Atmospheric Aerosol Characterization and Element Composition at Al-Ahsa Oasis of Saudi Arabia

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Received 18 January 2015 - Accepted 8 June 2015

ABSTRACT

This work is an observational study aiming to characterize and identify atmospheric aerosol and element composition in the arid environment of Al-Ahsa Oasis in Saudi Arabia during the period from 1988 to 2013. Historical data showed that ambient mean air temperatures ranged from 8.8 ºC to 46.1 ºC. Meanwhile, ambient air relative humidity means ranged from 13.3% to 77.5%. Total rainfall levels ranged from 13.9 to 266.1 mm/year with an average of 80 mm/year. This rainfall value is very low in relation to the evaporation rate (2600 mm/year). The annual means of number of days of blown dust and dust/sand storms were 89.3 and 16.2, respectively. The highest number of blown dust and dust/sand days occurred during the month of June while the fewest blown dust and dust/sand days occurred during the month of October. During the year 2013, mean values of total suspended particles (TSP), particulate matter smaller than or equal to 10 µm (PM_{10}) and those smaller than or equal to 2.5 µm ($PM_{2.5}$) were 783.2, 545.6 and 57 $\mu g/m^3$, respectively. Relationships shows that the PM concentrations is mostly increase with the increase of wind speed, air temperature and decrease with the increase of air relative humidity. Furthermore, relationship shows that the source of high PM concentrations (dust storms) mainly originated from north direction.

The study revealed that Al-Ahsa weather conditions are harsh and extreme and PM concentrations vary daily, monthly and seasonally. During the study, the quantity of atmospheric dust exceeded air quality limits several times. This potentially affected human, agricultural, and animal welfare.

Key Words: Aerosol, Air Quality, Dust, Saudi Arabia, Visibility.

INTRODUCTION

Al-Ahsa (also spelled Al-Hasa) is the largest oasis in Saudi Arabia. It is located in the Eastern Province (25° 23′N, 49° 35′E, at elevation 172 meters) in the middle of the Jafura Desert (fig.1). The Jafura sand sea covers the Gulf coastal region in the Eastern Province. It extends from an area of high wind energy in the north to one of low wind energy in the south, resulting in general sand drifting from south to southeast (Abdulmalik, 2005). For a long period of time, Al-Ahsa oasis of Saudi Arabia was famous for its fertile soil and huge underground water reservoir. However, In recent years increasing drought in addition to dust events have been extraordinary in terms of their intensity and dimensions. Furthermore, drifting and settling sand and moving dunes have been devastating the oasis where nearly half of the oasis may have been lost during the past ten centuries (Abolkhair, 1981).

Figure 1: Location of Al-Ahsa oasis, Saudi Arabia; map source: http://bit.ly/2nd2yOB. Retrieval Date: 18 March 2015.

Dust particles can affect both regional and global environments through reduction of visibility and can have detrimental effects on human health (Park *et al.,* 2003). These particles can also react with gaseous species during transport, thereby changing their properties (Song and Carmichael, 2001; and

Underwood *et al.,* 2001). Particulate matter smaller than 10 µm (PM_{10}) are considered highly dangerous because they can be inhaled. Several epidemiological studies have shown a strong association between elevated concentrations of inhalable particles and increased mortality levels (Namdeo and Bell, 2005). Despite many studies on indoor air quality at agricultural facilities, information on the characteristics and magnitude of outdoor atmospheric dust and its interactions and effects on that air quality is relatively scarce. Because agricultural and animal production continue to expand rapidly in Saudi Arabia, the facilities where such activities take place and zones surrounding air quality non-attainment areas are faced with major air quality challenges. Muller *et al*. (2008) stated that, for both forced and natural ventilation, the animal building envelope including ventilation openings and outside climatic conditions, had the dominant influences. The results of one study (Almuhanna *et al.,* 2011) show that increased air contaminants negatively affect the general productive performance and immune responses of commercial poultry. Almuhanna (2011, 2013) conducted several studies to classify air contaminants (particle size distribution, airborne particle and toxic gas concentrations) within housing facilities. He found that internal pollutants associated with animal husbandry were greatly affected by outdoor ambient pollutant concentrations. In Saudi Arabia, the Presidency of Meteorology and Environment (PME) that established the General Environmental Law that outlines environmental protection standards ambient particulate matter and other pollutants. The United States Environmental Protection Agency (EPA) and in Europe by the European Environment Agency (EEA) has their own standards (Table 1).

Table 1:Ambient air quality standards regulated by PME, EPA and EEA.

	Averaging time period	Acceptable Maximum µg/m^3 (ppm)			Number of Allowable Exceedance
		*PME, KSA	**EPA, USA	***EC, EU	
TSP	24-hours	--	--	300	--
	Yearly	--	--	150	--
PM_{10}	24-hours	340	150	50*	24 (35*) times per year
	Yearly	80	50	40	--
$PM_{2.5}$	24-hours	35	35	--	24 times per year
	Yearly	15	15	25	--

Sources*Air Quality Standards, General Environmental Law, Presidency of Meteorological and Environment, (PME), KSA.
**Clean Air Act, Environmental Protection Agency (EPA), USA
***Air Quality Standards, European Commission, European Environment Agency (EEA), EU

The aim of this study is to assess and develop accurate data for atmospheric aerosol and associated climatic conditions and visibility in terms of characteristics and element composition under Al-Ahsa conditions.

MATERIALS AND METHODS

In this research, a series of field-intensive sampling campaigns were carried out under different meteorological conditions to measure and characterize atmospheric particulate matter surrounding animal and agricultural activities at Al-Ahsa. Sampling and monitoring instruments were installed in the agricultural and veterinary training and research station of King Faisal University (KFU) of Saudi Arabia (25.3°N, 49.6°E, mean altitude above sea level 172 m) (fig. 2). This location is ~70 km inland of the seacoast. The following procedures were performed.

