Monitoring the dust deposition rate and trace metals levels in $PM_{1.0}$ from industrial areas of Kuwait

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Abstract

Factory emissions and frequent dust storms are known to affect the human health of residents in arid countries. This study was undertaken to better characterize dust deposition rates and trace metals of fine particulate matter (i.e., $PM_{1.0}$) at industrial and residential areas in Kuwait. Investigations on the $PM_{1.0}$ fugitive dust revealed a significant relationship between low wind velocity and high rate of dust deposition (RD) in the summer and winter. RD and trace metal levels in $PM_{1.0}$ were highest at the industrial areas and lowest at the residential areas. Trace metals were observed in the sequence of Al > Fe > Ni > Zn > Pb > Cd irrespective of the industrial areas or seasons. A high RD and trace metal levels in $PM_{1.0}$ was correlated with several factors including: vast open area, wind velocity, rapid industrialization, and anthropogenic sources. These findings are relevant for establishing preventative measures to fine particulates in an arid environment.

Keywords: $PM_{1.0}$, trace metals, pollution, Kuwait

1. Introduction

The arid climate of the Middle East and frequent wind storms lead to erosion and high levels of fugitive dust. The resulting fine dust particles of 2.5 µm and 1.0µm are a potential human health concern to the local inhabitants in this region of the world [1]. Advanced research on weather data, satellite imagery, geographical information systems and computer modeling has added with measuring, predicting and tracking plumes of dust originating from selected sources [2]. Therefore, the inhabitants may be adequately warned of impending plumes. However, an additional concern with fine particulate dust is that it may contain metals which are capable of causing respiratory ailments especially in arid countries [3-4]. High trace metal exposure studies have indicated that various biochemical disorders may occur in humans when exposed to fine particulates *via* inhalation or ingestion of contaminated food [5-7].

Kuwait's topography is characterized by a high frequency of windswept sand and dust, long hot and dry summers, and short, cool and sometimes rainy winters [8]. During the daylight hours, dust storms frequently take place that diminish visibility to less than a meter. Over the years, observations in Kuwait have revealed consistent dispersal of coarse (i.e., $PM_{2.5}$ to $PM_{1.0}$) and fine (i.e., $PM_{2.5}$ or less) dust particulates due to the frequent wind storms [4, 9-11]. Fine particulates are a public health concern because when inhaled, they can penetrate deep into the lungs and accumulate over time. In the Middle East, researchers have also observed high levels of trace metals, which appear to accumulate in the atmosphere due to seasonal variations and anthropogenic sources [12-14].

Based on the foregoing concerns that are especially relevant to arid geographies, the present study was undertaken to investigate two primary objectives. First, the dust deposition rate (RD) of $PM_{1.0}$ was studied in relation to the wind velocity, and second, the seasonal distributions of trace metal concentrations in PM1.0 in industrial and non-industrial Kuwait Governorate areas were evaluated.

2. Materials and Methods

2.1. Study areas and sampling sites

The following industrial (I1-I4) and non-industrial areas apportioned in the six Kuwait's Governorates (GI to GVI) were evaluated: (i) Kabd (GI-I1, Jahra: 29°20'13.2"N,47 ° 39'28.8"E): situated at the southern region of this Governorate comprising of several cement quarries, cement mixing plants, and desert areas besides few residential attached cattle farms, (ii) Shuwaikh (GII-I2, Kuwait City:

29°21'57.6"N,47°58'40.8"E): the central Kuwait zone with multifaceted industries for automobiles, hardware (sanitary, electrical, mechanical, construction materials), spare parts, welding, painting, woodwork, aluminum fabrication, commercial areas significant for its business centers, domestic wastewater outfalls, power and desalination plants, (iii) Hawalli (GIII-R1:29 °19'58.8"N, 48°01'44.4"E): a non-industrial business and residential areas, (iv) Mubarak Al-Kabeer (GIV-R2: 29°15'25.2"N, 48°03'25.2"E): with moderately populated residential and recreational activities, (v) Ardhiya and Sabahan (GV-I3, Farwaniya:29°16'37.2"N, 47°57'32.4"E): stations water treatment plants, small scale multipurpose commercial and domestic utility industries, besides the widespread residential areas, and (vi) Umm-Al-Haiman (GVI-I4, Ahmedi: 29°4'37.2"N, 48°05'2.4"E): Kuwait's southern region which stations petroleum refineries, power plants, fertilizer plants, a chlorine and soda plant, a commercial harbor and large oil loading terminals, besides multi-faceted chemical factories (Fig. 1). Two common features in Kuwait Governorate areas which make them ideal locations of study, are the topography and characteristic pollution pattern [14].

