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SPATIAL AND SEASONAL VARIATIONS OF THE PARTICULATE MATTERS (PM_{10}) AT SELECTED SITES IN THE STATE OF KUWAIT AIR WITHIN THE PERIOD 2010–2014

EMAN AHMED KALANDER[1] AND SURA AL-HARAHSHEH[2]

[1]*Kuwait Environment Public Authority*
[2] *Institute of Earth and Environmental Sciences, Al Al-Bayt University, Mafraq, Jordan*

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ABSTRACT

Air pollution is one of biggest environmental problems as it has many negative effects, including human health and ecosystem integrity. The sources of air pollution are either natural or human-induced activities leading to several airborne chemical pollutants. Air pollution is a major concern in the state of Kuwait, where petroleum industries, power plants (which run on fossil fuels), and road traffic contribute mainly to it. Kuwait suffers from air pollution effects. This research assessed the concentration of particulate matter pollutants (PM_{10}) in relation to the meteorological parameters (wind speed and direction, temperature, and relative humidity) in three areas—Al-Jahra, Al-Rumaithiya, and Al-Fahaheel—in Kuwait during the period 2010–2014. Many monitoring stations were set-up by the Kuwait Environmental Public Authority (KEPA). The data of the pollutants of these stations were compared with the ambient air quality standards (AAQS) set for Kuwait by EPA and with the average concentrations of PM_{10} pollutants in the three zones. The result of this study showed that there is a relationship between PM_{10} pollutants and meteorological parameters as PM_{10} increases when the temperature and wind increase, and when the humidity decreases, the current status of particulate matter pollutants exceed the KEPA standard limits. The highest concentration of dust is in Al-Rumaithiya station with an annual average concentration of 146–330 µg/m^3, followed by Al-Jahra station with an annual average concentration of 108–199 µg/m^3, and the lowest is in Al-Fahaheel station with an annual average concentration of 108–177 µg/m^3.

KEY WORDS : Air Pollution, Particulate matter, Air quality standards, Metrological parameters, Air quality management.

INTRODUCTION

Since the discovery of oil and its by-products, industrial revolution began and developed rapidly, and many of these industries and their associated processes of various scales have contributed significantly to air pollution (Al-Salem *et al.,* 2010). The rapid increase in human population causes an increase in the consumption of energy (coal, oil, and gas), which is the major fossil energy source of airborne pollutants that have contributed greatly and negatively to the ecosystem and population's health (Tang *et al.,* 2006). Air pollution is not only a local phenomenon but also a transboundary issue; in fact, the air pollutants emitted in one country may be transported in the atmosphere, and they can harm human health and the environment elsewhere (Haryanto, 2012).

A change in the physical, chemical, or biological properties of indoor or outdoor air is known as air pollution (WHO). Particulate matters (PM) refer to fine material particles. This material is a tiny particle that may be solid, liquid, or stuck in the gas. These particles are either PM_{10} (10 µ/m^3 particulate matter with an aerodynamic diameter less than 10 micrograms) or $PM_{2.5}$ (2.5 µ/m^3 aerodynamic diameter less than 2.5 micrograms).

In a country, such as Kuwait, dominated by petroleum industries, power stations (operating by fossil fuels), and road traffic, the primary pollutants are of major concern, especially those related to air quality. Kuwait suffers from air pollution (Al-Salem *et al.,* 2010). In 2001, new rules and regulations governing all environment-affecting industries in the state of Kuwait were established by KEPA. A huge anxiety about air quality in both urbanized and industrial areas exist (Al-Salem *et al.,* 2008).

The major source of air pollution in Kuwait is anthropogenic, and the only natural source is the dust storm (Zannetti, 2007). Dust storms are a common climate feature of Kuwait. The arid environment, high evaporation rate due to high temperature, long summer days, and winds are the major factors causing dust generation. Some anthropogenic sources are off-road vehicles and quarrying (Zannetti, 2007).

The impacts of particulate matter pollution on human health have been intensively studied in recent years. The results of these studies showed that they harm human health and particularly those who are already vulnerable because of their age as children and older people or suffer existing health problems (Khallaf, 2011). Particulate matter pollution is associated with a broad spectrum of acute and chronic health effects, the nature of which may vary depending on the constituent of the pollutants as well as the group of the population (Khallaf, 2011). Particulate matters have a diverse mechanical negative impact on plants as they are covering the stomata on the surface of the leaf and blocking them, thereby reducing the entry of sunlight, which leads to reduced photosynthesis (Khallaf, 2011). Also, they have an adverse effect on animals (Campbell *et al.,* 2005), whereby exposure (four hours, five days per week for two weeks) to a concentrated airborne particulate matter increases the inflammatory indices in the brain of the mice.

This study aims to investigate the particulate matter pollution of three urban areas in Kuwait, namely, Al-Jahra, Al-Rumaithiya, and Al-Fahaheel; to measure the atmospheric levels of these pollutants and compare their values with the KEPA standard limits for an urban area; to understand the spatial and seasonal variations of these pollutants; to study the distribution levels of these pollutants with respect to meteorological parameters such as wind speed and direction, and to find out which areas are affected more by particulate matter pollutants.

Particulate matter pollutants are highly dependent on meteorological factors. The amount of environmental pollutants is determined by the internal conditions for the environmental pollution area and the extent of the ongoing human contribution to reduce the size of those pollutants emitted in different sources. Some factors that determine the amount of pollutants are temperature (high surface temperature leads to rising active air movements, which cause pollutants to spread vertically, while the results from air cooling generated on that concentrate air pollutants near the surface) and wind (the distribution of particulate matter pollutants in the air is mainly affected by the speed and direction of the wind, where contaminants move toward the predominant wind (David *et al.,* 1999).

Three things are important in wind: First is the scales of air motion. On the macroscale, the movement originates in the unequal distribution of atmospheric temperature and pressure over the earth's surface. On the mesoscale and microscale, topographical features critically influence wind flow, and surface variations have an obvious effect on wind velocity and the direction of air flow (David *et al.,* 1999). Second is wind rose, which is a graphic display of the distribution of wind direction at allocation during a defined period. It is a set of wind statistics that describes the frequency, direction, intensity, and speed of wind (David *et al.,* 1999). Third is turbulence. Atmospheric turbulence usually includes those wind flow fluctuations that have a frequency of more than 2 cycles/hr. The more important fluctuations have frequencies between 0.01 and 1 cycle/sec range. Turbulence fluctuations occur randomly in both vertical and horizontal directions. This air movement is the most effective mechanism for dispersing and loosening pollutants (David *et al.,* 1999), and precipitation serves as an effective cleansing process of pollutants in the atmosphere.

