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Assessment of Air Quality in two Different Urban Localities

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ABSTRACT: This study assesses the air quality of two urban localities, Fahaheel and Al-Rabia City, to assist local authorities to generate information supporting the planning of pollution control strategies to keep pollutants within safe limits in the long run. In terms of diurnal and seasonal variations, almost all measured pollutants exhibited two peaks: one in the morning and another in the afternoon. These two peaks resulted from numerous activities (schools, open stores, traffic, restaurants and markets, and central heating) practiced in these two cities during associated peaks hours. Nevertheless, there were noteworthy differences in air pollutants' magnitude (values) between the two cities. There were a number of exceedances of KUEPA air quality threshold values in both urban localities; the highest numbers were in NMHC and the lowest numbers were in O_3 and CO. No exceedances were found in SO_2 in Al-Rabia City. In an attempt to identify the most probable sources of air pollution, concentration roses were plotted for annual durations for both Fahaheel and Al-Rabia. Furthermore, the Chemical Mass Balance (CMB) model was developed to quantify the contribution of each prevalent source to measured emission concentration. Results show that the main emission sources in Fahaheel were petroleum downstream facilities and highway traffic, which accounted for 69% and 17%, respectively. In Al-Rabia City, highway traffic and the area's commercial activity accounted for 79% and 13%, respectively.

Key words: Air Pollution, Diurnal variations, Monthly variations, Concentration roses, CMB model

INTRODUCTION

It is well known that clean air is considered a key requirement for human health and well-being. Several chemicals are released into the air from natural and anthropogenic sources. Despite the fact that the introduction of cleaner technologies in both stationary and mobile sources has contributed to the reduction of air pollutants, air pollution remains a major health risk (Gryparis *et al.,* 2004; Pénard-Morand *et al.,* 2005). Thus, many environmental agencies around the world have imposed stringent emission regulations. The assessment of air quality in urban localities using available air quality data will help generate information supporting the long-term planning of pollution control strategies to keep pollutants within safe limits (Ozden *et al.,* 2008).

Several studies have investigated major gaseous pollutants such as tropospheric O_3, CO, NO, NO_2, SO_2, non-methane hydrocarbons (NM-HCs), and volatile organic compounds (VOCs). One study (Riga-Karandinos and Saitanis 2005), investigated the ambient air quality of two Greek coastal cities, Patras and Volos. Concentrations of NO, NO_2 and SO_2 were found to be higher in Patras compared to concentrations in Volos; this was attributed to bigger size, higher urban traffic volume, and the larger and busier harbor of Patras. In contrast, O_3 levels in Volos were higher than those in Patras, while no difference was found for CO levels between the two cities. Another study (Han 2010) compared the air quality data of two industrial cities, Fushun City, northeast of China, and Kokkola City, in Finland, during the period 2001-2006. Almost all the concentrated pollutants in Fushun were higher than those in Kokkola, which was ascribed to more traffic and less stringent regulation in Fushun City compared to Kokkola City. A recent study (Azmi *et al.,* 2010) were investigated the trend and status of PM_{10}, CO, SO_2, O_3, NO_2 at three different monitoring stations, namely, Petaling Jaya, Shah Alam, and Gombak, in the Klang Valley in Malaysia. Records show that concentrations of CO, NO_2 and SO_2 were higher at Petaling Jaya, which is possibly due to the impact of heavy traffic. Conversely, it was reported that concentrations of PM_{10} and O_3 are related primarily to regional tropical factors, such as the impact of biomass burning and ultra violet radiation from sunlight. Moreover, Karaca et al. (2005) collected 86 daily aerosol samples in Istanbul between July 2002 and July 2003. Results show that the annual mean

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concentration of $PM_{2.5}$ was 20.8 µg/m^3, which is higher than the United States EPA standard of 15 µg/m^3.

