Levels of particulate matter in Western UAE desert and factors affecting their distribution

F. Al Jallad, E. Al Katheeri & M. Al Omar
National Energy and Water Research Center (NEWRC), Abu-Dhabi Water and Electricity Authority (ADWEA), UAE

Abstract

Levels of particulate matter and meteorological variables (atmospheric temperature, relative humidity and wind speed) for 2009 to 2011were analyzed and evaluated. Data used in this paper were obtained from an ambient air quality station located in the western desert of Abu Dhabi Emirate-United Arab Emirates. The variation patterns of PM_{10} concentrations were explored, and their relationships with meteorological parameters were identified. The study area is characterized by relatively low wind speed, high temperatures and humidity and elevated levels of suspended particle concentrations. Hourly levels of PM_{10} were found to range between 4 to 3474µg/m^3 with 27% of the daily average values exceeding the national standard limit of 150µg/m^3. The diurnal variation pattern of PM_{10} showed two concentration peaks, the first of which occurred in the afternoon whereas the second peak occurred at 16:00. The highest level of PM_{10} was observed on Tuesdays, while the lowest level was on Fridays. The highest main value of PM_{10} was observed on July where a level of 204µg/m^3 was reported and lowest level of 47µg/m^3 was reported in January. Pearson's analysis revealed a positive correlation between PM_{10} and temperature, low humidity (≤13%) and wind speed conditions. On the other hand, a strong inverse relationship was observed between PM_{10} concentrations and relative humidity higher than 13%.
Keywords: particulate matter, meteorological parameters, Abu Dhabi, statistical analysis.

1 Introduction

Particulate matter (PM) may currently be considered as one of the most serious pollutants in urban areas, due to its harmful effects on human health and its role

WIT Transactions on Ecology and The Environment, Vol 174, © 2013 WIT Press
www.witpress.com, ISSN 1743-3541 (on-line)
doi:10.2495/AIR130101

in climate change [1], in addition to ecosystem damage and degraded visibility [2]. PM is produced either from natural or anthropogenic sources. Natural PM includes material from the earth's crust, biological materials such as pollen and sea spray in coastal areas, whereas anthropogenic PM is directly emitted into the atmosphere or formed as a secondary pollutant when gaseous pollutants (*e.g*. SO_2, NO_x, NH_3 and VOCs) react to form fine particles [3]. Numerous studies have focused on variations in PM levels with respect to changes in meteorological parameters [2, 4–9]. Assuming the quantities of PM emitted from anthropogenic sources are constant in a certain season and area; therefore, the variations in PM levels can be partially attributed to the effects of meteorological conditions [5].

Wind speed, atmospheric temperature and relative humidity are thought to influence PM concentrations [10]. Stagnant wind conditions allow air pollutants to accumulate near Earth's surface, resulting in high localized concentrations of PM [11]. On the contrary, fast near surface winds are generally associated with high levels of particulate matter caused by resuspension of ground particles and long range transport of particulates between regions [2, 6]. Formation of secondary aerosols by gas to particle conversion is a temperature driven process in which atmospheric temperature plays a key role. Variations in the relative humidity have a clear effect on hygroscopic aerosol particle, where absorption of water increases the size of the individual particle and affect its lifetime in the atmosphere [12].

United Arab Emirates (UAE) has an arid climate. Winter seasons last from November through March, during which time temperatures seldom drop below 6°C. Summers, which last from April through September, are very hot and humid, with temperatures rising to about 48°C and humidity levels higher than 90%. Generally, winds are predominantly from the west and northwest with relatively low speed [13].

Abu Dhabi Emirate experiences elevated levels of air particles that are less than 10 micrometers in diameter (PM_{10}) [14]. The high concentrations of PM_{10} are generally caused by natural sources such as windblown desert sand and sea spray [15]. In this study, three years data (2009–2011) describing ambient PM_{10} concentrations, atmospheric temperature, relative humidity and wind speed were analyzed and evaluated for the western desert of Abu Dhabi Emirate, UAE. PM_{10} ambient levels, temporal variations and correlations with meteorological variables were determined.