In 2001, KEPA was recognized as a separate entity with legal authority. It governs the emissions and concentrations of airborne pollutants in the state of Kuwait by adopting rules and regulations for regulating air pollutant emissions and setting air quality standards and the permissible limits of these pollutants in residential and industrial areas (Al-Salem, 2008). KEPA developed environmental legislations during the '80s, and they were revised and updated during 1999–2000. Ambient air quality standards were set for long and short terms for both residential and industrial areas, along with vehicle emission standards (Zannetti, 2007) as shown in

Table 1. Air quality standards for KEPA (2001)

Pollutant	Average Time			
	Unit	Hour	Day	Year
SO_2	ppb	170	60	30
NO_2	ppb	100	50	30
CO	ppm	30	8	–
PM_{10}	µg/m^3	–	350	90
O_3	ppb	80	–	–
NH_3	ppb	800	–	140
H_2S	ppb	140	30	6

Table 1.

Study Area

Kuwait lies at the northwest corner of the Arabian Gulf, between the latitudes of 28 and 30 N and between the longitudes of 46 and 48 E. Most of the soil in Kuwait's desert is flat sandy, which descends from the westernmost part of Shigaya and Salmi (300 meters high) toward sea level in the east. Kuwait is dominated by a desert climate (Tang *et al.*, 2006). Kuwait is characterized by prolonged sunny, hot periods from late spring to autumn; short warm winter rain sometimes; and winds of dust blowing during the summer months (dust storm). The humidity is high during summer, and temperature sometimes reaches 50°C in shade (Al-Salem, 2008). The average temperature in winter is up to 18°C. The autumn and spring are short seasons. Winter rains are irregular and vary from year to year.

The city area of Kuwait has different sources of pollution. Traffic-related airborne pollutants, southern source emissions, highways and activities within the city, and harbor pollution from the northern stretch all contribute to the pollution. These factors cause air pollution in Kuwait.

The sources of pollution around Al-Jahra station are from northeast) Eastern and Western Doha station (from east (Al-Jahra water purification station), and from northwest (Raudhatain field). The sources of pollution around Al-Rumaithiya station are from south and southwest (Mishrif sewage pumping station located 5 kilometers toward the station), from east (Main Street is 950 meters toward), from west (Doha station is 28 kilometers away), and from northeast (Alsabiya station is 28 kilometers away). The sources of pollution around Al-Fahaheel station are from southeast (Mina Al-Ahmadi, storage tanks and refineries, 2 kilometers away; Shuaiba refinery, 4.6 kilometers away; and Mina Abdullah refinery, 8 kilometers away), from south (Shuaiba Industrial Area, factories, 8.8 kilometers away), and from west (Magwaa and Burgan fields 8 kilometers away) (KEPA, 2001).

Top of Form Bottom of Form Methodology

The data used in this study were taken from Al-

Fig. 1. Location map of the study area (Al-Jahra, Al-Rumaithiya, and Al-Fahaheel stations)

Jahra, Al-Rumaithiya, and Al-Fahaheel stations in the state of Kuwait during the period 2010–2014. The data were monitored for 24 hours with a five-minute interval using a private mobile laboratory by the Air Pollution Monitoring Division in KEPA, equipped with an automatic calibration and data storage system, all connected to a centralized system for collecting data over the Internet.

RESULTS AND DISCUSSION

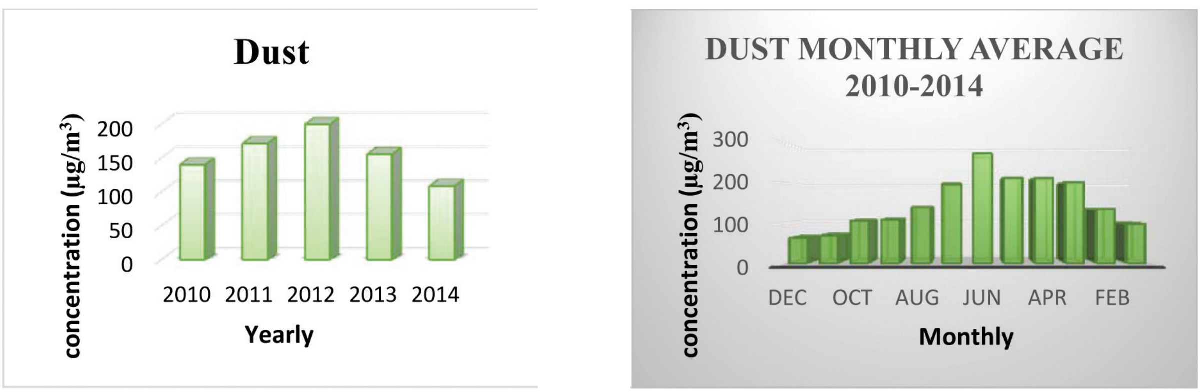
To reach the aim of the study, the air quality in the three urban areas was evaluated by analyzing the concentration values of the measured particulate pollutants and compared with the limits and guidelines specified in the recent regulations (Law 210/2001) (Salem, 2008).

The Wind Rose software was utilized to illustrate the speed and the prevailing direction of wind in the three stations during 2010–2014, which helped explain the presence of particulate matter pollutants and their sources.

The seasons in Kuwait are mainly two because of its desert climate: winter (January, February, March, April, November, December) and summer (May, June, July, August, September, October).

Al-Jahra Station Results

Figure 2A showed the annual average concentration of dust that ranged from 108 to 199 μg/m^3 for the period 2010–2014. The highest concentration was found in 2012 with 199 μg/m^3. This is likely due to an increase in the wind speed that raised dust and then an increase in particulate matter pollutants. The annual average of dust in 2010 through 2014 exceeded the KEPA standard limits, which is 90 μg/m^3. The average monthly concentration of dust ranged from 62.86 to 272.71 μg/m^3 as shown in Figure 2B. The highest concentration was found in June with 272.71 μg/m^3 due to an increase in temperature, which led to the rising of active air movements and actively working to spread



(A) Yearly average particulate matter concentration (μg/m^3)

(B) Monthly average particulate matter concentration (μg/m^3)

Fig. 2. Dust monthly and yearly average concentration (Jah 2010–2014)

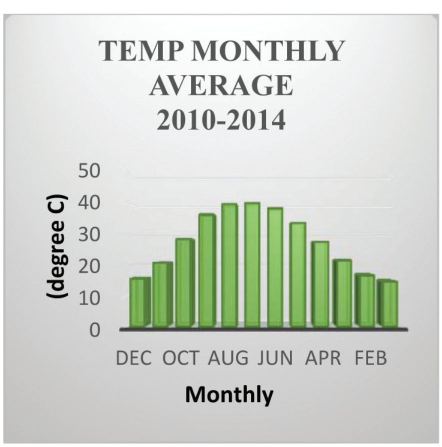


Fig. 3. Temperature monthly average (C) (Jah, 2010–2014)

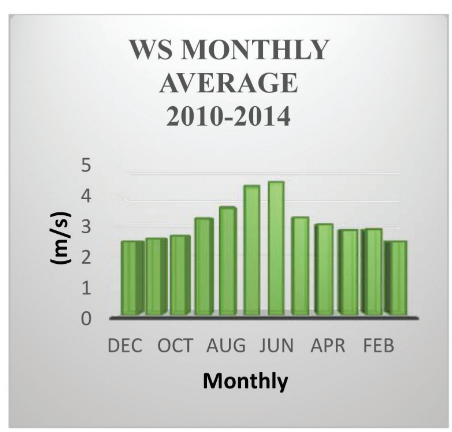


Fig. 4. Wind speed monthly average m/s (Jah, 2010–2014)

contaminants vertically to the maximum possible extent as shown in Figure 3; an increase in the wind speed, where contaminants move toward the prevailing wind as shown in Figure 4; and a decrease in relative humidity as shown in Figure 5, causing a rise in dust. These dust concentrations are due to the emissions from the Raudhatain field and traffic.