Numerous types of reactions are involved in the formation of air pollutants, and these reactions have engaged researchers' attention for many years. Tropospheric O_3 and other photochemicals are known not only to have detrimental effects and threaten human health (WHO 2003; Mulholland *et al.,* 1998), but they also have a close association with increases in particle air pollution (PM_{10}) (Meng *et al.,* 1997; Mulholland *et al.,* 1998; Ying and Kleeman 2003). Furthermore, the conversion of SO_2 and NO_2 to particulate sulfate and nitrate is the main characteristic of urban photochemical reaction (Monn and Shaeppi 1993; Matsumoto *et al.,* 1998). Sulphate and nitrate are key precursors to nitric and sulfuric acids, which cause acidification of soil and water, a decrease in visibility, and an increase in respiratory diseases among the human population (Riga-Karadinos and Saitanis 2005). Dilution and dispersion of air pollution depends on various factors, including weather conditions (meteorological conditions), topography and the local situation (Wijeratne and Bijker 2006). These factors cause large variation, even in small areas and control numerous photochemical reactions in the atmosphere that wheels the life span and cycle of respective pollutants. Ghazali et al. (2009) investigated the transformation of NO_2 into O_3 in the urban environment of Malaysia using a time series plot. The authors found that variations in O_3 amounts are closely related to temperature, with colder temperatures resulting in more polar stratospheric clouds and lower ozone levels. Another study (Khan and Al-Salem, 2007) also studied the impacts of meteorological conditions on three pollutants: methane (CH_4), benzene (C_6H_6), and NOx for three years in an urban area in Kuwait. The study reported seasonal variations in the measured air pollutants, induced by changing meteorological conditions.

In the present work, the air quality of two different urban localities, Fahaheel and Al-Rabia, is assessed and a comparison is made between the two cities, particularly with respect to NO_2, O_3, CO, NMHCs, and SO_2. The comparison is made based on the exceedances of the Kuwait Environment Public Authority (KUEPA) air quality threshold values, diurnal and seasonal variations,concentrations roses, and sources that contribute to emissions. The contribution of each prevalent source was quantified using the Chemical Mass Balance (CMB) model.

MATERIALS & METHODS

In this study, the air pollutant level and pattern for two cities, Fahaheel and Al-Rabia, are compared. The two locations of observation are shown in Fig.1. Fahaheel City is situated south of Kuwait City and has a population of about 102,000. The city is significantly polluted by a large number of small, medium, and large industries and vehicular traffic. It is bounded in the west by one of the largest highways (Road No.30) in Kuwait, which connects central Kuwait to the southern parts of the city. On the east side, Fahaheel is surrounded by seashore, which encompasses Al-Ahmad harbor and shopping malls. It is bounded on the south side by three large petroleum refineries, one of which has the highest oil capacity in Kuwait. The nearest refinery is Mina Al-Ahmadi. Numerous small, medium, and large petrochemical industries are situated in the south. One of the most important pollution sources and the second-largest oil field in the world in the southern part of Fahaheel is the Greater Burgan field. Al-Rabia City is situated south west of central Kuwait and has a population of about 35,000. Two of the largest major highways surround Al-Rabia City: the fifth ring road from the north, and the sixth ring road from the south. Another highway to the east connects Kuwait International Airport to the rest of the city. The Shuwaikh industrial area, consisting mainly of car repair garages, glass and tire workshops, and other small workshops, is located north of Rabia. Rabia is surrounded by Doha Power Station on the northwest side and by a waste-water treatment plant on the southwest side, in Al-Ardiya. Kuwait International Airport is located on the southeast side of Al-Rabia.

All hourly concentrations of NO_2, O_3, CO, NMHCs, and SO_2 for the two urban localities, Fahaheel and Al-Rabia, for 2009 have been provided by the Air Pollution Monitoring Division of the Kuwait Environment Public Authority (KUEPA). KUEPA monitoring stations are located on the roof of polyclinic buildings in the center of Fahaheel and Al-Rabia cities.

