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Ambient Levels of TSP, PM10, PM2.5 and Particle Number Concentration in Al Samha, UAE

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Abstract

The Arabian Peninsula experiences elevated levels of airborne particulate originated from both natural and anthropogenic sources. This study is mainly aimed to determine the ambient levels of TSP, PM_{10} and $PM_{2.5}$) at one of the monitoring locations "Al Samha" that is located in the northeast quadrant of UAE. Mass concentrations, particle count, as well as meteorological parameters were simultaneously measured using a spectrometer, PM_{10} beta attenuation monitor and weather sensors for the period from April 10 to December 31, 2011. The hourly mean concentrations of TSP, PM_{10}, $PM_{2.5-10}$ and $PM_{2.5}$ were 245, 110, 64 and 46 $\mu g/m^3$, respectively. About 34%, 15% and 56% of the monitored days had daily concentrations above the allowable limits for TSP, PM_{10} and $PM_{2.5}$, respectively. Diurnal peak occurred at 14:00 for TSP, at 10:00 for PM_{10}, and at 04:00 for $PM_{2.5}$ reaching values of up to 410, 122, and 54 $\mu g/m^3$, respectively. The highest concentrations were observed on Saturdays for TSP and PM_{10}, but on Sundays for $PM_{2.5}$. July had the greatest monthly level of PM compared to other months of this study. The average ratios of PM_{10}/TSP, $PM_{2.5}$/TSP and $PM_{2.5}$/PM_{10} were 0.61, 0.31 and 0.47, respectively. Weak relationships were found between the particle number and mass concentrations, while very strong to moderate correlations were observed among all PM size fractions as well as between TSP and wind speed. The measurement results of the light scattering spectrometer were strongly correlated with the beta attenuation monitor, but the mean value of the spectrometer was higher by 18%.

Keywords

Particulate Matters, Meteorological Parameters, Correlation

1. Introduction

Air pollution kills about 7 million people, 12.5% of the global deaths, every year across the world [1], and it is expected to become the top environmental cause of global mortality by 2050 [2]. Predominantly, airborne particulates contribute greatly to poor air quality and are considered to be one of the biggest threats to human health in urban environments [3] [4] [5] [6] [7].

Airborne particulate can be classified in various ways based on their properties such as; size, shape, formation mechanism, and composition. However, the most common classification is according to their characteristic size [8]. Total Suspended Particles (TSP) refers to all particles up to 50 micrometers (μm) in diameter that can remain suspended in the atmosphere for significant periods of time [9]. More precisely, Particulate Matter (PM) is usually labeled by a number indicating its aerodynamic diameter. For instance, PM_{10} (respirable) and $PM_{2.5}$ (fine) refer to particles with a nominal mean aerodynamic diameter of less than or equal to 10 μm and 2.5 μm, respectively [10]. The notation $PM_{2.5-10}$ is used to represent the coarse particles with an aerodynamic diameter between 2.5 μm and 10 μm [11].

The sources of PM are divided into three major categories; natural, anthropogenic and secondary. Windblown dust, sea sprays, volcanoes, fires and pollen are examples of natural sources. On the other hand, anthropogenic sources are further classified into stationary and mobile subcategories; stationary sources are fixed-site producers such as power plants, factories, mines, farms, and waste-disposal sites. Whereas, mobile sources are mainly the transportation means such as cars, trucks, planes and ships that emit pollutants while moving [12]. Finally, secondary fine particles are formed in the atmosphere through chemical reactions among the gaseous pollutants involving; sulfur dioxide (SO_2), nitrogen oxides (NO_x), volatile organic compounds (VOCs) and ammonia (NH_3) [13].

Elevated levels of ambient PM might lead to considerable adverse effects on public health and the environment. On one hand, it contributes to visibility degradation, acid deposition, and influences the climate either directly by scattering and absorbing sunlight radiation or indirectly through providing condensation nuclei for cloud droplets [14]. On the other hand, both short and long-term exposures to PM cause respiratory and cardiovascular diseases and are also linked to overall increased mortality [15]. However, the size of the particle plays an important role in its potential hazard. As such, smaller particles have a larger surface area available for physical and chemical interactions, travel farther distances, remain suspended for longer times, and penetrate deeper into the human respiratory system [16].

Therefore, strategic plans have been developed and implemented by many countries across the world to control PM levels and eventually minimize its adverse impacts [17]. In order to achieve the desired objectives, these control plans should be established based on reliable monitoring information, which highlights the importance of assessment and evaluation programs [18].

The Arabian Peninsula, including the United Arab Emirates (UAE), experiences elevated levels of PM originating from both natural and anthropogenic

sources [19] [20] [21]. Thus, comprehensive studies are very essential to understand the temporal and the spatial behavior of the suspended particulates, and to accordingly apply effective measures to achieve and maintain acceptable levels.

In this study, continuous measurements were carried out at Al Samha area for TSP, PM_{10} & $PM_{2.5}$ mass concentrations, particle count as well as meteorological parameters during the period from April 10 to December 31, 2011. The obtained results were comprehensively analyzed to examine different measurement techniques, verify the compliance with relevant standards, determine temporal variation patterns, and investigate inter-correlations between the measured parameters. The findings of this study might be of great relevance to scientists and decision-makers, providing them with a fundamental basis to establish further research studies and develop effective policies for pollution reduction.