1. TSP, PM_{10}, $PM_{2.5}$ and PM_1 particle levels were continuously recorded using a fixed monitoring station (Turnkey Optical Particle Analysis System, TOPAS), integrated with wind speed and direction sensors with a sampling flow rate 600 cc/min and accuracy ±0.1 μg/m^3.
2. Particle size distributions (PSD), real-time numbers and mass concentrations were measured using a particulate matter spectrometer (model PM-101P; HCT Co., Ltd.). This instrument measures particles from 0.3 to 25 μm with air-sampling rate 1 L/min using 15 channels.
3. Atmospheric visibility (meteorological optical range) was measured using a Sentry™ SVS1 Visibility Sensor (EnviroTech Sensors, Inc., Columbia, Maryland USA) with visibility range 30–10 km. The sensor uses a light source of 880 nm LED with accuracy ±10% RMSE.
4. Weather conditions were measured continuously using a HOBO U30 Weather Station (Onset Computer Corp., Bourne, MA, USA) located in the sampling area. Measurements were obtained at four-minute intervals, and average values were recorded at one-hour intervals.
5. Historical weather data were acquired from the KFU weather station database and Al-Ahsa (OEAH) airport weather station (Elev. 179 m; 25.29°N, 49.49°E) via the Weather Underground website <(http://bit.ly/2ph5Y1H)>.
6. Additional data were obtained from the RDMEC (Drought Monitoring and Early Warning Center, Middle East, 2014 Jeddah Regional Climate Center – JRCC, KSA).

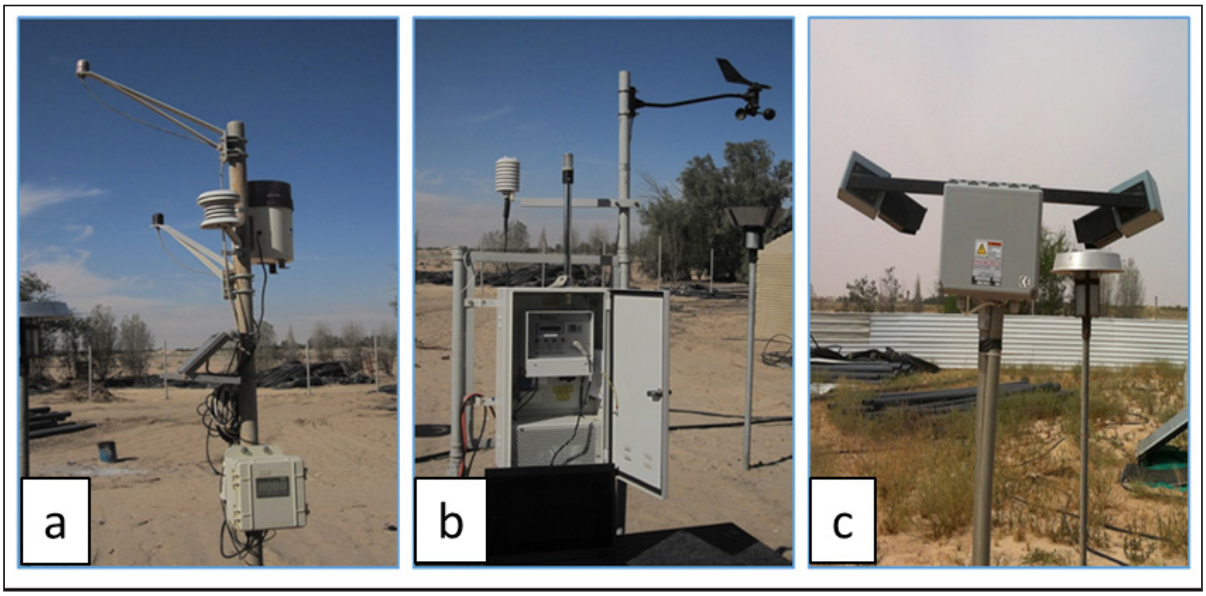

Figure 2: Photographs of instruments used: (a) Hobo U30 weather station, (b) TOPAS system, (c) Sentry™ SVS1 Visibility Sensor

Data were statistically analyzed using PROC GLM in SAS (version 9.1; SAS Institute, Inc., Cary, NC, USA). Particulate concentration mean comparisons were made using Duncan's multiple range test at 5% probability level.

RESULTS AND DISCUSSION

The climate in Al-Ahsa, Saudi Arabia is a typical harsh, dry desert environment with significant temperature extremes exceeding 50 °C, in addition to wide discrepancies between precipitation and evaporation rates. Based on annual means climatic conditions of a26-year period (1988–2013), the mean of minimum temperatures recorded in January was 8.8°C, while the mean of maximum in July was 46.1°C (fig. 3). Moreover, mean of minimum relative humidity percentage recorded in June was 13.3%, while the mean of maximum recorded in December was 77.5%. Figure 3 shows historical monthly means for ambient air temperature, relative humidity recorded in Al-Ahsa, Saudi Arabia (1988-2013).

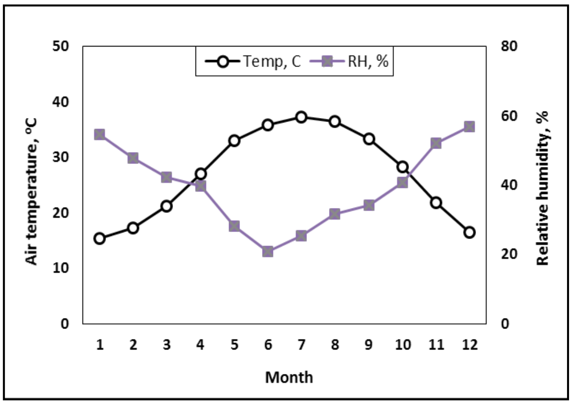

Figure 3. Historical monthly means values of ambient air temperature, relative humidity (Al-Ahsa, Saudi Arabia, 1988-2013).

Historical records of annual accumulated rain (1988–2013) at Al-Ahsa (Fig. 4a).

