YU H., KAUFMAN Y.J., CHIN M., FEINGOLD G., REMER L. A., ANDERSON T. L., BALKANSKI Y., BELLOUIN N., BOUCHER O., CHRISTOPHER S., DECOLA P., KAHN R., KOCH D., LOEB N., REDDY M. S., SCHULZ M., TAKEMURA T., ZHOU, M. A review of measurement-based assessments of the aerosol direct radiative effect and forcing. Atmospheric Chemistry and Physics **6**, 613, **2006**.
2. KAUFMAN Y.J., KOREN I. Smoke and pollution aerosol effect on cloud cover. Science, **313**, 655, **2006**.
3. BYTNEROWICZ A., OMASA K., PAOLLETTI E. Integrated effects of air pollution and climate change on forest: A northern hemisphere perspective. Environmental Pollution, **147**, 438, **2007**.
4. IPCC. Climate change: the scientific basis. In: Solomon S., DING Y., GRIGGS D. J., NOGUER M., VAN DER LINDEN P. J., DAI X., MASKELL K., JOHNSON C.A.(Eds.), Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge Univerisity Press,Cambridge **2007**.
5. RAJAMANI V., YADAV S. Air quality and trace metal chemistry of different size fractions of aerosols in N-NW India – implications for source diversity. Atmos Environ., **40**, 698, **2006**.
6. YUAN C.S., LEE C.G., LIU S. H., CHANG J.C., YUAN C., YANG H.Y. Correlation of atmospheric visibility with chemical composition of Kaohsiung aerosols. Atmos. Res., **82**, 663, **2006**.
7. GRIVAS G., CHALOULAKOU A., KASSOMENOS P. An overview of the PM10 pollution problem, in the Metropolitan Area of Athens, Greece. Assessment of controlling factors and potential impact of long range transport. Sci. Total Environ., **389**, 165, **2008**.
8. YATKIN S., BAYRAM A. Source apportionment of PM_{10} and $PM_{2.5}$ using positive matrix factorization and chemical mass balance in Izmir, Turkey. Sci. Total Environ. **390**, 109, **2008**.
9. STANEK L.W., SACKS J.D., DUTTON S.J., DUBOIS L.B. Attributing health effects to apportioned components and sources of particulate matter: an evaluation of collective results. Atmos. Environ., **45**, 5655, **2011**.
10. JAHN H.J., SCHNEIDER A., BREITNER S., EI [SS] NER R., WENDISCH M., KRAMER A. Particulate matter pollution in the megacities of the Pearl River Delta, China – a systematic literature review and health risk assessment. Int. J. Hyg. Environ. Health, **214** (4), 281, **2011**.
11. TAUS N., TARULESCU S., IDOMIR M., TAUS R. Respiratory exposure to air pollutants. J. Environ. Prot. and Ecol., **9**, 15, **2008**.
12. PERRONE M.G., GUALTIERI M., FERRERO L., LO PORTO C., UDISTI R., BOLZACCHINI E., CAMATINI M. Seasonal variations in chemical composition and *in vitro*

biological effects of fine PM from Milan. Chemosphere, **78**, 1368, **2010**.
13. LIM J.M., LEE J.H., MOON J.H., CHUNG Y.S., KIM K.H. Source apportionment of PM_{10} at a small industrial area using positive matrix factorization. Atmospheric Research, **95**, 88, **2010**.
14. MAKKONEN U., HELLÉN H., ANTTILA P., FERM M. 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, **2010**.
15. GUALTIERI M., LONGHIN E., MATTIOLI M., MANTECCA P., TINAGLIA V., MANGANO E., PROVERBIO M. C., BESTETTI G., CAMATINI M., BATTAGLIA C. Gene expression profiling of A549 cells exposed to Milan $PM_{2.5}$. Toxicology Letters, **209**, 136, **2012**.
16. WHO (World Health Organization), 2014. http://www.who.int/mediacentre/ news/releases/2014/air–pollution/en/, accessed in July **2014**.
17. ALMEIDA S.M., PIO C.A., FREITAS M.C., REIS M.A., TRANCOSO M.A. Approaching $PM_{2.5}$ and $PM_{2.5\text{-}10}$ source apportionment by mass balance analysis, principal component analysis and particle size distribution. Sci. Total Environ., **368**, 663, **2006**.
