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Research Paper

An assessment of ambient air quality in two major cities in the state of Kuwait

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Abstract

In this study, hourly mean continuous air pollution data for the year 2010 from two monitoring stations in major urban districts in the State of Kuwait were analyzed. The ambient air quality in the Al-Mansouriah and Al-Jahra districts was evaluated in terms of the hourly average concentrations of selected major air pollutants during the winter and summer seasons. The diurnal variations of these pollutants were analyzed, and in-depth comparisons of the two pollutant concentrations for the two districts were conducted to determine the predominant sources of the air pollutants. The concentrations of CO, PM_{10} and NO_2 in the two districts exhibited different patterns in the summer and winter due to differences in the activities that take place in the surrounding areas. The concentrations of SO_2 were high in both cities because of the Al-Doha power plant and oil fields near the city in Al-Jahra. The ozone concentration is highly correlated with NO_x emissions and is greater in the summer than in the winter. The results confirm that road traffic is a major source of air pollution in the Al-Mansouriah district. The Al-Doha power plant and the oil fields near Al-Jahra greatly affect the air quality in that district.

Keywords: *Air Pollution; Meteorological Data; Seasonal Changes.*

1. Introduction

Atmospheric pollutants associated with chemical and physical processes negatively affect ecosystems and human health. Air pollution is a significant risk to human health and is closely related to mortality from respiratory and cardiovascular diseases. For example, exposure to high levels of ozone (O_3) has been linked to a variety of health problems, such as asthma, respiratory irritation, cardiovascular illness and diminished lung function [1-4]. Therefore, air pollution and its public Therefore; ts have become matters of increasing concern to environmental agencies. In the State of Kuwait, the Kuwait Environment Public Authority (KU-EPA) has set standards and guidelines for outdoor pollutant levels. The standards are not to be exceeded if human health and public welfare are to be protected. The KU-EPA has been considering making these standards stricter. Many scientists have studied air pollution monitoring and standardizing air pollution rules and regulations for cities around the world [5]. This issue has become more significant in light of the estimate of the United Nations that over 600 million people in urban areas worldwide are exposed to unsafe levels of traffic-generated air pollutants [6].

Kountouriotis et al., [7] has studied the evaporation of liquid fuels in the area of petrol stations for several Volatile Organic Compounds (VOCs) leak into the atmosphere. They considered in their study the effect of wind speed and direction, as well as of air temperature on the VOCs emissions.

There are many sources of air pollution in Kuwait. The most obvious ones are point sources, such as power plants, refineries, and petrochemical plants, and on-road mobile sources such as light- and heavy-duty gasoline and diesel vehicles. Large quantities of non-methane hydrocarbons (NM-HC), a precursor to ground-level O_3 formation, are emitted to the ambient air by vegetation and from a variety of anthropogenic sources, such as incomplete combustion sources (automobile emissions and fossil-fuel-burning power plants), fuel storage and transport [8]. In addition, Kuwait is experiencing steady growth in its population, human activities, transportation fleet and demands for power. All these factors contribute to air pollution in the urban environment in Kuwait. The urban population is growing by 3.4% per year on average, and the number of vehicles increased from 543,000 in 1980 to 912,800 in 2002, at an average growth rate of 3.0% per year [9]. In Kuwait, unfortunately, there is no demand for public transportation; therefore, meeting air quality standards will continue to be a challenge

Al-Temeemi [10] reported that transport affects air quality through traffic emissions and also increases fuel consumption and damage to infrastructure, resulting in road congestion.

In the State of Kuwait, the topic of air pollution has been discussed by many researchers [11-16]. Abdul-Wahab [13] studied two cases of air pollution in an industrial area in the Sultanate of Oman and in an urban residential area in Kuwait and performed a statistical analysis of data collected over the course of one year. She reported that in the Khaldiya, residential area of Kuwait, the levels of NM-HC and nitrogen dioxides (NO_2) exceeded the proposed new ambient air quality standards for residential areas in Kuwait by 56.8 % and 26.9 %, respectively. In addition, in the suburban industrial area at Oman LNG, the levels of NM-HC and NO_2 exceeded the proposed new ambient air quality standards by 48.7 % and 1.1 %, respectively. However, in Kuwait, there is one set of ambient air quality standards for residential areas and another for industrial areas, so one should not compare data for these two different types of areas.

Al-Mutairi and Koushki [17] reported that the NOx and SO_2 levels exceeded the permitted monthly average levels at three monitoring stations, Al-Mansouriah, Al-Reqa and Al-Rabia. However, the authors only analyzed pollution data on a monthly basis.

Many authors [18-20] have reported that NM-HC levels exceeded the ambient air quality standard for residential areas in Kuwait. The presence of NM-HC in the atmosphere is a key concern. Jallad and Cyntia [20] found that the diurnal patterns of NM-HC and NO_2 concentrations exhibit three peaks that are directly dependent on the traffic density.

Al-Awadhi and Al-Awadhi [18] studied daily NM-HC concentrations in Kuwait. Their objectives were to study the distribution of NM-HC with respect to time, meteorological parameters and space and to use this distribution information to predict the concentration of NM-HC at other sites in Kuwait using the Gaussian random field technique. They concluded that in the areas surrounded by oil fields and refinery activities, such as Um-Alhayman, NM-HC levels exceed the proposed ambient air quality standard for residential areas in Kuwait (0.24 ppm).

Al-Rashidi et al. [14] reported that the concentration of SO_2 exceeded the allowable daily limit in many locations in the State of Kuwait, such as Abdullah Al-Salem, Sulaibikat, Sabah Al-Naser and Doha, in 2001. However, their study showed that the locations of the existing KU-EPA fixed monitoring stations were not suitable for measuring the actual impact of SO_2. They, therefore, concluded that these monitoring stations should be relocated to increase the efficiency of the KU-EPA monitoring network.

Al-Awadhi, [21] used passive sampler technology to measure many air pollutants gases in Kuwait city on the monthly basis. He reported that gas pollutants had low concentrations compared to KU-EPA standards for residential areas.

In this paper, outdoor air quality data collected in 2010 were quantitatively analyzed to assess the ambient air quality in two districts in Kuwait. The two districts were Al-Mansouriah, which is a residential area in Al-Asemah, the “Capital” Governorate (Kuwait), which is very congested, and Al-Jahra, which is the largest governorate in the State of Kuwait and is surrounded by a power station and oil fields. The predominant sources of pollutants affecting ambient air quality in these two districts were compared. The year 2010 was divided into two main seasons (winter and summer), which were further divided into three months each: winter (January to March) and summer season (July to September).

2. Description of study areas, locations and measurements

The Al-Jahra district is a valuable test site for several reasons. Al-Jahra is surrounded by several utility industries, the northern oil fields, power and desalination plants, a wastewater treatment plant and freeways connecting it to the rest of Kuwait and to neighboring countries. As Figure 1 shows, the Al-Jahra area is located in the path of the predominantly northwesterly winds that blow most of the time throughout the year, transporting pollutants to the city. Kuwait municipality records for 2003 describe Al-Jahra as a relatively run-down residential suburb of central Kuwait, covering a total area of 11,230 km^2. Al-Jahra has a total population of 269,915, housed in 34,755 residential blocks [22]. The district is situated on a major freeway, the 6th ring road, at the north end. The monitoring station in Al-Jahra is located above the polyclinic in the middle of the residential area.

