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Source of Heavy Metals in Aerosol Particles in Atmosphere of Jeddah City, Saudi Arabia

Iqbal M Ismal[1], **Jalal M Basahi**[1,2], **Ibrahim A Hassan**[1,3*], **Ahmed S Summan**[1,2] **and Essam Hammam**[4]

[1]*Air Pollution Laboratory (APL), Centre of Excellence in Environmental Studies (CEES), King Abdulaziz University, Jeddah, Saudi Arabia*

[2]*Environment and Agriculture of Arid Environment, King Abdulaziz University, Jeddah, Saudi Arabia*

[3]*Alexandria University, Alexandria, Egypt*

[4]*Department of Chemistry and Biochemistry, University of North Carolina, Wilmington, North Carolina, USA*

[*]**Corresponding author:** Ibrahim A Hassan, Air Pollution Laboratory (APL), Centre of Excellence in Environmental Studies, King Abdulaziz University, Jeddah, Saudi Arabia, Tel: (00966)0599251910; E-mail: ihassan_eg@yahoo.com

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Abstract

Chemical characteristics of aerosols were elucidated through studying concentrations of total suspended particulate matter (TSP) and their elemental composition at industrial, urban and residential sites in Western coast of Saudi Arabia. The average concentration of total particulates were 225, 121 and 98 μg m^{-3} at industrial, urban and residential sites, respectively. The present study showed that the concentrations of measured heavy metals were in the order of Residential<Urban<Industrial. Moreover, EFs of most of elements collected from an industrial site were the highest.Principle component analysis (PCA) indicated that the major source of Al, Ca, Mg, Fe, Mn and K is road dust (vehicular emissions); Cu is vehicular abrasion; Zn and V is residual oil combustion and Ni is metal plating.

Keywords: PM; Heavy metals; Principle component analysis; Source identification; EF

Introduction

Trace metals are the most important constituents of aerosol particles [1-3]. Sources of these heavy metals are various depending on human activities, population as well as nature [4].

Due to their complex structure, PM is important environmental indicator for air quality [5]. Moreover, geography and cultural practices affect the chemical characteristics of aerosols pollution sources [6,7].

Due to rapid urbanization and industrialization Saudi Arabia is experiencing pollution problems [8]. Moreover, the number of motor vehicles has increased substantially [8,9]. Emissions of PM with their associated trace metals into the atmosphere worsen life quality [10,11]. Some of these metals are toxic and catalyze oxidative stress [12]. However, very few studies have been conducted in Saudi Arabia for source apportionment and identification.

The aim of the present investigation was to identify major source types of heavy metals using principle component analysis (PCA).

Materials and Methods

Sampling sites

Residential, urban and industrial sites were selected for the present investigation [6,7].

Sampling and analysis

Samples were collected using a "pesticide" sampler (TE-PUF, Tisch Environmental Inc.) which draws air (240-300 m^3 per day) through a TSP inlet onto a preheated quartz microfibre filter (TE-QMA4; 10.16 cm) to collect particulate matter for 24 hours at the three sites.

The concentration of metals was analyzed using a non-destructive X-ray Fluorescence (XRF) Spectrometer (EX-6600-AF, Jordan Valley) with spectral software XRF2000v3.1 (U.S. EPA and ManTech Environmental Technology, Inc.) [13].

Data analysis

Analysis of variance (ANOVA) and principal component analysis (PCA) were performed using STSTGRAPHICS (STATGRAPHICS 5.0) statistical package.

Results and Discussion

TSP was in the order of residential < urban < industrial, and the mean concentrations were 98, 121 and 225 μg m^{-3} at these sites, respectively (Table 1).

Study Area	TSP (μg m^{-3})			
	No of samples	Min	Max	Mean
Residential	21	54	339	98.67 + 8.7a
Urban	24	64	251	121.82 + 14.15b
Industrial	23	73	883	225.43 + 34.65c

Table 1: Concentrations of TSP at the studies sites (n =21 + SE for residential and urban areas, and n = 23 + SE for the industrial site).

Similarly, the sum of the concentrations of measured elements were in the order of industrial>urban>residential. The highest concentrations recorded were 101.32, 60.55, 51.7, 39.87 and 32.07 µg m-3 for Ca, Zn, Mg, Al and Fe, respectively at the industrial site, while Mg, Fe, Al had the highest concentrations at urban site; 29.86, 25.39 and 18.4 µg m^{-3}, respectively. At the residential site, Al, Mg and Fe had the highest concentrations (6.4, 26.73 and 22.98 µg m^{-3}, respectively) (Figure 1). Elements varied significantly ($P<0.05$) among site and even more sites had significant effects ($P<0.01$) on elemental composition of TSP (Figure 1).