2 Methodology

2.1 Study area

Western Region constitutes the western part of Abu Dhabi Emirate. It represents around 80% of the total Emirate area. Jabal Al Dhanna is a coastal area located in the western region at approximately 235km west of Abu Dhabi city (Figure 1). An ambient air quality monitoring station is installed in this area which will be

Figure 1: Map of United Arab Emirates showing the study area at the western region.

referred to as “the study area”. The main anthropogenic air pollution sources in the area are as follows:

Shuweihat Power and Desalination Complex (SPDC): Located approximately 2km northwest (upwind) of the study area, this complex consists of power and desalination facilities powered primarily by natural gas, although heavy fuel oil and diesel are also used occasionally [16]. The data used in this study was obtained from an ambient air quality monitoring (AAQM) station located in the south-eastern corner of this Complex. The latitude and longitude of the monitoring station are 24° 8'55.93"N and 52°35'2.51"E, respectively.

Ruwais industrial Complex (RIC): Located approximately 8km southeast of the study area. The complex encompasses three main industrial activities, oil refinery, polymer production and natural gas industry.

Transportation emissions: In addition to transportation of material and public, main highway is located at approximately 3km south of the study area. The traffic movement may be described as mild with mostly light vehicles and trucks.

Population of the entire western area surrounding Jabal Al Dhanna and its vicinities is rather limited and does not exceed seventeen thousands according to recent census [17]. Ruwais Housing Complex is the most densely populated part in the study area; it is located at about 8km to the south-east of the monitoring station and consists of about 1300 units and houses. As far as natural sources of dust are concerned, the area is part of the desert region with no vegetation cover; however, soil is composed of coarse sand particles. Nevertheless, fine sand particles can also be found as a result of off road movement of vehicles in addition to construction.

2.2 Air quality monitoring instrument

Data used in this paper were obtained from the Al Shuweihat AAQM station. The station is owned and operated by the National Energy and Water Research Center (NEWRC) on behalf of the Abu Dhabi Water and Electricity Authority (ADWEA). Suspended particle concentrations were monitored on hourly basis using a beta attenuation dust monitor (Environment S.A., France, model MP101M) equipped with a PM_{10} size selective inlet mounted 3m above ground level and operated with a full scale measurement range of 5000μg/m^3. The sample flow rate is automatically regulated at 1m^3/hr, and the sampling probe is heated to 50°C to prevent moisture condensation.

A wind speed sensor (LSI-LASTEM, Italy, model DNA021) and thermohygrometer (LSI-LASTEM, Italy, model DMA685) are mounted at 10m mast in the same monitoring station. The meteorological data are originally retrieved on five minute intervals. For calculation of the hourly averages, a minimum of 75% of the hour's records must be available; otherwise the value is considered as missing.

3 Results and discussion

The average concentrations of PM_{10} were calculated at different observations of the meteorological parameters to investigate their relationships using Pearson's correlation analysis [18]. The recommended guideline value of PM_{10} in Abu Dhabi Emirate is set as 150μg/m^3 according to the national ambient air quality standard [1].

During the study period, a total of 24,359 valid hourly PM_{10} values were obtained from the monitoring station. Meteorological data that had been simultaneously recorded was also collected. Temporal variation of the PM_{10} concentrations and meteorological variables were analyzed, and their relationships were identified.

Monthly average values along with standard deviation for the meteorological parameters are presented in Table 1. The maximum values for wind speed (WS), relative humidity (RH) and temperature were observed in March, December and August, respectively. Monthly mean values during the study period was found to be 4.2m/sec for wind speed, 62% for relative humidity and 27.3°C for atmospheric temperature. These findings indicate that the study area is characterized by relatively low wind speed and high temperatures and humidity. Hourly values of PM_{10} during the study period ranged from 4μg/m^3 to 3474μg/m^3, with a mean value of 128μg/m^3. The 98th percentile of PM_{10} observations was less than 623μg/m^3, which is less than one fifth of the maximum monitored value. Daily mass concentrations of PM_{10} ranged from 14 to 1188μg/m^3 (Figure 2). About 27% of the daily average concentrations exceeded the limit of 150μg/m^3 stated in the national air quality standard.

Table 1: Monthly average values of some meteorological parameters (wind speed, relative humidity and temperature) in the study area for the years 2009–2011.

