Effect of meteorological factors on the daily average levels of particulate matter in the Eastern Province of Saudi Arabia: A Cross-Sectional Study

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Abstract: Particulate matter (PM) is a key indicator of air pollution. Particles with an aerodynamic diameter less than 10 µ (PM_{10}), and 2.5 µ ($PM_{2.5}$); are inhaled and deposited in the respiratory system. The fate of air pollutants, including PM, is highly dependent on meteorological parameters as they control natural emissions, transport, chemistry and deposition. This study was a cross-sectional one aimed at assessing the effect of meteorological factors on the daily average levels of PM in the Eastern Province of Saudi Arabia during year 2012. Two monitoring stations with the HORRIBA APDA-371 Continuous Particulate Monitors were distributed in Dammam and Khobar governorates for incessantly recording the hourly ambient levels of $PM_{10}$and $PM_{2.5}$. Simultaneously, the meteorological parameters (wind speed, wind direction, air temperature, relative humidity, barometric pressure, and precipitation) were recorded by the WS600-UMB weather parameters' sensor. The daily average levels PM_{10}, and $PM_{2.5}$ exceeded the U.S. National Ambient Air Quality Standards (NAAQS) for 19.5%, and 45.8% in the Dammam station measurement days and 27.1% and 36.1% in the Khobar measurement days respectively. They were correlated positively with wind speed and air temperature. Their relationships with wind direction, relative humidity, atmospheric pressure, and precipitation were negative.

Key words: air pollution, meteorological factors, particulate matter, Saudi Arabia.

Introduction

Eastern Province has the largest and the most important governorates in the Kingdom of Saudi Arabia (KSA) from both the number of population and the developed economy points of view. Dammam is the capital of the Eastern Province and represents its major seaport. Its population is about 768,602 inhabitants. It presents at 26.43°N latitude, and 50.11°E longitude, and at 10 m above the sea level. Khobar is the second important large city in this region. Its population is about 165,799 inhabitants. It presents at 26.28°N latitude, and 50.21°E longitude. Its height above sea level is similar to that of Dammam. Due to the presence of several industrial, commercial, educational and recreational areas, there is an increase in the migration of people to these two governorates with a subsequent increase in the human and traffic activities. Consequently, a change in the air quality level is expected (El-Sharkawy & Zaki, 2012).

Air pollution becomes a significant challenge all over the world, especially in the developing countries (C. K. Chan & Yao, 2008). In recent years, particulate matter (PM) is considered the most important air pollutant from the public health point of view (Hu, Jia, Wang, & Pan, 2013; Qiu et al., 2012). Respirable (PM_{10}), and fine ($PM_{2.5}$) particulate matters are suspended particles with aerodynamic diameters ≤ 10 µm and 2.5 µm respectively. Their multiple sources include natural, industrial and traffic (Tian, Qiao, & Xu, 2014).

Many scientific studies have linked particulate matters' breathing to a series of significant health problems, including asthma aggravation, increase in respiratory symptoms, reduced lung function, cardiovascular disease, and premature death. The excess of daily mortality and morbidity are associated with exposure to respirable and fine particulates (Pandey et al., 2013; Reyna, Bravo, López, Nieblas, & Nava, 2012; Valavanidis, Vlachogianni, Fiotakis, & Loridas, 2013). In addition to health hazards, respirable and fine particulates play a vital role on climate change through their impact on radiative balance and aerosol–cloud interaction (Trivedi, Ali, & Beig, 2014; Vellingiri et al., 2014). In addition, PM can contribute to the variation of the visual range, which is the most obvious sign of atmospheric pollution to the public(Cheung, Wang, Baumann, & Guo, 2005; Yang et al., 2007).

The air quality situation of an area is largely dependent on the emission strength in combination with meteorology. The fates of air pollutants are highly determined by meteorological parameters such as wind speed, wind direction, air temperature, humidity, barometric pressure and height of the mixing layer. Moreover, they control natural emissions, transport, chemistry and deposition. Changing meteorological conditions on short and long time scales may affect the atmospheric pollutants' concentrations (Tai, Mickley, & Jacob, 2010; F. Zhang, Wang, Lv, Krafft, & Xu, 2011). For particulate matter, the limited number of studies do not agree on the direction of the anticipated change with meteorological factor (Jacob & Winner, 2009).The importance of air pollution attracts many studies in the recent decades towards understanding the spatio-temporal distribution and the effect of meteorology on the evolution of particulate matters (Ali, Budhavant, Safai, & Rao, 2012; Gugamsetty, 2012). Since particulate matter consists of many components with different physical and chemical properties, the effect of the meteorological parameters on the individual components varies and is more uncertain than for other pollutants (e.g. ozone)(Dayan et al., 2011; Mues et al., 2012; Whiteman, Hoch, Horel, & Charland, 2014).