Al-Mansouriah is a classic urban residential and commercial area and is impacted by the heavy traffic of Kuwait City, which is the capital of Kuwait.

Fig. 2 shows satellite imagery of the Al-Mansouriah area. Al-Mansouriah is surrounded by many industrial sites, such as the Al Megwa oil field, the Al Doha power plant and the Al Subiya power plant. Al-Mansouriah is also close to Kuwait Bay and the Arabian Gulf, so wind plays a major role in the intensity of pollutants. The monitoring station is located above the polyclinic in the middle of the residential area and is situated near the area’s Co-Op, which is associated with restaurant- and human-related pollution emissions. In addition, Cairo Street, which is one of the busiest streets in the State, especially during rush hours, is located north of the monitoring station. Data from this monitoring station provide a clear picture of the area’s air pollution by automobiles and local sources.

Air quality data in Kuwait are collected using fixed air quality monitoring stations (AQMS) operated by KU–EPA that measure the concentrations of various pollutants continuously every 5 minutes. The 5-min readings are most likely subject to some measurement error; therefore, in this study, data were aggregated into hourly records to obtain a 24-h reading for each day and for each station. The sampling sites were selected based on the availability of power, safekeeping and the topography of the area.

Fig. 1: Al-Jahra Residential Area and Neighboring Areas in Kuwait.

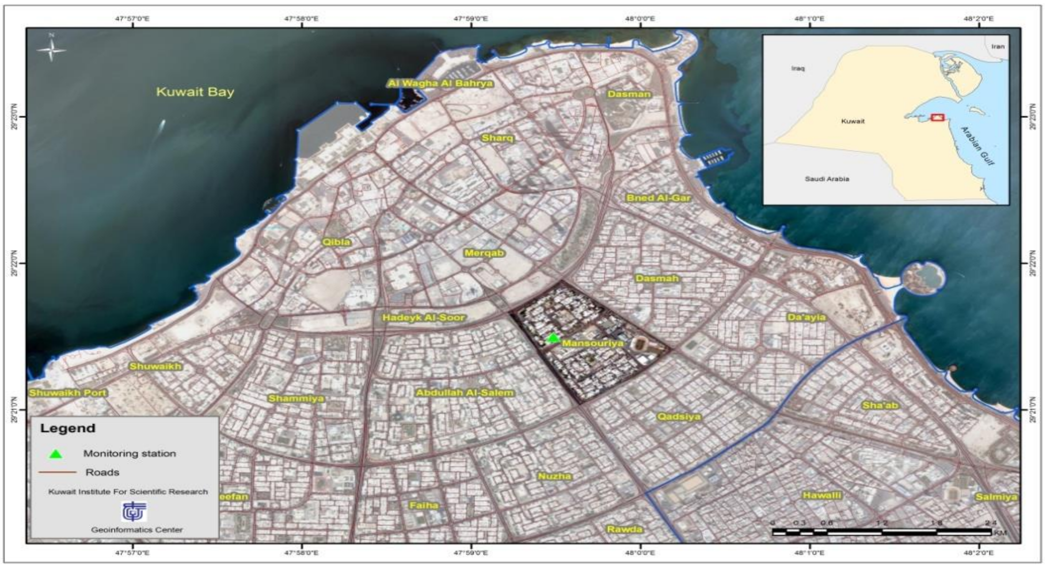

Fig. 2: Al-Mansouriah Residential Area.

3. Results and discussion

The ambient air quality in the Al-Mansouriah and Al-Jahra districts was evaluated by measuring selected pollutants, namely, NO_2, CO, NM-HC, M-CH, CO_2, SO_2, O_3 and PM_{10}, calculated as hourly average concentrations for the winter and summer seasons separately. This was accomplished using data from fixed monitoring stations established by KU-EPA at selected sites. The data obtained for each district, and each season are plotted in Figures 3–11 to show the seasonal effects on the air pollution. For the sake of comparison, each graph contains data for one pollutant for both districts during the same season.

In examining the air pollution data, one should keep in mind the following factors that contribute to pollutant concentration levels:

- Exposure monitoring data from monitoring stations are not accurate enough for epidemiologic studies due to spatial variations in the pollutant levels [23]. However, data from fixed monitoring stations can be used to assess local air quality, which is strongly affected by meteorological conditions.
- All of the graphs show similar trends for particular pollutants throughout the year, except for CO, because the data collected from the fixed monitoring stations are not accurate for this particular pollutant [23]. This could be partly due to CO's long decay life.

3.1. Assessment of various air pollutant concentrations (diurnal variation)

3.1.1. Nitrogen dioxide (NO_2)

Nitrogen oxides (NO_x) are responsible for many human health problems, such as mortality and serious respiratory illness, because of their potential role in ground-level ozone formation. In this study, NO_2 concentrations were monitored to investigate the air-quality impact of NO_2 on the Al-Jahra and Al-Mansouriah residential areas. Fig. **3**(a) shows the hourly average NO_2 concentrations for the cities of Al-Jahra and Al-Mansouriah during the summer season. As mentioned previously, the trends are almost the same for the two cities. The lowest NO_2 concentrations were recorded between 13:00 and 15:00, while the highest concentrations were recorded at 20:00. From 13:00 to 15:00, the ambient temperature during the summer reached its maximum (high solar radiation intensity), which would have enhanced photochemical reactions, leading to more NO_x breakdown and, as a result, low NO_x levels. On the other hand, maxima were recorded for both districts at 7:00 and 20:00, with the latter being of greater magnitude. This is clearly due to heavy traffic volumes during the rush hours and to low ozone concentrations, which resulted in fewer titration of NOx. This confirms that NO_2 variation follows a pattern of systemic variation that is strongly influenced by on-road mobile source emissions. This pattern is also illustrated by the NO_2 concentrations measured in Al-Mansouriah, which were consistently higher than those measured in Al-Jahra for the same periods. These higher NO_2 levels can be attributed to the Al-Mansouriah district's proximity to the downtown area (the city center), which is a central urban district with high-traffic density, surrounded by main highways and cities with tall urban buildings that result in poor pollutant dispersion.

The Al-Jahra district, on the other hand, is considered an open rural district in comparison to Al-Mansouriah. Al-Jahra is surrounded by deserts and the newly constructed city of Sa'ad Al-Abdullah, where the summer wind picks up speed and becomes active in diluting pollutant concentrations.

In the winter, similar trends and lower magnitudes were observed for both cities (Figure 3(b)). However, the NO_2 concentrations recorded in Al-Jahra during this season exceeded those recorded in Al-Mansouriah, mainly because Al-Jahra is located near a power station and oil fields, which are responsible for large volumes of NO_2 emissions. For example, the Al-Doha power plant is located to the north of Al-Jahra, which puts the city on the path of the predominantly northwesterly wind that transports pollutants to the area.