2. Material and Methods

2.1. Site Description

The measurements were conducted in Al Samha area (Figure 1), which is located approximately 40 km northeast of Abu Dhabi City at about the midway to

Figure 1. Map showing the location of the study area.

Dubai. The area is surrounded by various contributors of particulate matters, from sources such as desert sand, power plants, an aluminium smelter, and construction activities, in addition to road and sea traffic. Furthermore, sandstorms are a common occurrence across the entire region, especially during the summer months.

The UAE generally has a subtropical and arid climate, being hot, humid and very dry during summer (April to September), and becoming cooler with occasional rainfall during the winter season (October to March) [22].

2.2. Instrumentation

In this study, TSP, PM_{10}, $PM_{2.5}$ mass concentrations and Particle Number (PN) were simultaneously measured using a Grimm aerosol spectrometer (Grimm Aerosol Technik GmbH, Germany, model EMD 365), which is also equipped with weather sensors (LufftGmbH, Germany, model WS600) to jointly monitor meteorological parameters such as wind speed, wind direction, relative humidity and temperature. The mass concentrations of the coarse particles ($PM_{2.5\text{-}10}$) were calculated as the difference between PM_{10} and $PM_{2.5}$ concentrations. Concurrently, PM_{10} mass concentrations were measured continuously using a beta attenuation monitor (Environment S.A., France, model MP101M). For comparison and verification purposes, TSP and $PM_{2.5}$ daily levels were also gravimetrically determined by collecting of some random samples.

The spectrometer (EDM 365) is designed on the principle of orthogonal light scattering, where air containing multiple particle sizes passes through a flat laser beam. The scattered signal is collected at approximately 90° to the beam by a mirror and is detected by a high speed photodiode. Each signal is then counted and classified into different size channels by an integrated pulse height analyzer. Eventually, these counts are converted to a mass distribution using the density factor established for urban environments. The EDM 365 utilizes a diffusion dryer to avoid condensation during measurement, which is activated when the relative humidity exceeds 70%. In the beta attenuation monitor, the sampling stream is slightly heated to avoid water condensation, and the air sample is sucked at a constant flow rate (16.7 L/min) from PM_{10} size-selective inlet and pulled through a filter to deposit particles. At the end of a predefined hourly sampling cycle, the loaded filter is positioned between a carbon 14 beta source and a Geiger-Mueller detector to determine attenuation of the beta ray signal which is directly proportional to the mass of dust accumulated on the filter.

Finally, a particulate sampler (Environment S.A., France, model MP162) was used to collect daily random samples of TSP and $PM_{2.5}$, where an air sample is drawn for 24 hours at a constant flow rate of 16.7 L/min through a size-selective inlet (TSP or $PM_{2.5}$) and then collected on a 47 mm filter membrane. The filters were conditioned and weighted prior and after sampling to determine net weight gain due to the collection of sample and eventually estimate the concentration.

2.3. Regulations and Guidelines

Air quality standards for suspended PM have been established by different entities

in order to protect public health and the environment (Table 1). These standards identify the maximum acceptable concentrations in ambient air, which should not be exceeded during a specified time interval. In this study, the UAE standards were used to assess the daily concentrations of TSP and PM_{10}, while the $PM_{2.5}$ daily limit of 35 μg/m^3 was also consulted since it is widely applied in many countries such as the Kingdom of Saudi Arabia (KSA), United States (USA) and others.

Table 1. Ambient air quality standards for airborne particles (μg/m^3).

Max Allowable Limit	UAE	Saudi Arabia	WHO	US-EPA	European Union
TSP					
Daily	230	-	-	-	150
Annual	90	-	-	-	-
PM_{10}					
Daily	150	340*	50	150	50
Annual	-	80	20	-	40
$PM_{2.5}$					
Daily	-	35*	25	35*	-
Annual	-	15	10	15	25

*Based on a percentile value.

2.4. Statistical Analysis

All statistical analyses were performed using Microsoft Excel and SPSS Statistics. Pearson's correlation analysis was used to determine the linear correlations between the measured parameters, where the existence and strength of the relationship is assessed based on the correlation coefficient (r) as follows: negligible if r < 0.19, weak if r is between 0.2 and 0.39, moderate if r is between 0.4 and 0.59, strong if between 0.6 and 0.79, and very strong if r > 0.8 [23].

3. Results and Discussion

3.1. Mass Concentrations and Particle Number

Descriptive statistics of the hourly concentrations obtained throughout the study period are summarized in Table 2. Based on mean value, TSP was approximately 2.2, 3.8 and 5.3 times greater than PM_{10}, $PM_{2.5-10}$ and $PM_{2.5}$, respectively; while PM_{10} was higher than $PM_{2.5-10}$ by a factor of 1.7 and $PM_{2.5}$ by a factor of 2.4. Hourly concentrations of the particulate number varied widely from 34,035 cm^{-3} to 2,085,556 cm^{-3} with a median of 247,431 cm^{-3}.

Table 2. Statistical analysis results for measurements of hourly concentration conducted during the study period.

