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Short Communication

Total Suspended Particulate Matter (TSP) and Its Associated Heavy Metals in Atmosphere on the Western Coast of Saudi Arabia

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Abstract

Total suspended particulates (TSP) in ambient air of three sites representing a gradient transect of urbanization along the western coast of Saudi Arabia were collected and their heavy metal contents were analyzed. The sampling was conducted at three sites simultaneously between 16 June to 7 July 2013, 17 September to 1 October 2013 (summer), and 23 December 2013 to 30 January 2014 (winter). The concentration of TSP was very high in ambient air of the two northern sites, ranging between 73 and 883 μg m^{-3} in the far northern site (Rayes, industrial) which is located south to Yanbu industrial city, and it was between 64 and 251 μg m^{-3} in the other site (Rabegh, urban). The southern site (Abhur, residential) showed relatively lower levels of TSP (ranging between 54 and 339 μg m^{-3}). TSPs were also analyzed for 11 heavy metals (Al, Ca, Cu, Mg, Fe, Mn, Zn, Ni, Cr, K, and V) using x-ray fluorescence (XRF) spectrometry. The Fe, Km and Zn concentrations were higher than other elements and they differed significantly among the studied areas. The present study showed that the concentrations of measured elements decreased in the order of industrial > urban > residential.

Keywords: particulate matter, trace metals, XRF, Jeddah

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Introduction

Particulate matter (PM) is of great concern due to its impact on air quality and global climate change [1]. Ambient levels and composition of PM depend on the emission sources and metrological conditions [2-6]. PM is a complex mixture of particles of different origins with large surface areas, and the significant portion of its mass is made up of inorganic constituents (trace metals and water-soluble ions), which plays an important role in aerosol chemistry [3]. Therefore, PM is an important environmental indicator for air quality and climate change [7-11].

Saudi Arabia is experiencing a rapid increase in urbanization and industrialization with annual urban population growth rates estimated to be 3.9% in 2010 [8]. Moreover, the number of motor vehicles has increased substantially [6, 9, 12]. Emissions of pollutants of PM into the atmosphere are increasing rapidly with urbanization, industrialization, and increased numbers of motor vehicles, which would reduce visibility, damage natural vegetation, affect public health, increase risks, and worsen life quality [14-15].

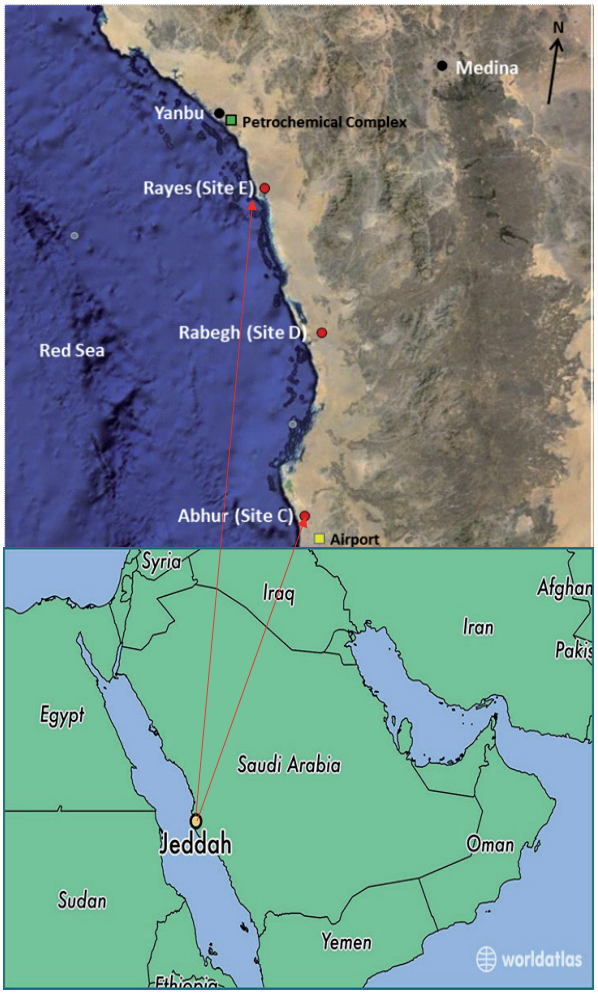

Fig. 1. Map of the western coast of Saudi Arabia showing the sampling locations.

Table 1. Concentrations of TSP at the study sites.