18. ATSDR (Agency for Toxic Substances and Disease Registry). Toxicological profile information sheet, http://www.atsdr.cdc.gov/toxprofiles **2003**.
19. WILLERS S., GERHARDSSON L., LUNDH T. Environmental tobacco smoke (ETS) exposure in children with asthma-relation between lead and cadmium, and nicotine concentrations in urine. Respiratory Medicine, **99**, 1521, **2005**.
20. SARNAT J.A., MARMUR A., KLEIN M., KIM E., RUSSELL A.G., MULHOLLAND J.A., HOPKE P.K., SARNAT S.E., PEEL J.L., TOLBERT P.E. Associations between source-resolved particulate matter and cardiorespiratory emergency department visits. Epidemiology, **17**, S267, **2006**.
21. HEINRICH J., SLAMA R. Fine particles, a major threat to children, International Journal of Hygiene and Environmental Health, **210**, 617, **2007**.
22. LÜ X., BAO X., HUANG Y., QU Y., LU H., LU Z. Mechanisms of cytotoxicity of nickel ions based on gene expression profiles. Biomaterials, **30**, 141, **2009**.
23. LIU L., RUDDY T., DALIPAJ M., POON R., SZYSZKOWICZ M., YOU H.Y., DALES R.E., WHEELER A.Z. Effect of Indoor, outdoor and personal exposure to particulate air pollution on cardiovascular physiology and systemic mediators in seniors. J. Occup. Environ. Med., **51**, 1088, **2009**.
24. FANG G.C., HUANG Y.L., HUANG J.H. Study of atmospheric metallic elements pollution in Asiaduring 2000-2007. J. Hazard Mater., **180**, 115, **2010**.
25. MAVROIDIS I., CHALOULAKOU A. Characteristics and expected health implications of annual PM10 concentrations in Athens, Greece. Intern. J. of Environ. and Poll., **41**, 124, **2010**.
26. SEATON A., TRAN L., AITKEN R., DONALDSON K. Nanoparticles, human health hazard and regulation. Journal of the Royal Society Interface, **7**, S119, **2010**.
27. GARCIA V.C., GEGO E., LIN S., PANTEA C., RAPPAZZO K., WOOTTEN A., RAO S.T. An evaluation of transported pollution and respiratory–related hospital admissions in the state of New York. Atmospheric Pollution Research, **2**, 9, **2011**.
28. MAGAS O.K., GUNTER J.T., GEGENS J.L. Ambient air pollution and daily pediatric hospitalizations for Asthma. Environmental Science and Pollution Research, **14**, 19, **2007**.
29. STORTINI A.M., FREDA A., CESARI D., CAIRNS W.R. L., CONTINI D., BARBANTE C., PRODI F., CESCON P.A. Gambaro An evaluation of the $PM_{2.5}$ trace elemental composition in the Venice Lagoon area and an analysis of the possible sources. Atmos. Environ., **43**, 6296, **2009**.
30. BYRD T., STACK M., FUREY A. The assessment of the presence and main constituents of particulate matter ten microns (PM_{10}) in Irish, rural and urban air. Atmos. Environ., **44**, 75, **2010**.
31. IM U., MARKAKIS K., KOÇAK M., GERASOPOULOS E., DASKALAKIS N., MIHALOPOULOS N., ET A.L. Summertime aerosol chemical composition in the Eastern Mediterranean and its sensitivity to temperature. Atmos. Environ., **50**,164, **2012**.
32. MISHRA S. K., TRIPATHI S. N. Modeling optical properties of mineral dust over the Indian Desert. J. Geophys. Res. **113**, D23201, **2008**. http://dx.doi.org/10.1029/ 2008JD010048
33. ENGELBRECHT J.P., MCDONALD E.V., GILLIES J.A., JAYANTY R.K.M., CASUCCIO G., GERTLER A.W. Characterizing mineral dusts and other aerosols from the Middle East – Part 1: ambient sampling. Inhalation Toxicol., **21**, 297, **2009**.
34. PARK E.J., KIM D.S., PARK K. Monitoring of ambient particles and heavy metals in a residential area of Seoul, Korea. Environmental Monitoring and Assessment, **137**, 441, **2008**.
35. KOTHAI P., SARADHI I.V., PRATHIBHA P., HOPKE P.K., PANDIT G.G., PURANIK V.D. Source Apportionment of Coarse and Fine Particulate Matter at Navi Mumbai, India. Aerosol Air Qual. Res., **8**, 423, **2008**.
