

Assessment of respirable particulates in two residential areas of Kuwait State during dusty and nondusty storms: A time-series comparative study

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Original Article

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ABSTRACT

Background: Kuwait State is branded by the recurrent dust storms and high pollution level. It has the highest dust concentration and surface temperature in Peninsula. The aim of the present study was to assess the respirable particulates during days with and without dust storms in two residential areas in Kuwait State.

Materials and Methods: This time-series comparative study was accomplished during the period from 1 January 2013 to 31 December 2013. It was conducted by recording the local meteorological data in the two sampling stations at Mansoria (A) and Ali Sabah Al-Salem (B) residential areas, in addition to the sampling and analysis of respirable particulates (PM10) using the SOP-10 High-Volume PM10 Samplers' Standard Method.

Results: There were 256 and 278 measurement days (70.1 and 75.1% of the yearly days) in monitoring stations A and B, respectively, with a total of 119 (46.5%) and 134 (48.2%) days with dust storms, respectively. The daily concentrations of PM10 were higher than the National Ambient Air Quality Standards of Kuwait State (150 µg/m³) at the two stations. The annual PM10 concentration of B station [192.5 (264.5) µg/m³] was nonsignificantly higher than that of A [191.2 (182.7) µg/m³]. At the two stations, the levels of PM10 during days with dust storms were significantly higher than that during days without.

Conclusion: Respirable particulate is slightly higher in Ali Sabah Al-Salem than in Mansoria. Days with dust storms have significantly greater PM10 levels than those without. The study recommends application of land-use planning, and windbreaks, combating desertification, and enhancing stoppage of outdoor activities during dust storms among public.

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Key Words: Ali Sabah Al-Salem, dust storms, Kuwait State, Mansoria, residential areas, respirable particulates.

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INTRODUCTION

Dust storms are a natural phenomenon, in which dust particles can travel up to thousands of kilometers, resulting in high ambient dust concentrations. This means that pollutants emitted in a certain area worldwide can affect the concentrations in all countries. It is considered as one of the signs of desertification^[1]. Dust storms transport yearly ~2.2 billion tons of soil and dry sediments throughout the earth^[2]. Furthermore, many studies reported increased hospital admittance for respiratory and cardiovascular diseases owing to exposure to dust storms^[3,4]. In addition to the public health effects, the agriculture, air traffic, and tourism are also affected^[5-7]. Dust storms have great environmental effects, including reduction of visibility, soil erosion, ground water salinization, and climatic

change. Moreover, it may cause disease transmission, air pollution, closing of businesses, car ignition failure, road accidents, stoppage of electrical insulators, and drinking water contamination^[2,8,9].

Dust particles are classified into fine and respirable. Most of the fine particulates (PM_{2.5}) originate from industrial sources such as fossil-fuel combustion. They have a huge influence on health owing to penetration of the deepest parts of the lungs. Respirable particulates (PM₁₀) are mainly of natural sources such as soil and crustal materials. They are the dominant part of dust during dust storms^[1]. The PM₁₀ concentrations vary according to its source (man-made or natural); in addition, the meteorological parameters are the main factors affecting it. Dust storms are one of the major natural sources of respirable particulates in Kuwait

State^[10,11], Several European^[3,12], USA^[13], Middle East^[7,14], Kuwait^[15,16], and Chinese studies^[17] revealed high risk of lung cancer, heart diseases, and chronic obstructive lung diseases among those exposed to PM10.

Kuwait is a subtropical desert in the Arabian Peninsula. It has a large petroleum industry that affects the urban land use. Air quality in Kuwait's state is influenced by multiple factors that increase the state's energy demands, including topography, meteorology, socioeconomic development, population growth, and the elevated rate of industrialization and urbanization. It is branded by the recurrent dust storms and high pollution level. It has the highest dust concentration and surface temperature in Peninsula^[18–20]. In residential areas, the levels of PM10 are influenced by the presence of the surrounding human activities, such as traffic, commercial, and industrial. Mansoria and Ali Sabah Al-Salem are two residential areas in Kuwait with various surrounding activities.