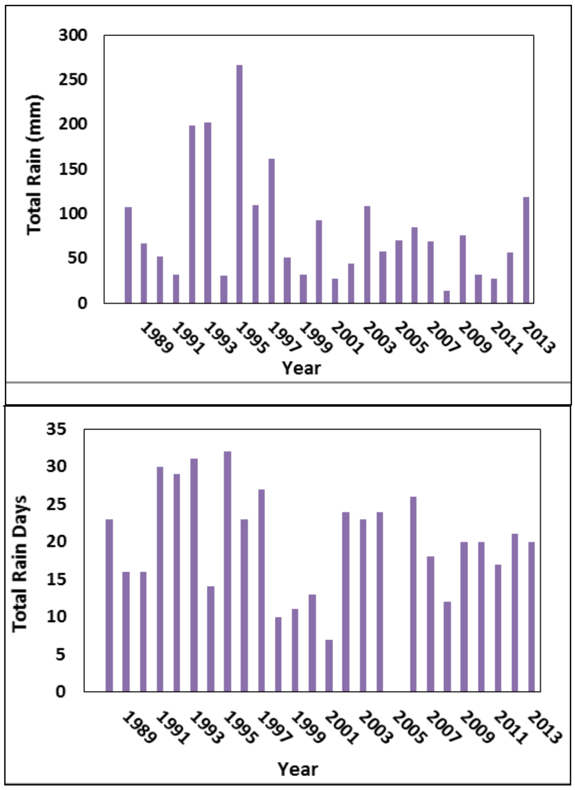

Figure 4: Historical annual records of total rainfall at Al-Ahsa. (a) Annual total rainfall; (b) annual days of rainfall.

It ranged between 13.9 and 266.1 mm, with an average of 80 mm. As these rain amounts are very low in relation to the annual evaporation (2600 mm), in addition to threshold value wind, soil dryness and erosion are prevalent conditions, which allows soil particles to be easily dislodged from the ground. Figure 4b shows the mean of annual number of rainy days.

Historical records of blown dust and dust/sand storm mean number of days per month for Al-Ahsa over the period 1988–2013 are presented in Fig. 5. The figure shows that the majority of blown dust and dust/sand days occurred between March and July, whereas the lowest number was between August and November. The greatest number of blown dust and dust/sand days was in June, and the fewest in October. This figure also shows that blown dust and dust/sand days in winter were ~50% of the number of days with these characteristics during summer.

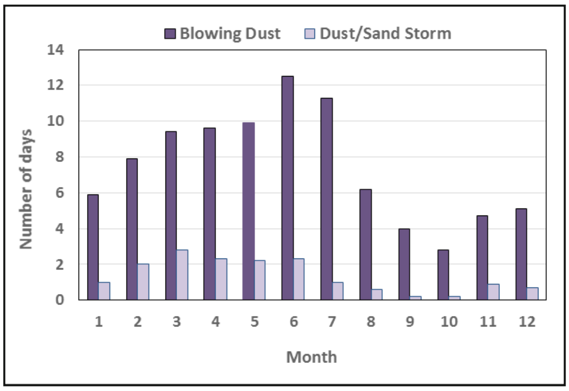

Figure 5: Monthly variations in number of blown dust and dust/sand storm days. Historical mean monthly values for 1988–2013

Table 2 shows the monthly mean number of days during which weather phenomena occurred at Al-Ahsa over the period 1988–2013. There was an average annual total of 89.3 blown dust days and 16.2 days with dust or sand storms. The table also shows that during June, the number of rainy days declined to zero. The greatest numbers of rainy days were in January and March.

Table 2:Historical mean monthly number of days with occurrence of weather phenomena at Al-Ahsa (1988–2013)*

Month	Rain	Mist	Fog	Blown Dust	Dust/Sand Storm
1	8.7	5.5	1.7	5.9	1.0
2	5.8	4.3	1.0	7.9	2.0
3	9.1	2.3	0.1	9.4	2.8
4	7.3	0.7	0.2	9.6	2.3
5	2.0	0.2	0.0	9.9	2.2
6	0.0	0.1	0.0	12.5	2.3
7	0.1	0.4	0.1	11.3	1.0
8	0.2	1.8	0.1	6.2	0.6
9	0.0	2.5	0.5	4.0	0.2
10	0.3	4.1	1.1	2.8	0.2
11	3.1	5.2	1.3	4.7	0.9
12	7.2	7.2	2.5	5.1	0.7
Total	43.8	34.3	8.6	89.3	16.2

*Source: RDMEC Drought Monitoring and Early Warning Center, Middle East, 2014 Jeddah Regional Climate Center (JRCC), KSA.

Monitoring of atmospheric dust and associated climatic conditions during 2013

In 2013, mean ambient air temperature (Fig. 6a) was between 10 °C and 46.4 °C. Relative humidity (Fig. 6b) was between 9.4% and 89.5%. Previous data and maximum and minimum records show that the hottest and driest weather at Al-Ahsa was during summer, when ambient air temperatures reached the 50 °C range and relative humidity dropped to nearly 5%.

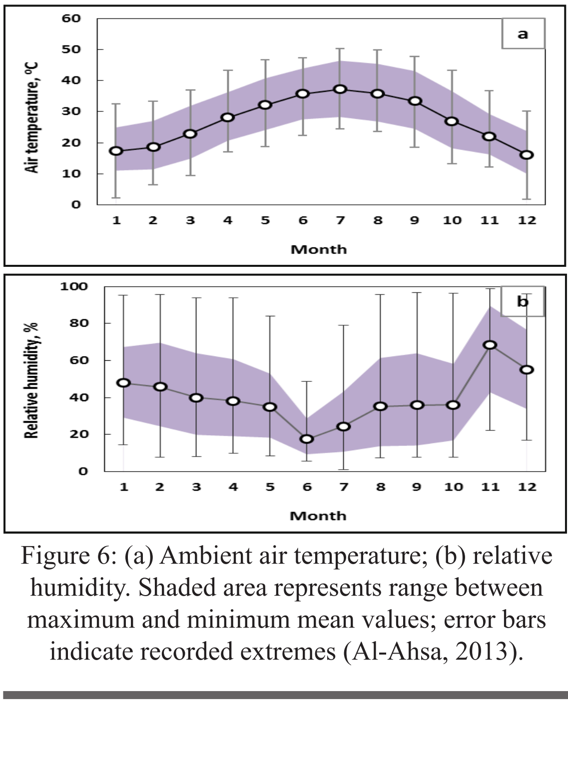

Figure 6: (a) Ambient air temperature; (b) relative humidity. Shaded area represents range between maximum and minimum mean values; error bars indicate recorded extremes (Al-Ahsa, 2013).

Relationship between PM size ranges and ambient air temperature (2013) are shown in Fig. 7, which indicate fair association between dust concentration and air temperature. This relationship shows that the dust concentrations is mostly increase with the increase of air temperature.