Month	WS ± S.D (m/s)	RH ± S.D (%)	Temp. ± S.D (°C)
January	3.8 ± 2.5	67.3 ± 21.1	17.8 ± 4.3
February	4.7 ± 2.1	56.8 ± 23.3	19.9 ± 3.1
March	5.1 ± 2.4	55.0 ± 19.1	22.7 ± 3.0
April	4.9 ± 2.7	51.5 ± 20.1	27.0 ± 4.3
May	4.5 ± 2.5	48.8 ± 13.6	31.3 ± 3.3
June	4.2 ± 2.4	55.5 ± 22.5	33.1 ± 3.4
July	4.2 ± 2.6	58.6 ± 23.5	34.1 ± 3.7
August	3.9 ± 2.7	66.8 ± 20.0	34.4 ± 4.1
September	3.6 ± 2.5	68.8 ± 22.2	32.2 ± 3.9
October	3.4 ± 2.1	71.0 ± 21.1	28.9 ± 3.6
November	3.8 ± 2.1	67.6 ± 21.2	24.9 ± 3.4
December	4.1 ± 2.1	74.1 ± 21.0	20.1 ± 3.0
Annual	4.2 ± 2.5	61.8 ± 22.4	27.3 ± 6.8

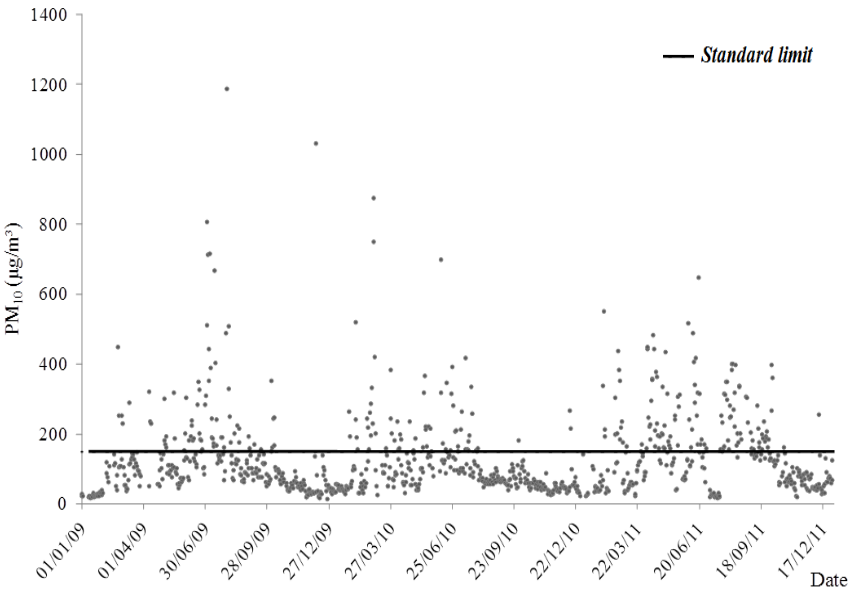

Figure 2: A dispersion diagram of the daily average concentrations of PM_{10} in air.

The diurnal variation pattern of PM_{10} mass concentrations during the study period is shown in Figure 3. The minimum average value was found to occur at 07:00. On the contrary, two peaks concentrations were observed for PM_{10}, the primary peak occurred during the afternoon and the secondary peak occurred at

16:00. The diurnal variation of PM_{10} is compared with the meteorological variation pattern in Figure 4, concluding that the lowest concentrations of 113μg/m^3 coincided with high humidity (71%) and relatively low wind speed (3.1m/sec) and atmospheric temperature (23.9°C), while the peak concentrations of 148μg/m^3 coincided with low humidity (49%) and relatively high wind speed (6.0m/sec) and atmospheric temperature (30.6°C).

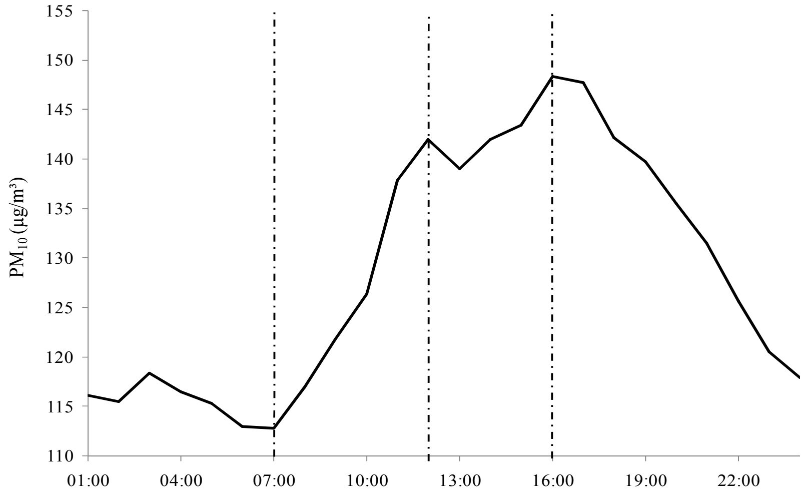

Figure 3: Diurnal variation pattern of PM_{10} at the study area for the period 2009–2011.