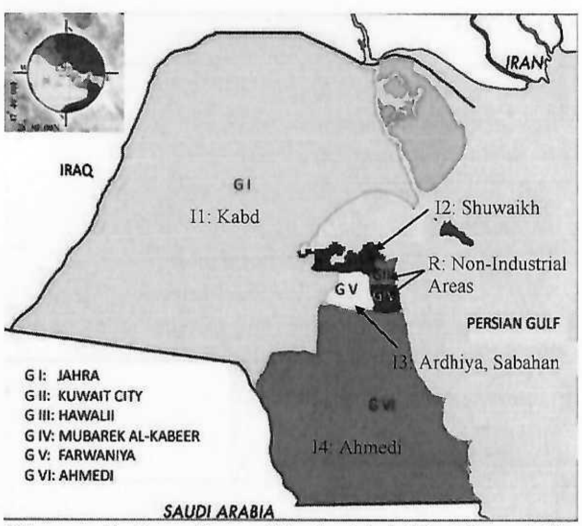

Figure. 1. Location of industrial (I1-I4) and the non-industrial (R) areas of the Kuwait Governorates (GI-VI).

2.2. Sampling and analysis

Three different particulate impactor sizes namely PM_{10}, $PM_{2.5}$ and $PM_{1.0}$ are available in EPAM-5000 (Haz Dust Air monitoring system, Inc., USA). The present study chose $PM_{1.0}$ among the other particulate sizes due to its detrimental effect on the respiratory system of residents in Kuwait, and because of this particulate size being often neglected as a result of inadequate infrastructural facilities and protracted time required for air pollution studies in Kuwait. $PM_{1.0}$ replicate samples (10 each) from the six Governorate areas, were collected over a period of 24h every month during the years 2007-2010 using EPAM-5000 [19]. Based on the two prevalent seasons in Kuwait, samples were grouped into summer (April-September) and winter (October-March). Particle concentration was measured by light scattering. Sampling was conducted with an interval of 8h duration and 10min rest in 24hr/batch, with $PM_{1.0}$ impactor fixed at 1m above the ground level using a tripod stand. An air volume of 1.68 m^{-3} ±0.05 was collected for every sample. The air particulate was impacted through a 47Ømm membrane filter of EPA-FRM (Federal Reference Method) style. The particles collected on the filter were weighed and analyzed by gravimetric analysis. The 24h.month^{-1} dust deposition rate (RD in 10^{-2}g.sec^{-1}) and the mean for the two seasons was calculated. Simultaneously, for trace metal analyses, gravimetric filter samples (0.2 g) from each area of the Kuwait Governorates were collected and predigested with 3ml of nitric acid (Aristar grade-69%: BDH laboratories, England) in polystyrene sterile centrifuge tubes and left overnight. The samples were then diluted in de-ionized water (50 ml) and digested in a microwave digester (Ethos1, Milestone, Italy). Metal concentrations were measured using ICP-MS (820-MS, Varian Inc., U.S.) to determine the metals concentrations [12]. Quality assurance was ensured by employing replicates, for the standard trace metals (ICP grade, Fisher Scientific, U.S.) and blanks (for every 5 samples). Instrument precision was assessed by using Standard Reference Material (SRM: 8785 Urban dust) for particulate matter from the U.S. National Institute of Standards Technology (NIST, Maryland, U.S.A.). Samples were recovered (98 ± 2 %) in agreement with certified values. Samples with recoveries >95% alone were considered for data analyses.

Using an air monitoring system, Kestrel-4200 (Nielsen-Kellerman, U.S.A.), the mean 24h meteorological data for the summer (April-September) and winter (October-March) seasons were recorded and compared to RD values. The following meteorological data were collected: wind direction, air flow rate, relative humidity, temperature and dew point.

Statistical software SPPSS-16 (StataCorp LP, Texas, U.S.A.) was used to test the significance (ANOVA) between the seasonal rate of pollutant emission, RD, and trace metal concentrations in $PM_{1.0}$ dust collected from six Governorates.

3. Results and Discussions

Studies showed the rate of dust deposition influenced Kuwait's weather condition [6, 15]. The apportionment of $PM_{1.0}$ dust was high from the industrial areas (I1-I4) when compared to dust distribution in the non-industrial areas (R1-R2) of the Kuwait Governorates (GI to GVI).