The aim of the present study was to assess the respirable particulates during days with and without dust storms in two residential areas in Kuwait State (Mansoria, and Ali Sabah Al-Salem).

MATERIALS AND METHODS

This time-series comparative study was accomplished during the period from 1 January 2013, to 31 December 2013. It was conducted by recording the local meteorological data, in addition to the daily sampling and analysis of respirable particulates (PM10). PM10 concentration was used in the present study as an indicator of the dust storm (El-Tows) phenomenon^[7].

The study was performed in two residential areas in Kuwait State, Mansoria and Ali Sabah El-Salem. These two areas were selected specifically because they represent 50% of the total number of residential areas, one of which lies in the north and the other in the south, and the feasibility is a further reason of selection. The first is located in the north of Kuwait with residential and commercial activities. It is surrounded by heavy traffic roads, including Jassim Mohamed El-Wazzan, Cairo, Khalid Yousef El-Marsouk, and Issa Abdulla Bahmin Streets. Mansoria is close to Kuwait's bay and the Arabian Gulf. The sampling station was located above the polyclinic of Al-Mansoria at 29.360108°N, and 47.997259°E (Fig. 1)^[15].

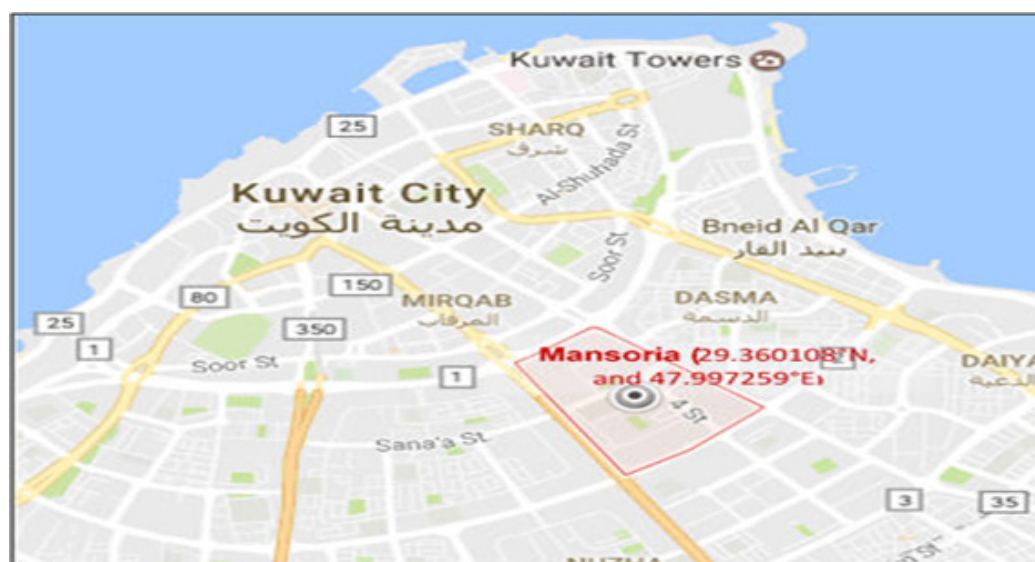


Fig. 1: Location of Mansoria Sampling Station, Kuwait, at 29.360108°N, and 47.997259°E.

Ali Sabah Al-Salem is a residential area located in Southern Kuwait. It is bounded on the west and south by the King Fahad Bin Abdulaziz road, on the north by the Wafrah road, and on the east by the Fahaheel Expressway/Saudi road. It is ~1 km from the Arabian Gulf coast. The industrial areas of harbor Abdulla and Shuaibah are located within 2 km to the north and north-north west of Ali-

Sabah-Al-Salem. It is surrounded by four industrial areas, including the eastern Shuaiba industrial area to the north, the western Shuaiba industrial area to the north-west, the Greater Burgan oil field to the north-west and west, and Umm Al-Hayman wastewater treatment plant to the southeast. The sampling site is located above the National Bank of Kuwait at 28.962276°N, 48.160023°E (Fig. 2)^[16].