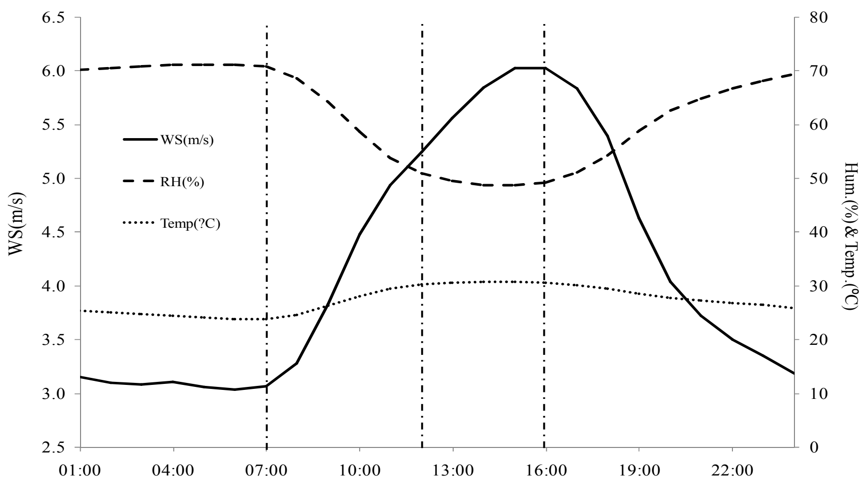

Figure 4: Diurnal variations of meteorological variables at the study area for the period 2009–2011.

Data analysis for PM_{10} concentrations revealed that the highest mean concentration of 130μg/m^3 found to occur on Tuesdays, whereas the lowest value of 125μg/m^3 was recorded on Fridays (Figure 5); this finding may be attributed to less public activities in the weekends.

Monthly and seasonal variations of PM_{10} during the study period were not consistent as can be seen in Figure 6. The highest monthly average value was 319μg/m^3 recorded in July 2009, while the lowest average value of 24μg/m^3 was

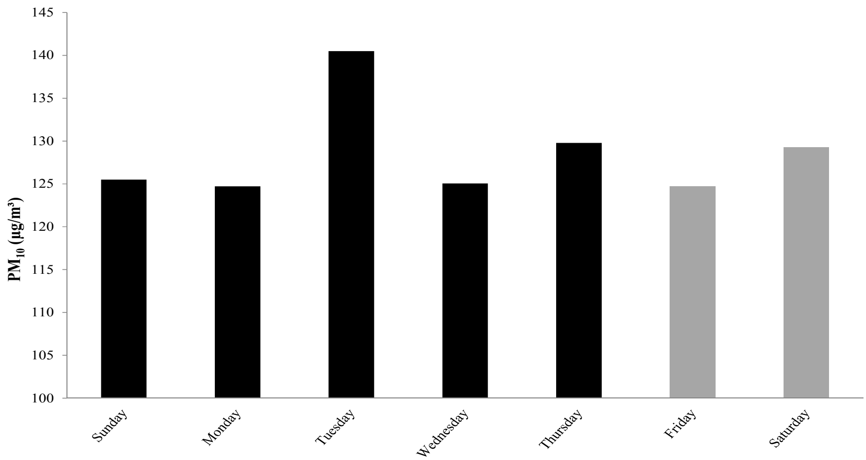

Figure 5: Weekdays/weekends variation of PM_{10}.