The present study was aimed to assess the effect of meteorological factors on the daily average levels of respirable and fine particulate matters in the Eastern Province of Saudi Arabia during year 2012.

Materials and Method

This study was a cross-sectional analytical study, in which two different locations were selected as fixed air pollution monitoring stations in the Eastern Province of Saudi Arabia (Figures 1 and 2). Station No. 1 was located in the west municipality of Dammam at 26.40˚N latitude, 50.04˚E longitude, while station No. 2 was located at El-Khobar housing region at 26.06˚N latitude, and 50.21˚E longitude.

The study period extended from January 1, 2012 to December 31, 2012. The concentration of respirable (PM_{10}), and fine particulates ($PM_{2.5}$) were measured and recorded by the Horiba APDA-371 Continuous Particulate Monitor(Ielpo, Paolillo, de Gennaro, & Dambruoso, 2014; Solomon, Hopke, Froines, & Scheffe, 2008)using the beta attenuation principle. This monitor depends on collection of particulates on glass-fiber filter. The carbon-14 (C_{14}) represents a continuous source of high-energy electrons (beta rays), which attenuates as they collide with the clean filter. These beta rays are detected and counted by a sensitive scintillation detector to determine a zero reading. The Monitor automatically advances this spot of tape to the sample nozzle, where a vacuum pump then pulls a measured and controlled amount of dust-laden air through the filter tape, loading it with ambient dust ($PM_{2.5}$ or PM_{10}, depending upon the sampling head). At the end of an hour, this dirty spot is placed back between the beta source and the detector thereby causing an attenuation of the beta ray signal, which is used to determine the mass of the particulate matter on the filter tape and the mass concentration of particulate matter in the ambient air. The decrease of the signal scintillation counter is inversely proportional to the mass loading on the filter. For quality control, the monitor was automatically calibrated, and the zero testing of blank filter paper is performed at the beginning and end of the measurement period(CPCB, 2011).

The meteorological parameters were simultaneously recorded by the WS600-UMB weather parameters' sensors that compact weather station measures air temperature, relative humidity, precipitation quantity, air pressure, wind direction, and wind speed. Temperature was measured using a highly accurate NTC-resistor, while humidity was measured using a capacitive humidity sensor. Both sensors were located in a ventilated radiation shield to reduce the effects of solar radiation. Absolute air pressure was measured using a built-in MEMS sensor. The wind sensor used four ultrasound sensors, which take cyclical measurements in all directions. The resulting wind speed and direction were calculated from the measured run-time sound differential.

The above instruments were adjusted to save the measured concentrations and meteorological data as one-hour averages in the character-separated values (csv) format that easily transformed to excel sheet. The daily averages' concentrations and meteorological parameters, including prevailing wind directions were subsequently calculated. Local daily wind speed was then classified according to the Beaufort's wind force scale(Y. Zhang, Duc, Corcho, & Calbimonte, 2012) into light, and gentle-moderate.

The data were entered and statistically analyzed using the Statistical Package for the Social Sciences (IBM SPSS Statistics-21). The PM_{10}, $PM_{2.5}$, and the meteorological parameters (numeric variables) were classified according to the sampling station, season, local wind speed, and its prevailing direction (categorical variables) and expressed as [median (Inter quartile range[1])]. The Kolmogorov-Smirnov Z test was used to check normality of the numeric data. Mann-Whitney, Kruskal-Wallis H tests