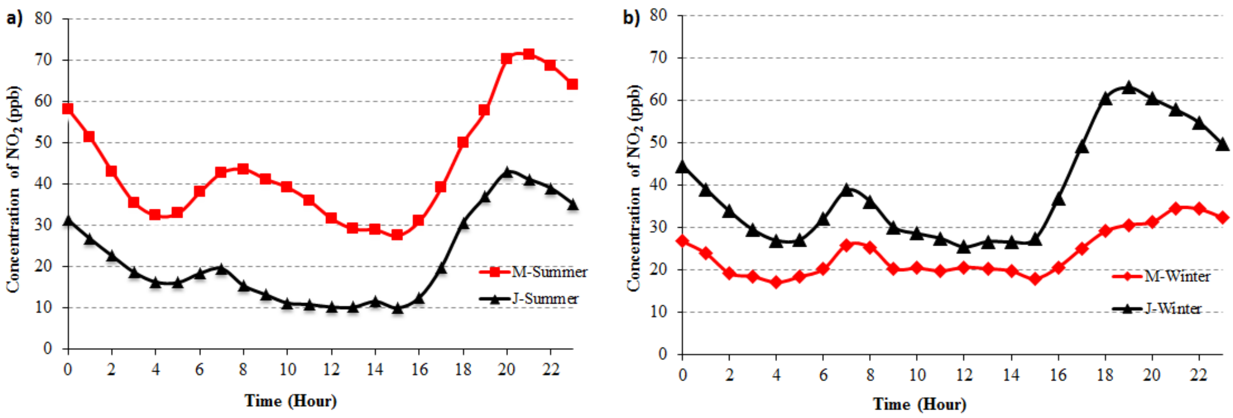

Fig. 3: Hourly Average NO_2 Concentrations in (a) Summer and (b) Winter for Al-Mansouriah and Al-Jahra.

3.1.2. Carbon monoxide (CO)

In air quality assessment studies, another important pollutant of interest is CO. In general; the CO profile concentration does not follow a systematic pattern of variation, and thus the trends are not consistent for the two seasons. CO is more stable than NO_2 due to its long decay life, which results in a constant background concentration that does not follow any systematic pattern. Figure 4 (a) shows that the CO concentration fluctuates throughout the day in Al-Mansouriah during the summer, reaching its highest value of 1.0 ppm at 21:00, which is 30% higher than that recorded for the Al-Jahra district during the same season. The concentration of CO in Al-Jahra is more stable, exhibiting insignificant variation. This is due to anthropogenic activities such as restaurants around the monitoring station in Al-Mansouriah, which

greatly impact the diurnal pattern of CO concentration. The peaks in winter at 7:00 and 20:00 reflect rush-hour traffic, as high-traffic volumes and shopping activities usually occur at these times.
In the winter, the situation is almost the opposite: higher CO values were measured in the Al-Jahra area, as shown by the two peaks in Figure 4(b), with a peak value of 1.62 ppm at 20:00. This value is approximately 44% higher than the highest concentration measured in Al-Mansouriah during the same season. The population density, reflected by the traffic intensity, urban construction, road layout and meteorological conditions all contribute to CO variation and behavior. During the one year of monitoring, the CO levels did not exceed the limit set by KU-EPA, which are an hourly mean of 30 ppm and a daily mean of 8 ppm.

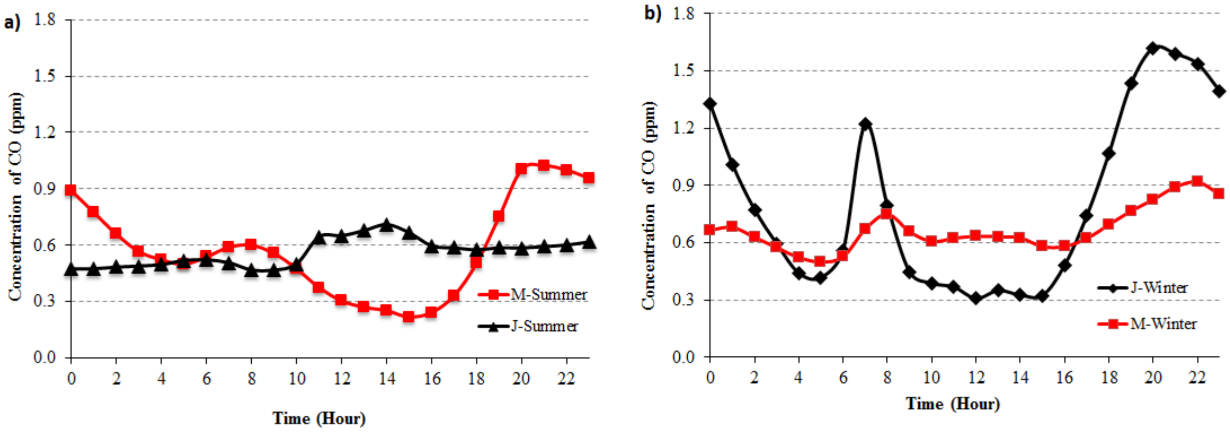

Fig. 4: Hourly Average CO Concentrations in (a) Summer and (b) Winter for Al-Mansouriah and Al-Jahra.

3.1.3. Carbon dioxide (CO_2)

The presence of CO_2 at acceptable concentrations (0.038%) is vital for life on earth in that CO_2, and other greenhouse gases help to maintain moderate temperature for all living things to enjoy. Figure 5(a and b) shows the seasonal variation in CO_2 levels in the two districts under study. The data show that the CO_2 concentration in the Al-Jahra district is consistently greater than in the Al-Mansouriah district by approximately 7% in the summer and winter. Furthermore, the data show that Al-Jahra has an almost constant diurnal CO_2 profile, unlike Al-Mansouriah, for which the anthropogenic activities around the monitoring station play a large role in the fluctuating CO_2 concentrations. The highest values of all (381 ppb) were recorded during the summer season in Al-Jahra. This is due, mainly to Al-Jahra being located close to power plants that operate at full capacity during the summer to meet public demand for energy and the prevailing wind blowing in the direction of Al-Jahra City.

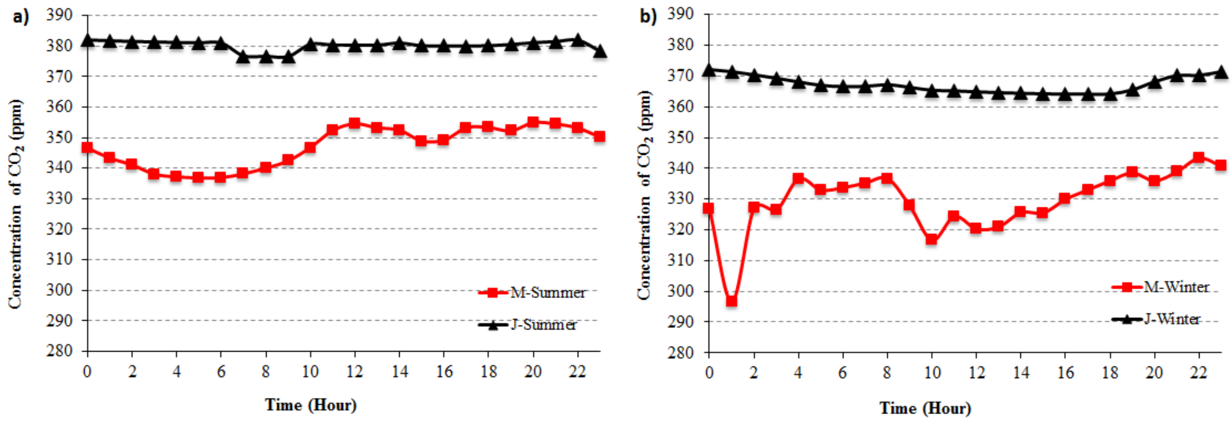

Fig. 5: Hourly Average CO_2 Concentrations in (a) Summer and (b) Winter for Al-Mansouriah and Al-Jahra.