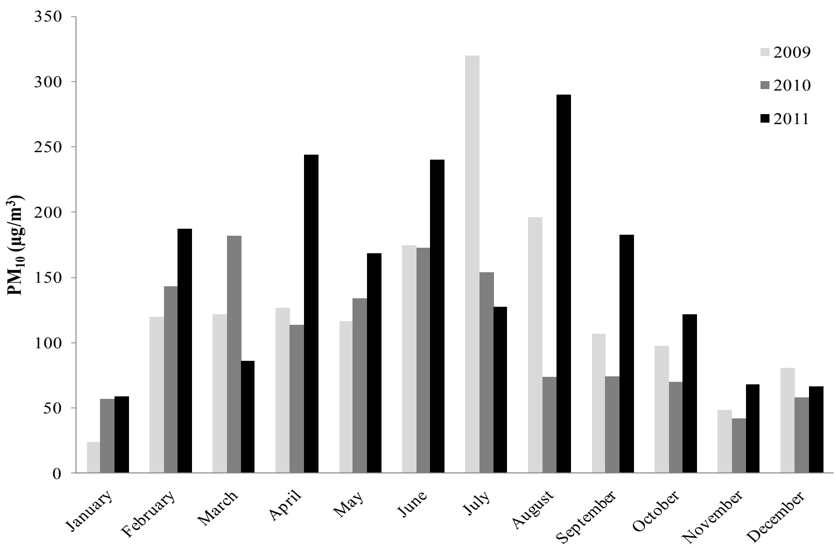

Figure 6: Seasonal variation of PM10 during 2009 to 2011.

observed in January 2009. Table 2 includes statistical analysis for PM_{10} daily average values during the study period. The maximum daily mean value was found to be 1188 μg/m^3 and recorded on 08 January 2009. The highest annual mean value of 148μg/m^3 was calculated for the year 2011.

Table 2: Minimum, maximum and mean annual values of PM_{10} in the study area.

Year	No. valid observations	Concentrations of PM_{10} in air (μg/m^3)		
		Minimum	Maximum	Mean ± S.D
2009	323	14	1188	125 ± 135
2010	341	23	875	106 ± 100
2011	323	17	646	148 ± 114

The relationships between suspended particle concentrations and meteorological variables (wind speed, relative humidity and ambient temperature) were investigated using Pearson's correlation analysis, the analysis results are shown in Table 3 and Figure 7. A strong positive correlation was found between PM_{10} and the atmospheric temperature (r = 0.87). This correlation can be explained by the effects of temperature on formation of new particles through gas to particle conversion processes. The effect of atmospheric temperature on PM_{10} levels is very obvious in the seasonal variation pattern of PM_{10}.

High humidity conditions (>13%) are inversely correlated with PM_{10} concentrations, as indicated by the moderate negative coefficient (r = -0.58). This correlation might be attributed to the effects of air moisture on coalescence

Table 3: Correlations of between PM_{10} and different meteorological parameters in the study area during 2009 to 2011.

Parameter	Criteria	Pearson Correlation Coefficient (r)	Coefficient of Determination (R^2)
Temperature (°C)	All observations	0.87	0.76
	≤37	0.99	0.97
	>37	0.80	0.64
Relative Humidity (%)	All observations	-0.20	0.04
	≤13	0.87	0.75
	>13	-0.58	0.33
Wind speed (m/sec)	All observations	0.64	0.42
	< 10	0.80	0.64
	≥10	0.49	0.24