Experimental Site	TSP (µg m^{-3})			
	Number of samples	Min	Max	Mean
Rayes (industrial)	23	73	883	225
Rabegh (urban)	24	64	251	121
Abhur (residential)	21	54	339	98
Spatial Variation				***

*** $p < 0.001$

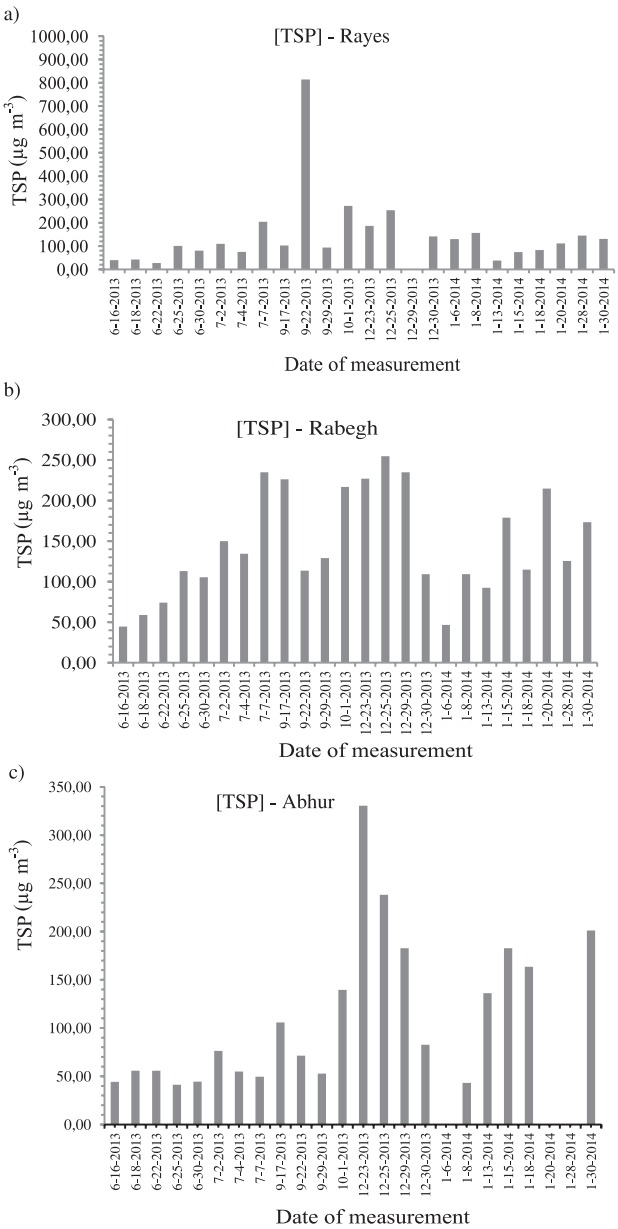

Fig. 2. Average daily concentrations of TSP (µg m^{-3}) at a) Rayes, b) Rabegh, and c) Abhur.

Table 2. Spatial variation of selected trace metals (μg m^{-3}); figures are means ± SD.

Element	Site						
	Rayes (n = 23)		Rabegh (n = 24)		Abhur (n = 21)		Spatial Variation
	Mean	S.D.	Mean	S.D.	Mean	S.D.	
Al	0.018	0.033	0.002	0.021	0.041	0.031	**
Ca	0.130	0.028	0.050	0.023	0.080	0.041	***
Cu	0.131	0.023	0.062	0.008	0.003	0.002	**
Mg	0.094	0.026	0.063	0.017	0.082	0.022	**
Fe	0.368	0.094	0.186	0.059	0.131	0.066	**
Mn	0.086	0.008	0.040	0.005	0.003	0.002	**
Zn	0.180	0.072	0.091	0.041	0.035	0.021	***
Ni	0.084	0.064	0.081	0.033	0.086	0.058	--
Cr	0.101	0.076	0.065	0.005	0.003	0.003	***
K	0.261	0.088	0.094	0.062	0.051	0.043	**
V	0.003	0.002	0.002	0.002	0.001	0.001	--
Total	**1.456**		**0.736**		**0.489**		***

The arid environment and vast deserts of Saudi Arabia have increased the frequency of dust storms along with their intensity and duration [16]. Moreover, there is a lack of awareness regarding air pollution and its impact on ecosystems in Saudi Arabia.

The main goals of the present study were to determine the concentrations of total suspended particles (TSP) and associated trace metals along a gradient of urbanization on the western coast of Saudi Arabia.

Experimental

Sampling

Three areas were selected for the present study to present different gradients of urbanization, namely Rayes (23.5756ºN 38.6058ºE**)**, Rabegh **(**22.8122ºN 39.0664ºE), and Abhur (21.7572ºN 39.1147ºE) (Fig. 1). Samples were collected using a "pesticide" sampler (TE-PUF, Tisch Environmental Inc.) simultaneously at the three

Table 3a. Correlation matrix for TSP and trace metals in Rayes (bold figures are significant at P<0.05).