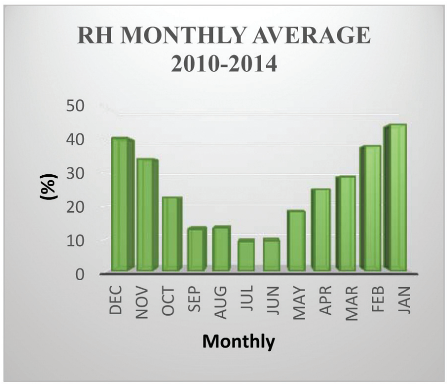
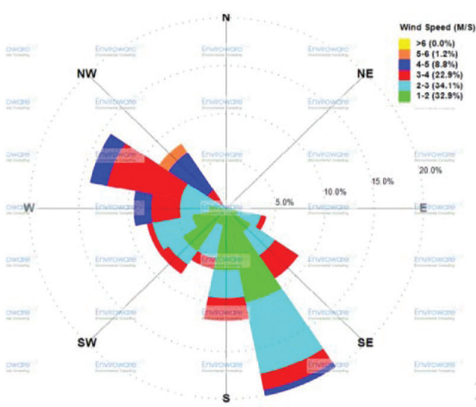


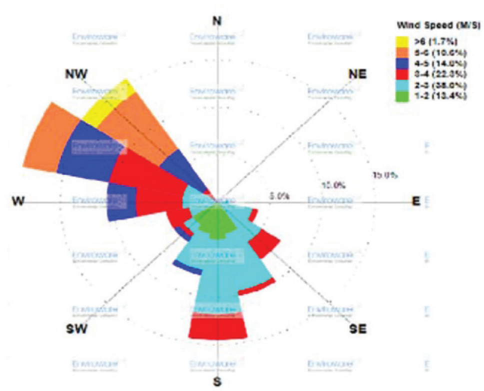
Fig. 5. Relative humidity monthly average RH % (Jah 2010–2014)

Al-Rumaithiya Station Results

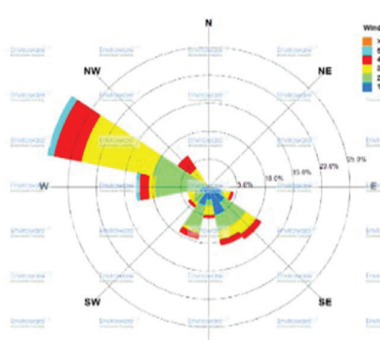
Figure 6A showed the annual average concentration of dust that ranged from 146 to 330 µg/m^3 for the period 2010–2014. The highest concentration was found in 2012 with 330 µg/m^3. This is likely due to an increase in the wind speed that raised dust and then an increase in particulate matter pollutants. The annual average of dust in 2010 through 2014 exceeded the KEPA standard limits, which is 90 µg/m^3. The average monthly concentration of dust ranged from 136.94 to 371.29 µg/m^3 as shown in Figure 6B. The highest concentration was found in June with 371.29 µg/m^3 due to an increase in temperature, which led to the rising of active air movements and actively working to spread contaminants vertically to the maximum possible extent as shown in Figure 7; an increase in the wind speed as shown in Figure 8 and a decrease in relative humidity as shown in Figure 9, raising dust. These dust concentrations are due to the emissions from the Mishrif sewage pumping station and traffic.



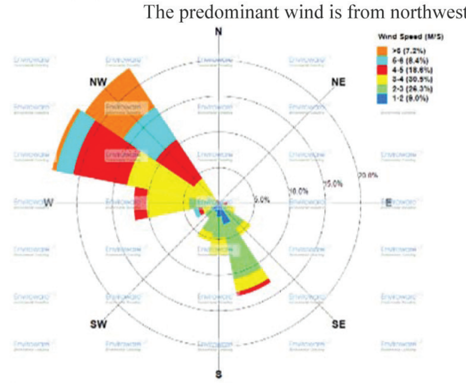
(4A) Wind Rose of Al-Jahra station (Winter 2010)
The predominant wind is from southeast.



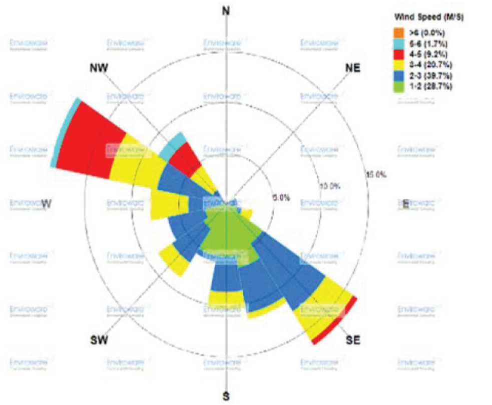
(4B) Wind Rose of Al-Jahra station (Summer 2010)
The predominant wind is from northwest.



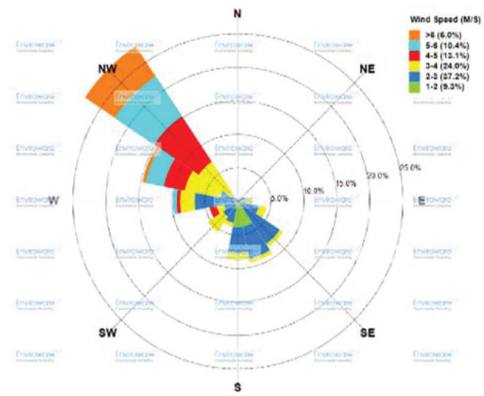
(4C) Wind Rose of Al-Jahra station (Winter 2011)
The predominant wind is from northwest.



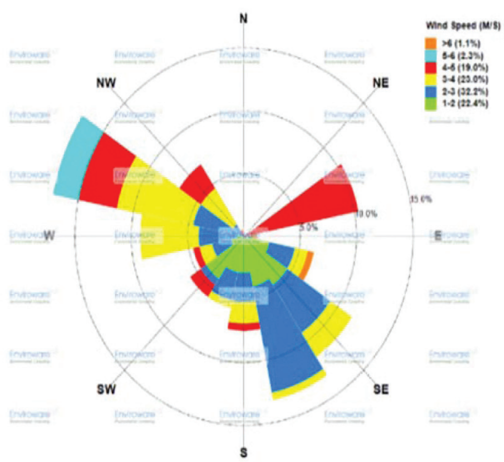
(4D) Wind Rose of Al-Jahra station (Summer 2011)
The predominant wind is from northwest.