36. XUE Y.H., WU J.H., FENG Y.C., DAI L., BI X.H., LI X., ZHU T., TANG S.B., CHEN M.F. Source Characterization and Apportionment of PM10 in Panzhihua, China. Aerosol Air Qual. Res., **10**, 367, **2010**.
37. SHAH M.H., SHAHEEN N. Seasonal behaviours in metal composition of atmospheric aerosols collected in Islamabad, Pakistan. Atmospheric Research, **95**, 210, **2010**.
38. CHENG K., DAHER N., KAM W., SHAFER M. M., NING Z., SCHAUER J.J., SIOUTAS C. Spatial and Temporal Variation of Chemical composition and mass closure of ambient coarse particulate matter ($PM_{10\text{-}2.5}$) in the Los Angeles Area. Atmos. Environ., **45**, 2651, **2011**.
39. HEDBERG E., GIDHAGEN L., JOHANSSON C. Source contributions to PM10 and arsenic concentrations in Central Chile using positive matrix factorization. Atmos. Environ., **39**, 549, **2005**.
40. BIRMILI W., ALLEN A., BARY F., HARRISON R. Trace metal concentrations and water solubility in size-fractionated atmospheric particles and influence of road traffic. Environ. Sci. Technol., **14** (4), 1144, **2006**.
41. WU Y.S., FANG G.C., LEE W.J., LEE J.F., CHANG C.C., LEE C.Z.. A review of atmospheric fine particulate matter and its associated trace metal pollutants in Asian countries during the period 1995-2005. J. Hazard Mater., **143**, 511, **2007**.
42. LI X.D., POON C.S., LIU P.S. Heavy metal contamination of urban soils and street dusts in Hong Kong. Appl. Geochem., **16**, 1361, **2001**.
43. SALMA I., MAENHAUT W. Changes in elemental composition and mass of atmospheric aerosol pollution between 1996 and 2002 in a Central European city. Environ. Pollut., **143**, 479, **2006**.
44. IIJIMA A., SATO K., YANO K., TAGO H., KATO M., RIMURA H., ET A.L. Particle size and composition

distribution analysis of automotive brake abrasion dusts for the evaluation of antimony sources of airborne particulate matter. Atmos. Environ., **41**, 4908, **2007**.
45. FANG G.C., WU Y.S., CHANG S.Y., HUANG S.H., RAU J.Y. Size Distributions of Ambient Air Particlesand Enrichment Factor Analyses of Metallic Elements atTaichung Harbor near the Taiwan Strait. Atmos. Res., **81**, 320, **2006**.
46. ZHAO J., ZHANG F., XU Y., CHEN J., YIN L., SHANG X., ANDXU L. Chemical Characteristics of Particulate Matter during a Heavy Dust Episode in a Coastal City, Xiamen, 2010. Aerosol Air Qual. Res., **11**, 299, **2011**.
47. STONE E.A., YOON S.C., SCHAUER J.J. Chemical Characterization of Fine and Coarse Particles in Gosan, Korea during Springtime Dust Events. Aerosol Air Qual. Res., **11**, 31, **2011**.
48. TAYLOR S.R. Abundance of chemical elements in the continental crust: a new table. Geochimica et Cosmochimica Acta, **28**, 1273, **1964**.
49. TAYLOR S.R., MCLENNAN S.M. The Continental Crust: Its Composition and Evolution, Oxford, England, Blackwell Scientific Publications, 312, **1985**.
50. MASON B. Principles of Geochemistry. Wiley, New York, **1966**.
51. U.S. EPA (U.S. Environmental Protection Agency), Integrated Risk Information System, IRIS Substance List **1998**.
52. U.S. EPA (U.S. Environmental Protection Agency), Guidelines for Carcinogen Risk Assessment and Supplemental Guidance for Assessing Susceptibility from Early–Life Exposure to Carcinogens, Guidelines for Carcinogen Risk Assessment, EPA/630/p 03/001f, 2005, Research and Development, National Centre for Environmental Assessment **2005**.
53. U.S. EPA (U.S. Environmental Protection Agency), Region 9, Preliminary Remediation Goals, Air-Water Calculations **2004**.