TSP	Al	Ca	Cu	Mg	Fe	Mn	Zn	Ni	Cr	K	V
TSP	**0.67**	**0.58**	**0.67**	0.83	0.97	0.55	0.64	0.67	0.52	0.59	0.77
	Al	**0.77**	-0.18	**0.67**	**0.79**	**0.88**	0.11	**0.59**	**0.69**	**0.99**	**0.96**
		Ca	0.27	0.41	**0.67**	**0.59**	**0.77**	0.33	-0.27	-0.37	**0.68**
			Cu	0.39	0.22	0.38	-0.37	0.18	-0.18	-0.27	0.41
				Mg	**0.99**	**0.51**	0.49	0.50	-0.23	-0.19	-0.28
					Fe	0.99	-0.28	-0.44	-0.42	0.37	0.29
						Mn	0.65	0.44	-0.28	-0.41	-0.37
							Zn	0.51	0.21	-0.11	0.25
								Ni	**0.61**	**0.53**	0.38
									Cr	**0.74**	0.41
										K	**0.75**
											V

Table 3b. Correlation matrix for TSP and trace metals in Rabegh (bold figures are significant at P<0.05).

TSP	Al	Ca	Cu	Mg	Fe	Mn	Zn	Ni	Cr	K	V
TSP	**0.56**	**0.87**	0.58	0.61	0.66	0.98	0.88	0.67	0.59	0.67	0.53
	Al	**0.99**	**0.68**	**0.55**	**0.54**	**0.65**	**0.57**	**0.88**	0.44	**0.75**	0.55
		Ca	**0.87**	**054**	**0.77**	**0.78**	0.42	**0.69**	0.49	**0.65**	0.50
			Cu	**059**	**0.98**	**0.99**	0.33	0.47	0.56	**0.59**	0.44
				Mg	**0.99**	**0.86**	0.49	0.42	0.33	**0.87**	0.36
					Fe	**0.67**	**0.78**	**0.83**	**0.85**	**0.69**	**0.89**
						Mn	**0.87**	**0.98**	**0.88**	**0.78**	**0.63**
							Zn	**0.67**	**0.74**	0.46	0.52
								Ni	**0.76**	**0.62**	**0.67**
									Cr	**0.63**	0.58
										K	**0.79**
											V

Table 3c. Correlation matrix for TSP and trace metals in Abhur (bold figures are significant at P<0.05).

TSP	Al	Ca	Cu	Mg	Fe	Mn	Zn	Ni	Cr	K	V
TSP	**0.55**	0.56	0.66	0.71	0.53	0.59	0.57	0.69	0.61	0.58	0.66
	Al	0.50	**0.54**	**0.58**	**0.69**	**0.65**	**0.55**	**0.55**	**0.51**	0.67	0.54
		Ca	-0.42	**0.58**	**0.76**	**0.86**	0.48	0.43	0.38	0.28	0.32
			Cu	0.49	0.48	**0.57**	**0.87**	0.39	**0.78**	**0.89**	-0.34
				Mg	-0.43	**0.52**	0.44	0.50	**0.54**	0.48	0.38
					Fe	**0.79**	0.51	**0.66**	**0.66**	**0.67**	**0.67**
						Mn	**0.78**	**0.83**	-0.37	0.76	0.49
							Zn	-0.32	0.33	0.93	0.36
								Ni	-0.26	0.37	**0.55**
									Cr	0.26	-0.09
										K	-0.15
											V

sites between 16 June to 7 July 2013, 17 September to 1 October 2013 (summer), and 23 December 2013 to 30 January 2014 (winter) [10]. Peak hourly temperatures ranged from 38-47ºC and 23-30ºC (summer and winter).

Filters were preheated at 500°C for 24 h, wrapped in a clean foil, and placed in airtight glass containers. The sampling was conducted for 24 hours at all sites and the mass of TSPs was determined by weighing the filter before and after sampling using a microbalance (model MT5, Mettler-Toledo Inc.) in a temperature- and humidity-controlled weighing room. The mass on the quartz microfibre filter was measured.

Element Metal Analysis

The concentration of metals was analyzed using a non-destructive x-ray fluorescence (XRF) spectrometer (S2 PICOFOX, BURKER). Qualitative multi-element spectral measurement and analysis were carried out simultaneously [16].

Data Analysis

Data were subjected to a one-way analysis of variance (ANOVA) and means were separated using Tukey's

multiple comparison test ($p>0.05$) to assess the significant difference among the mean values of different attributes from different sites.