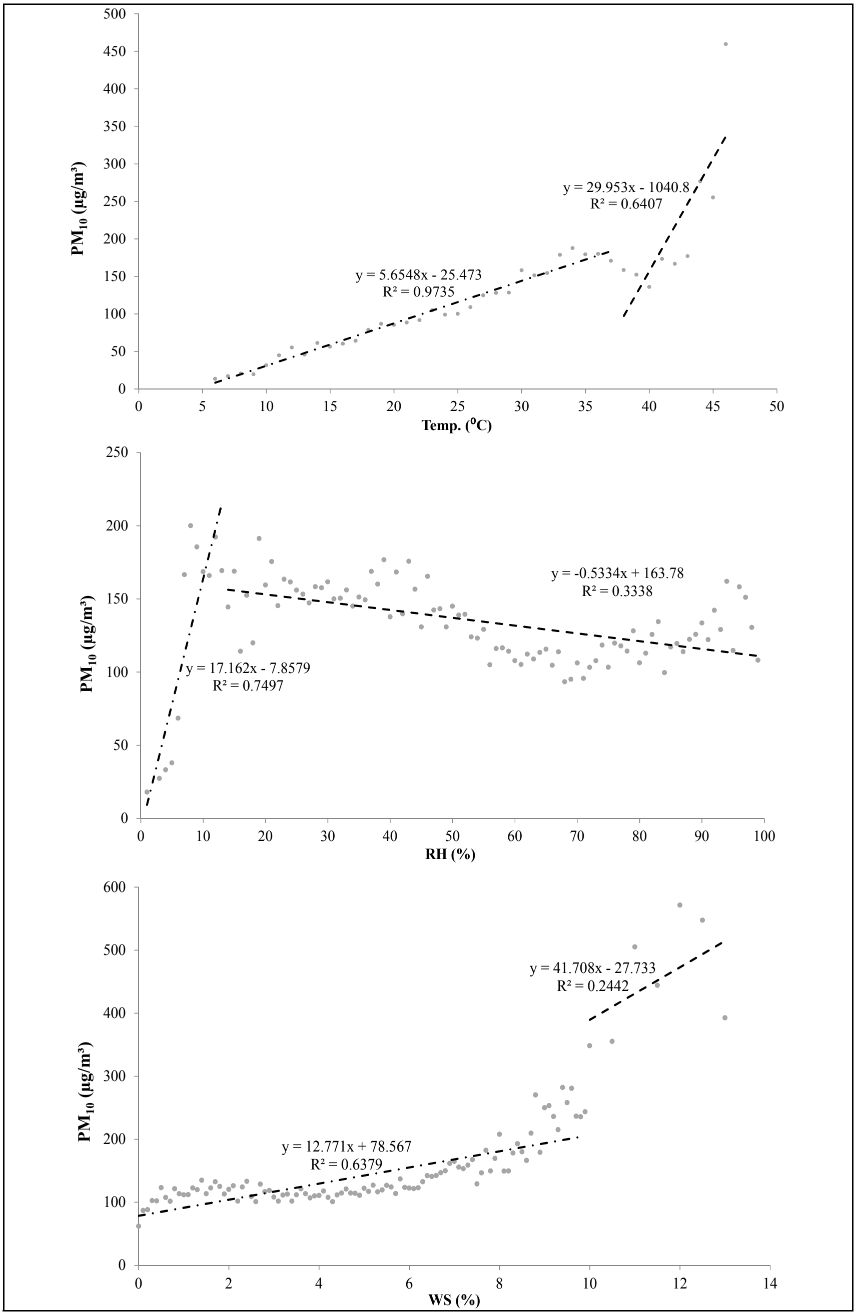

Figure 7: Linear regression between suspended particles and meteorological variables (temperature, relative humidity and wind speed).

and settling of suspended particles from the atmosphere. Conversely, dry conditions (≤13% relative humidity) are strongly correlated with PM_{10} (r = 0.87), which may be attributed to the effects of humidity on coagulation and propagation of ultrafine particles. Finally, a moderate positive correlation was observed between wind speed and PM_{10} (r = 0.64) due to the re-suspension effect of wind and the potential of winds to transport particulates between regions around the study area. However, strong correlation (r = 0.80) was observed for the wind speed s lower than 10 m/sec, where the more observations can be found and correlated.

4 Conclusion

Based on the analyses of PM_{10} and their correlation with meteorological parameters, the following conclusions can be reached:

- The study area is characterized by relatively low wind speed and high temperatures and humidity.
- Elevated levels of suspended particles were observed in the study area, where 27% of the daily average values exceeded the national standard limit of 150μg/m^3.
- The diurnal variation pattern of PM_{10} levels showed two concentration peaks, the primary peak occurred during the afternoon and the secondary peak occurred at 16:00. Seasonal variations in PM_{10} did not follow a similar pattern during the study period. However, dry seasons showed a higher level of PM_{10}, while the lowest concentrations were recorded in the wet seasons. Tuesdays showed higher concentrations of PM_{10}, while the lowest level was found to be on Fridays (weekend).
- Pearson's analysis showed that there is positive correlation between the ambient PM_{10} level and each of atmospheric temperature, wind speed and low humidity conditions. Conversely, there is a strong inverse correlation between PM_{10} and relative humidity levels greater than 13%.

Acknowledgements

The authors are thankful to Eng. Khaled Al Ameri/Head of the Technical Support Section at the National Energy & Water Research Center (NEWRC) for his cooperation and to Eng. Santosh K.L. for his efforts to maintain AAQM instruments during the study period.