54. PARK K., HEO Y., PUTRA H.E. Ultrafine Metal Concentration in Atmospheric Aerosols in Urban Gwangju, Korea. Aerosol Air Qual. Res., **8**, 411, **2008**.
55. HIEU N.T., LEE B.K. Characteristics of particulate matter and metals in the ambient air from a residential area in the largest industrial city in Korea. Atmospheric Research, **98**, 526, **2010**.
56. MASSEY D.D., KULSHRESTHA A., TANEJA A. Particulate matter concentrations and their related metal toxicity in rural residential environment of semi–arid region of India. Atmospheric Environment, **67**, 278, **2013**.
57. HUSSEIN T., ALGHAMDI M.A., KHODER M., ABDELMAKSOUD A.S., AL-JEELANI H., GOKNIL M.K., SHABBAJ I.I., ALMEHMADI F.M., HYVÄRINEN A., LIHAVAINEN H., HÄMERI K. Particulate matter and number concentrations of particles larger than 0.25 μm in the urban atmosphere of Jeddah, Saudi Arabia. Aerosol and Air Quality Research, **14**, 1383, **2014**.
58. PEY J., RODRÍGUEZ S., QUEROL X., ALASTUEY A., MORENO T., PUTAUD J.P., VAN DINGENEN R. Variations of urban aerosols in the western Mediterranean. Atmospheric Environment **42**, **2008**.
59. GERASOPOULOS E., KOULOURI E., KALIVITIS N., KOUVARAKIS G., SAARIKOSKI S., MÄAKELÄ T., HILLAMO R., MIHALOPOULOS N. Size-segregated mass distributions of aerosols over Eastern Mediterranean: seasonal variability and comparison with AERONET columnar size-distributions. Atmospheric Chemistry and Physics, **7**, 2551, **2007**.
60. DAHER N., ARIORUPRECHT, INVERNIZZI G., DE MARCO C., MILLER-SCHULZE J., BAEHEO J., SHAFER M.M., SHELTON B.R., SCHAUER J.J., SIOUTAS C. Characterization, sources and redox activity of fine and coarse particulate matter in Milan, Italy. Atmospheric Environment, **49**, 130, **2012**.
61. TECER L.H., TUNCEL G., KARACA F., ALAGHA O., SÜREN P., ZARARSIZ A., KIRMAZ R. Metallic composition and source apportionment of fine and coarse particles using positive matrix factorization in the southern Black Sea atmosphere. Atmospheric Research, **118**, 153, **2012**.
62. ABU-ALLABAN M., LOWENTHAL D.H., GERTLER A. W., LABIB M. Sources of PM_{10} and $PM_{2.5}$ in Cairo›s ambient air. Environmental Monitoring and Assessment, **133**, 417, **2007**.
63. SALIBA N.A., EL JAM F., EL TAYAR G., OBEID W., ROUMIE M. Origin and variability of particulate matter (PM_{10} and $PM_{2.5}$) mass concentrations over an Eastern Mediterranean city. Atmospheric Research, **97**, 106, **2010**.
64. LÓPEZ L.M., CEPPI S., PALANCAR G.G., OLCESE L.E., TIRAO G.,. TOSELLI B.M. Elemental concentration and source identification of PM_{10} and $PM_{2.5}$ by SR-XRF in Córdoba City, Argentina. Atmospheric Environment, **45**, 5450, **2011**.
65. WANG J., ZIMEI H.U., CHEN Y., CHEN Z., SHIYUANXU. Contamination characteristics and possible sources of PM_{10} and $PM_{2.5}$ in different functional areas of Shanghai, China. Atmospheric Environment, **68**, 221, **2013**.
66. KOTHAI P., SARADHI I.V., PANDIT G.G., MARKWITZ A., PURANIK, V.D. Chemical Characterization and Source Identification of Particulate Matter at an Urban Site of Navi Mumbai, India. Aerosol and Air Quality Research, **11**, 560, **2011**.
67. WHO, **2006**. World Health Organization air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide. Global update 2005. http://whqlibdoc.who.int/hq/2006/WHO_SDE_PHE_OEH_06.02_eng.pdf
68. SRIMURUGANANDAM B., NAGENDRA, S.M.S. Application of Positive Matrix Factorization in Characterization of PM_{10} and $PM_{2.5}$ Emission Sources at Urban Roadside. Chemosphere, **88**, 120, **2012**.