3.1.4. Sulfur dioxide (SO_2)

Sulfur dioxide, SO_2, is a common air pollutant that is the focus of intense concern. SO_2 can react in the atmosphere to form acids, sulfates and sulfites and contributes to acid rain. The data plotted in Figure 6(a and b) show the seasonal variation in SO_2 for the two selected cities in summer and winter, respectively. Al-Mansouriah showed a consistent diurnal pattern of SO_2 levels in both seasons, with a maximum of four ppb at 12:00 PM. SO_2 concentrations are significantly higher in Al-Mansouriah than in Al-Jahra during the summer, by approximately one ppb on average, because the SO_2 measured during the summer is due, mainly to on-road diesel vehicles. Al-Mansouriah is surrounded by other major cities and a number of major highways and is adjacent to the city center. As a result, the Al-Mansouriah district experiences considerable traffic congestion, especially diesel vehicles, and poor dispersion of vehicle emissions. The monitoring data showed that in the winter, the opposite was true: SO_2 concentrations measured in Al-Jahra city were approximately five ppb higher on average than those measured in Al-Mansouriah, as shown in Figure 6(b). It is obvious that this tangible difference resulted from the flue gases emitted by power stations and oil refineries directly into the open air around Al-Jahra City. These findings for Al-Jahra are consistent with those reported by Ettouney et al. [24] and Al-Rashidi et al., [14] for the years 2001 to 2004.

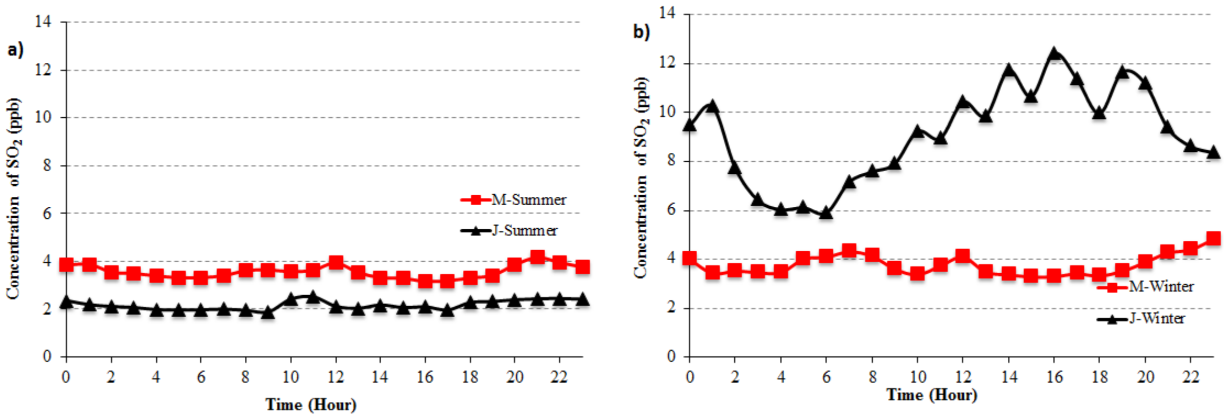

Fig. 6: Hourly Average SO_2 Concentrations in (a) Summer and (b) Winter for Al-Mansouriah and Al-Jahra.

3.1.5. Methane and non-methane hydrocarbons

NM-HC and M-HC are known as ozone precursors, and M-HC is a potent greenhouse gas that contributes to global warming. Among traffic-related NM-HCs are BTEX compounds (isomers of xylene), which are human carcinogens.
In the current study, the NM-HC concentrations in the Al-Mansouriah district were found to be 19% and 12% higher in the summer and winter, respectively, than in the Al-Jahra district (Figure 7(a and b)). The NM-HC concentrations in Al-Mansouriah exceeded the limit set by KU-EPA (0.24 ppm for the three hours from 6:00 to 9:00 AM) in both seasons. In general, the monitoring data show no significant differences in the NM-HC concentrations between the summer and winter. This is due, mainly to the consistency of NM-HC emissions from their main sources. The same was true of M-HC to a lesser extent; however, KU-EPA has not yet established any regulations or standards for M-HC in Kuwait. Figure 8 (a and b) shows that the M-HC concentrations measured in Al-Mansouriah were only 5% greater than those in Al-Jahra during the summer and only 2% greater during the winter. These slight differences can be attributed to the population, automobiles and prevailing meteorological conditions. For example, Al-Mansouriah, an urban area, has tall urban buildings in the city center, congested roads and highways connecting the area to other main cities. These conditions result in poor pollutant dispersion and hence accumulation of pollutants at high concentrations. Furthermore, other factors, such as the condition of cars, influence the NM-HC concentration in the ambient air.

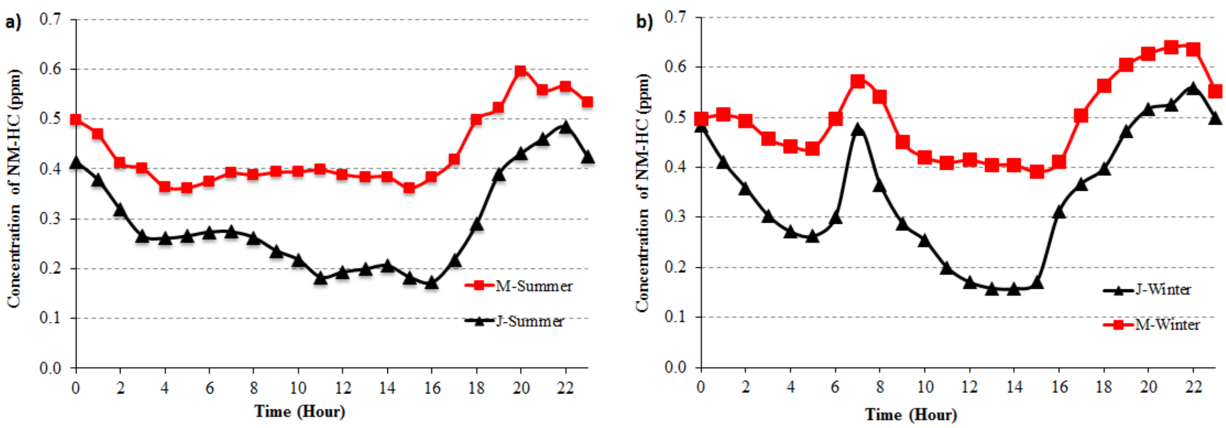

Fig. 7: Hourly Average NM-HC Concentrations in (a) Summer and (b) Winter for Al-Mansouriah and Al-Jahra.