The average diurnal profiles and seasonal variations were constructed for each pollutant along with their descriptive statistics using Statistica 6 software. Subsequently, the exceedances of the limits/ threshold values set by KUEPA were calculated. Concentration roses of air pollutants and the Chemical Mass Balance (CMB) model were performed using advanced Microsoft Excel add-ins programs.

RESULTS & DISCUSSION

Table 1 lists the descriptive statistics, the maximum, minimum, average, and standard deviation (SD), and the coefficient of variation (CV), of O_3, NO_2, CO, NMHC, and SO_2 in both Fahaheel and Rabia cities. Measured concentration values of the selected pollutants have been compared with the limit and guide values specified

Fig. 1. Image of two localities

by guidelines of the KUEPA Law 210/2001 (KUEPA 2001) to estimate the number of violations. The numbers of exceedances were estimated and are listed in Table 1.

The annual average concentration of NO_2 recorded in Fahaheel City was 43 ± 30 (SD) ppb, with a maximum value of 485.8 ppb. In Al-Rabia City, the annual average concentration of NO_2 was about 25.4 ± 20 ppb, with a maximum value of 170.3 ppb. It is obvious from the NO_2 descriptive statistics (Table 1) that the level in Fahaheel City was higher than that in Al-Rabia City. This is likely due to numerous activities that form NO_2 in Fahaheel City compared to Al-Rabia City. This will be discussed in detail below. KUEPA has set a limit of 100 ppb as an hourly rolling average for ground level NO_2 to reduce its detrimental health impact. In Fahaheel City, 320 exceedances per year were recorded during 2009 for the short-term (one hour) limit, while only 43 exceedances were observed in Al-Rabia City (Table 1).

Table 1. Descriptive statistics, KUEPA limit, and number of exceedances of air pollutants in both Fahaheel and Al-Rabia cities

Pollutants		Fahaheel	Al-Rabia	KUEPA limit	Number of exceedances*	
					Fahaheel	Al-Rabia
NO_2 (ppb)	Max.	485.8	170.3	100 ppb [a]	320	43
	Min.	0.08	0.08			
	Ave.	43	25.4			
	S.D.	30	20			
	C.V.	0.71	0.8			
O_3 (ppb)	Max.	91.7	110.8	80 ppb [a]	3	10
	Min.	0.08	0.083			
	Ave.	16.5	15			
	S.D.	14	12			
	C.V.	0.9	0.8			
CO (ppm)	Max.	44.3	9.4	8 ppm [b]	3	4
	Min.	0.02	0.01			
	Ave.	1.1	1.1			
	S.D.	0.9	0.9			
	C.V.	0.9	0.9			
NMHC (ppm)	Max.	15.7	6.3	0.24 ppm [c]	1227	1039
	Min.	0.001	0.001			
	Ave.	0.7	0.4			
	S.D.	0.8	0.37			
	C.V.	1.0	0.86			
SO_2 (ppb)	Max.	272.3	141.8	170 ppb [a]	15	none
	Min.	0.08	0.08			
	Ave.	13.3	4.9			
	S.D.	17.9	6.7			
	C.V.	1.3	1.4			

a: Hourly, **b**: Daily, **c**: Set a daily permissible for the period 6-9 am.

In the case of O_3, the annual average concentration of O_3 in both urban cities was below the hourly limit (80 ppb) set by KUEPA. The annual average concentration of O_3 was 16.5 ± 14 ppb in Fahaheel City, and 15 ± 12 ppb in Al-Rabia City. There was high seasonal variation in the concentration of O_3 in both urban cities; the coefficients of variation (CV) were 0.9 and 0.8 in Fahaheel and Al-Rabia, respectively. For O_3, KUEPA has set an hourly limit of 80 ppb. Three exceedances per year were observed in Fahaheel City, while 10 exceedances per year were recorded in Al-Rabia City, as shown in Table 1.