References

[1] Hueglin, C., Gehrig, R., Baltensperger, U., Gysel, M., Monn, C., and Vonmont, H, Chemical characterization of $PM_{2.5}$, PM_{10} and coarse particles at urban, near-city and rural sites in Switzerland. *Atmospheric Environment*, 39(4), pp. 637–651, 2005.

[2] Wise, E. K., and Comrie, A. C., Meteorologically adjusted urban air quality trends in the southwestern United States. *Atmospheric Environment*, 39: 2969–2980, 2005.

[3] United States Environmental Protection Agency (US-EPA), Guidelines for developing an air quality (ozone and $PM_{2.5}$) forecasting program, EPA-456/R-03-002, pp. 1–2, 2003.

[4] Hien, P. D., Bac, V. T., Tham, H. C., Nhan, D. D., and Vinh, L. D., Influence of meteorological conditions on $PM_{2.5}$ and $PM_{2.5–10}$ concentrations during the monsoon season in Hanoi, Vietnam. *Atmospheric Environment*, 36, pp. 3473–3484, 2002.

[5] Giri, D., Krishna, M. V., and Adhikary, P. R., The influence of meteorological conditions on PM_{10} concentrations in Kathmandu Valley. *International Journal for Environmental Research*, 2(1), pp. 49–60, 2008.

[6] Gietl, J. K., and Klemm, O., Analysis of traffic and meteorology on airborne particulate matter in Münster, northwest Germany. *Air and Waste Management Association*, 59 (7), pp. 809–818, 2009.

[7] Akyuz M., and Çabuk, H., Meteorological variations of $PM_{2.5}/PM_{10}$ concentrations and particle-associated polycyclic aromatic hydrocarbons in the atmospheric environment of Zonguldak, Turkey. *Journal of Hazardous Materials,* 170(1), pp. 13–21, 2009.

[8] Galindo, N., Varea, M., Gil-Molto, J., Yubero, E., and Nicolas, J., The influence of meteorology on particulate matter concentrations at an urban Mediterranean location. *Water, Air, and Soil Pollution*, 215, pp. 365–372, 2010.

[9] Bhaskar, B. V., and Mehta, V. M., Atmospheric particulate pollutants and their relationship with meteorology in Ahmedabad. *Aerosol Air Quality Research*, 10, pp. 301–315, 2010.

[10] Gebhart, K. G., Kreidenweis, S. M., and Malm, W. C., Back trajectory analyses of fine particulate matter measured at Big Bend National Park in the historical database and the 1996 scoping study. *Science of the Total Environment*, 276, pp. 185–204, 2001.

[11] Chaloulakou, A., Kassomenos, P., Spyrellis, N., Demokritou, P., and Koutrakis, P., Measurements of PM_{10} and $PM_{2.5}$ particle concentrations in Athens, Greece. *Atmospheric Environment*, 37, pp. 649–660, 2003.

[12] Nilsson, B. A., Model of the relation between aerosol extinction and meteorological parameters. *Atmospheric Environment,* 28(5), pp. 815–825, 1994.

[13] Initial National Communication to the United Nations Framework Convention on Climate Change. Ministry of Energy (MoE), UAE, 2006, pp. 14–15.

[14] Annual Bulletin of Climate and Air Statistics. Statistics Centre of Abu Dhabi (SCAD), Abu Dhabi Emirate, UAE, 2010, pp. 14–23.

[15] Al-Aidrous, F., Madi, M. T., and Bener, A., Air quality in Abu-Dhabi and health effect. A paper presented at the *4th Annual UAE University Research Conference*, held in Al Ain, UAE on April, 2003.

[16] Waste and pollution sources of Abu Dhabi Emirate, State of Environment, Environment Agency of Abu Dhabi (EAD), Abu Dhabi Emirate, UAE, pp. 71–91, 2008.
[17] Personal communication, May 2007, Statistician, Ministry of Economy, Abu Dhabi, UAE.
[18] Peck, R., Olsen, C., and Devore, J., *Introduction to Statistics and Data Analysis*, 4th edition. Belmont, CA: Thomson Brooks/Cole, 2011, pp. 742–752.
[19] Regulation Concerning Protection of Air from Pollution, Council of Ministers, Decree No. (12), 2006, Annex #8, Ambient Air Quality Standards, Air Pollutants Limits in the Ambient Air, p. 61.