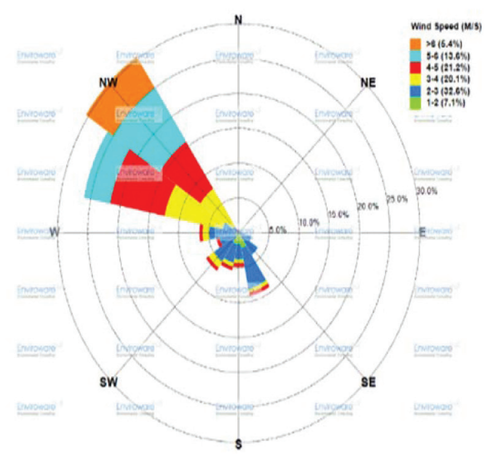
(4E) Wind Rose of Al-Jahra station (Winter 2012)
The predominant wind is from southeast.



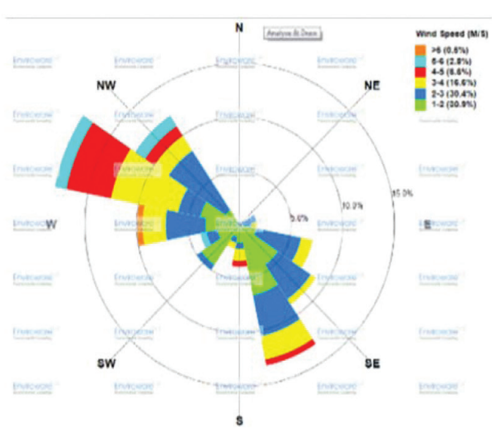
(4F) Wind Rose of Al-Jahra station (Summer 2012)
The predominant wind is from northwest.



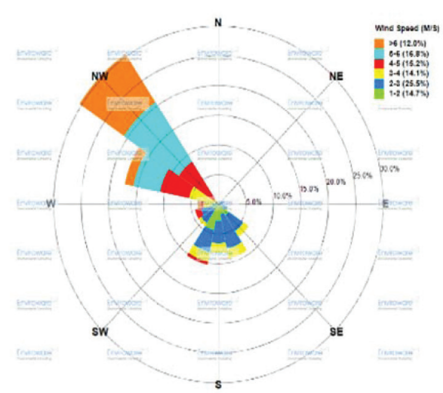
(4G) Wind Rose of Al-Jahra station (Winter 2013)
The predominant wind is from northwest.



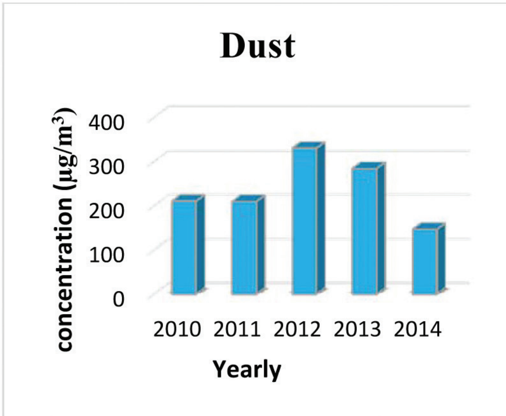
(4H) Wind Rose of Al-Jahra station (Summer 2013)
The predominant wind is from northwest.



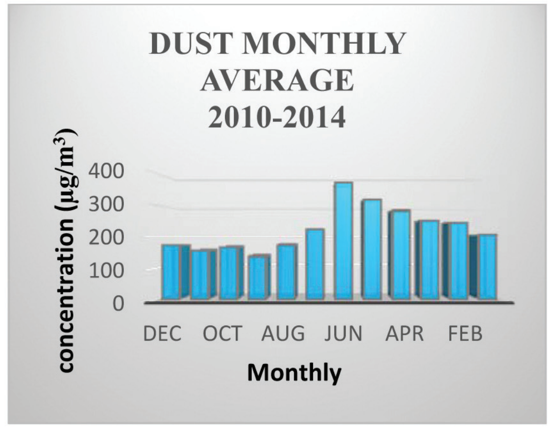
(4I) Wind Rose of Al-Jahra station (Winter 2014)
The predominant wind is from northwest.



(4J) Wind Rose of Al-Jahra station (Summer 2014)
The predominant wind is from northwest.



(A) Yearly average particulate matter concentration (μg/m³)



(B) Monthly average particulate matter concentration (μg/m³)

Fig. 6. Dust monthly and yearly average concentration (Rum 2010–2014)

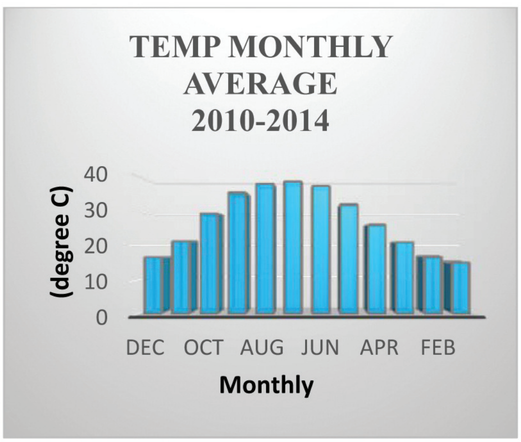


Fig. 7. Temperature monthly average (C) (Rum 2010–2014)

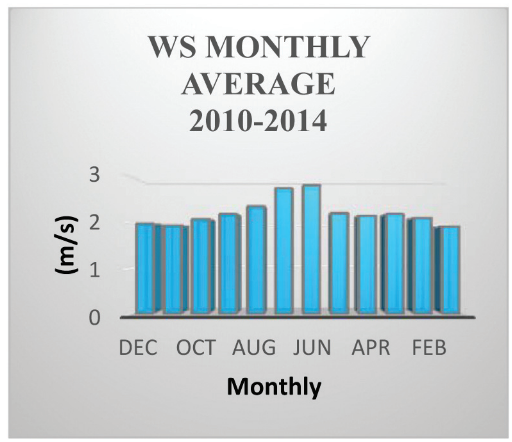


Fig. 8. Wind speed monthly average m/s (Rum 2010–2014)

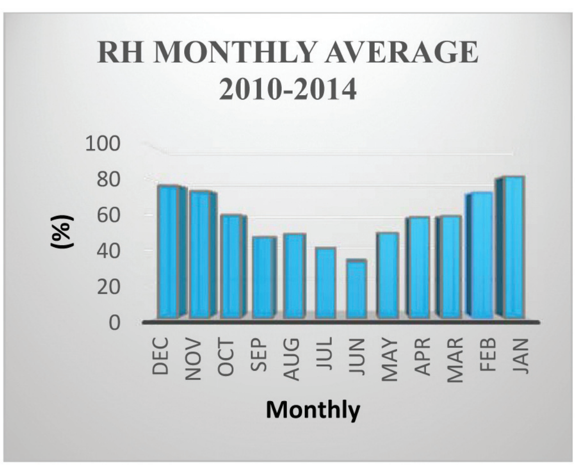


Fig. 9. Relative humidity monthly average RH (%)(Rum 2010–2014)