Fig. 2: Location of Ali Sabah Al-Salem Sampling Station, Kuwait, at 28.962276°N, 48.160023°E.

Respirable particulates were sampled using PM10 high-volume air sampler Tisch Environmental Inc. TE-6000 series. US. EPA Federal References Number RFPS-0202-141 according to SOP-10 PM10 High Volume Air Sampler Standard Methods^[21]. Sampling stations were placed on the roof of the buildings, at a height of 5 m above the ground levels. For quality control of data, the overall equipment was periodically maintained. The operators were trained twice a year. The instruments were calibrated monthly, and the work stations were regularly audited. The measurement days were categorized into days with and without dust storms according to the PM10 concentrations.

Each of the Met-One meteorological stations of KNMN is fixed on a 10-m tower and has four main components. The first part was the one that has combined wind speed and direction sensor (sonic type wind sensor) at the 10-m height [(Met-One/Model: 50.5) uncertainty: ± 0.2 m/s (≤ 11.3 m/s) or $\pm 2\%$ (≥ 11.3 m/s) wind speed, $\pm 3^\circ$ wind direction]. The second was the combined relative humidity and temperature sensors (capacitive/resistive type sensor) with solar shield (Met-One/Model: 083E/Uncertainty: $\pm 2\%$ RH, $\pm 0.1^\circ\text{C}$). The third part was the atmospheric pressure sensor (Met-One/Model: 090D/Uncertainty: $\pm 1.35\text{mBar}/\pm 1.25\%$ FS). The two meteorological stations were equipped with data logger to measure the sensors, store both data and programs, and communicate via modems (Campbell Scientific/Model: CR3000), and GSM/GPRS modem for wireless communication (Sierra wireless/Model: Fastrack Xtend).

Statistical analysis

The data were statistically analyzed using IBM SPSS statistics version 21 (IBM Corporation, Armonk, NY: IBM). The measurement days were classified into with ($>200 \mu\text{g}/\text{m}^3$) and without ($\leq 200 \mu\text{g}/\text{m}^3$) dust storms according to the concentration of PM10^[7]. One-sample

Kolmogorov–Smirnov test was conducted to check the distribution of the variables. Kruskal–Wallis H-test was used to check the significance of variations of variables with more than two independent categories, with 95% confidence interval (CI). Mann–Whitney U-test was used to check the significance of variations with variables with two independent categories, with 95% confidence interval (CI)^[22,23]. Differences at P-value up to 0.05 are considered significant.

RESULTS

The highly significant one-sample Kolmogorov–Smirnov test indicates that the main variable (PM10 concentration) was nonparametric. So, all variables were expressed in the present study as median (interquartile range).

There were 256 measurement days (70.1% of the yearly days) in Mansoria monitoring station, with a total of 119 days with dust storms (46.5%). In Ali Sabah Al-Salem station, there were 278 sampling days (75.1% of the yearly days), with a total of 134 days with dust storms (48.2%). The total number of measurements was different in the two areas owing to different maintenance and calibration times in the two areas. Percentage days with dust storms during January, March, April, May, June, July, and August in Ali Sabah Al-Salem (37.50, 68.18, 50.00, 60.87, 86.21, 81.48, and 60.87%, respectively) were higher than that in Mansoria (30.43, 40.00, 47.62, 50.00, 80.77, 80.00, and 33.33%, respectively). In contrast, they were lower in Ali Sabah Al-Salem during February, September, October, November, and December. In addition, 100% of the sampled weekends (Saturday and Friday) and 43.15% of the weekdays in Mansoria were days with dust storms. In Ali Sabah Al-Salem, 85.71% of Saturdays, 93.75% of Fridays, and 44.04% of weekdays were days with dust storms. The annual median of PM10