An overall view revealed an increase in RD with decreasing wind velocity in the $PM_{1.0}$ deposited samples irrespective of the two seasons especially in industrial areas than in the $PM_{1.0}$ dust deposited elsewhere in Kuwait arid areas (Figs. 2 to 5). This characteristic feature was found in line with the earlier findings [1-5]. Comparatively, season-wise analyses showed higher RD during the summer than during the winter. High RD in summer could be attributed to wind velocity [6-7] which peaks during the summer months of June-July and reaches a nadir in the month of September (Fig. 5). During the winter season, the wind velocity reaches its high in February-March and low in December (Fig. 5). Observations showed the influence of high temperature causing frequent dust storms due to less dense dust particles during summer [8-10]. $PM_{1.0}$ RD in the industrial and residential areas was observed in the increasing order of I4: GVI > I1: GI > I2: GII > I3: GV > R2: GIV > R1: G-III (Fig. 2). The influence of oil industries and open area subjected by dust storms and wind action could be attributed to the high RD of $PM_{1.0}$ in G-VI. Industrial activities influencing the increase of inorganic and organic pollutants in particulates >PM_{10} were observed by earlier investigators [12-14]. $PM_{1.0}$ dust deposition rate was found the least in R1: GIII among the analyzed samples due to few industrial establishments, lesser open space areas and dense residential buildings. Statistically, ANOVA tests revealed significant relationship between the rate of dust deposition in $PM_{1.0}$ among the sampled areas and the two seasons (Table 1).

Table 1. ANOVA on Governorate and season-wise rate of pollutant emission, rate of dust deposition and metals wise analyses in Kuwait

	df	MS	F	p-Value	F crit	Significance
Rate of dust deposition						
Area-wise	5	6.40	6.09	0.00014	2.38	*
Season-wise	11	65.46	62.30	< 0.001	1.96	*
Error	55	1.05				
Total	71					
Metals wise analyses						
Area-wise	5	6.601	21.087	< 0.001	2.38	*
Metals-wise	11	323.006	1031.75	< 0.001	1.96	*
Error	55	0.3130				
Total	71					

*: significant at $p < 0.001$

High concentrations of trace metals in $PM_{1.0}$ dust was observed in the sequence of Al > Fe > Zn > Ni > Pb > Cd irrespective of the two seasons and the Kuwait Governorate areas (Figs. 3-4). Al, Fe and Zn in high concentrations attributes to the exhaust fumes from small scale and oil industries (I3: GV, I4: GVI) increase in automobile pollution (I1: GI, I2: GII, R1: GIII), wind action (I1: G1, I4: GVI, R2: GIV) distributing these metals in Kuwait's arid environment besides soil dusting, salt and sea-spray sources. Our findings in this direction were found similar to that of the earlier findings [2, 4, 13]. High trace metals levels in $PM_{1.0}$ dust were found in summer (Fig. 3) than in winter (Fig. 4) due to the prevalent dust storms, and high atmospheric temperature that makes the $PM_{1.0}$ dust less dense in Kuwait's ambient atmosphere. Area wise analyses on trace metals in $PM_{1.0}$ dust revealed the order of sequence similar to that of the observations in Fig. 2. The earlier findings [16, 18] showed such similarities to that of the present study. These observations were also in line with statistical tests by ANOVA revealed significant differences between the area-wise and trace metals-wise analyses during the two seasons (Table 1).

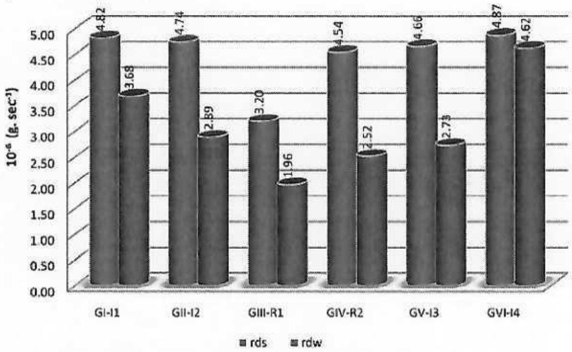

Figure 2. Rate of $PM_{1.0}$ dust deposition in the industrial (I) and non industrial areas (R) of Kuwait Governorates

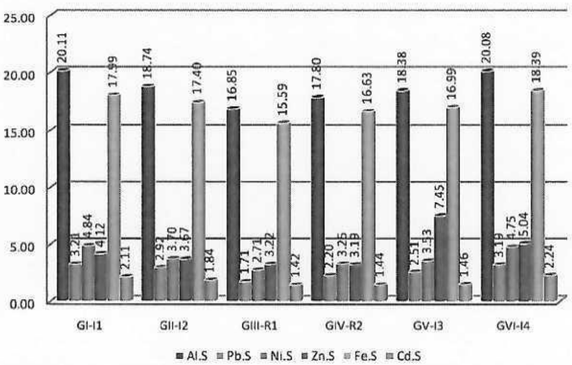

Figure 3. Trace metals levels in $PM_{1.0}$ in the industrial (I) and non-industrial areas (R) of Kuwait Governorates (summer)