Al-Fahaheel Station Results

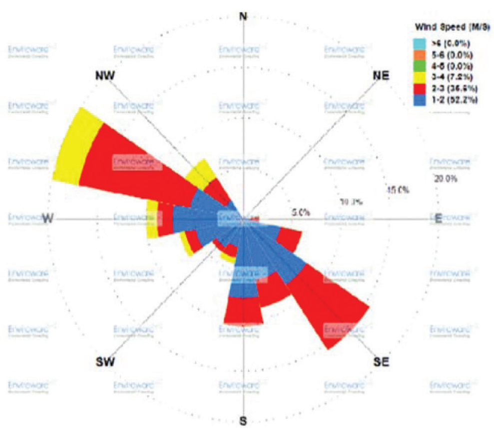
Figure 10A showed the annual average concentration of dust that ranged from 108 to 177 μg/m³ for the period 2010–2014. The highest concentration was found in 2012 with 177 μg/m³. This is likely due to an increase in the wind speed that raised dust and then an increase in particulate matter pollutants. The annual average of dust in year 2010 through 2014 exceeded the KEPA standard limits, which is 90 μg/m³ yearly. The average monthly concentration of dust ranged from 67.71 to 299.57 μg/m³ as shown in Figure 10B. The highest concentration was found in June with 299.57 μg/m³ due to an increase in temperature, which lead to the rising of active air movements and actively working to spread contaminants vertically to the maximum possible extent as shown in Figure 11; an increase in the wind speed as shown in Figure 12; and a decrease in relative humidity as shown in Figure 13, raising dust. These dust concentrations are due to the emissions from Mina Al-Ahmadi refinery, Shuaiba refinery, Mina Abdullah refinery, Shuaiba Industrial Area, Magwaa and Burgan fields, and traffic.

Table 2. Number of days that particulate matter pollutants exceeded the national standard during 2010–2014 in Al-Jahra, Al-Rumaithiya, and Al-Fahaheel stations

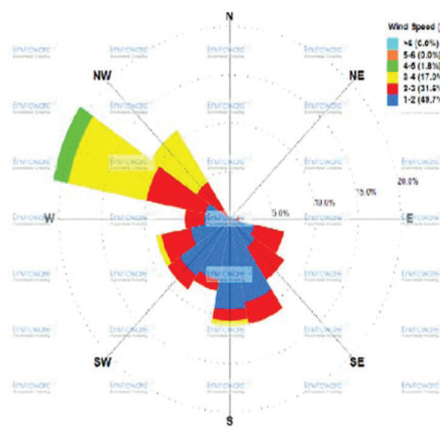
Year	Number of exceeds daily PM_{10} pollutants		
	Al-Jahra	Al-Rumaithiya	Al-Fahaheel
2010	20	40	34
2011	34	35	23
2012	46	63	35
2013	23	52	33
2014	10	22	11

DISCUSSION

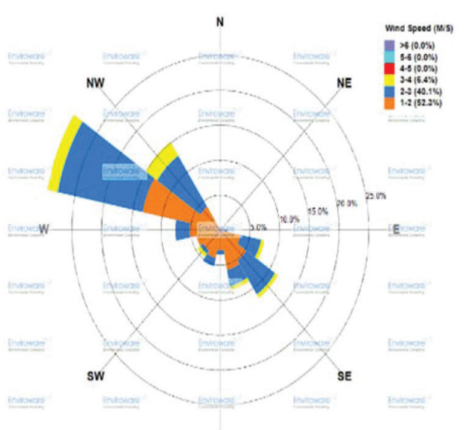
A study conducted by Abdul-Wahab *et al.* (2000) on measuring air pollution in the Shuaiba Industrial Area in the state of Kuwait included analyzing the behavior of particulate matter with respect to wind speed and direction over one year. Wind speed and direction, air temperature, relative humidity, solar radiation, and atmospheric pressure were monitored. The results showed that there were significant differences in some concentrations of pollutants. Daytime differences were observed with two ceilings in suspended dust concentrations. The results also indicated a common source of dust



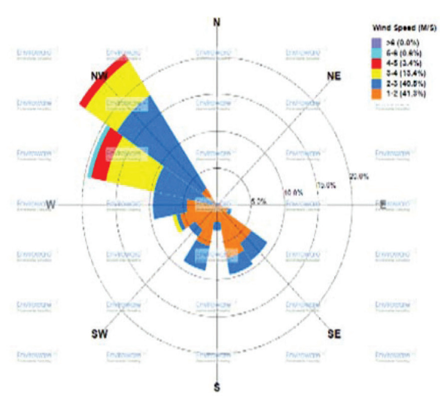
(8A) Wind Rose of Al-Rumaithiya station (Winter 2010)
The predominant wind is from northwest.



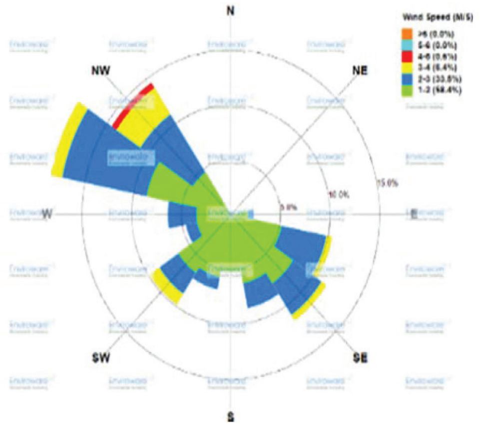
(8B) Wind Rose of Al-Rumaithiya station (Summer 2010)
The predominant wind is from northwest.



(8C) Wind Rose of Al-Rumaithiya station (Winter 2011)
The predominant wind is from northwest.

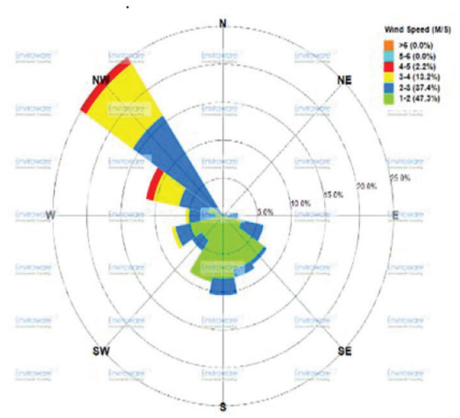


(8D) Wind Rose of Al-Rumaithiya station (Summer 2011)
The predominant wind is from northwest.



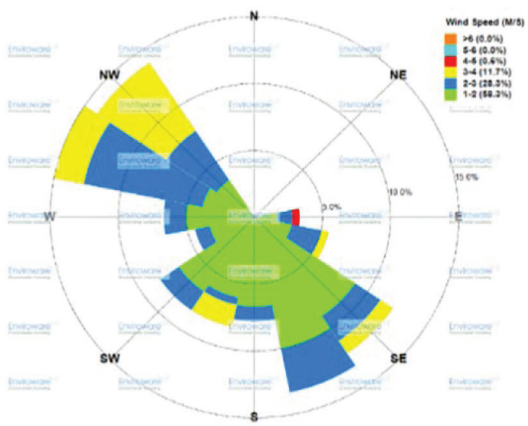
(8E) Wind Rose of Al-Rumaithiya station (Winter 2012)

The predominant wind is from northwest.