concentrations in Mansoria monitoring station [191.21 (182.66) $\mu\text{g}/\text{m}^3$] was nonsignificantly lower than that in Ali Sabah Al-Salem [192.47 (264.46) $\mu\text{g}/\text{m}^3$] (Table 1). The daily concentrations of PM10 were greater than the National Ambient Air Quality Standards of Kuwait State (150 $\mu\text{g}/\text{m}^3$) in both Mansoria and Ali Sabah Al-Salem (Fig. 3). Kruskal–Wallis test revealed that the PM10

concentrations in both Mansoria and Ali Sabah Al-Salem showed highly significant variations among different days ($P < 0.05$, 95% CI). Further analysis using Mann–Whitney test showed significant variation in PM10 concentrations during Saturday and Friday and during other working days in both Mansoria and Ali Sabah Al-Salem ($P < 0.05$, 95% CI).

Table 1: Monthly and daily numbers and percent of days with dust storms in Mansoria and Ali Sabbah Al-Salem areas, Kuwait, 2013

Months	Mansoria station		Ali Sabah Al-Salem station	
	N (T) ^a	% ^b	N (T) ^a	% ^b
January	7 (23)	30.43	9 (24)	37.50
February	6 (19)	31.58	4 (21)	19.05
March	8 (20)	40.00	15 (22)	68.18
April	10 (21)	47.62	11 (22)	50.00
May	9 (18)	50.00	14 (23)	60.87
June	21 (26)	80.77	25 (29)	86.21
July	20 (25)	80.00	22 (27)	81.48
August	7 (21)	33.33	14 (23)	60.87
September	12 (20)	60.00	11 (23)	47.83
October	9 (19)	47.37	3 (19)	15.79
November	4 (19)	21.05	1 (19)	5.26
December	6 (25)	24.00	5 (26)	19.23
Total	119 (256)	46.48	134 (278)	48.20
Annual median of PM10 ($\mu\text{g}/\text{m}^3$)	191.2 (182.7)		192.5 (264.5)	

^aN (T) is the number of days with dust storms out of the total number of sampling days/month.

^b% is the percentage days with dust storms as related to the total sampling days/month.

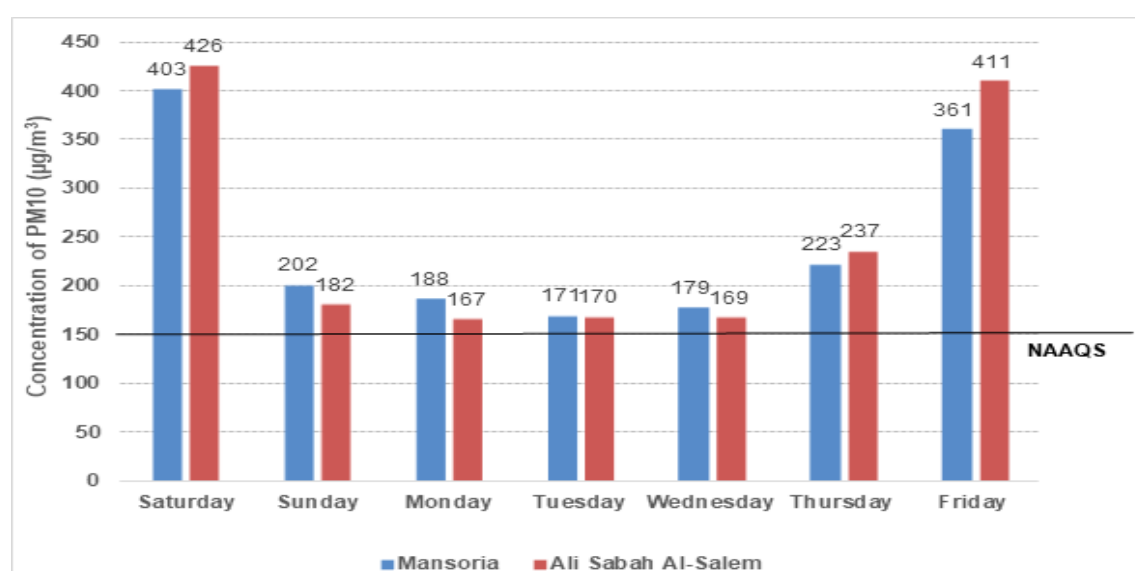


Fig. 3: Daily medians of respirable particulates (PM10) in Mansoria and Ali Sabah El-Salem Monitoring Stations, Kuwait, 2013.