[1] the difference between the first and third quartiles of a set of data

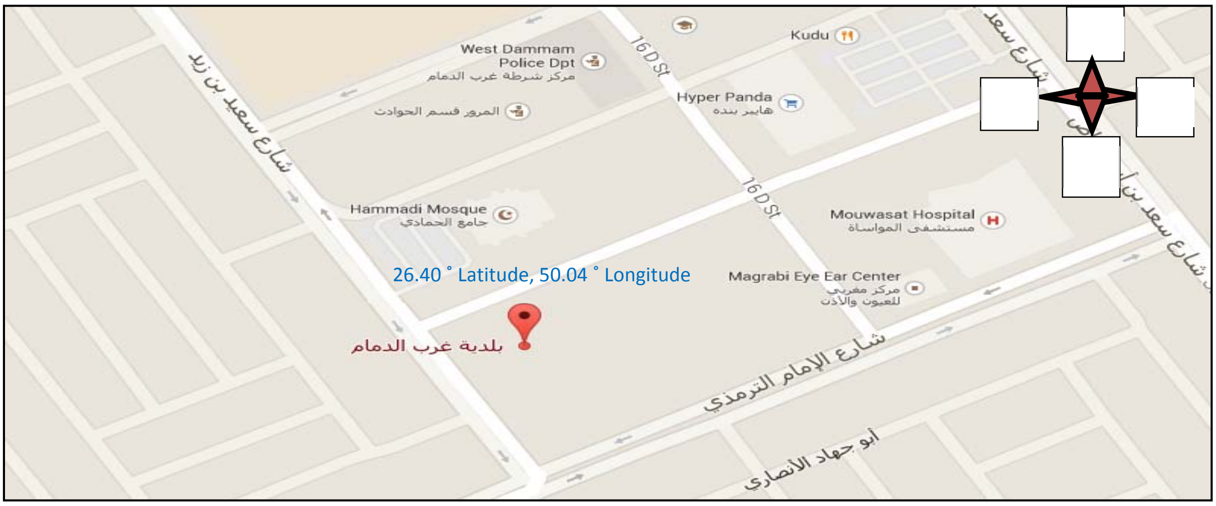

Figure 1: Location of Dammam Particulate Matter Monitoring Station

Figure 2: Location of El-Khobar Particulate Matter Monitoring Station

were used to check the significance of discrepancy in case of variables with two, and more classes respectively. The power, significance, and direction of relationships between two variables were tested using Spearman's rho correlation coefficient (Ott; & Longnecker., 2010; Peng; & Dominici., 2008).

Results

There were totally 618 measurement days, 308 for station-1 in Dammam and 310 for station-2 in El-Khobar. Levels of PM_{10} and $PM_{2.5}$ in Dammam were higher than the Saudi National Ambient Air Quality Standards for 60 (19.48%), and 141 (45.78%) measurement days, while those in El-Khobar exceeded this standard for 84 (27.1%), and 112 (36.13%) measurement days (Table 1). The PM_{10} and $PM_{2.5}$ showed non-parametric behavior (highly significant Kolmogorov-Smirov test of normality). The [Median (Interquartile range)] for PM_{10} and $PM_{2.5}$ in Dammam station [81.72 (92.20) μg/m^3] and [32.96 (31.52) μg/m^3] were higher than those in El-Khobar [80.81 (127.34) μg/m^3] and [27.17(32.62) μg/m^3] respectively (Table 2). These levels had a positive weak highly significant Spearman's rho correlation coefficients with local wind speed [0.272, 0.172] and air temperature [0.282, 0.300] at 0.001 level. They exhibited negative greatly significant coefficients with prevailing wind direction [-0.383, -0.308 respectively], relative humidity [-0.538, -0.180], and barometric pressure [-0.517, -0.468]. The precipitation exhibited very weak negative correlation coefficient with PM_{10} [-0.109] and $PM_{2.5}$ [0.079] [Figure 3].

The overall data indicates that the highest daily PM_{10} concentration [116.4 (117.7) μg/m^3] was found during the fall season with the lowest relative humidity [18.5 (11.6)%], followed by summer [91.9 (136.9) μg/m^3], spring [76.4 (80.7) μg/m^3]. While the lowest mean level was recorded during winter.