Datum	TSP	PM_{10}	$PM_{2.5-10}$	$PM_{2.5}$	PN
	(μg·m^{-3})				(cm^{-3})
Min	20	12	2	6	34,035
Max	4496	967	601	409	2,085,556

Continued

Median	147	83	43	38	247,431
Mean	245	110	64	46	302,985
Stand. Deviation	317	94	66	34	212,882
98th Percentile	1164	399	278	140	924,524

As shown in Figure 2, elevated daily concentrations were observed during the study period for TSP, PM_{10} and $PM_{2.5}$ reaching values of up to 1160 μg/m^3, 657 μg/m^3 and 252 μg/m^3, respectively. Furthermore, about 34%, 15% and 56% of the monitored days had 24-hour average concentrations above the maximum allowable limits of TSP, PM_{10} and $PM_{2.5}$, respectively. These elevated levels might be attributed to various factors including; increased human activities (e.g. industries and traffic), frequent natural events (e.g. dust storms) and the significant influence of climate conditions (e.g. enhanced formation conditions of secondary particles with high temperatures and intense sunlight in addition to re-suspension of surface dusts in dry conditions).

(a)

(b)

(c)
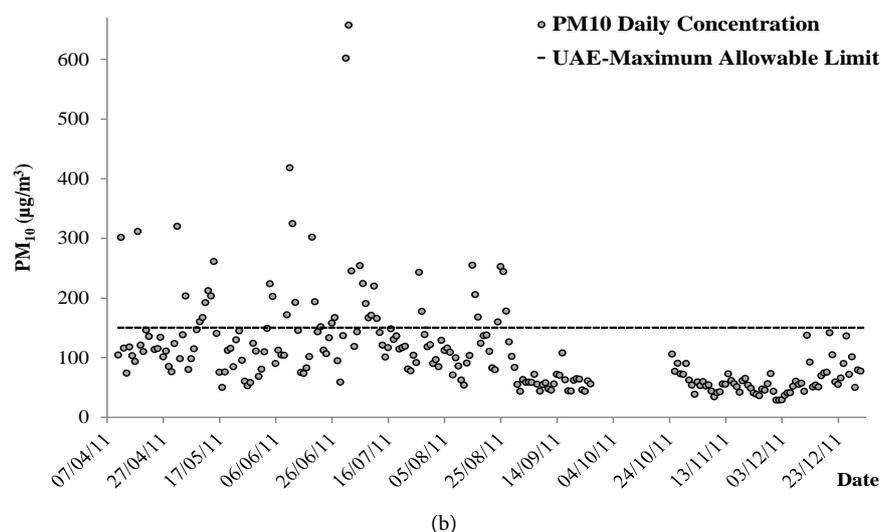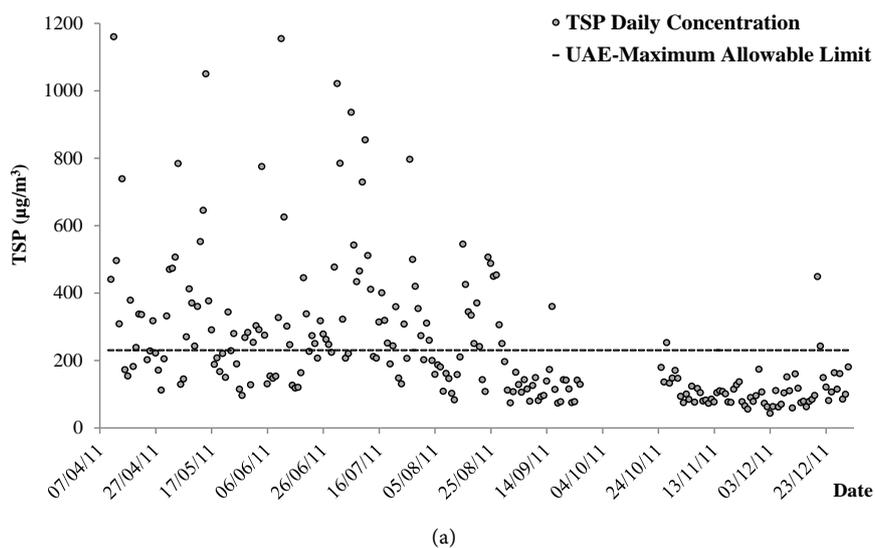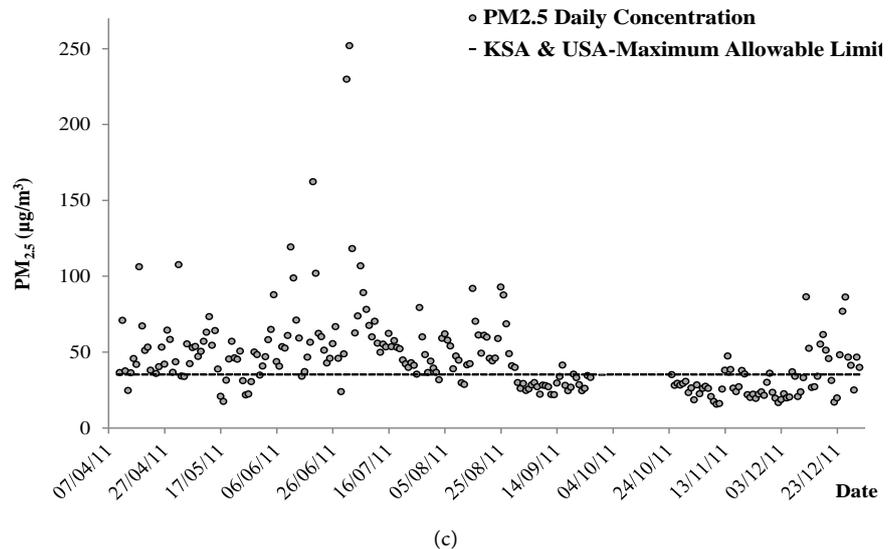
Figure 2. Daily mass concentrations of airborne particulates (a) TSP, (b) PM_{10} and (c) $PM_{2.5}$.