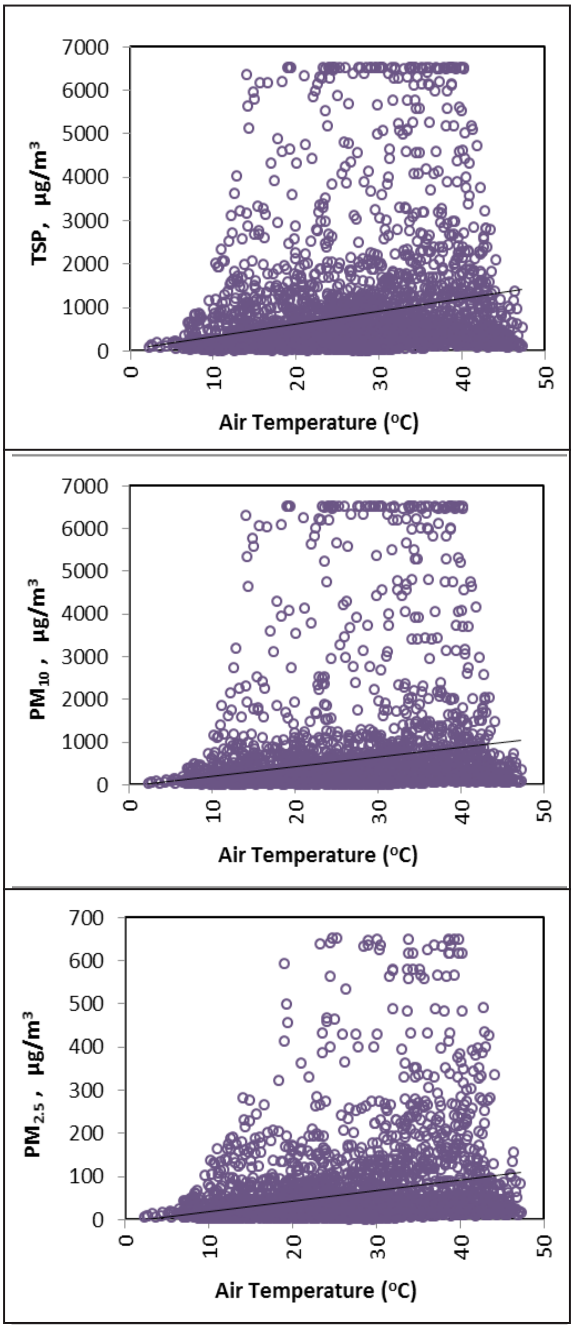

Figure 7: Relationship between PM size ranges and air temperature at Al-Ahsa in 2013.

Relationship between PM size ranges and ambient air relative humidity (2013) are shown in Fig. 8, which indicate fair association between dust concentration and air relative humidity. This relationship shows that the dust concentrations is mostly decrease with the increase of air relative humidity.

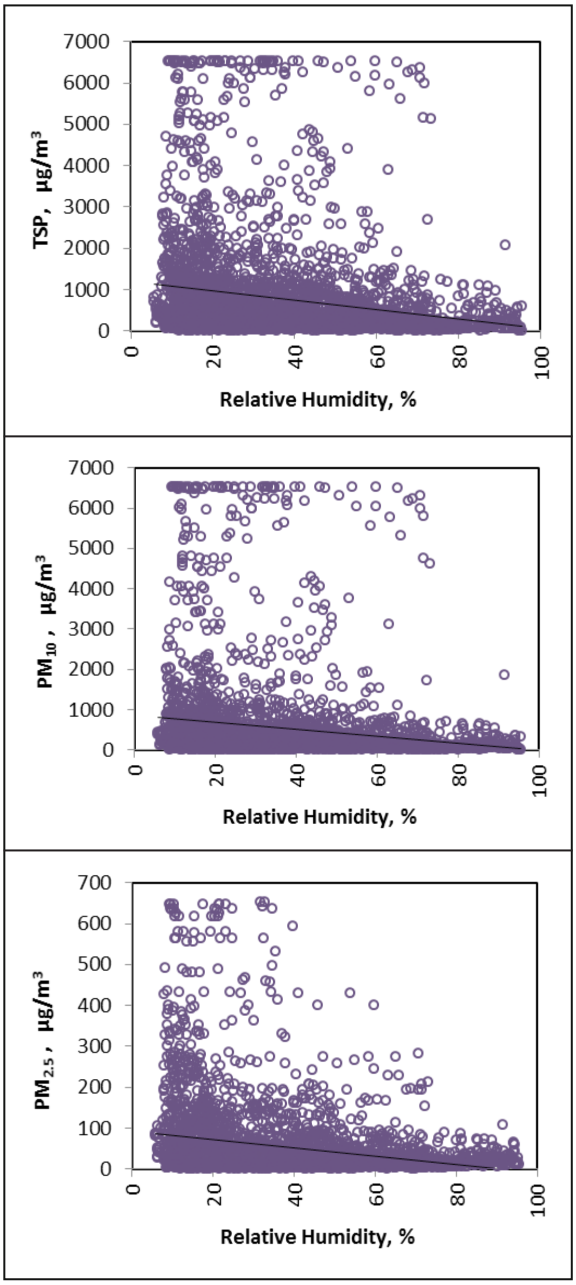

Figure 8: Relationship between PM size ranges and air relative humidity at Al-Ahsa in 2013.

Total annual precipitation level reached 113.4 mm, which occurred on 20 rainy days. Figure 9 shows that in 2013, November was the wettest month at Al-Ahsa, with a total 82 mm of precipitation. The driest period spanned June through October and, in January and December, no precipitation was recorded.

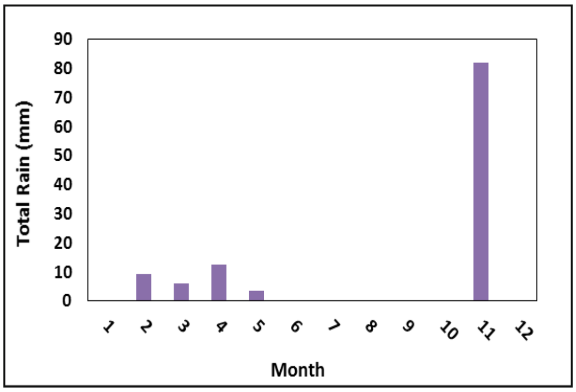

Figure 9: Monthly total precipitation at Al-Ahsa in 2013.