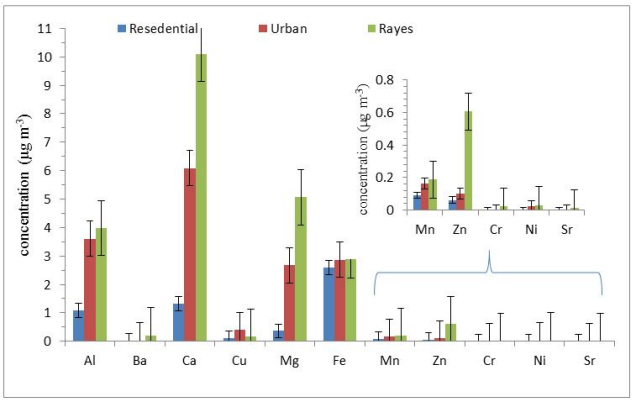

Figure 1: The average concentrations of measured elements at the study areas.

Construction activities could be the reason of the very concentration of Ca at an industrial area [13].

Table 2 shows the results of principle component analysis (PCA) for the combination of all three sampling sites. Four possible sources were identified; PC1 is heavily loaded with Al, Ca, Mg, Fe, Mn and K. It indicates road dust enriched with vehicular emissions [14]. The second principle component (PC2) contains Cu only, which is abundant in brake wear indicating that its potential source is heavily impacted by vehicular abrasion [15].

The third principle component (PC3) was heavily loaded with Zn and V, suggesting that its potential source is impacted by combustion sources. Moreover, V indicated ship emission and burning of other residual oil [16].

In the fourth principle component (PC4), high loading of Ni and Cr were observed which indicates industrial activities such as metal plating [13]. This could be the case in our study as there were many industrial units very near to sampling sites. All of these four components together explain about 96% of the total variance of the dataset.

Enrichment factors (EFs) of elements in aerosol were employed to the results to separate trace elements from crustal and non-crustal sources for the three sampling sites. The EF_{Crust} of element E in aerosols is calculated according to the following equation

$$EFCrust = \frac{(E/R)Air}{(E/R)Crust} \qquad (1)$$

Where, R is a reference element of crustal material, $(E/R)_{Air}$ is the concentration ratio of E to R in aerosol sample, and $(E/R)_{Crust}$ is the concentration ration of E to R in the crust [4].

Fe was used as the reference element in our study [13]. EF ranged between 0.04-1.58, 0.08-1.18 and 0.06-3.16 at the residential, urban and industrial sites, respectively (Table 3). The highest EF recorded was 1.58 and 1.16 for AL and Mg at the residential area, respectively, while Mg had the highest EF at urban area (1.18).

Ca had the highest EF (3.16) at the industrial area followed by Zn, Mg and Al (1.89, 1.61 and 1.24, respectively).

Elements	Principle Component			
	PC1: Road Dust	PC2: Vehicular Abrasion	PC3: Residual Oil Combustion	PC4:Multi-source (e.g. metal plating)
Al	0.948			
Ca	0.916			
Cu		0.766		
Mg	0.856			
Fe	0.823			
Mn	0.902			
Zn			0.778	
Ni				0.872
Cr				0.903
K	0.936			
V			0.889	
Initial eigen value	7.67	1.98	1.35	3.22
% Variance	49.4	19.9	9.3	18.4
% Cumulative	56.9	67.3	78.4	67.3

Table 2: Principle component analysis for metal and elements for the three sampling locations combined.

The EFs for all elements at the three sites were <10, which indicates that these elements come from vehicle emission and fossil fuel combustion [4].

Recently, Aslam et al. [4] reported that a low EF of an element (i.e., EF<10) indicates its crustal source, while a high EF (i.e., EF>10) is an indication of a non-crustal source.

Moreover, Table 3 shows that EFs of most of elements collected from the industrial site were relatively higher than that collected from other locations, which indicate that they mainly came from re-suspended soil containing previously deposited PM [13]. Nevertheless, EFs for crust related elements (Al and Mg) were similar.

However, EFs for coal burning and traffic related element (Zn and Cu) were much lower at the residential site than those at other locations. These highlight the danger posed by element pollution at these urban and industrial sites [6].

	EF		
Element	**Rayes (Industrial)**	**Rabegh (Urban)**	**Abhur (Residential)**
Al	1.24	0.72	1.58
Ca	3.16	0.55	0-.26
Cu	0.52	0.46	0.17
Mg	1.61	1.18	1.16
Fe	1	1	1
Mn	0.58	0.36	0.38
Zn	1.89	0.55	0.26
Ni	0.11	0.12	0.12
Cr	0.06	ND	ND
K	0.13	0.08	0.04
V	ND	ND	ND

Table 3: Enrichment factor (EF) analysis of the measured elements at the three sites.

Conclusion

The concentrations of TSP and selected trace metals in aerosol were the highest at the industrial site among three sites.

PCA was used to identify the impact of local sources in ambient air. PCA analysis indicates four sources, and of them combustion emission, crust related sources, traffic related sources and volatile species from coal combustion were identified.

This preliminary research may help researchers and policy makers to improve air quality through managing and developing strategies for air pollution control and abatement to protect people from the hazardous effects arising from elevated atmospheric trace metal levels by the systematic study of air pollution.

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