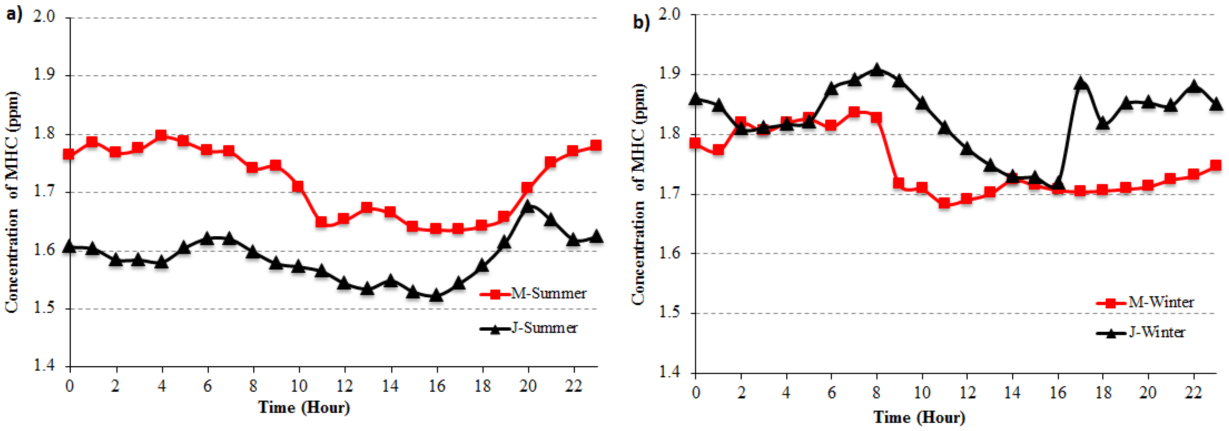

Fig. 8: Hourly Average M-HC Concentrations in (a) Summer and (b) Winter for Al-Mansouriah and Al-Jahra.

3.1.6. Ozone (O_3)

Ground-level ozone (O_3) is a common pollutant that needs to be monitored regularly. KU-EPA has set hourly average and 8-hour average limits of 80 ppb and 60 ppb, respectively, for O_3. These standards are not to be exceeded more than twice during a 30-day period at the same site (KU-EPA, 2001). Figure 9 (a and b) shows how the O_3 concentrations varied during the winter and summer seasons of 2010 for both districts. As the figures show, the hourly average O_3 concentrations measured in Al-Jahra were 30% higher than those measured in Al-Mansouriah in the summer and 74% higher in the winter. The O_3 concentrations measured in Al-Jahra approximately five times higher in the summer than in the winter, and those measured in Al-Mansouriah were approximately 14 times higher in the summer than in the winter. This is due to the predominance in summer of O_3 precursors, such as sunlight, high temperatures and pollutants (e.g., hydrocarbons) resulting from burning ever larger amounts of fossil fuel in power plants to run air conditioning and produce potable water to meet growing demands. Intense solar radiation enhances daytime photochemical reactions, leading to ozone build-up in the atmosphere. Furthermore, the data show that O_3 concentrations increase in the early morning due to NOx disbenefit (i.e., O_3 concentrations increasing as NOx emissions decrease in the morning, which results in less titration of ozone [25]. These results are consistent with those reported by Abdul-Wahab [13] and Bell et al., [3].

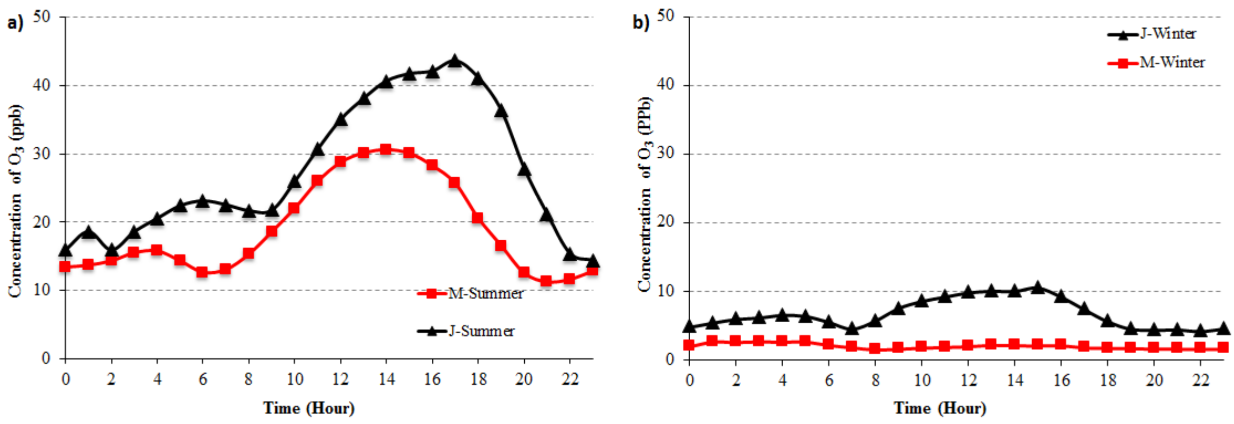

Fig. 9: Hourly Average O_3 Concentrations in (a) Summer and (b) Winter for Al-Mansouriah and Al-Jahra.

3.1.7. Particulate matters (PM)

Particulate matter (PM_{10}), including particles and aerosols, remain suspended in the atmosphere for some time. The weather of the State of Kuwait is typical of desert regions due to its location between the latitudes of 28.30º and 30.06º north of the equator and between the longitudes of 46.30º and 48.3º east of the Greenwich meridian [22]. The weather in the summer is dry and dusty. In addition, Kuwait receives little rainfall, which leads to a high rate of desertification. The rainfall pattern from 2000 to 2009 is shown in Figure 10. The annual amount of rainfall increased to a maximum of 216.8 mm [22] in 2004 and then decreased steadily to a low of 47.8 mm in 2009. These and other meteorological conditions disturb surficial soils and contribute to high PM_{10} values. Figure 11 (a and b) shows two representative sets of data for the two districts for the same season. Figure 11(a) shows that in the summer season, the PM_{10} values recorded in Al-Jahra were slightly higher than those recorded in Al-Mansouriah, due to the higher winds in the former district and the fact that Al-Jahra is surrounded by desert. In both districts, the PM_{10} limit set by KU-EPA (350 $\mu g/m^3$) was exceeded; however, the PM_{10} levels in excess of this limit are not shown in Figure 11(a and b) because they represent the hourly "average" concentrations during a 3-month period. In winter, on the other hand, higher PM_{10} concentrations were observed in Al-Mansouriah (Figure 11(b)), due to heavy traffic.

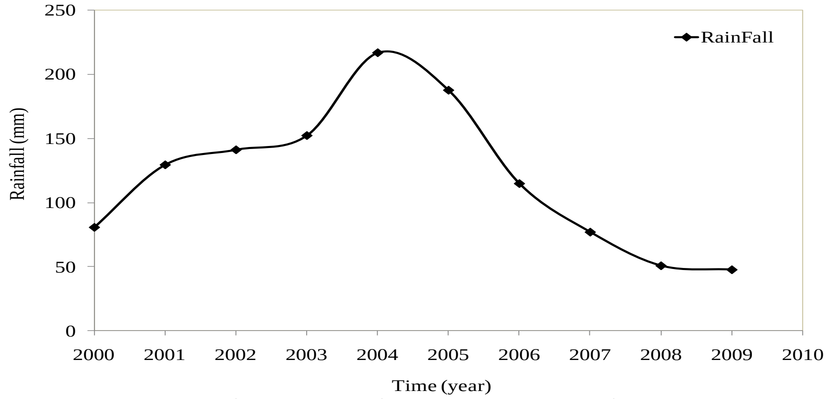

Fig. 10: Rainfall in the State of Kuwait over the Course of 10 Years.