3.2. Temporal Variation of PM

As it is obvious in **Figure 3**, the diurnal variation of PM with different size fractions did not follow a similar pattern because of their divergence characteristics as well as the variance of their behaviors in the atmosphere. The lowest levels of TSP and PM_{10} were observed during the early morning hours between 01:00 - 02:00 am, where the human activities are minimal and the climate is relatively cool, damp, with an eastern low-speed wind. After sunrise, the concentrations remarkably started to rise in conjunction with increased temperature and wind speed and reduced humidity, reaching primary and secondary peaks at 10:00 am and at 13:00 pm for PM_{10} and one hour later for TSP, and then began to decline. The rise in TSP and PM_{10} levels might be justified by a longer lifetime of particles at low humidity conditions, re-suspension of surface dusts by higher wind speed, and formation of secondary aerosols at high temperatures. The observed time lag between PM_{10} and TSP can be explained by the longer time required to transport larger and heavier particles by the wind, in addition to the contribution of the small particles that are agglomerated and coalesced to form greater ones over time. On the other hand, the least level of $PM_{2.5}$ occurred at 12:00 noon associated with high temperature, low humidity, and moderate-speed western wind, and then $PM_{2.5}$ level increased gradually to reach its peak at 04:00 am. The humid conditions are associated with high levels of $PM_{2.5}$ which might be attributed to the role of moisture in forming secondary fine aerosol such as ammonium nitrate through the gas-to-particle conversion. Changes in prevailing wind directions have no noticeable effect on the average diurnal concentrations.

As illustrated in **Table 3**, the highest mean concentrations were observed on Saturdays for TSP and PM_{10} and on Sundays for $PM_{2.5}$. On the other hand, the lowest levels were recorded on Thursdays for TSP and on Wednesdays for PM_{10} and $PM_{2.5}$. The elevated PM levels during Saturday and Sunday might be attributed to the increased human and industrial activities during the free-time

(a)

(b)
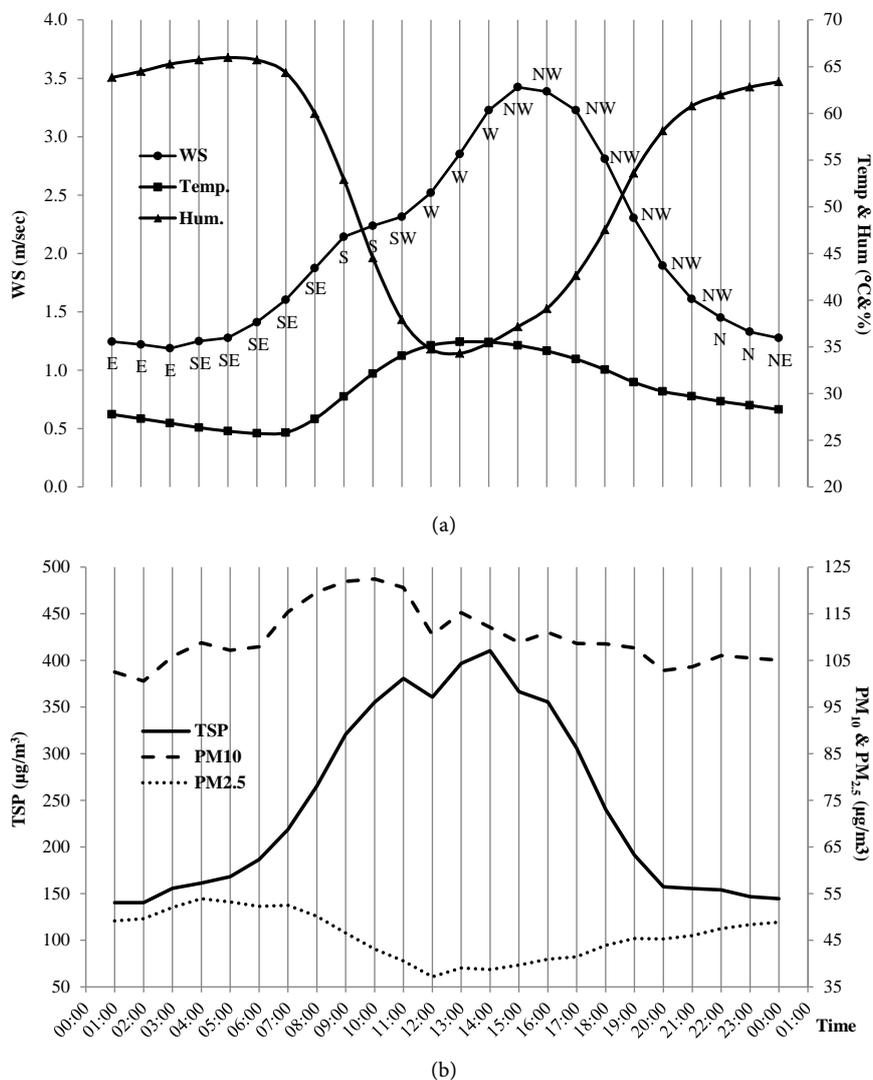
Figure 3. Diurnal variation patterns of the meteorological parameters and airborne particulates during the study period.