69. KULOGLU E., TUNCEL G. Size distribution of trace elements and major ions in the eastern Mediterranean atmosphere. Water Air Soil Pollut., **167** (1–4), 221, **2005**.
70. LEDOUX F., COURCOT L., COURCOT D., ABOUKAÏS A., PUSKARIC E.A. Summer and winter apportionment of particulate matter at urban and rural areas in northern France. Atmos. Res., **82** (3–4), 633, **2006**.
71. SLEZAKOVA K., PEREIRA M.C., REIS M.A., ALVIM-FERRAZ M.C. 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, **2007**.
72. LEGRET M., PAGOTTO C. Evaluation of pollutant loadings in the runoff waters from a major rural highway. The Science of the Total Environment, **235**, 143, **1999**.
73. ADACHI K., TAINOSHO Y. Characterization of heavy metal particles embedded in tire dust. Environment International, **30**, 1009, **2004**.
74. YOUNG T.M., HEERAMAN D.A., SIRIN G., ASHBAUGH L.L. Resuspension of soil as a source of airborne lead near industrial facilities and highways. Environmental Science and Technology, **36**, 2484, **2002**.
75. TÜZEN M. Determination of heavy metals in soil, mushroom and plant samples by atomic absorption spectrometry. Micro chemical Journal, **74**, 289, **2003**.

76. YONGMING H., PEIXUAN D., JUNJI C., POSMENTIER E. S. Multivariate analysis of heavy metal contamination in urban dusts of Xi'an central China. The Science of the Total Environment, **355**, 176, **2006**.
77. KABADAYI F., CESUR H. Determination of Cu, Pb, Zn, Ni, Co, Cd and Mn in road dusts of Samsun City. Environ. Monit. Assess., **168**, 241, **2010**.
78. AMATO F., PANDOLFI M., MORENO T., FURGER M., PEY J., ALASTUEY A., BUKOWIECKI N., PREVOT A. S.H., BALTENSPERGER U., QUEROL X. Sources and variability of inhalable road dust particles in three European cities. Atmos. Environ., **45**, 6777, **2011**.
79. WHO. Guidelines for Air Quality. World Health Organization, Geneva, 2000. Retrieved from http://www.who.int/environmentalinformation/Air/ Guidelines/aqguide7.pdf.
80. ATSDR. Regulations and Guidelines Applicable. Agency for Toxic Substances and Disease Registry, **2002**. Retrieved from http://www.atsdr.cdc. gov/toxprofiles/tp11-c8.pdf.
81. EC (European Commission). DG Environmental Working Group on Arsenic, Cadmium and Nickel Compounds, Ambient Air Pollution by As, Cd and Ni Compounds, **2000**. Position Paper (Final Version).
82. BAO Z., FENG Y.C., JIAO L., HONG S.M., LIU W.G., Characterization and source apportionment of $PM_{2.5}$ and PM_{10} in Hangzhou. Environmental Monitoring in China, **26**, 44, **2010**.
83. KULSHRESTHA A., SATSANGI P.G., MASIH J., TANEJA A. Metal concentration of $PM_{2.5}$ and PM_{10} particles and seasonal variations in urban and rural environment of Agra, India. Science of the Total Environment, **407**, 6196, **2009**.
84. LIMBECK A., HANDLER M., PULS C., ZBIRAL J., BAUER H., PUXBAUM H. Impact of mineral components and selected trace metals on ambient PM_{10} Concentrations. Atmospheric Environment, **43**, 530, **2009**.
85. VON SCHNEIDEMESSER E., STONE E.A., QURAISHI T.A., SHAFER M.M., SCHAUER J.J. Toxic metals in the atmosphere in Lahore, Pakistan. Science of The Total Environment, **408**, 1640, **2010**.
86. GUGAMSETTY B., WEI H., LIU C.-N., AWASTHI A., HSU S.-C., TSAI C.-J., ROAM G.-D., WU Y.-C., CHEN C.-F. Source Characterization and Apportionment of PM_{10}, $PM_{2.5}$ and $PM_{0.1}$ by Using Positive Matrix Factorization. Aerosol and Air Quality Research, **12**, 476, **2012**.
87. DAS R., KHEZRI B., SRIVASTAVA B., DATTA S., SIKDAR P. K., WEBSTER R. D., WANG X. Trace element composition of $PM_{2.5}$ and PM_{10} from Kolkata – a heavily polluted Indian metropolis. Atmospheric Pollution Research, **6**, 742, **2015**.