Table 1: Days of daily average concentrations of respirable and fine particulates higher than the Saudi National Ambient Air Quality Standards

	Station-1 (the west municipality of Dammam at 26.40 ° latitude, 50.04 ° longitude)	Station-2 (El-Khobar housing region at 26.06° latitude, and 50.21° Longitude)
	No (%)	
Number of days of daily average PM_{10}>150μg/m^3	60 (19.48%)	84 (27.10%)
Number of days of daily average PM_{10}<150μg/m^3	248 (80.52%)	226 (72.90%)
Total	**308**	**310**
Number of days of daily average $PM_{2.5}$>35μg/m^3	141(45.78%)	112 (36.13%)
Number of days of daily average $PM_{2.5}$<35μg/m^3	167 (54.22%)	198 (63.87%)
Total	**308**	**310**

[45.0 (74.7) μg/m3] of maximum relative humidity (55.5%). There was highly significant PM10 variation at different seasons. The maximum PM2.5 was recorded during summer season [40.1 (62.5) μg/m3], followed by winter [29.5 (25.8) μg/m3], fall [29.5 (24.5) μg/m3], and spring [27.9 (20.4) μg/m3]. The fine particulate concentrations had non-significant variation with seasons. Generally, the PM10, and PM2.5 were higher at gentle-moderate winds than at light ones (Table-2).

In Dammam station, the "southeast light wind" was the most frequent (34.2% of the total measurement days), followed by the "southeast gentle-moderate" (17.9%), "south light" (16.0%), and "southwest light" (11.4 %). The maximum PM_{10} level was at the "southern gentle-moderate wind" [**215.1 (154.2)** μg/m^3**]** during summer, while the minimum one [**21.1 (13.6)** μg/m^3]) was at the "western gentle moderate wind" during winter. The highest $PM_{2.5}$ [84.0 (23.0) μg/m^3] was at the "southeast light wind" during fall, and the lowest [16.9 (13.8)μg/m^3] was at the "south light wind" during spring (Table 3).

In El-Khobar station, the "southeast light" winds were the most frequent (47.5%), followed by "south light" (18%), and "southeast gentle-moderate" (11.8%). Winter season recorded the highest PM_{10} and $PM_{2.5}$ [218.6 (124.4), 91.5 (167.5) μg/m^3] at "southeast gentle-moderate winds", and "southwest gentle-moderate winds" respectively. The PM_{10}, and $PM_{2.5}$ were of the lowest values at the "southeast light winds" during the summer season (Table 4).

Discussion

Dammam is the capital of the Eastern Province of Saudi Arabia, and its area is bigger than El-Khobar. In addition; the industrial, commercial, educational, recreational and traffic activities in Dammam are higher than those in El-Khobar(Al-Homaidan, 2008).. For this reason, the daily PM_{10} and $PM_{2.5}$ levels in Dammam were the highest in Dammam. This finding is in accordance to the results of another study, which was previously conducted in the same two cities (El-Sharkawy & Zaki, 2012).

In the present study, the PM_{10} and $PM_{2.5}$ levels had a positive weak highly significant Spearman's rho correlation coefficient with air temperature. This may be due to the increased road dust re-suspension, and contribution of secondary particles on the relatively warm sunny days. This result is consistent with the results of similar studies in different areas of the world such as Athens (Vardoulakis & Kassomenos, 2008), China (Trivedi, et al., 2014), and United States (Tai, et al., 2010). On the other hand, this positive correlation is contradictory to other studies in Brimingham ammonium nitrates on particulates, and the reduced particulate matter dispersion under cold stable meteorological conditions may be the main cause of the negative correlation.

The positive statistically significant correlation of PM_{10} and $PM_{2.5}$ with local wind speed may be related to dust excitation at the stronger winds that may carry PM from other areas (southeast is the daily prevailing wind direction in the two sampling stations in 53.5% of the measurement days). This result is in accordance with the result of the Buenos Aires study during summer (Bogo et al., 2003; Trivedi, et al., 2014). On contrary, other studies in Athens and Brimingham (Vardoulakis & Kassomenos, 2008),

Table 2: Spatial and seasonal variation of the daily average PM_{10}, and $PM_{2.5}$ concentrations and meteorological factors of Dammam and El-Khobar monitoring stations, 2012