Table 3. Levels of airborne particulates ($\mu g/m^3$) during the weekdays and weekends of the study period.

Day	TSP			PM$_{10}$			PM$_{2.5}$		
	Min	Max	Mean ± S.D.	Min	Max	Mean ± S.D.	Min	Max	Mean ± S.D.
Sun	27	2875	255 ± 329	23	714	119 ± 92	11	286	52 ± 34
Mon	35	2591	248 ± 248	27	736	120 ± 94	11	347	51 ± 36
Tue	21	3530	243 ± 321	20	709	106 ± 73	6	158	43 ± 21
Wed	28	3831	246 ± 335	14	712	98 ± 71	8	245	40 ± 23
Thu	20	2029	230 ± 255	19	473	99 ± 67	8	173	41 ± 24
Fri	27	4496	230 ± 330	12	967	107 ± 112	7	409	45 ± 42
Sat	27	3347	260 ± 381	16	927	121 ± 131	10	348	51 ± 44

weekend (Saturday) and the first working day of the week (Sunday). As shown

in **Figure 4**, relatively elevated concentrations were observed over extended time for the days of maximum records (Saturday for TSP and PM_{10} and Sunday for $PM_{2.5}$) as compared with other days.

(a)

(b)

(c)
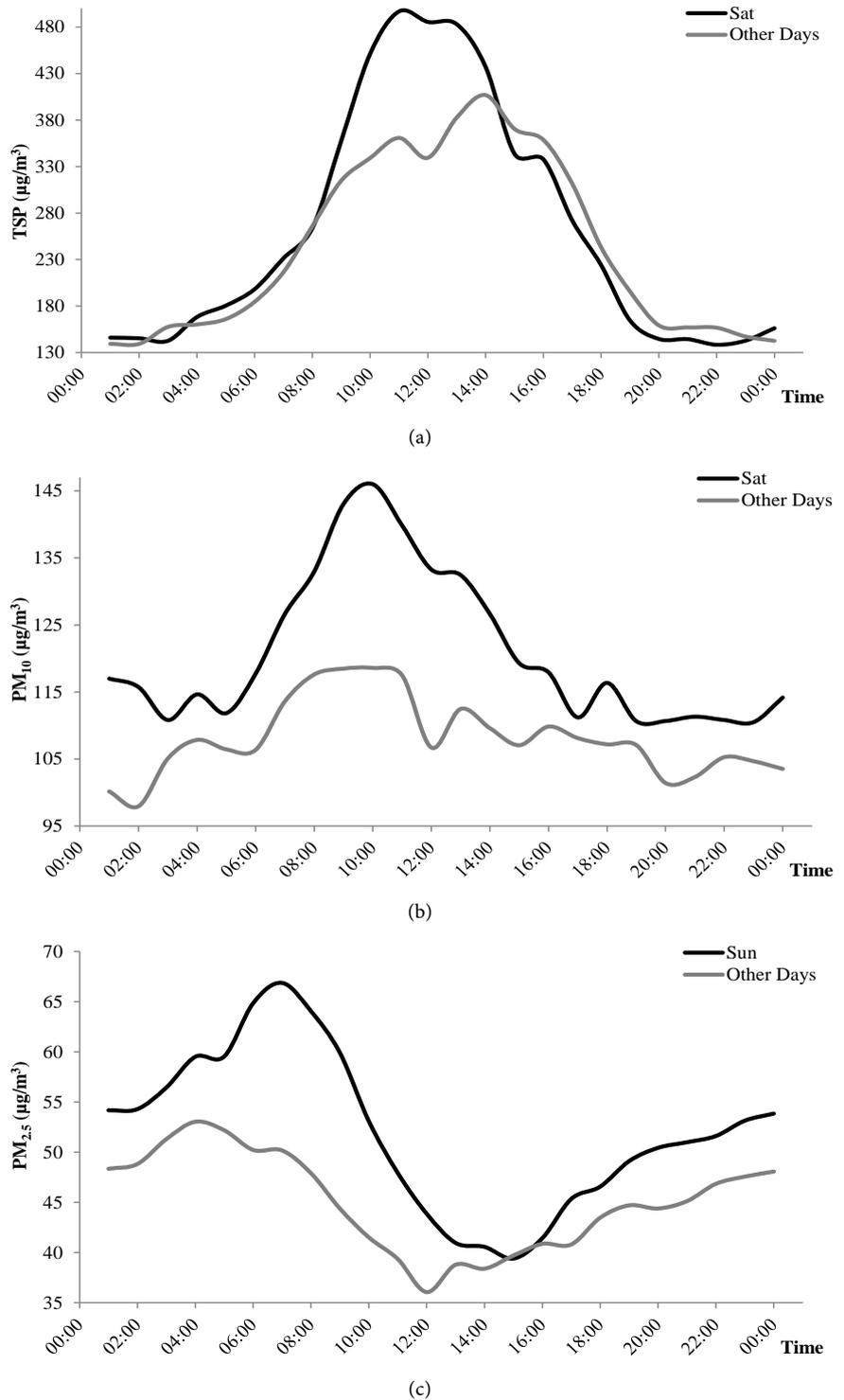
Figure 4. Diurnal variation patterns during the days when the maximum concentrations were observed as compared with other days for (a) TSP, (b) PM_{10} and (c) $PM_{2.5}$.