PM concentrations, visibility and weather data from 2013 were measured and investigated. Mean values for TSP, PM_{10} and $PM_{2.5}$ were 783.2 µg/m³ (SD=399 µg/m³), 545.6 µg/m³ (SD=314.7 µg/m³) and 57 µg/m³ (SD=29.4 µg/m³), respectively. Mean maximum concentrations of TSP and PM_{10} recorded in July were 1736.3 and 1262.3 µg/m³, respectively, whereas $PM_{2.5}$ levels in June reached 121.2 µg/m³ (Table 3).

Higher particle concentrations are common in Saudi Arabia during summer. This trend may be related to the frequent occurrence of northern winds and little rainfall, which increases atmospheric turbulence, re-suspends roadside dust, and blows sand particles from surrounding areas (Habeebullah, 2013). North winds may also cause saltation, which involves a specific type of particle transport by fluids, such as wind. Saltation occurs when loose material is removed from a bed and carried by the fluid before being transported back to the surface. Minimum values of TSP, PM_{10} and $PM_{2.5}$ in November 2013 were 52.3, 26.1 and 6.1 µg/m³, respectively, and these recorded low levels may be related to wet deposition and washout processes caused by maximum recorded rain amounts in that month. Annual average PM_{10} concentration in 2013 was 545.6 µg/m³, which is greater than six times the threshold established in the PME standards (80 µg/m³). These levels may have negative effects on human health by transporting microorganisms, and may aggravate ailments such as asthma, bronchitis, and other lung conditions. PM_{10} constituted 69.8% of TSP, and $PM_{2.5}$ made up 7.3%. This suggests that the majority of particles are classified by mass as larger than 2.5 µm.

Table 3: Monthly means of TSP, PM_{10}, and $PM_{2.5}$ concentrations (µg/m³) measured in 2013.

Month	TSP			PM_{10}			$PM_{2.5}$		
	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.
1	486.5	1239.4	131.9	320.9	945.0	77.4	33.0	80.7	11.6
2	399.0	1000.6	124.7	241.6	659.2	74.3	27.6	66.9	9.8
3	424.9	995.7	150.6	252.0	632.0	89.9	34.3	71.1	14.1
4	1057.1	2636.1	307.9	788.6	2312.3	178.5	71.6	190.1	21.2
5	1039.6	2280.1	346.7	704.9	1807.5	178.2	54.8	146.3	18.8
6	1459.2	2543.4	587.2	1118.1	2160.7	338.6	121.2	225.2	39.8
7	1736.3	5819.3	269.7	1262.3	4884.8	124.0	117.9	388.9	19.2
8	526.3	4136.7	269.7	290.5	954.5	124.0	36.7	102.0	19.2
9	385.8	886.4	136.5	232.6	562.2	82.1	42.0	102.4	14.5
10	268.5	597.5	108.5	165.7	398.6	64.5	27.3	61.5	10.9
11	121.2	241.0	52.3	103.1	174.1	26.1	15.6	32.3	6.1
12	1493.5	5819.3	269.7	1067.6	4884.8	124.0	101.6	388.9	19.2
Annual mean	783.2	2349.6	229.6	545.6	1698.0	123.5	57.0	154.7	17.0
SD	547.9	1952.6	145.9	417.5	1609.0	81.3	37.2	122.6	8.6

Figure 10 shows monthly mean concentrations of TSP, PM_{10}, and $PM_{2.5}$ measured at Al-Ahsa in 2013. It is evident that dust concentrations varied daily, monthly, and seasonally. The highest mean TSP concentrations were in July and the lowest in November.

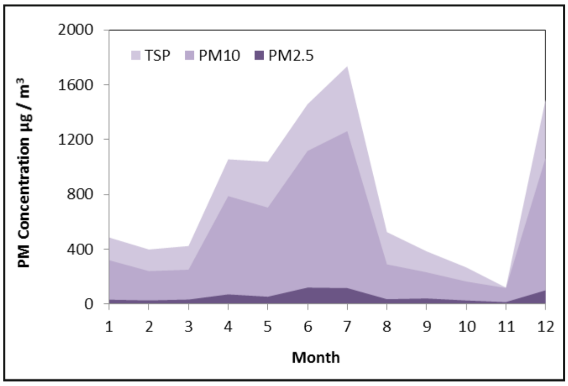

Figure 10: Mean monthly values of TSP, PM_{10}, and $PM_{2.5}$ measured in 2013.

The PME, among other agencies like the WHO, European Union and EPA, established health-based standards for a number of air pollutants, including PM. Concentrations of particulates of different size ranges should remain within these prescribed standards to maintain acceptable health conditions.

Figure 11a and b shows that dust concentrations varied daily (each point represent a daily mean), monthly and seasonally. The quantities of atmospheric dust greatly exceeded the air quality limits established by the PME, especially in summer.

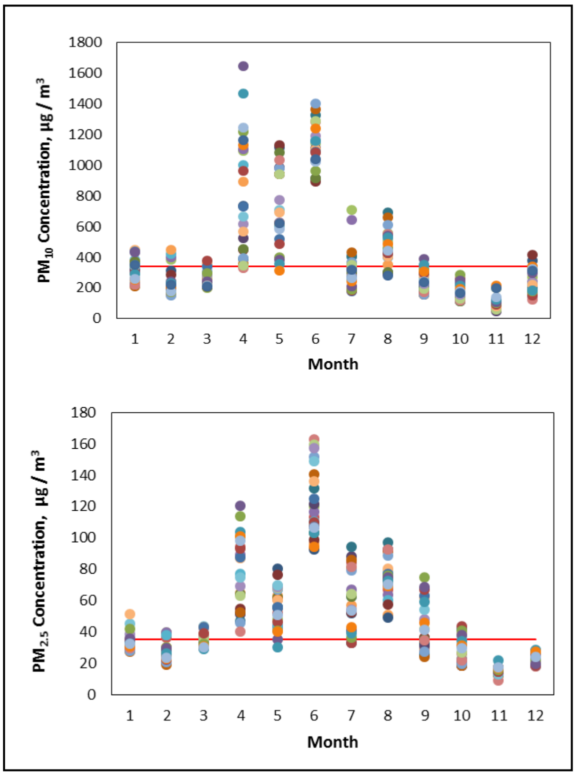

Figure 11: Daily mean (a) PM_{10} (b) and $PM_{2.5}$ concentrations (µg/m³) in 2013. Straight line denotes exceedance of 24-hour air quality limits (a: 340 µg/m³, b: 35 µg/m³) established by PME.