88. TERZI E., ARGYROPOULOS G., BOUGATIOTI A., MIHALOPOULOS N., NIKOLAOU K., SAMARA C. Chemical composition and mass closure of ambient PM_{10} at urban sites. Atmospheric Environment, **44**, 2231, **2010**.
89. KHILLARE P.S., SARKAR S. Airborne inhalable metals in residential areas of Delhi, India: distribution, source apportionment and health risks. Atmospheric Pollution Research, **3**, 46, **2012**.
90. THEODOSI C., IM U., BOUGIATIOTI A., ZARMPAS P., YENIGUN O., MIHALOPOULOS N. Aerosol chemical composition over Istanbul. Science of the Total Environment, **408**, 2482, **2010**.
91. HAN Y.M., DU P.X., CAO J.J., POSMENTIER E.S. Multivariate Analysis of Heavy Metal Contamination in Urban Dusts of Xi'an Central China. Sci. Total Environ., **355**, 176, **2006**.
92. HIEN P.D., BINH N.T., TRUONG Y., NGO N.T., SIEU L.N. Comparative receptor modelling study of TSP, PM_2 and PM_{2-10} in Ho Chi Minh City. Atmospheric Environment, **35**, 2669, **2001**.
93. HAO Y., GUO Z., YANG Z., FANG M., FENG J. Seasonal variations and sources of various element in the atmospheric aerosols in Qingdao, China. Atmospheric Research, **85**, 27, **2007**.
94. LOUGH G.C., SCHAUER J.J., PARK J.S., SHAFER M.M., DEMINTER J.T., WEINSTEIN J.P. Emissions of metals associated with motor vehicle roadways. Environmental Science and Technology, **39**, 826, **2005**.
95. CAO J.J., SHEN Z.X., CHOW J.C., QI G.W., WATSON J.G. Seasonal variations and sources of mass and chemical composition for PM_{10} aerosol in Hangzhou. China, Particuology, **7**, 161, **2009**.
96. HSU S.C., LIU S.C., TSAI F., ENGLING G., LIN I.I., CHOU C.K.C., KAO S.J., LUNG S.C.C., CHAN C.Y., LIN S.C., HUANG J.C., CHI K.H., CHEN W.N., LIN F.J., HUANG C.H., KUO C.L., WU T.C., HUANG Y.T. High wintertime particulate matter pollution over an offshore island (Kinmen) off southeastern China: an overview. J. Geophys. Res., **115**, D17309, **2010**.
97. PACYNA J., PACYNA E. An assessment of global and regional emissions of trace metals to the atmosphere from anthropogenic sources worldwide. Environmental Reviews, **9**, 269, **2001**.
98. QUEROL X., ALASTUEY A., ROSA J., SANCHEZ DE LA CAMPA A., PLANA F., RUIZ C. Source apportionment analysis of atmospheric particulates in an industrialized urban site in southwestern Spain. Atmospheric Environment, **36**, 3113, **2002**.
99. STERNBECK J., SJODIN A., ANDREASSON K. Metal emissions from road traffic and the influence of resuspension - results from two tunnel studies. Atmospheric Environment, **36**, 4735, **2002**.
100. PUXBAUM H., GOMISCEK B., KALINA M., BAUER H., SALAM A., STOPPER S., PREINIG O., HAUCK H. A dual site study of $PM_{2.5}$ and PM_{10} aerosol chemistry in the larger region of Vienna, Austria. Atmospheric Environment, **38**, 3949, **2004**.
101. HANDLER M., PULS C., ZBIRAL J., MARR I., PUXBAUM H., LIMBECK A. Size and composition of particulate emissions from motor vehicles in the Kaisermu¨hlen-Tunnel, Vienna. Atmospheric Environment, **42**, 2173, **2008**.
102. CHEN H.-W. Characteristics and risk assessment of trace metals in airborne particulates from a semiconductor industrial area of Northern Taiwan. FFresenius Environmental Bulletian, **16**, 1288, **2007**.
103. KHANNA I., KHARE M., GARGAVA P. Health Risks Associated with Heavy Metals in Fine Particulate Matter: A Case Study in Delhi City, India. Journal of Geoscience and Environment Protection, **3**, 72, **2015**.