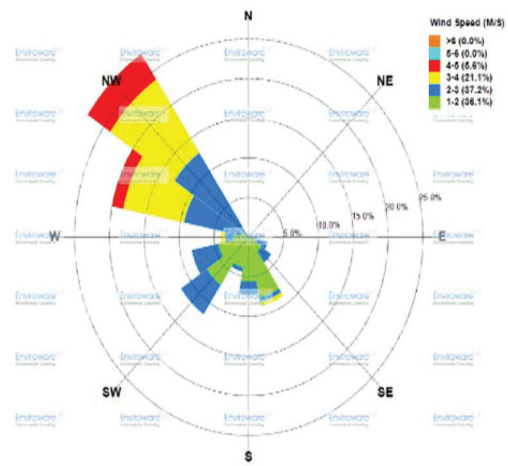
(8F) Wind Rose of Al-Rumaithiya station (Summer 2012)

The predominant wind is from northeast.



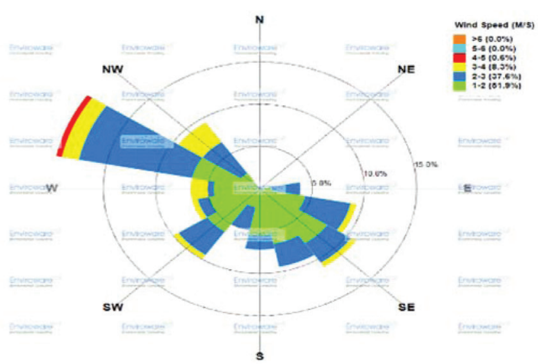
(8G) Wind Rose of Al-Rumaithiya station (Winter 2013)

The predominant wind is from northwest.



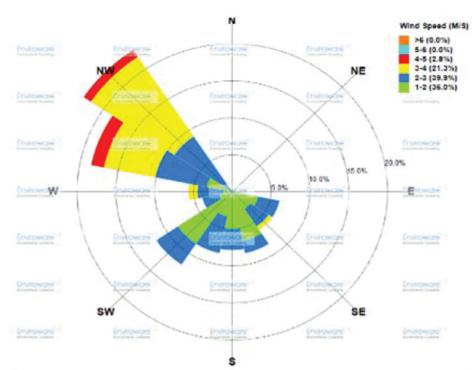
(8H) Wind Rose of Al-Rumaithiya station (Summer 2013)

The predominant wind is from northwest.



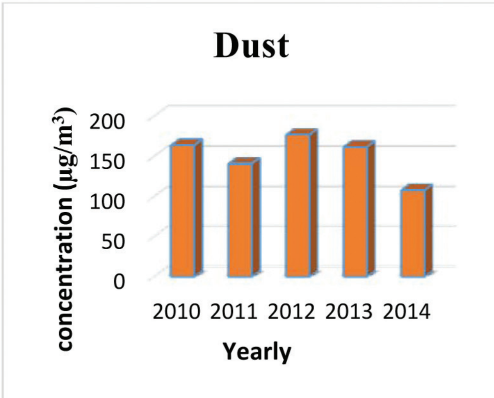
(8I) Wind Rose of Al-Rumaithiya station (Winter 2014)

The predominant wind is from northwest.

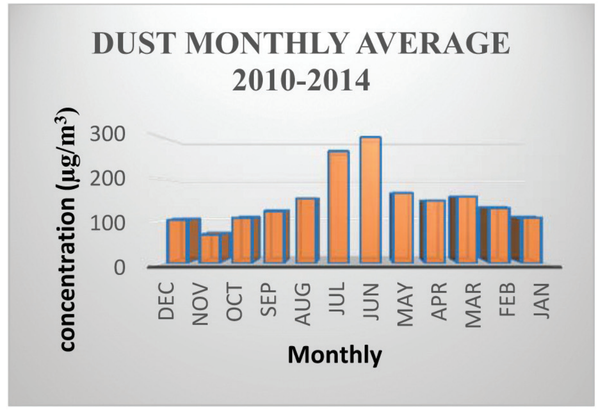


(8J) Wind Rose of Al-Rumaithiya station (Summer 2014)

The predominant wind is from northwest.



(A) Yearly average particulate matter concentration (μg/m³)



(B) Monthly average particulate matter (μg/m³)

Fig. 10. Dust monthly and yearly average concentration (Fah 2010–2014)

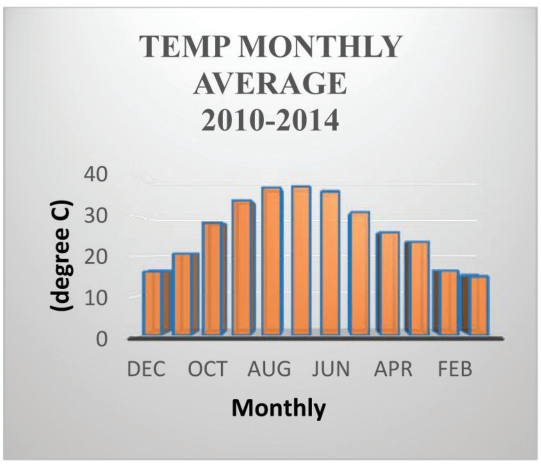


Fig. 11. Temperature monthly average (C) (Fah 2010–2014)

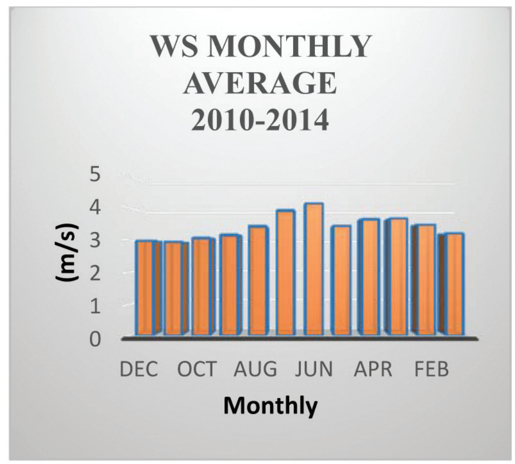


Fig. 12. Wind speed monthly average m/s (Fah 2010–2014)

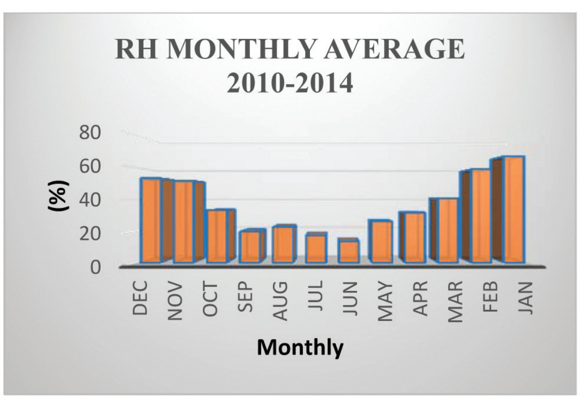


Fig. 13. Relative humidity monthly average RH % (Fah 2010–2014)

suspension in the northwest of the monitoring station (NW).