The spread of dust can quickly reduce visibility to a few meters and can have negative environmental and safety repercussions. Reductions of visibility can be caused not only by dust, but also by other phenomena such as fog and smoke. Table 4 shows monthly average dust concentrations (µg/m^3) compared with visibility reduction (< 10 km) and total monthly rainfall.

Table 4: Monthly mean values of dust concentration (µg/m^3) compared with visibility and total monthly rainfall in 2013.

Month	Rain total (mm)	Average dust Concentrations (µg/m^3)			Visibility (km)		
		TSP	PM_{10}	$PM_{2.5}$	Max	Mean	Min
1	3.05	486.5	320.9	33.0	10.0	8.1	5.9
2	1.01	399.0	241.6	27.6	9.9	8.4	6.4
3	7.11	424.9	252.0	34.3	10.0	8.5	6.4
4	9.90	1057.1	788.6	71.6	9.8	8.0	5.2
5	5.08	1039.6	704.9	54.8	10.0	7.9	5.5
6	0.00	1459.2	1118.1	121.2	9.5	6.5	4.6
7	0.00	1736.3	1262.3	117.9	10.0	8.1	6.4
8	0.00	526.3	290.5	36.7	10.0	9.2	8.0
9	0.00	385.8	232.6	42.0	10.0	8.5	6.3
10	0.00	268.5	165.7	27.3	10.0	8.9	8.0
11	92.20	121.2	103.1	15.6	10.0	8.7	6.0
12	0.00	1493.5	1067.6	101.6	10.0	8.6	6.5

Figure 12a and b shows mean values for wind speed (m/s) and atmospheric pressure (mbar) adjusted to sea level. Furthermore, thermal low-pressure area may occurred during summer months accompanied by increase in wind speed.

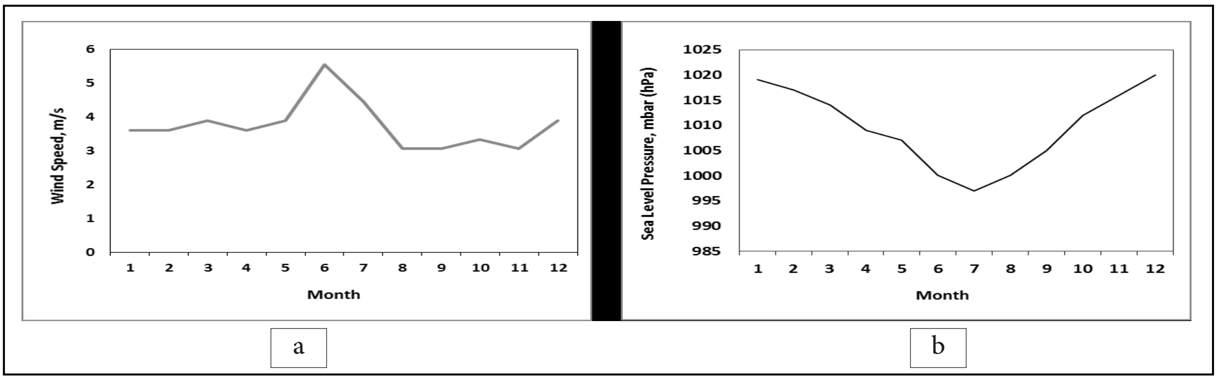

Figure 12: Monthly (a) mean and maximum wind speed (m/s); (b) mean sea level atmospheric pressure (mbar) in 2013.

Relationship between PM size ranges and wind direction (2013) shown in Fig. 13, which indicate strong association between dust concentration and wind direction. This relationship shows that the source of high dust concentrations (dust storms) mainly originated from north direction.

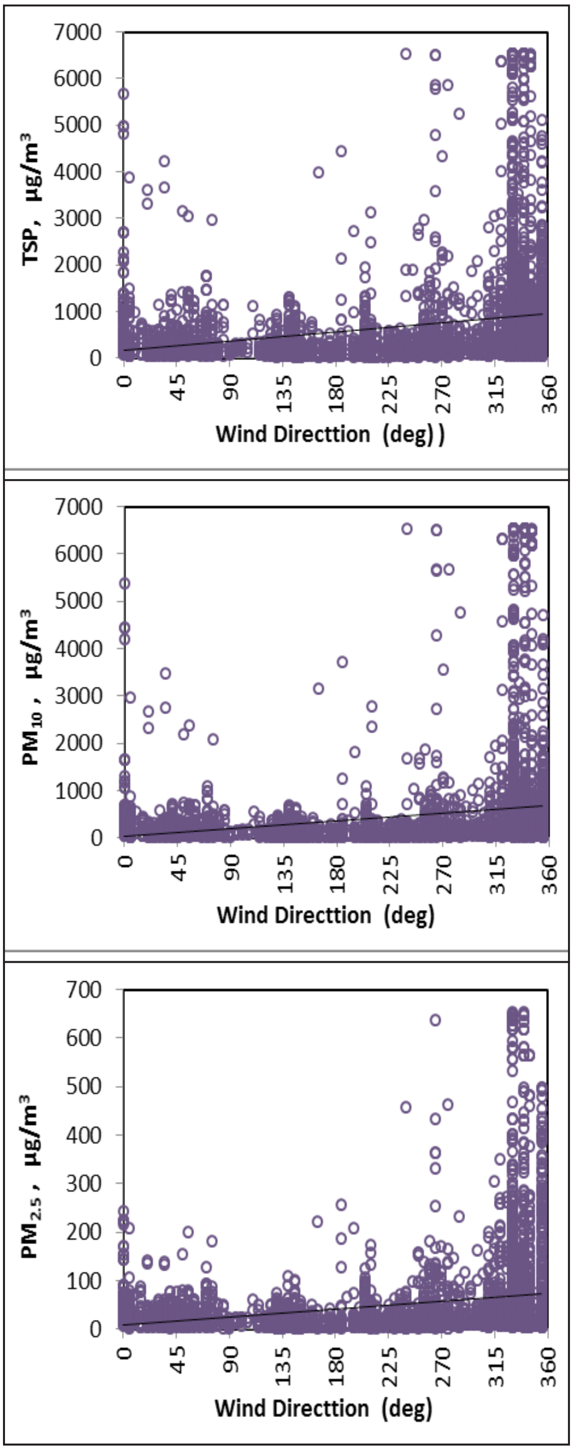

Figure 13: Relationship between PM size ranges and wind direction at Al-Ahsa in 2013.