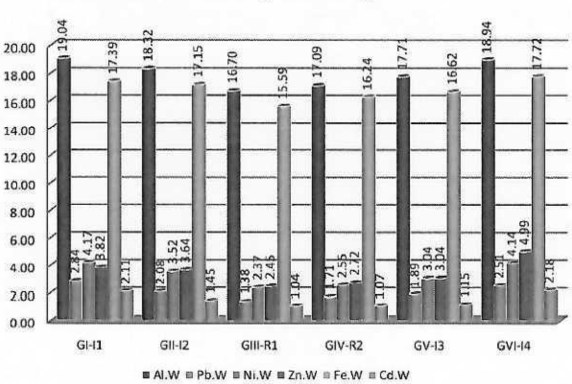

Figure 4. Trace metals levels in $PM_{1.0}$ in the industrial and non-industrial areas (R) of Kuwait Governorates (winter)

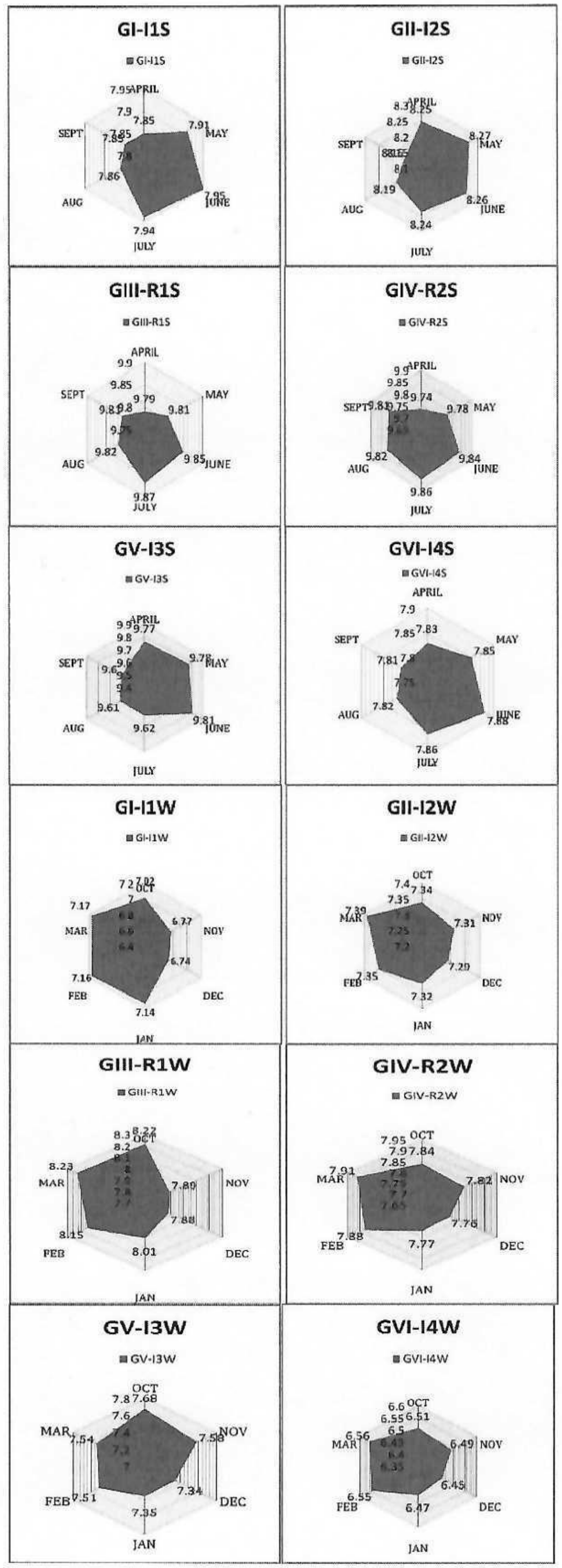

Figure 5. Wind velocity in Kuwait Governorates during summer and winter GI-GVI: Kuwait Governorates, S: Summer, W: Winter, I: Industries, R: Residential areas

4. Conclusion

Recently, residents from Kuwait arid Governorates experienced different respiratory illness due to respirable $PM_{1.0}$ [15, 17]. The present study revealed $PM_{1.0}$ contained high trace metals concentrations besides other pollutants that attributed to the high anoxic conditions. The causes are related to the natural dust dispersion, rapid industrialization, anthropogenic sources and global environmental changes. Air pollution in Kuwait revealed significant relationship between low wind velocity and high dust deposition rate (RD) in the sampled industrial areas when compared to the non-industrial areas of Kuwait's Governorates during summer than in winter thus, characterizing: (a) $PM_{1.0}$ dust as a potential tool to determine the quantitative dust deposition, (b) the composition of the major trace metals concentrations in $PM_{1.0}$ dust and (c) the seasonal apportionment of trace metals in $PM_{1.0}$ dust in Kuwait's arid environment besides instigating future environmentalists to take stringent measures to curtail air pollution.

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