In both Mansoria and Ali Sabah Al-Salem, during all months, the concentrations of PM10 during days with dust storms were significantly higher than that during days without dust storms ($P < 0.05$, 95% CI), except in the second station during November (Table 2). The annual

PM10 concentration of Ali Sabah Al-Salem [192.5 (264.5)] was nonsignificantly higher than that of Mansoria [191.2 (182.7)]. During most of the year, the concentrations of PM10 during days with dust storms were higher in Ali Sabah Al-Salem than in Mansoria.

Table 2: Monthly medians of PM10 concentrations in days without and with dust storms in Mansoria and Ali Sabah Al-Salem monitoring station, Kuwait, 2013

Months	Case	Mansoria						Ali Sabah Al-Salem					
		No ¹	Median ²	Q1 ³	Q3 ⁴	IQR ⁵	P-value ⁶	No	Median	Q1	Q3	IQR	P-value
January	Without	16	127.2	104.4	158.6	54.2	<0.05	15	143.1	122.8	155.2	32.4	<0.05
	With	7	548.4	258.0	1860.1	1602.1		9	827.2	270.2	1896.8	1626.6	
February	Without	14	130.9	118.1	169.9	51.8	<0.05	17	140.8	102.7	167.5	64.8	<0.05
	With	6	246.0	216.4	600.8	384.4		4	438.7	280.0	843.5	563.5	
March	Without	12	126.5	102.2	177.8	75.6	<0.05	7	133.7	106.1	169.6	63.5	<0.05
	With	8	300.2	248.3	364.9	116.6		15	433.5	320.1	677.2	357.0	
April	Without	11	124.4	106.3	183.3	77.0	<0.05	11	142.2	102.5	168.6	66.1	<0.05
	With	10	338.2	260.7	446.6	185.9		11	451.2	297.4	857.5	560.1	
May	Without	9	122.6	103.1	132.1	29.0	<0.05	8	159.7	97.5	172.7	75.2	<0.05
	With	9	332.3	268.6	525.7	257.1		14	526.9	249.7	875.4	625.7	
June	Without	5	137.4	118.2	158.2	40.0	<0.05	4	165.3	150.8	186.9	36.1	<0.05
	With	21	540.9	297.2	874.7	577.5		25	586.0	369.1	1344.3	975.2	
July	Without	5	159.7	122.1	186.6	64.5	<0.05	4	156.7	144.9	176.6	31.7	<0.05
	With	20	323.0	248.1	424.3	176.1		22	394.5	292.1	602.0	309.9	
August	Without	14	180.1	165.8	189.0	23.3	<0.05	8	164.1	142.6	172.7	30.1	<0.05
	With	7	277.2	229.0	626.1	397.1		14	235.9	217.0	415.8	198.8	
September	Without	8	157.3	131.6	173.5	41.9	<0.05	11	144.4	135.8	174.6	38.8	<0.05
	With	12	338.5	226.0	447.1	221.1		11	269.7	241.3	360.3	119.0	
October	Without	10	132.0	101.8	158.7	56.9	<0.05	16	127.9	115.7	156.5	40.8	<0.05
	With	9	303.9	245.8	383.7	137.9		3	416.3	264.9	–	–	
November	Without	14	105.5	78.9	141.9	63.0	<0.05	18	87.4	66.3	109.6	43.2	>0.05
	With	4	245.0	217.2	291.2	74.0		1	272.1	–	–	–	
December	Without	19	96.6	73.4	123.8	50.4	<0.05	20	105.0	93.5	127.0	33.5	<0.05
	With	6	291.6	245.3	595.2	349.9		5	360.5	217.9	872.5	654.6	

1: Number of measurement days.