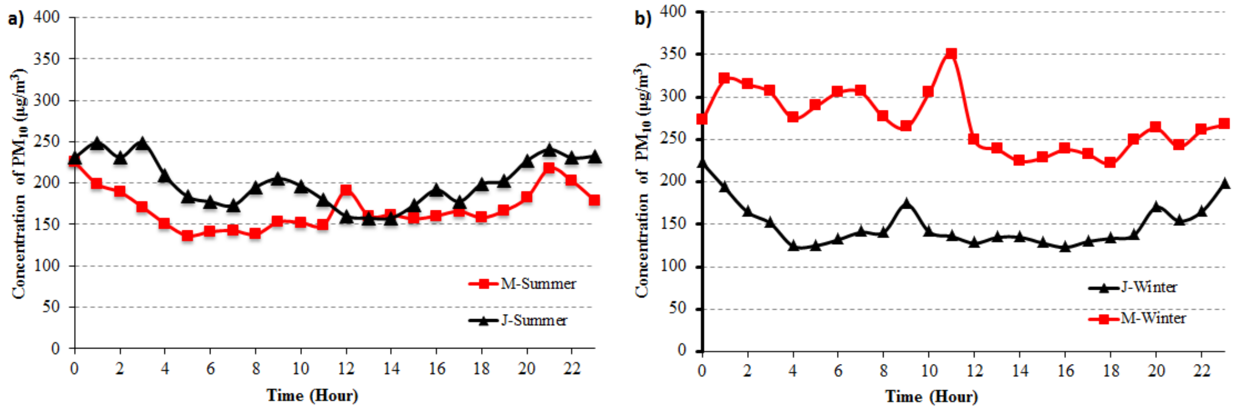

Fig. 11: Hourly Average PM_{10} Concentrations in (a) Summer and (b) Winter for Al-Mansouriah and Al-Jahra.

3.2. Assessment of meteorological condition

3.2.1. Wind speed and direction

To study the influence of meteorological conditions in Al-Jahra and Al-Mansouriah on the prediction of the ground-level concentrations of air pollutants, the prevailing wind direction and magnitude in 2010 were analyzed. The prevailing wind direction is from the northwest. There is a strong influence of the neighboring Gulf countries, as Kuwait is located on the cost of the sea, resulting in strong sea breezes blowing from the north.

Figures 12 (a and b) and 13 (a and b) **Fig** show wind roses for Al-Jahra and Al-Mansouriah for the winter and summer seasons, respectively. The wind speed decreases in the winter. In Al-Jahra, a maximum wind speed of 6.00 m/sec was recorded on the 18th of March at 13:00, bearing 143.750^{o} southeast. Similarly, in Al-Mansouriah, a maximum wind speed of 6.70 m/sec was recorded on the 1st of March at 10:00, bearing 172.58^{o} south. These were the lowest wind speeds recorded during the whole study period and reflect the influence of winter meteorological conditions (low temperatures, calm winds and low inversion layers).

The highest hourly wind speed recorded in the summer in Al-Jahra was 6.94 m/sec, on the 4th of September at 04:00, bearing 300.5^{o} northwest. Similarly, in Al-Mansouriah, the highest hourly wind speed recorded in the summer was 6.63 m/sec, on the 2nd of July at 11:00, bearing 307.58^{o} west–northwest, reflecting the dominant influence of the wind direction.

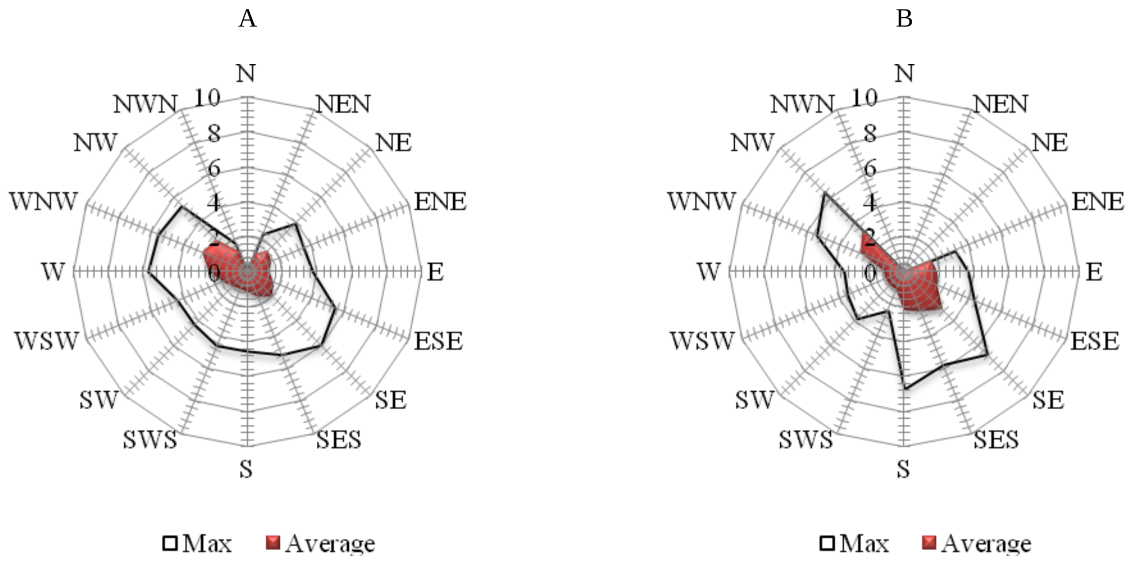

Fig. 12: Wind Rose for the Winter Season,(a) Al-Jahra (b) Al-Mansouriah.

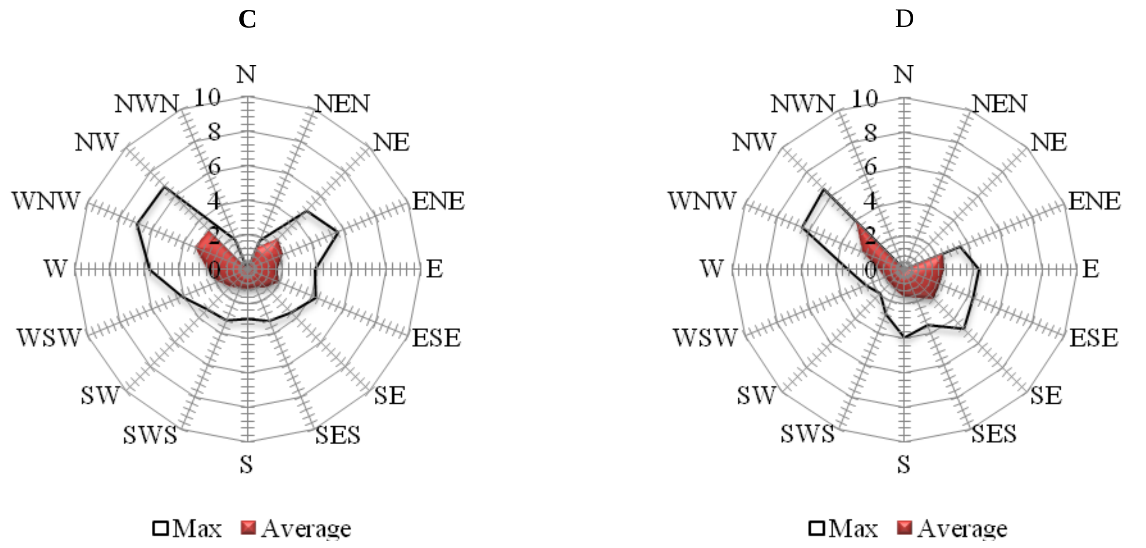

Fig. 13: Wind rose for the summer season, (c) Al-Jahra (d) Al-Mansouriah.