The relationships between concentrations of TSP and different elements at different sites were analyzed using the correlation coefficient test. All analyses were performed using SPSS 16.0 statistical package (SPSS Inc., USA)

Results and Discussion

The Temporal distribution of TSP at the three sites is illustrated in Fig. 2, while the minimum, maximum, and average arithmetic mean values for TSP are presented in Table 1. The mean concentrations were 225, 121, and 98 μg m^{-3} at Rayes, Rabegh, and Abhur, respectively (i.e., TSPs were in the order of Rayes > Rabegh > Abhur). However, there are extreme values for Rayes (883 μg m^{-3} on 23 Sept.), Rabegh (251, 240, and 229 μg m^{-3} on 26 Dec., 8 July, and 30 Dec. , respectively; Fig. 2 b) and for Abhur the extreme record was 339 μg m^{-3} on 24 Dec. If these extreme values are not included in the average TSP, then the averages in these sites would be 210.11, 135.37, and 67.64 μgm^{-3}, respectively, (Table 1, Figs 1a-c).

These extreme values occurred on days when dust storms passed through the western coast of Saudi Arabia. Dust storms in Saudi Arabia occur around six to seven times per year, especially in the spring and fall. At that time of year, air quality deteriorates and visibility is greatly reduced [8-9, 17]. However, the samplings were carried out during summer and winter in the present study and there were two dust storms during those times.

The General Authority of Meteorology and Environment in Saudi Arabia has established air quality standards (AQA), and it states that the guidelines for TSP for a 12-month period outdoors should not exceed 80 μg m^{-3}. This PME guideline has been exceeded 10 times at Abhur and 20 times at the other locations (Figs 2a-c). However, these concentrations are much lower than those recorded in Riyadh (578-662 μg m^{-3}) and in Makkah (336.4 μg m^{-3}) in Saudi Arabia [15].

Similarly, the sum of the concentrations of measured elements were in the order of Rayes > Rabegh > Abhur. The total concentration of measured elements were 1.456, 0.736, and 0.489 μg m^{-3} at these sites respectively (Table 2).

The highest concentrations recorded were 0.368, 0.261, 0.180, 0.131, and 0.130 μg m^{-3} for Fe, K, Zn, Cu, and Ca, respectively, at the industrial site (Rayes), while at the urban site (Rabegh) the highest concentrations recorded were 0.186, 0.094, and 0.091 μg m^{-3} for Fe, K, and Zn, respectively (Table 2). At the residential (Abhur), which is the southern site, Fe, Ni, Mg, and Ca had the highest concentrations (0.131, 0.086, 0.082, and 0.08 μg m^{-3}, respectively; Table 2). Elements varied significantly ($0.05<P<0.01$) among sites (Table 2).

Duan et al. [17] attributed the high concentrations of Ca at their field sites to construction activities; this could be the case at the Rayes site in our study.

The correlation matrix for various metals and TSP is shown in Table 3. TSPs were correlated significantly to all elements ($r>0.5$). Fe, Mn, and Mg had the highest correlations ($r = 0.97$, 0.98, and 0.71 μg m^{-3} at Rayes, Rabegh, and Abhur, respectively) with TSP (Table 3a-c). As for the metal-to-metal correlation, Al is highly correlated with K ($r = 0.99$) and Mg is highly correlated with Fe ($r = 0.99$) at the Rayes site (Table 3a). Moreover, V was highly correlated with Al ($r = 0.96$) at the same site.

At Rabegh, Cu was highly correlated with Mn and Fe ($r = 0.99$, 0.98, respectively), and Mg was significantly correlated with Fe ($r = 0.99$). Similarly, Mn was highly correlated with Ni ($r = 0.98$) (Table 3b).

On the southern site, Abhur, the correlation was lower than that in the northern sites (Rayes and Rabegh), but still highly significant. The highest correlations recorded were between Cu and K ($r = 0.89$), Ca and Mg ($r = 0.89$), and Mn and Ni ($r = 0.83$) (Table 3c). The correlation between V and Ni was high ($r = 0.55$ and 0.67 at Rabegh and Abhur, respectively), and it is often used as tracers for oil combustion [17].

Conclusions

Ambient concentrations of TSP and their elemental composition at the three different sites – Rayes (industrial), Rabegh, (urban), and Abhur (residential) along the western coast of Saudi Arabia – are presented in this investigation for elucidating the chemical characteristics of aerosols. The concentrations of TSP exceeded the daily limit of 80 μgm^{-3}. The concentrations of selected trace metals in aerosol at Rayes were the highest among the three sites. Industrial processes, vehicle emissions, and road dust are the main source-types affecting the local atmosphere. The results of the present study may help researchers and policymakers to manage and develop strategies for air pollution control and abatement in order to improve air quality to protect people from the hazardous effects arising from elevated atmospheric trace metals.

It is necessary to carry out specific size-segregated PM studies in the region in order to provide more information on the maximum size of particles being sampled.

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