Another study was conducted by Abdul-Wahab (2009) on air quality in an industrial area on the outskirts of the Sultanate of Oman (Oman Liquid Natural Gas Plant [OLNG]) in Qalhat near Tire, on the eastern coast of the Sultanate of Oman, and a residential area in Kuwait (Atan, affected by heavy traffic). The study aimed to measure the levels of particulate matter in the atmosphere and then compare the trends and behaviors in these two regions to understand the monthly differences of the results. The results showed that the levels of particulate matter in the urban residential area of Kuwait are higher than in a suburban industrial area in Oman.

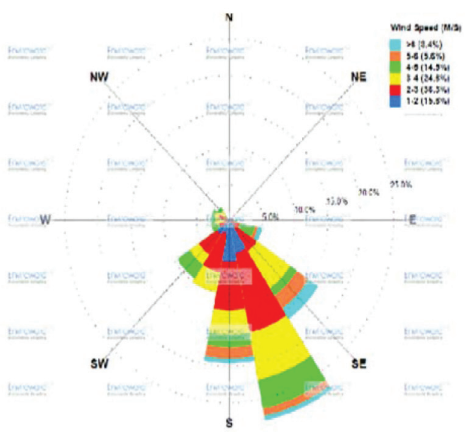
Air pollution measurements and analysis provide insights into the status and levels of air pollution and how they compare to KEPA standard limits. The results and analysis presented in this study show that the current status of particulate matter pollutants have exceeded the KEPA standard limits (Tang *et al.*, 2006). By comparing the monthly average of the particulate matter pollutants from 2010 through 2014 for the three stations, it is found that the highest concentration of particulate matter pollutants is in Al-Rumaithiya station, followed by Al-Fahaheel station, and the lowest is in Al-Jahra station. A big difference in the concentration level of the pollutants among the three stations exist. It was also found that the monthly average of the particulate matter pollutants in summer season are more than winter season, this is due to high temperatures, high wind activity and low humidity during the summer months.

The formation and development of meteorological parameters events has a great impact on the diffusion, accumulation and transport of air pollutants, and causes great changes in the particulate pollution level. It is very important to study their influence on particulate pollution (Feng *et al.*, 2012).

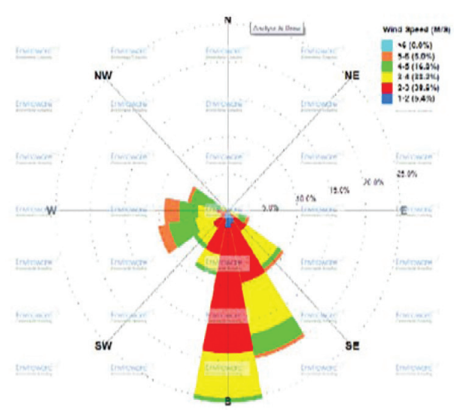
CONCLUSION

Analysis of the spatial and seasonal distribution of particulate matter pollutants in the three urban areas shows that variations are consistent with precursor emission patterns and meteorological conditions (Rozbicka *et al.*, 2014).

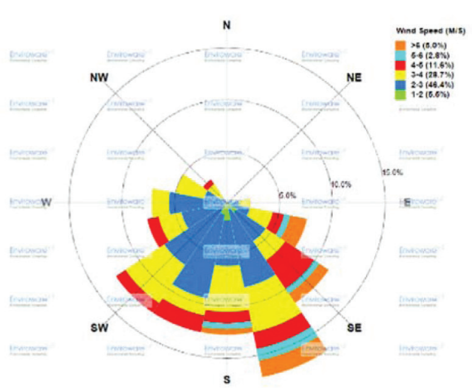
In Al-Jahra Station the annual average concentration of dust that ranged from 108 to 199 μg/m^3 for the period 2010–2014 exceeded the KEPA standard limits, which is 90 μg/m^3 yearly. The highest concentration was found in 2012 with 199



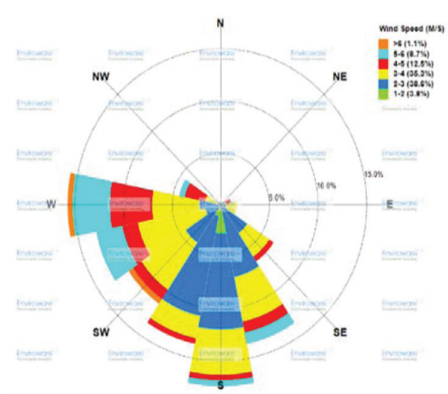
(12A) Wind Rose of Al-Fahaheel station (Winter 2010)
The predominant wind is from southeast.



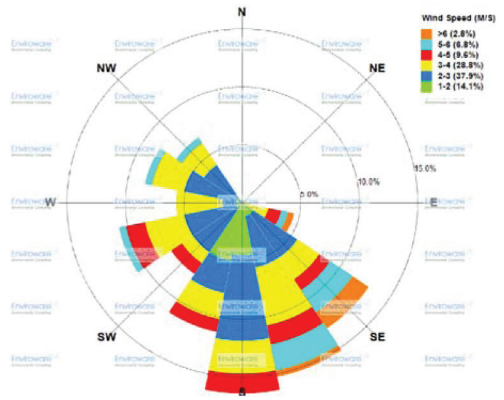
(12B) Wind Rose of Al-Fahaheel station (Summer 2010)
The predominant wind is from south.

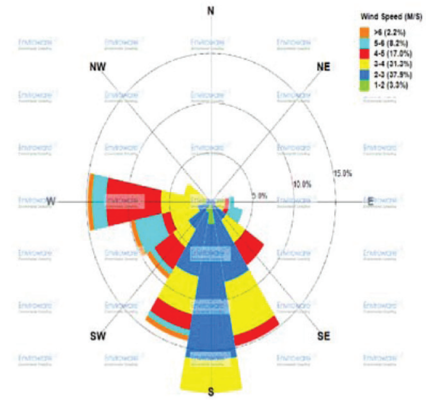


(12C) Wind Rose of Al-Fahaheel station (Winter 2011)
The predominant wind is from southeast.