2 :The middle value of the ranked ordered data set.

3: The middle value of the first half of the ranked ordered data set.

4: The middle value of the second half of the ranked ordered data set.

5: The difference between Q3 and Q1.

6: *P*-value using Mann–Whitney test.

7: Without dust storms.

8: With dust storms.

In Mansoria, the prevailing wind directions all over the years were the north–west and west–north west. However, in Ali Sabah Al-Salem, the most common prevailing wind directions are the north–west and west–north west, in

addition to west, south–south east, east, east–north east, and south. During June and July, the prevailing wind directions in both Mansoria and Ali Sabah Al-Salem were north–west (Table 3).

Table 3: Monthly prevailing wind directions in Mansoria and Ali Sabah Al-Salem areas, Kuwait, 2013

Month	Prevailing wind direction (deg.)	
	Mansoria	Ali Sabah Al-Salem
January	NW	W and WNW
February	NW	WNW
March	NW	WNW, SSE, E
April	WNW and NW	E, ENE
May	NW and WNW	E, WNW, ENE
June	NW	NW
July	NW and WNW	NW
August	WNW and NW	WNW, ENE
September	WNW and NW	WNW
October	NW and WNW	WNW, ENE, and W
November	WNW and NW	ENE, WNW
December	NW and WNW	SSE, WNW, S

E, east; N, north; S, south; W, west.

In both Mansoria and Ali Sabah Al-Salem, June and July were of the highest wind speed. However, June, July, August, and September were of the highest air temperatures

in the two residential areas (Fig. 4). In the two monitoring stations, June, July, and August had the lowest relative humidity, and atmospheric pressures (Fig. 5).

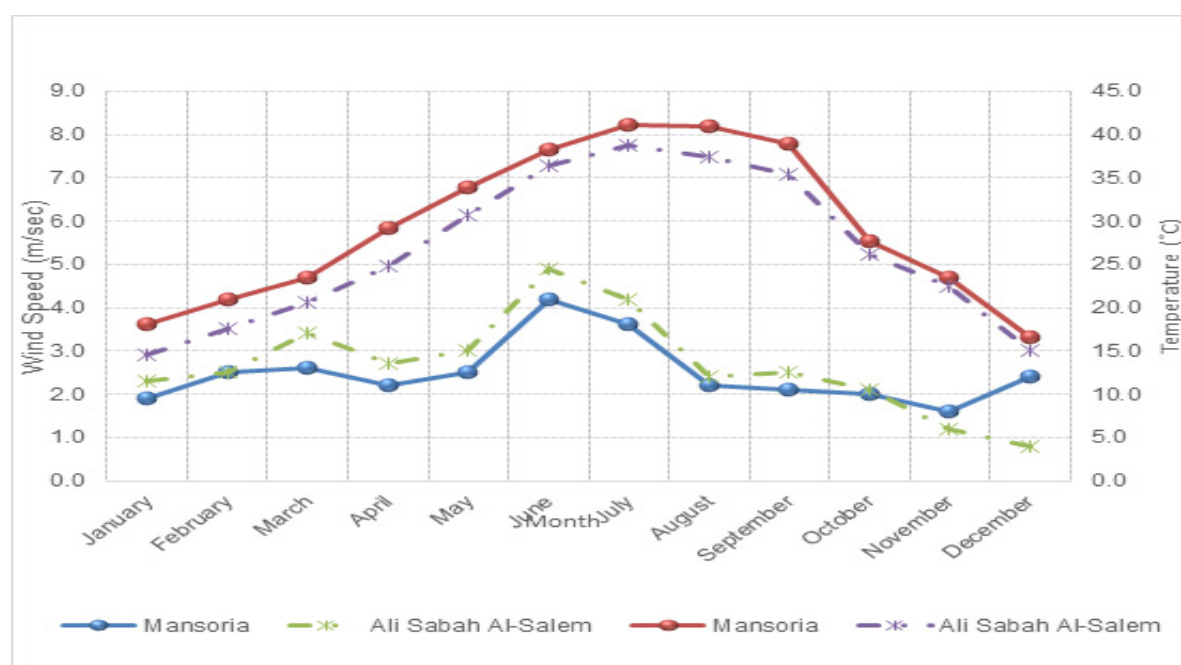


Fig. 4: Monthly wind speed and air temperature in Mansoria and Ali Sabah Al-Salem, Kuwait, 2013.