As for CO, the annual average concentration in both Fahaheel and Al-Rabia cities was identical (1.1± 0.9 ppm) (Table 1). The maximum concentrations in both urban cities were observed in the winter months (December and January), while minimum concentrations were noticed in the summer months (June and July). The highest concentrations of CO in both cities were noticed at 6:30 am and 8:00 pm. This is attributed to the increase in vehicular traffic at these times (Lal *et al.,* 2000; Beig *et al.,* 2007). Similar observations were made in both Kolkata and Haldia, in the northeast of India (Purkait *et al.,* 2009). To limit increases in the level of CO, KUEPA has set a limit of 8 ppm as a daily rolling average for ground level CO. Exceedances in the CO limit were the least compared with other pollutants. Three violations were recorded in Fahaheel City and four were recorded in Al-Rabia City in 2009 (Table 1).

The statistical measurements of non-methane hydrocarbons (NMHC) are also listed in Table 1. The annual average concentration levels were 0.7± 0.8 ppm and 0.43± 0.4 ppm in both Fahaheel and Al-Rabia cities, respectively. The level of NMHC in Fahaheel was higher than that in Al-Rabia, mainly due to petroleum and petrochemical industries downstream of Fahaheel City. KUEPA has set a daily permissible limit (0.24 ppm) for the period 6-9 am for NMHC. The number of exceedances in NMHC was the highest among all other pollutants in both urban cities. The number of violations in Fahaheel was 1227 compared to 1039 violations in Al-Rabia City. Unlike other pollutants, NMHC needs special attention from local authorities to protect human health, animals, and vegetation.

The sulfur dioxide (SO_2) level in both Fahaheel and Al-Rabia cities was also monitored, and statistical descriptions are listed in Table 1. The annual average concentration of SO_2 was 13.3 ppb in Fahaheel City, and 4.9 ppb in Al-Rabia City. SO_2 variations were the highest among other pollutants; CV was 1.3 in Fahaheel City and 1.4 in Al-Rabia City. The permissible KUEPA hourly rolling average for SO_2 is 170 ppb. In terms of exceedance, 15 exceedances were observed for SO_2 in Fahaheel City whereas no exceedances were recorded in Al-Rabia City. Again, Fahaheel City is bounded by petroleum and petrochemical industries downstream in addition to vehicular traffic sources. This would in turn increase the level of SO_2 in Fahaheel City compared with Al-Rabia City.

Diurnal mean concentrations and monthly variations of O_3, NO_2, CO, NMHC, and SO_2 have been assessed for both Fahaheel and Rabia cities for the sake of comparison. The results are shown in Fig. 2. In terms of diurnal patterns, it is evident from Fig. 2 that almost all measured pollutants exhibited two peaks: one in the morning and another in the afternoon. These two peaks originated from various activities (schools, open stores, traffic, restaurants and markets, and central heating), and occurred in these two cities during associated peak hours. For SO_2, there was a discrepancy in its diurnal patterns in both Fahaheel and Al-Rabia City. This could be ascribed to the different activities and sources in each city as will be illustrated in the CMB section below.

Differences in the magnitude of air pollutants between the two cities are, of course, clear and significant as illustrated in Fig. 2. Formation of NO_2 in the atmosphere results from complex reactions between oxides of nitrogen, NOx, and ozone (Leksmono *et al.,* 2006). The NO_2 level in Fahaheel City (Fig.2, left) was higher than that in Al-Rabia City. Such increases in the NO_2 level in Fahaheel City could probably be ascribed to its bigger size and thus its bigger population of urban residents, and secondly and most importantly, its large and busier eastern harbor and neighboring industrial complex. The high level of NO_2 in both cities was observed during cooler periods in Kuwait (January-March and October-December). This observation is consistent with previous studies (Riga-Karadinos and Saitanis 2005; Al-Salem 2007) as solar radiation intensity decreases in the cooler months, the extent of photochemical reactions would reduce NO/NO_2 destruction. It is important to mention that similar observations were also noted for NO, but for the sake of brevity, only NO_2 is discussed in this study.