(12D) Wind Rose of Al-Fahaheel station (Summer 2011)
The predominant wind is from south



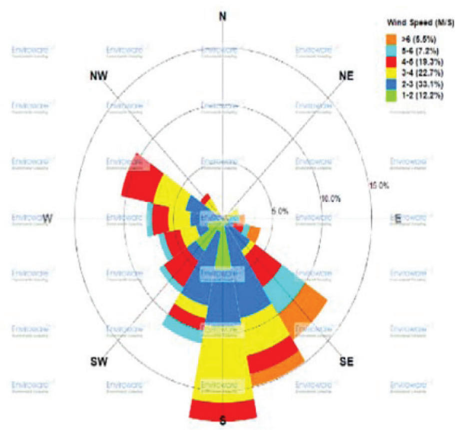


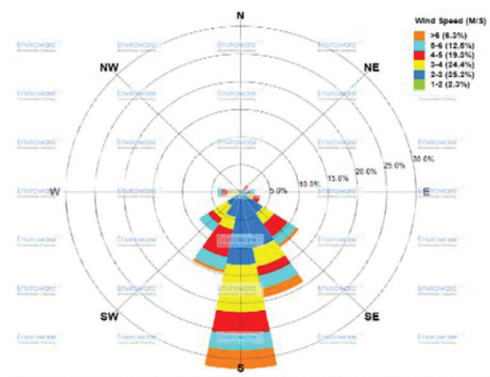
(12E) Wind Rose of Al-Fahaheel station (Winter 2012)

(12F) Wind Rose of Al-Fahaheel station (Summer 2012)

The predominant wind is from south.

The predominant wind is from south.



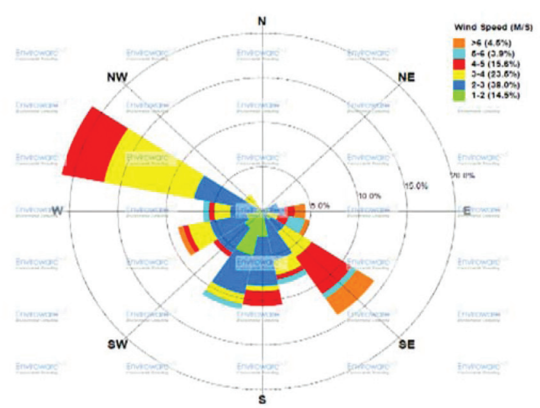


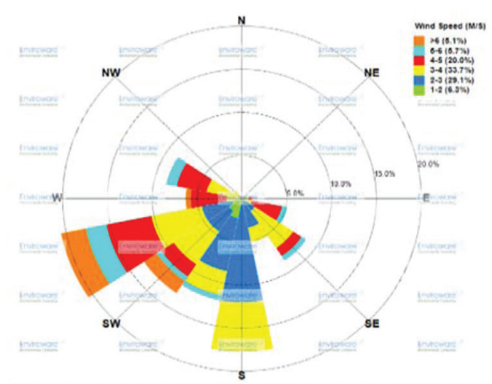
(12G) Wind Rose of Al-Fahaheel station (Winter 2013)

The predominant wind is from south.

(12H) Wind Rose of Al-Fahaheel station (Summer 2013)

The predominant wind is from south.





(12I) Wind Rose of Al-Fahaheel station (Winter 2014)

The predominant wind is from northwest.

(12J) Wind Rose of Al-Fahaheel station (Summer 2014)

The predominant wind is from southwest.

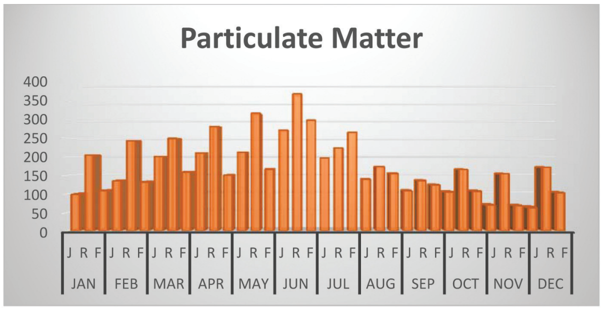


Fig. 14. Monthly average of particulate matter in Al-Jahra, Al-Rumaithiya, and Al-Fahaheel stations

μg/m³. The average monthly concentration of dust ranged from 62.86 to 272.71 μg/m³. The highest concentration was found in June with 272.71 μg/m³. These high concentrations are due to an increase in temperature, increase in the wind speed, and a decrease in relative humidity. These dust concentrations are due to the emissions from the Raudhatain field and traffic.

In Al-Rumaithiya Station the annual average concentration of dust that ranged from 146 to 330 μg/m³ for the period 2010–2014 exceeded the KEPA standard limits, which is 90 μg/m³ yearly. The highest concentration was found in 2012 with 330 μg/m³. The average monthly concentration of dust ranged from 136.94 to 371.29 μg/m³. The highest concentration was found in June with 371.29 μg/m³. These high concentrations are due to an increase in temperature, increase in the wind speed, and a decrease in relative humidity. These dust concentrations are due to the emissions from the Mishrif sewage pumping station and traffic.

In Al-Fahaheel Station the annual average concentration of dust that ranged from 108 to 177 μg/m³ for the period 2010–2014 exceeded the KEPA standard limits, which is 90 μg/m³ yearly. The highest concentration was found in 2012 with 177 μg/m³. The average monthly concentration of dust ranged from 67.71 to 299.57 μg/m³. The highest concentration was found in June with 299.57 μg/m³. These high concentrations are due to an increase in temperature, increase in the wind speed, and a decrease in relative humidity. These dust concentrations are due to the emissions from Mina Al-Ahmadi refinery, Shuaiba refinery, Mina Abdullah refinery, Shuaiba Industrial area, Magwaa and Burgan fields, and traffic.

The highest concentration of dust is in Al-Rumaithiya station with an annual average concentration of 146–330 μg/m³, followed by Al-Jahra station with an annual average concentration of 108–199 μg/m³, and the lowest is in Al-Fahaheel station with an annual average concentration of 108–177 μg/m³, It was also found that the monthly average of the particulate matter pollutants in summer season are more than winter season, this is due to high temperatures, high wind activity and low humidity during the summer months.

The study showed an increase in particulate matter pollutants concentration as a result to the human activities primarily energy production, petroleum industries, power plants, transportation, and desalination plants . The concentration of particulate matter pollutants various according to the spatial and season due to the type of activity and metrological factors (Al-Kasser *et al.,* 2018).

Investigation and analysis of data showed that there is a need for an air quality management system to achieve compliance with AAQS within a given geographical area at an acceptable overall health, economic, and environmental cost (David and Bela, 1999). This requires that air pollution standards be reviewed periodically by KEPA and the Competent Authorities to ensure that they provide adequate health and environmental protection, and that these standards are updated as necessary (USEPA, 2018).

Recommendation

Since there is a relationship among temperature, wind speed, humidity, and particulate matter, as the study demonstrated that particulate matter increases with high temperature, high wind speed, and low humidity, a method must be used to treat pollution resources, isolate the residential areas from industrial areas, spraying open areas with treated wastewater at the appropriate level to reduce high temperature, and windbreaks should be placed to reduce wind speed, thus minimizing dust stirring. As the standard limit for dust in KEPA is low compared with the real situation of air in Kuwait, it should be modified, or there should be a plan to reduce the high concentration of dust. Additionally, risk management plans should be prepared, including a program to evaluate accidental-release scenarios, mitigation actions, and consequences

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