		24-Hour Average PM_{10} Concentration (µg/m^3)						24-Hour Average $PM_{2.5}$ Concentration (µg/m^3)						Meteorological Factors as [Median (IQR)]						
		N[1]	Median[2]	Q_1[3]	Q_3[4]	IQR[5]	P-Value	N	Median	Q_1	Q_3	IQR	P-Value	Wind Speed (m/sec)	Wind Direction (˚)	Prevailing Wind Direction	Air Temperature (°C")	Relative Humidity (%)	Pressure (hpa)	Precipitation (mm)
Spatial variation	Station-1[6]	308	81.7	41.7	133.9	92.2	>0.05[7]	308	33.0	23.0	54.5	31.5	<0.05	2.7 (1.1)	146.9 (27.2)	SE	33.0 (13.3)	27.9 (25.5)	998.7 (9.4)	0.0 (0.0)
	Station-2[8]	310	80.8	32.5	159.8	127.3		311	27.2	14.0	46.6	32.6		2.3 (1.3)	147.7 (27.9)	SE	32.2 (8.9)	24.7 (24.1)	999.5	0.0 (0.0)
Seasonal Variation	Fall	172	116.4	49.1	166.8	117.7	<0.05[9]	172	29.5	19.8	44.3	24.5	>0.05	2.5 (1.0)	158.1 (65.7)	SE	27.6 (10.1)	18.5 (11.6)	997.6 (4.1)	0.0[10]
	Winter	160	45.0	26.6	101.3	74.7		160	29.5	19.5	45.3	25.8		2.5 (1.5)	202.2 (68.2)	S	19.0 (7.4)	55.3 (29.6)	1013.9 (7.3)	0.0 (0.0)
	Spring	163	76.4	46.6	127.3	80.7		163	27.9	19.8	40.2	20.4		2.5 (1.7)	144.9 (13.2)	SE	32.0 (6.9)	29.5 (19.9)	1003.1 (5.1)	0.0 (0.0)
	Summer	123	91.9	19.3	156.2	136.9		123	40.1	7.6	70.1	62.5		2.7 (1.3)	143.1 (7.1)	SE	36.5 (3.1)	27.7 (19.9)	995.9 (4.3)	0.0[10]

[1] Number of measurement day

[2] The middle number between the smallest and the highest numbers

[3] The middle number between the smallest number and the median of the data set (the first quartile).

[4] The middle number between the median and the highest number of the data set (the third quartile).

[5] Interquartile Range.

[6] Atthe west municipality of Dammam at 26.40 ˚ latitude, 50.04 ˚ longitude

[7] P-value using Mann-Whitney test

[8] El-Khobar housing region at 26.06˚ latitude, and 50.21˚ Longitude

[9] P-value using Kruskal-Wallis H test

[10] Precipitation is constant during fall, and summer seasons (zero mm)

Table 3: Wind speed and prevailing wind direction as related to the particulate matter concentrations in Dammam air monitoring station at 26.40 ° latitude, 50.04 ° longitude, Saudi Arabia, 2012

			Light wind (<3.1 m/sec)				Gentle-Moderate wind (3.1-7.8 m/sec)				
Season	Prevailing Local Wind Direction	No[1]	PM10 Concentration (µg/m³)	P-Value[2]	PM2.5 Concentration (µg/m³)	P-Value	No	PM10 Concentration (µg/m³)	P-Value	PM2.5 Concentration (µg/m³)	P-Value
Fall	SE[3]	14	170.0 (64.8)		84.0 (23.0)		1	--		--	
	S[4]	24	115.8 (57.7)		34.7 (21.4)		5	179.5 (72.7)		73.1 (45.2)	
	SW[5]	15	46.1 (76.6)	<0.05	32.6 (10.0)	<0.05	6	126.6 (82.3)	<0.05	26.9 (56.4)	<0.05
	W[6]	5	91.2 (84.6)		36.4 (13.0)		4	119.8 (194.5)		30.9 (96.7)	
	NW[7]	3	--		--		4	149.7 (53.3)		28.7 (55.8)	
Winter	E[8]	0	--		--		2	--		--	
	SE	6	25.5 (28.3)		19.5 (9.5)		2	--		--	
	S	19	35.2 (20.7)	>0.05	27.7 (13.1)	>0.05	0	--	>0.05	--	>0.05
	SW	12	31.6 (22.1)		20.7 (19.0)		6	25.7 (23.1)		17.1 (4.0)	
	W	12	30.0 (23.4)		24.9 (22.6)		13	21.1 (13.6)		18.2 (6.9)	
	NW	1	--		--		0	--		--	
Spring	SE	38	69.7 (52.8)		26.5 (14.8)		36	131.2 (102.6)		42.1 (39.2)	
	S	6	26.8 (22.4)	<0.05	16.9 (13.8)	<0.05	1	--	<0.05	--	<0.05
	SW	8	51.2 (16.1)		35.9 (5.6)		0	--		--	
	W	2	--		--		0	--		--	
Summer	SE	47	95.2 (35.6)	-	54.7 (32.8)	--	16	215.1 (154.2)		80.8 (63.6	--

Jinan, China (Yang, et al., 2007), and Milan, Italy (Marcazzan M. Grazia, Vaccaro, Valli, & Vecchi, 2001)revealed a negative correlation between PM_{10} concentration and the wind speed. The better dispersion and the consequent PM dilution at higher wind speed are the main cause of the negative relation.