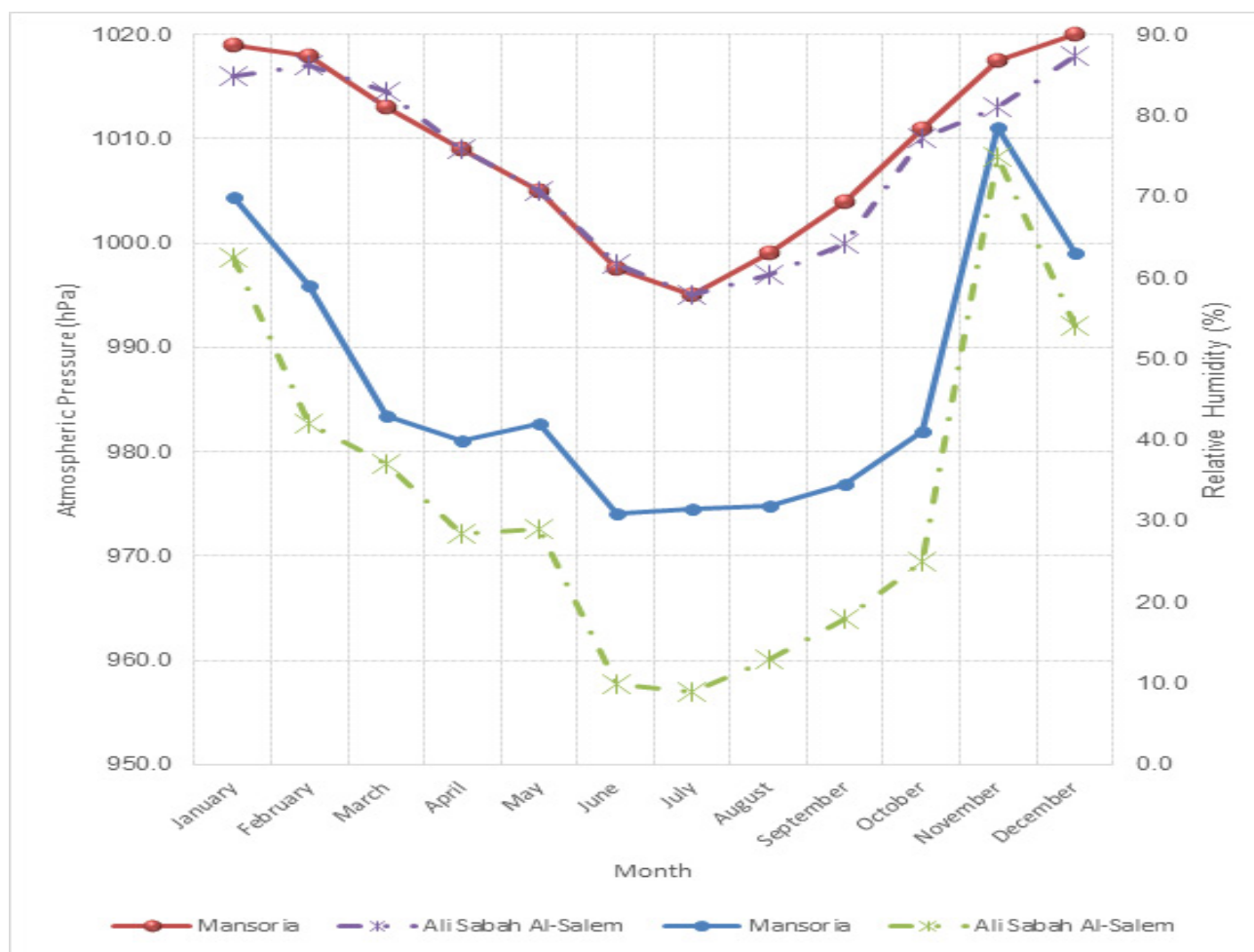


Fig. 5: Monthly atmospheric pressure and relative humidity in Mansoria and Ali Sabah Al-Salem, Kuwait, 2013.