Monthly variations of PM mass concentrations are given in Table 4. The highest mass mean concentrations were observed for all size fractions in July primarily due to the frequent occurrence of dust storms during this period of time. The pattern of TSP during April to July is consonant with the wind speed pattern, which indicates that there is a notable influence of wind speed on large particulate levels. As expected, the lowest PM levels were recorded during the cool winter season as a result of the humid and occasionally rainy conditions. As presented in Figure 5, non-identical pattern of higher diurnal concentrations of particulate matters was observed during the summer months (April-August) as compared to the winter months (September, November and December).

Table 4. Monthly levels of airborne particulates ($\mu g/m^3$) during the study period.

Day	TSP			PM$_{10}$			PM$_{2.5}$		
	Min	Max	Mean ± S.D.	Min	Max	Mean ±S.D.	Min	Max	Mean ± S.D.
Apr	38	4496	345 ± 449	27	709	130 ± 91	12	159	49 ± 28
May	41	2875	331 ± 358	32	736	129 ± 90	8	269	46 ± 27
Jun	21	3347	307 ± 348	20	714	151 ± 104	18	286	61 ± 37
Jul	64	3831	415 ± 422	48	967	175 ± 147	19	409	70 ± 55
Aug	39	3248	256 ± 269	24	525	122 ± 74	12	185	52 ± 24
Sep	36	1291	124 ± 137	28	252	58 ± 23	14	72	28 ± 8
Oct*	-	-	-	-	-	-	-	-	-
Nov	20	710	95 ± 62	12	137	51 ± 20	6	85	26 ± 13
Dec	24	3530	115 ± 157	14	693	68 ± 51	8	347	38 ± 27

*Data is not available from September 26, 20:00 to October 24, 14:00 due to power supply failure.

(a)

(b)

(c)
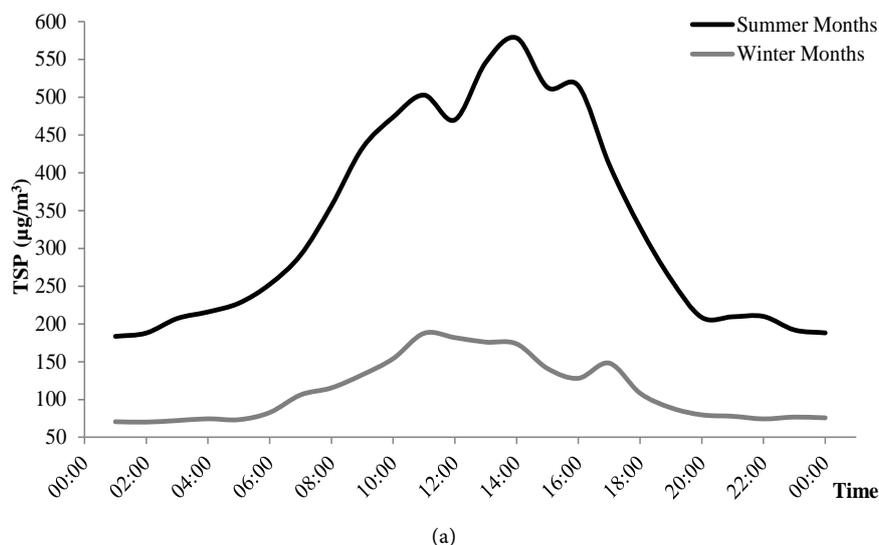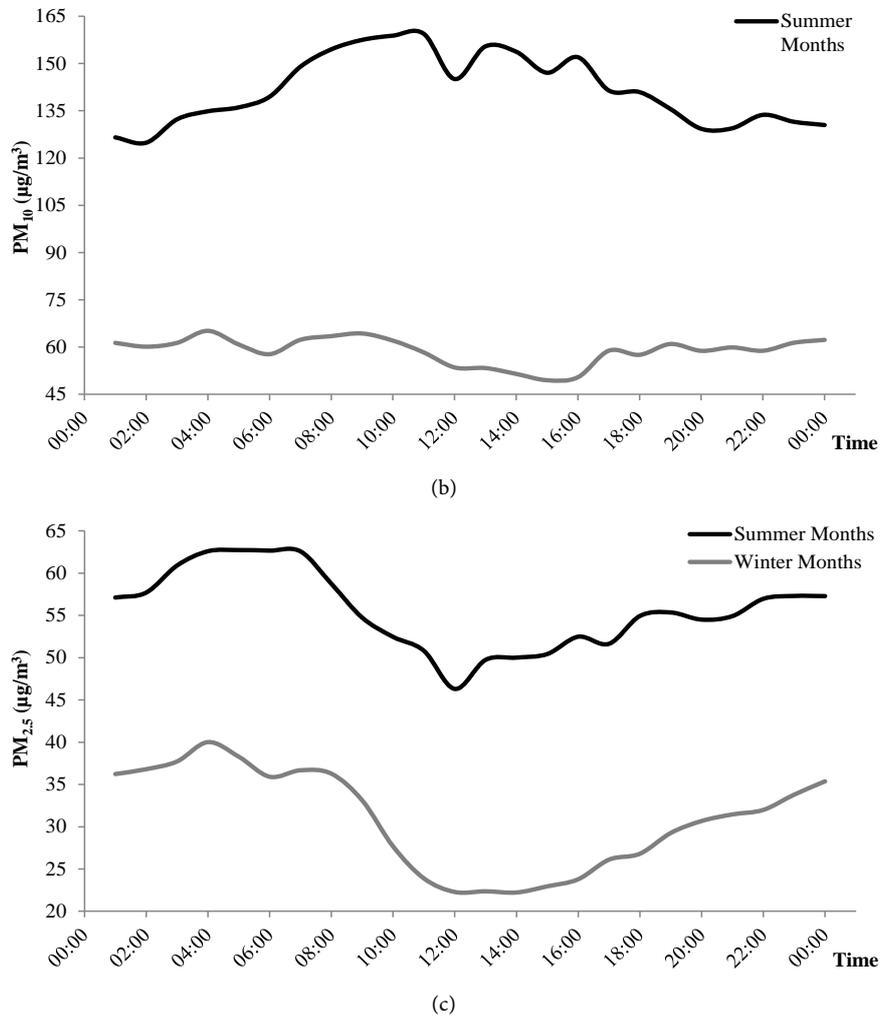
Figure 5. Diurnal variation patterns during summer and winter months for (a) TSP, (b) PM_{10} and (c) $PM_{2.5}$.