The particulates' concentrations disclosed negative correlation with relative humidity because of the settlement and removal of particulate matter, especially coarse size out of the humid atmosphere. This negative relation is compliant with those of the Delhi (Trivedi, et al., 2014), and European studies (Vardoulakis &

[1] Number of measurement days

[2] P-value using Kruskal-Wallis H test

[3] South-East

[4] South

[5] South-West

[6] West

[7] North-West

[8] East

Kassomenos, 2008), while it is contradictory to studies that have been conducted in Jinan, China(Yang, et al., 2007)and Hangzhou, China(Jian, Zhao, Zhu, Zhang, & Bertolatti, 2012). This discrepancy is due to the formation of secondary particles at high relative humidity.

Due to the limited amount of rainfall in Saudi Arabia all over the year, levels of PM_{10} and $PM_{2.5}$ showed a negative weak correlation coefficient with the precipitation which usually acts as a scavenging sink for particulates. This result is consistent with that of the European (Vardoulakis & Kassomenos, 2008), Beijing (Tian, et al., 2014), and United States (Tai, et al., 2010) studies.

Table 4: Local Wind speed and prevailing wind direction as related to the particulate matter concentrations in El-Khobar air monitoring station at 26.06˚ latitude, and 50.21˚ Longitude, Saudi Arabia, 2012

Season	Prevailing Local Wind Direction	Light wind (<3.1 m/sec)					Gentle-Moderate wind (3.1-7.8 m/sec)				
		No[1]	PM10 Concentration (µg/m³)	P-Value[2]	PM2.5 Concentration (µg/m³)	P-Value	N	PM10 Concentration (µg/m³)	P-Value	PM2.5 Concentration (µg/m³)	P-Value
Fall	N[3]	2	--		--		0	--		--	
	E[4]	1	--		--		0	--		--	
	SE[5]	48	38.2 (109.3)		18.4 (19.4)		6	172.1 (205.8)		42.7 (53.4)	
	S[6]	18	168.3 (106.8)	<0.05	26.8 (44.3)	>0.05	2	--		--	<0.05
	SW[7]	5	131.6 (95.9)		24.2 (17.0)		0	--		--	
	W[8]	4	139.3 (38.8)		25.1 (16.3)		0	--		--	
	NW[9]	5	148.2 (100.2)		31.8 (11.1)		0	--		--	
Winter	N	2	--		--		0	--		--	
	NE	2	--		--		0	--		--	
	E	20	91.7 (66.2)		46.9 (25.3)		0	--		--	
	SE	62	64.9 (110.1)	<0.05	22.0 (28.5)	<0.05	15	218.6 (124.4)	<0.05	75.8 (47.2)	<0.05
	S	34	113.6 (155.5)		30.5 (24.6)		9	135.3 (127.1)		36.6 (27.6)	
	SW	14	43.9 (107.7)		21.1 (11.5)		4	205.9 (500.4)		91.5 (167.5)	
	W	8	78.3 (95.0)		30.8 (13.8)		1	--		--	
	NW	5	148.2 (100.2)		31.8 (11.1)		2	--		--	
Spring	SE	43	78.6 (81.7)	[illegible]	25.2 (21.5)		7	137.9 (90.0)	[illegible]	39.7 (13.7)	[illegible]

[1] Number of measurement days

[2] P-value using Kruskal-Wallis H test

[3] North

[4] East

[5] South-East

[6] South

[7] South-West

[8] West

[9] North-West

	S	18	42.3 (46.9)	17.9 (12.7)	3	--	24.4 (6.7)
	SW	1	--	--	0	--	--
Summer	SE	37	12.0 (35.0)	3.3 (15.2)	19	143.3 (251.2)	41.5 (78.8)
	S	2	--	--	1	--	--

On the other hand, the concentrations of the two PM types showed a negative highly significant coefficient with barometric pressure. This is similar to the Beijing study (Tian, et al., 2014), and non-compliant with the European study (Vardoulakis & Kassomenos, 2008).