3.2.2. Solar intensity

In Al-Jahra (Figure 14 (a)), the highest hourly solar intensity recorded in the summer of 2010 was 774.08 w/m^2, measured on the 3^{rd} of July at 11:00. The average seasonal solar intensity in the summer was 193.71 ± 0.89 σ w/m^2, and the standard deviation (σ) was equal to 227.470 w/m^2. In the winter, the highest hourly solar intensity was 728.50 w/m^2, recorded on the 27^{th} of March at 12:00. The average seasonal solar intensity in the winter was 151.49 ± 0.85 σ w/m^2, and the standard deviation (σ) was equal to 204.65 w/m^2, based on hourly data.
In Al-Mansouriah (Figure 14 (b)), the highest hourly solar intensity recorded in the summer of 2010 was 877.50 w/m^2, measured on the 3rd of July at 12:00. The average seasonal solar intensity in the summer was 220.190 ± 0.46 σ w/m^2, and the standard deviation (σ) was equal to 271.78 w/m^2. In the winter, the highest hourly solar intensity was 727.750 w/m^2, recorded on the 22^{nd} of March at 12:00. The average seasonal solar intensity in the winter was 141.62 ± 0.53 σ w/m^2, and the standard deviation (σ) was equal to 200.56 w/m^2, based on hourly data.

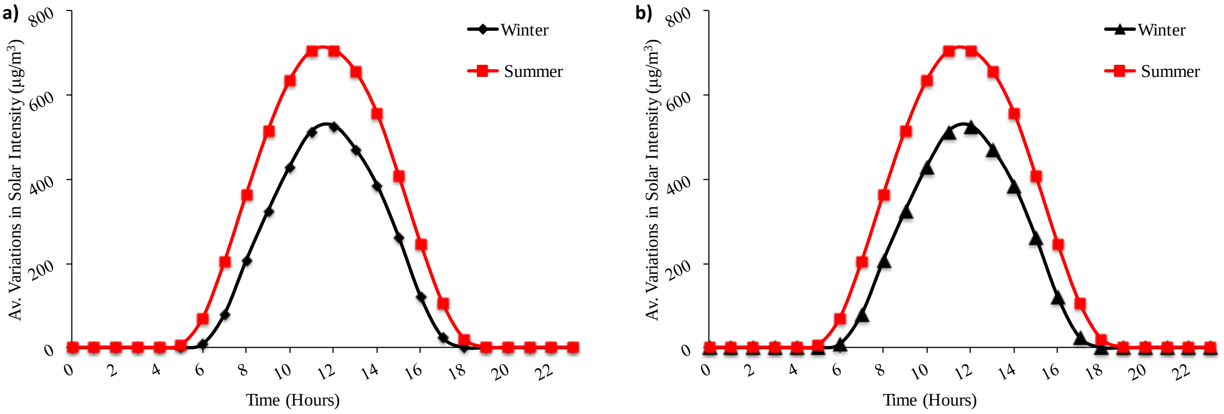

Fig. 14: Average Solar Intensity Variations in 2010 in (a) Al-Jahra and (b) Al-Mansouriah.

3.2.3. Temperature variations

The harsh weather conditions in Kuwait result in temperatures of up to 50 °C , especially in the summer season. The temperature variation in Al-Jahra in 2010 is shown in Figure 15 (a). The maximum temperature of 49.96 °C in the summer was recorded on the 16th of July at 15:00. The average temperature in the summer season was 39.48 ± 0.85 σ ^{o}C, and the standard deviation (σ) is 4.65 ^{o}C. In the winter, the maximum temperature was 40.43 °C, recorded on the 16th of March at 14:00. The average temperature in the winter season was 20.10 ± 0.78 σ ^{o}C, and the standard deviation (σ) was 5.77 ^{o}C.

The temperature variation in Al-Mansouriah in 2010 is shown in Figure 15 (b). The maximum temperature of 51.09 °C in the summer was recorded on the 13th of July at 14:00. The average temperature in the summer season was 40.63 ± 0.64 σ °C, and the standard deviation (σ) was 3.69 °C. In the winter, the maximum temperature was 38.46oC, recorded on the 15th of March at 12:00. The average temperature in the winter season was 21.53 ± 0.66 σ °C, and the standard deviation (σ) was 4.93 °C. Al-Mansouriah has high temperatures due to its location close to the city center and its being surrounded by many cities, while Al-Jahra is in an open area, and thus its temperatures are lower.

These seasons are characterized by high winds that cause severe dust storms that disperse the high pollutant emissions. These two contradictory factors result in high ground-level concentrations of pollutants dominated by meteorological conditions.

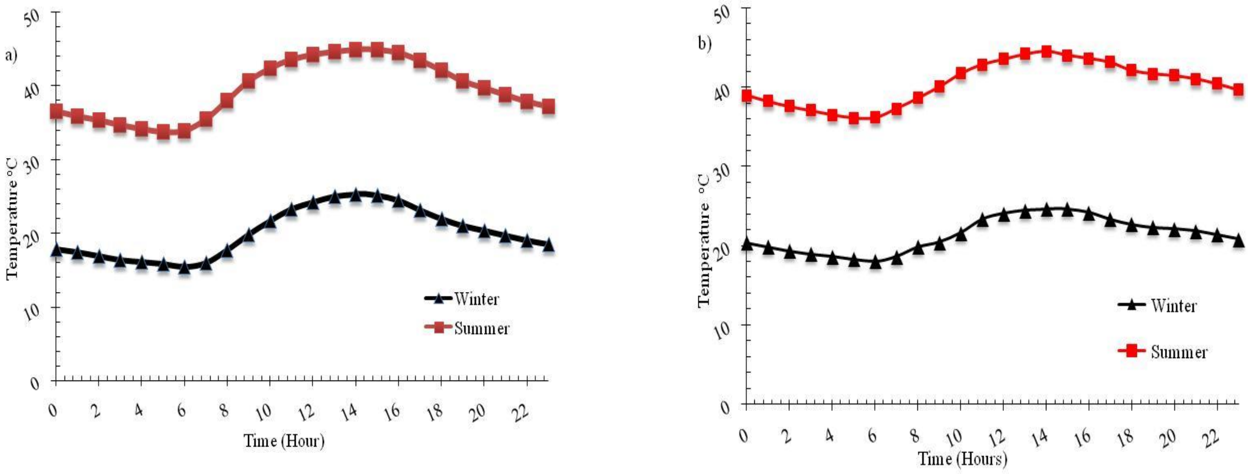

Fig. 15: Average Temperature Variations in 2010 in (a) Al-Jahra and (b) Al-Mansouriah.