3.3. PM Mass Ratios

Based on the mean ratio values shown in Table 5, TSP contains nearly 39% of particles with an aerodynamic diameter greater than 10 μm ($PM_{>10}$), and the rest (61%) is PM_{10}, which consists of 47% $PM_{2.5}$ and 53% $PM_{2.5-10}$. These results are inconsistent with the results of Engelbrecht *et al.* [24] for daily samples collected in the UAE, where the reported ratios of PM_{10}/TSP and $PM_{2.5}$/PM_{10} were 0.71 and 0.37, respectively. The deviations between the obtained results and the above mentioned reported results by Engelbrecht *et al.* are mainly due to the influence of temporal and spatial variation in PM ambient levels. However, our results are closer to the typical $PM_{2.5}$/PM_{10} ratio of 0.5 that have been documented for urban areas in developing countries [25], and reported for urban sites in Iran [26].

Table 5. Mass ratios between airborne particulate of different size fractions at the study area.

Datum	PM_{10}/TSP	$PM_{2.5-10}$/TSP	$PM_{2.5}$/TSP	$PM_{2.5-10}$/PM_{10}	$PM_{2.5}$/PM_{10}
Min	0.09	0.05	0.02	0.06	0.18

Continued

| Max | 1.00 | 0.65 | 0.94 | 0.82 | 0.94 |
| Mean ± S.D. | 0.61 ± 0.26 | 0.30 ± 0.13 | 0.31 ± 0.20 | 0.53 ± 0.15 | 0.47 ± 0.15 |

As shown in Table 6, very strong to moderate inter-correlations are found between PM of different size fractions. The weak correlations between total particle number and mass concentrations of particulate matter with different sizes indicate that the number of particles is an inadequate indicator of the mass levels and vice versa. The moderate correlation between TSP and wind speed is noticeable by the influence of wind on the diurnal variations of TSP. Figure 6 indicates that the highest average concentrations of airborne particulate are associated with wind coming from the south and south-southwest directions, where heavy highway traffic flow exists (re-suspension of surface dusts).

Table 6. Pearson correlation coefficient for airborne particulates and meteorological parameters during the study period.

	TSP	PM_{10}	$PM_{2.5}$	TC	W. Speed	Temp.
PM_{10}	0.700 Strong	-	-	-	-	-
$PM_{2.5}$	0.454 Moderate	0.890 Very strong	-	-	-	-
TC	−0.175 Very weak	−0.015 Very weak	0.254 Weak	-	-	-
W. Speed	0.410 Moderate	0.143 Very weak	0.001 Very weak	−0.282 Weak	-	-
Temp.	0.432 Weak	0.240 Weak	0.066 Very weak	−0.164 Very weak	0.421 Moderate	-
Humidity	−0.359 Weak	−0.148 Very weak	0.141 Very weak	0.350 Weak	−0.464 Moderate	−0.551 Moderate
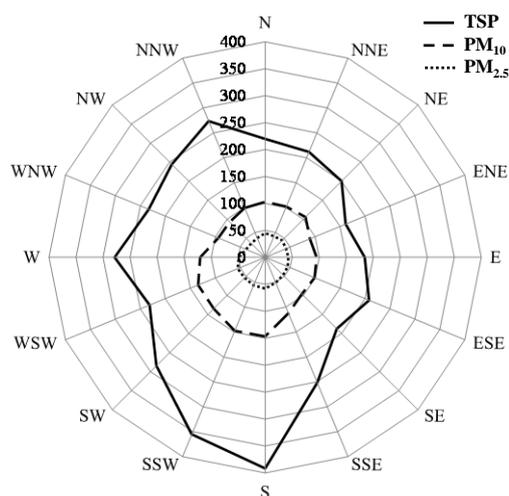
Figure 6. TSP, PM_{10} & $PM_{2.5}$ pollution rose at Al Samha during the study period.