CO results from incomplete combustion of natural gas, diesel, or gasoline in traffic engines, and point sources include industrial processes, non-transportation fuel combustion, and natural sources such as wild forest fires. The diurnal patterns of CO along with monthly variations for both urban localities are shown in Fig. 2. Like NO_2, two CO peaks were observed at an exactly similar time to those observed with NO_2 and inversely to the ozone pattern. In contrast to O_3 and NO_2, CO levels in Al-Rabia City were higher than Fahaheel. CO levels increased gradually throughout the year in the Al-Rabia urban area. The high level of CO in the Al-Rabia area could be likely due to the large number of road networks, resulting in high traffic congestion and then higher emission (Han and Naeher 2006). CO levels in Fahaheel City were also high, but less than in Al-Rabia City. Potential sources of CO in Fahaheel City are incomplete crude oil burning as well as emissions in upstream facilities and flaring, which result in such accumulations of CO in the ambient air. In both Fahaheel and Al-Rabia cities, CO levels reached a maximum in winter and a minimum in summer. This is mainly due to seasonal variations in the rates of CO production and removal (Lyman and Jensen 2001).

O_3 is a secondary pollutant, formed in the presence of sunlight, NOx, and a pre-curser VOCs. As mentioned above, the NO/NO_2 concentration in Fahaheel City was higher than that in Al-Rabia City, and since O_3 build-up is highly dependent on the NO/NO_2 level, it would be expected that O_3 formation is higher in Fahaheel City. As shown in Fig. 2, the O_3 level was also found to be higher in Fahaheel City compared with Al-Rabia City. In both cities, two peaks for O_3 were detected: the first peak was found at around 1:30-2:00 am, while the second peak was observed from 12:00-2:00 pm. The first O_3 peak (1:30-2:00 am) is believed to have been the result of tropospheric oxidation reactions of CO in the presence of sufficient NO/NO_2. Comparing the diurnal patterns of O_3 and CO (Fig. 2), it is apparent that depletion of CO induces the formation of O_3 during non-photochemistry hours (1:30-2:00 am). As time passes and reaches about 7:00 am, the intensity of sunlight increases and gradually triggers photochemical reactions of ozone formation, until it reaches maxima at noon (12:00-2:00 pm), when maximum sunlight intensity is reached. This is the main cause of the second O_3 peak observed in both cities, as shown in Fig. 2. Few discrepancies in the O_3 diurnal pattern in Al-Rabia City could be attributed to high traffic emissions during traffic congestion compared with Fahaheel. The increased traffic emissions would induce competitive reactions, with more favorable reactions towards the higher concentration of pollutants. The high CO concentration in Al-Rabia City (Fig. 2) could explain discrepancies in the O_3 diurnal pattern. It is