4. Conclusion and recommendations

Air pollution, wind roses and meteorological data have been measured and analyzed for two districts in Kuwait, Al-Jahra and Al-Mansouriah, for the recent year of 2010. Data recorded at 5-min intervals were processed to obtain annual hourly averages and annual 1-h maxima. The effects of winter (January to March) and summer (July to September) seasonal changes on ambient air pollutant concentration levels in the two districts were then analyzed to identify the most probable pollution sources so that pollution abatement methods can be applied in the future.

The concentrations of CO, PM_{10} and NO_2 exhibited different patterns in the two districts and in summer and winter due to different activities in the surrounding areas. The concentrations of SO_2 were high in both cities, in Al-Mansouriah

because of the dense traffic of diesel vehicles and in Al-Jahra because of the flue gases from the Al-Doha power plant and oil refineries near the city. Particulate matter concentrations were relatively high but did not exceed the limits set by KU-EPA. The data recorded in the Al-Jahra and Al-Mansouriah districts of Kuwait showed that the districts have difficulty in meeting the air standards for NM-HC because of traffic congestion and oil field activities.
The concentration rose for NM-HC in winter in Al-Jahra reflects the oil field activities surrounding this district. The concentration roses for CO and NO_2 exhibit almost uniform distributions, reflecting the effects of traffic all around the monitoring stations.
Both districts have an arid climate with an average temperature of 40 °C in the summer, accompanied by strong northwesterly winds. The winter temperatures are moderate: close to 20 °C.
It is important to maintain high standards of air quality in both districts to minimize the effects of air pollutants on the health of the population of Kuwait. The recommended mitigation strategy is to reduce air pollution by introducing public transport buses, trams, and a metro, which could considerably reduce the number of cars on the roads and encourage a switch in consumption from traditional petroleum fuels (gasoline and diesel) to biofuels such as ethanol (E85) and biodiesel (B100).

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References

[1] Yang, W. and S.T. Omaye, "Air pollutants, oxidative stress and human health", *Mutation Research/Genetic Toxicology and Environmental Mutagenesis,* 674, 1–2, (2009), 45-54.
[2] Shao Lin, X.L., Linh H. Le, and Syni-An Hwang "Chronic Exposure to Ambient Ozone and Asthma Hospital Admissions among Children. Environ Health Perspect", *Environmental Health Perspectives,* 116, 12, (2008), 1725–1730.
[3] Bell, M.L., McDermott, A., Zeger, S. L., Samet, J. M., & Dominici, F. J, "Ozone and Short-term Mortality in 95 US Urban Communities, 1987-2000", *Journal of the American Medical Association,* 292, 19, (2004), 2372-2378.
[4] EPA., U.S.,Air quality criteria for ozone and related photochemical oxidants.Washington, DC, (2006)
[5] Al-Haider, S.A. and S.M. Al-Salem, "Outdoor air quality data analysis of Al-Mansoriah residential area (Kuwait): air quality indices results", *Transactions on Ecology and the Environment,* 116, (2008), 189-196. http://dx.doi.org/10.2495/AIR080201.
[6] Cacciola, R.R., M. Sarvà, and R. Polosa, "Adverse respiratory effects and allergic susceptibility in relation to particulate air pollution: flirting with disaster", *Allergy,* 57, 4, (2002), 281-286.
[7] Kountouriotis, A., P.G. Aleiferis, and A.G. Charalambides, "Numerical investigation of VOC levels in the area of petrol stations", *Science of The Total Environment,* 470–471, 0, (2014), 1205-1224.
[8] Placet, M., C.O. Mann, R.O. Gilbert, and M.J. Niefer, "Emissions of ozone precursors from stationary sources:: a critical review", *Atmospheric Environment,* 34, 12–14, (2000), 2183-2204.
[9] Institute of Banking Studies,Economic and Financial Data base for Bankers, Research Unit, Kuwait. Institute of Banking Studies, (2004)
[10] Al-Temeemi, A.-S., "Climatic design techniques for reducing cooling energy consumption in Kuwaiti houses", *Energy and Buildings,* 23, 1, (1995), 41-48.
[11] Ettouney, R.S., J. G. Zaki, M. A. El-Rifai, and H. M. Ettouney, "An assessment of the air pollution data from two monitoring stations in Kuwait", *Toxicological and Environ Chemistry,* 92, 4, (2010), 655-668.
[12] Al-Azmi, B.N., V. Nassehi, and A. Khan, "SO2 and NOx Emissions from Kuwait Power Stations in Years 2001 and 2004 and Evaluation of the Impact of These Emissions on Air Quality Using Industrial Sources Complex Short-Term (ISCST) Model", *Water, air, and soil pollution,* 203, 1-4, (2009), 169-178
[13] Abdul-Wahab, S.A., "Two case studies of air pollution from Oman and Kuwait", *International Journal of Environmental Studies,* 66, 2, (2009), 179-191.
[14] Al-Rashidi, M.S., V. Nassehi, and R.J. Wakeman, "Investigation of the efficiency of existing air pollution monitoring sites in the state of Kuwait", *Environmental pollution,* 138, 2, (2005), 219-229.
[15] Al-Bassam, E. and A. Khan, *Air pollution and road traffic in Kuwait*, in *WITPress*. 2004: Dresden, Germany. p. 741-750.
[16] Bouhamra, W.S. and S.A. Abdul-Wahab, "Description of outdoor air quality in a typical residential area in Kuwait", *Environmental pollution,* 105, 2, (1999), 221-229.
[17] Al-Mutairi, N.a.P.K., " Potential Contribution of Traffic to Air Pollution in the State of Kuwait", *American Journal of Environmental Sciences,* 5, 3, (2009), 218-222.
[18] Al-Awadhi, F.A. and S.A. Al-Awadhi, "Spatial-temporal model for ambient air pollutants in the state of Kuwait", *Environmetrics,* 17, 7, (2006), 739-752.
[19] Abdul-wahab, S.A. and W.S. Bouhamra, "Diurnal variations of air pollution from motor vehicles in residential area", *International Journal of Environmental Studies,* 61, 1, (2004), 73-98.
[20] Jallad, K.N. and E.-J. Cyntia, "Analysis of ambient ozone and precursor monitoring data in a densely populated residential area of Kuwait", *Journal of Saudi Chemical Society,* 14, 4, (2010), 363-372.
[21] Al-Awadhi, J., "Measurement of Air Pollution in Kuwait City Using Passive Samplers", *Atmospheric and Climate Sciences,* 4, 2, (2014), 253-271.
[22] General Statistic Office, K., Annual Statistical Abstract, 2008.State of Kuwait, (2009)
[23] Han, X. and L.P. Naeher, "A review of traffic-related air pollution exposure assessment studies in the developing world", *Environment International,* 32, 1, (2006), 106-120.
[24] Ettouney, R.S., J.G. Zaki, M.A. El-Rifai, and H.M. Ettouney, "An assessment of the air pollution data from two monitoring stations in Kuwait", *Toxicological and Environmental Chemistry,* 92, 4, (2010), 655-668.
[25] Seinfeld, J.H., & Pandis, S. N. , Atmospheric chemistry and physics: from air pollution to climate change, the University of Michigan: Wiley.2006.