3.4. Measurement Techniques Comparison

Measurement results of PM_{10} mass concentrations obtained by the light scattering

spectrometer were compared with the concentrations measured by the beta attenuation monitor, as shown in Figure 7. Consequently, a correlation coefficient of r = 0.73 (coefficient of determination r^2 = 0.539) indicates a strong linear relationship between the two measurement techniques. However, the PM_{10} mean value of the spectrometer results was 18% higher than its counterpart obtained by the beta attenuation monitor with the presence a statistically significant difference between the two data sets. This difference can be explained by the fact that both techniques may misestimate the actual concentrations [27] [28], and therefore their results need to be corrected by applying site specific and seasonal correction factors developed in line with the standard reference methods [29] which is beyond the scope of this study. However, TSP and $PM_{2.5}$ results measured by the spectrometer are perfectly correlated (r > 0.995) with its counterparts obtained by gravimetric analysis of randomly collected samples as shown in Figure 8, noting that the spectrometer overestimated the TSP and underestimated the $PM_{2.5}$ concentrations of the collected sample, especially at the high levels.
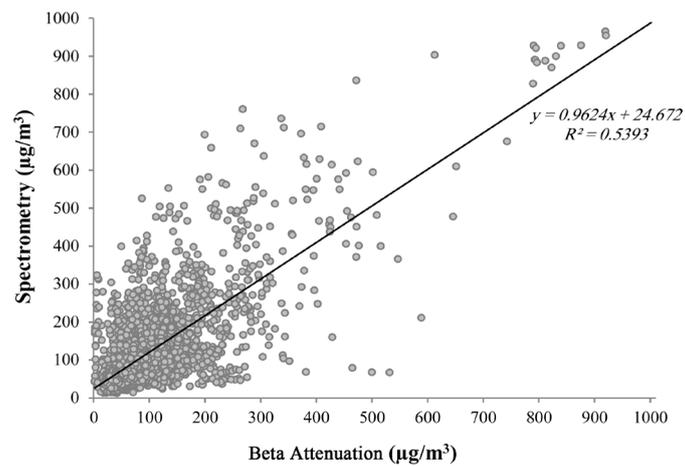
Figure 7. Comparison between PM_{10} concentrations measured by spectrometry and beta attenuation techniques.
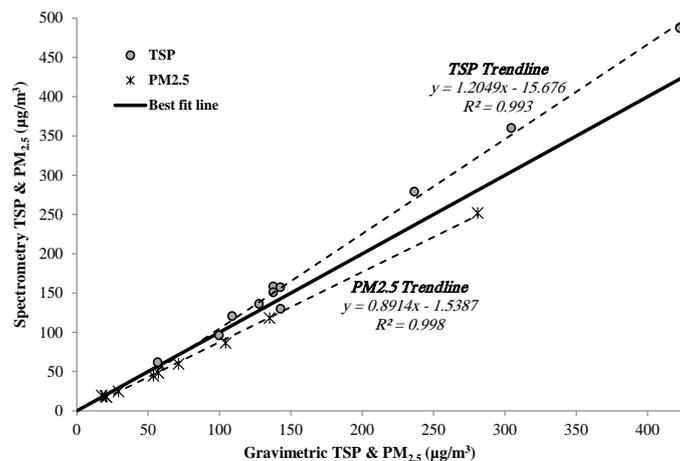
Figure 8. Comparison between TSP & $PM_{2.5}$ concentrations measured by gravimetric and spectrometry techniques.

4. Conclusions and Recommendations

Based on the results of our study, the following major conclusions can be made:

- The study area experienced elevated levels of particulate matters, where the relevant maximum allowable limits were repeatedly violated. Therefore, long and short-term strategies should be implemented to reduce the levels of ambient particulate thereby improving the environment which in turn would enhance quality of human life.

- Diurnal peak occurred at 14:00 for TSP, at 10:00 for PM_{10}, and at 04:00 for $PM_{2.5}$. The diurnal variation of TSP had nearly a similar trend of PM_{10}, but quite the opposite of the $PM_{2.5}$ pattern. These trends might be justified by the varying effects of the atmospheric conditions on the levels of different-size particles, fluctuations of human activities, and the dynamic interaction with other pollutants.

- The most polluted days were Saturdays for the large particles (TSP & PM_{10}) and Sundays for fine particles ($PM_{2.5}$), while Thursdays and Wednesdays were relatively the cleanest days. That can be attributed to the traffic density alteration through the weekdays and its effect on the levels of ambient particulate matter.

- The highest levels for all PM size fractions were observed in July and the lowest levels were noted in November. This might be linked to several factors such as the roles of meteorological parameters in air quality, differences between daytime and night time with associated changes in human activities, varying climatic conditions, and the frequency of sandstorm occurrences.

- On average, the mass of suspended dust in the study area contained nearly 39% of large particles ($PM_{>10}$), 30% of coarse particles ($PM_{2.5-10}$), and 31% of fine particles ($PM_{2.5}$). On the other hand, PM_{10} consisted of 53% $PM_{2.5-10}$ and 47% $PM_{2.5}$.

- PM_{10} concentrations strongly correlated with TSP and $PM_{2.5}$, but on the other hand TSP levels were moderately linked with $PM_{2.5}$ and wind speed. In addition, the particle number concentration was found to be a poor indicator of the ambient levels of airborne particulates.

- The measurement results of the light scattering spectrometer strongly correlated with the values of the beta attenuation monitor, but the mean value of the spectrometer was higher by 18%. Therefore, specific and seasonal correction factors should be developed and applied to the results of both investigated techniques based the standard reference methods.

In order to investigate the seasonal and the spatial variations, long-term measurements are recommended to be carried out at different locations. Short- and long-term strategies should be established and implemented to reduce the concentrations of anthropogenic and secondary PMs in ambient air, which can be achieved by controlling the stationary source emissions, developing an environmentally friendly transport system, raising public awareness of environmental issues, and expanding of green areas.

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