DISCUSSION

Unlike most of the researches, the concentrations of PM₁₀ in this study during weekends were significantly greater than that during weekdays in both Mansoria and Ali Sabah Al-Salem. A Southern California (2004)^[24], a Brazilian study (2013)^[25], and a Korean one (2017)^[26] concluded higher weekdays than weekends' concentrations. They explained this finding based on the high-traffic activities during weekdays that increase exhaust emissions, corrosion of tires, brakes, and roads that enhance PM₁₀ excitation. In Mansoria and Ali Sabah Al-Salem, 100 and 87.7% of the weekends, respectively, were affected by dust storms' events; and this may be the main cause of the observed contradiction with the other studies.

In both Mansoria and Ali Sabah Al-Salem, during all months, the concentrations of PM₁₀ during days with dust storms were significantly higher than that during days without dust storms. An Arabian Peninsula study (2018)^[27] and an Indian study (2017)^[28] reported high PM₁₀ concentrations during dust storms' episodes owing to large distance travels of particulate matters.

In most months, the PM₁₀ levels during days with dust storms were higher in Ali Sabah Al-Salem than Mansoria. This may be attributed to human activities and meteorological parameters. Regarding human activities, the two areas have similar commercial, and traffic activities, but the Ali Sabah Al-Salem is downwind the industrial activities at the west, north west, and north, which were the prevailing wind directions all over the year^[15,16]. Regarding meteorological parameters, the air temperature and relative humidity in Mansoria were higher than that in Ali Sabah Al-Salem. The wind speed in Mansoria was lower than that in Ali Sabah Al-Salem. This reduced the PM₁₀ levels in Mansoria^[29].

During November, in Ali Sabah Al-Salem, the concentrations of PM₁₀ during days without dust storms were nonsignificantly lower than those with. This nonsignificance was owing to the presence of only 1 day with dust storm during this month. So the significance of variation could not be estimated.

June and July were the months of the highest PM₁₀ concentrations in both Mansoria and Ali Sabah Al-Salem. This can be explained based on meteorological factors,

where these 2 months were of the highest wind speed and the lowest relative humidity in the two residential sites. A study conducted in Kathmandu Valley in 2008^[30], and another one in Korea in 2006^[31] established a direct relation of PM10 concentrations and wind speed and an inverse relation with relative humidity.

LIMITATIONS OF STUDY

The lack of hospital admission, morbidity, and mortality data to be correlated with dust storms events represents a limitation of this study. Based on our limited knowledge, no major changes were conducted in the two residential areas after the study. In addition, we do not have any concentration data after the study.

CONCLUSION

The daily respirable particulates' concentrations in the two residential areas in Kuwait State are very high as compared with the ambient air quality standards. This situation may cause poor ambient air quality and deterioration of public health. The annual levels of PM10 is slightly higher in Ali Sabah Al-Salem than in Mansoria. Days with dust storms have greater PM10 levels than those without.

The results of the present study motivate most countries to use the basis of land-use planning in designing new residential areas (residential areas must be upwind the industrial ones). It also urges the governments and media to enhance public to stop all outdoor activities during dust storms. In addition, establishing windbreaks around the residential areas, and combating desertification in Kuwait may mitigate the effects of dust storms. Further research dealing with the chemical composition of PM10 and its correlation with hospital admission, morbidity, and mortality data is recommended. Moreover, additional study interested in risk assessment of dust storms in Kuwait is also advised.

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