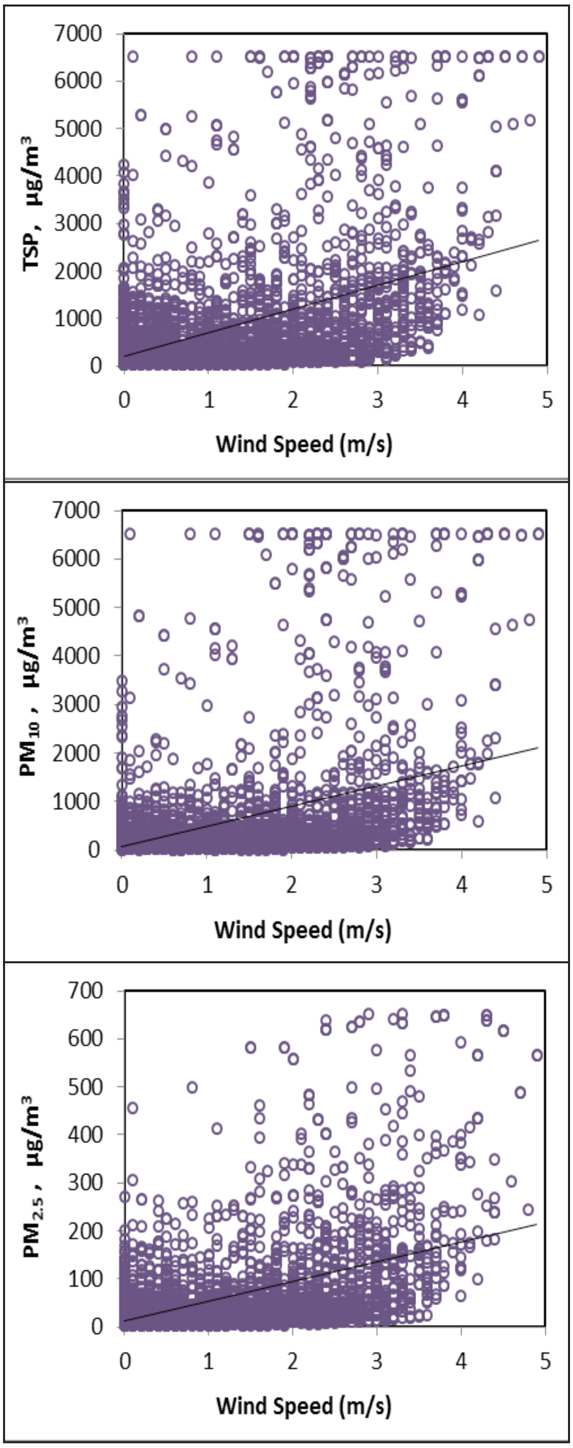

Figure 14: Relationship between PM size ranges and wind speed at Al-Ahsa in 2013.

Relationship between PM size ranges and wind speed (2013) shown in Fig. 14, which indicate fair association between dust concentration and wind speed. This relationship shows that the dust concentrations is mostly increase with the increase of wind speed.

Results of regression analysis for dust concentrations with visibility are shown in Fig. 15, which indicate strong correlation between the two variables.

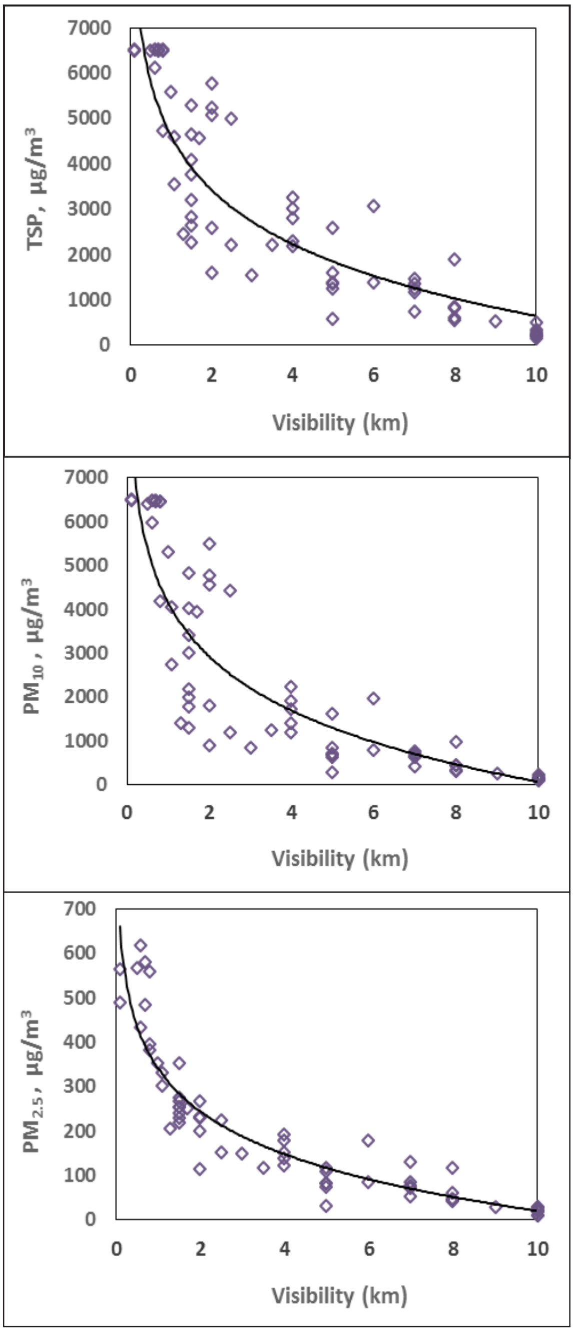

Figure 15: Relationship between average PM size ranges and average visibility (2013).