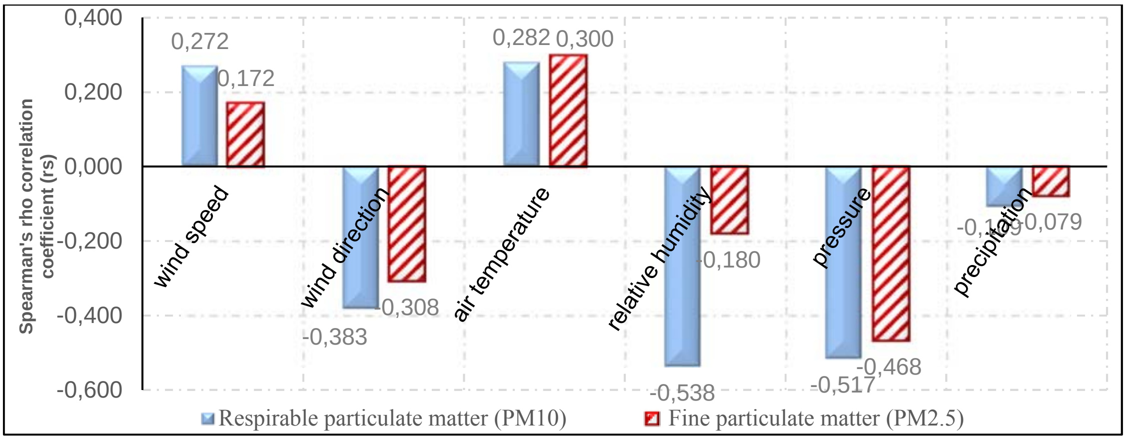

Figure 3: Spearman's rho correlation coefficient of PM_{10}, $PM_{2.5}$ and the major meteorological factors

The overall data of the present study indicates that the fall season was of the highest PM10 concentrations due to the lowest relative humidity. The winter season had the lowest PM10levels because of the maximum relative humidity and wet deposition, in addition to the highest barometric pressure. The Italian study (Marcazzan, Vaccaro, Valli, & Vecchi, 2001) stated that the winter values of particulate matter were higher those of summer due to the frequent persistent thermal inversions during winter, and the greater wind speed that broadens the mixing layer and improves air quality during summer.

The highest PM2.5 level that has been recorded during the summer season in the present study may be attributed to the highest air temperature and the lowest atmospheric pressure, while the lowest PM2.5value was recorded during the spring season. Based on several studies, the seasonal variation differs from one location to another. For example; A Buenos Aires study indicated higher PM2.5 during the summer season (congruent with this study) due to the slightly higher wind speed that may generate more PM2.5(Bogo, et al., 2003). While the Korean and Hong Kong studies revealed that the highest PM2.5was during winter because of the thermal inversion (L. Y. Chan & Kwok, 2001; Vellingiri, et al., 2014).

In Dammam station, the maximum PM_{10} concentration [215.1 (154.2) µg/m^3] was recorded at the "southeast gentle-moderate wind" during summer. This may be due to the high wind speed, in addition to the highest air temperature, and the lowest pressure. The lowest level of PM_{10} [21.1 (13.6) µg/m^3**]** was found at the “western gentle moderate wind” during winter because of the high relative humidity and the very low human activities at the western area. As for $PM_{2.5}$, the highest concentration which was found at the “southeast light wind” during fall is due to the presence of dense population and high traffic activity in this direction.

In El-Khobar, the winter season recorded the highest PM10, and PM2.5 levels at gentle-moderate southeastern and southwestern directions. This may be owing to thermal inversion during this cold season. The lowest levels of both PM types that were found during the summer season at the “light southeast winds” can be attributed to the higher air temperature and lower atmospheric as stated in the Italian and European studies(Marcazzan, et al., 2001; Vardoulakis & Kassomenos, 2008).

Conclusions

Concentrations of both PM_{10}, and $PM_{2.5}$ have the positive weak highly significant Spearman’s rho correlation coefficients with local wind speed and air temperature, while they have negative significant coefficients with prevailing wind direction, relative humidity, and barometric pressure. In addition, precipitation has a very weak negative coefficient with the two types.

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