Correlations between variables were as follows: visibility and TSP, 0.92; visibility and PM_{10}, 0.92; visibility and $PM_{2.5}$, 0.94). Equations for the variables (TSP, PM_{10}, $PM_{2.5}$ and visibility) were used to predict visibility (Vis) with dust concentrations and vice versa:

$$Vis = -2.93 \ln(TSP) + 26.4 \quad (R^2 = 0.85) \qquad (1)$$

$$Vis = -2.45 \ln(PM_{10}) + 21.81 \quad (R^2 = 0.85) \qquad (2)$$

$$Vis = -2.99 \ln(PM_{2.5}) + 18.83 \quad (R^2 = 0.88) \qquad (3)$$

The correlation analysis shows strong association between dust concentration and visibility. Their logical relationship is that elevated dust concentrations produce poor visibility; however, poor visibility may be caused not only by elevated dust concentrations but also by other factors (fog, smoke, and others).

CONCLUSION

Elevated dust concentrations and dust storms associated with dustfall in the Al-Ahsa oasis region of Saudi Arabia are common phenomena that can have many adverse effects. These can be classified as follows: effects on human and animal respiratory systems, increased indoor dust associated with animal husbandry, and adverse dust effects on plant health and productivity.

This study provides basic knowledge about the nature and characteristics of atmospheric aerosol (mainly dust) affecting the arid region of Al-Ahsa. A summary is presented for the monitored atmospheric conditions and dust events of 2013.

From 1988 to 2013, ambient mean air temperatures ranged between 8.8 ºC and 46.1 ºC. Meanwhile, ambient air relative humidity means ranged between 13.3% and 77.5%. Total rainfall levels ranged between 13.9 and 266.1 mm/year with an average of 80 mm/year. This rainfall value is very low in relation to the evaporation rate (2600 mm/year). The annual blown dust and dust/sand day means were 89.3 and 16.2, respectively, while the highest number of blown dust and dust/sand days occurred during the month of June. The fewest blown dust and dust/sand days occurred during the month of October. In 2013, measured mean values of TSP, PM_{10} and $PM_{2.5}$ were 783.2, 545.6 and 57 µg/m³, respectively. Mean maximum concentrations of TSP and PM_{10} in July were 1736.3 and 1262.3 µg/m³, respectively, whereas the maximum $PM_{2.5}$ was recorded in June (121.2 µg/m³). The 2013 annual average PM_{10} concentration was 545.6 µg/m³ which is more than six times the threshold established in the PME standards (80 µg/m³). These values suggest possible negative human health effects. PM_{10} constituted 69.8 % of TSP and $PM_{2.5}$ made up 7.3 %, indicating that the majority of particles based on mass were larger than 2.5 µm. Ambient air temperature means were between 10 °C and 46.4 °C. Relative humidity was 9.4%-89.5%. Total annual precipitation was 113.4 mm, which occurred on 20 rainy days. November was the wettest month at Al-Ahsa, with 82 mm of precipitation, and the driest period was June through October; no rainfall was recorded in January.

Relationships shows that the dust concentrations is mostly increase with the increase of wind speed, air temperature and decrease with the increase of air relative humidity. Furthermore, relationship shows that the source of high dust concentrations (dust storms) mainly originated from north direction.

This study examined 1 year of sampling data, one dust event and one location. Therefore, more sampling periods at different locations are needed to clarify the long-term spatiotemporal effects of dust storms. More studies are also needed to link ambient and atmospheric dust effects to animal welfare and husbandry and methods of protection. Moreover, understanding of links between atmospheric dust and plant health and productivity is required. The economic impact and health effects of elevated dust concentrations and associated dustfall on residential and industrial areas is also a fertile area for future study.

ACKNOWLEDGMENT

The author would like to thank the Deanship of Scientific Research of King Faisal University, Hofuf, Saudi Arabia, for financial support (Grant No. 140038). The author also wish to acknowledge the technical support provided by the Agricultural and Veterinary Training and Research Station of King Faisal University. Acknowledgements are also extended to the agencies, publishers and authors mentioned for their supportive and valuable information.

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توصيف الهباء والعناصر الجوية المكونة في واحة الأحساء بالمملكة العربية السعودية

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استلام 18 يناير 2015م - قبول 8 يونيو 2015م

الملخص

هذه الورقة دراسة رصدية لتوصيف الهباء (الجسيمات المعلقة بالهواء) والعناصر الجوية المكونة في البيئة الجافة والمناخ القاسي لواحة الأحساء في المملكة العربية السعودية.

البيانات التاريخية للفترة من عام 1988 إلى 2013 بينت أن درجات حرارة الهواء المحيطة تراوحت بين 8.8 و46.1 درجة مئوية. ومن ناحية أخرى تراوحت متوسطات الرطوبة النسبية للهواء المحيط بين 13.3 و 77.5 % إضافة إلى ذلك تراوح الهطول الكلي للأمطار السنوية بين 13.9 و266.1 مم/ سنة بمتوسط 80 مم/ سنة مثل ذلك قيمة هطول منخفضة جداً في مقابل معدل عالٍ جداً للبخر (2600 مم/ السنة).

أوضحت الدراسة أيضاً أن معدل العدد السنوي للأيام المغبرة والعواصف الرملية والغبارية قد بلغ 89.3 و 16.2 يوماً على التوالي، في حين أن أكبر عدد للأيام المغبرة والعواصف الرملية والغبارية كان خلال شهر يونيو وأقل عدد كان خلال شهر أكتوبر.

خلال عام 2013، كانت القيم المتوسطة السنوية للجسيمات المعلقة الكلية (TSP) والجسيمات المعلقة بقطر يساوي أو أصغر من 10 ميكرومتر (PM_{10}) والجسيمات المعلقة بقطر يساوي أو أصغر من 2.5 ميكرومتر ($PM_{2.5}$) هي 783.2 و545.6 و57 ميكروغرام/ م^3، على التوالي.

أبانت العلاقات أن تراكيز الجسيمات المعلقة في الغالب تزداد مع زيادة سرعة الرياح ودرجة حرارة الهواء وتنخفض مع زيادة الرطوبة النسبية للهواء. وعلاوة على ذلك، أبانت العلاقات أيضاً أن التراكيز العالية من الجسيمات المعلقة (العواصف الترابية) تنشأ أساسا من اتجاه الشمال غالباً.

أوضحت الدراسة أن تراكيز الغبار تتباين يوميا وشهريا وموسميا وأن كمية الجسيمات المعلقة قد تتجاوز الحدود المعيارية لجودة الهواء مما يحتمل أن يؤثر على راحة وصحة الإنسان، والحيوان، والمزروعات.

الكلمات المفتاحية: جودة الهواء، الغبار، مدى الرؤية، المملكة العربية السعودية، الهباء.