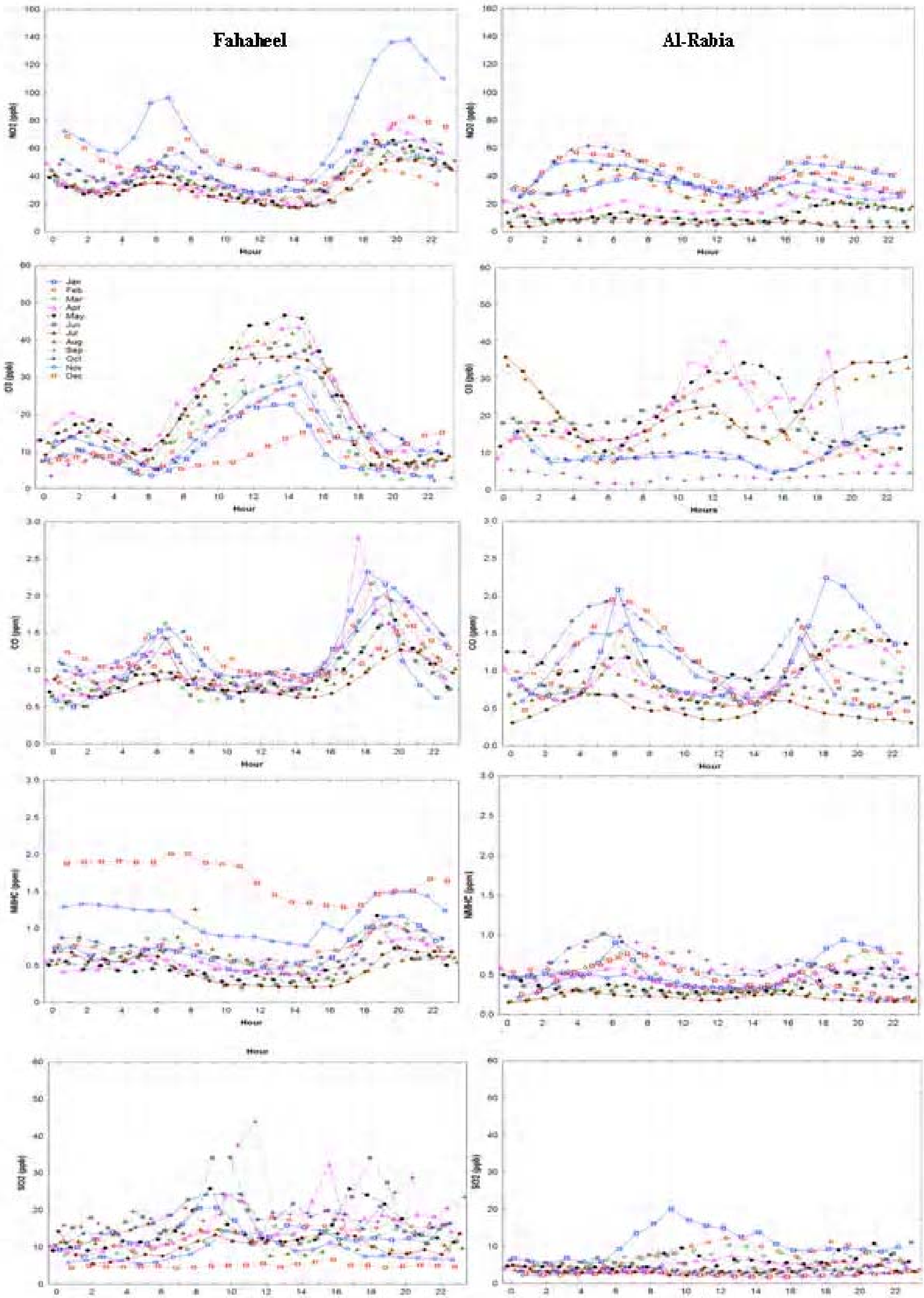

Fig. 3. Annual wind rose plot for year 2009 for (a) Fahaheel urban area, (b) Al-Rabia urban area

also important to note that CO levels revealed an inverse to O_3 seasonal fluctuation, with a maximum occurring in winter and a minimum in summer. These seasonal fluctuations could be enhanced by the seasonal variations due to lower temperature and a shallow planetary boundary layer.

NMHC forms from incomplete combustion of hydrocarbon fuels either from traffic engines and/or different petroleum and petrochemical activities. The diurnal variation NMHC for the 12 months for both urban cities is shown in Fig. 2. Similar to other pollutants, two peaks were a feature for both cities. The NMHC values in Fahaheel City were always higher than those in Al-Rabia City. This indeed was expected since Fahaheel City is surrounded by various petroleum and petrochemical industries beside highways. The concentration of NMHC in Fahaheel City starts increasing from October, attaining maxima in December, then decreasing and attaining minima in May. For Al-Rabia City, the concentration of NMHC starts increasing from September, attaining maxima in October, then decreasing and attaining minima in July. It is clear that maximum levels of NMHC in both cities were recorded in the cooler months, as high temperatures in hot months induce the dispersion of air pollutants, and hence the concentration at certain receptor points are quite low.

The diurnal patterns of SO_2 in different months of the year in both localities are shown in Fig. 2. The SO_2 levels in Fahaheel City were higher than those in Al-Rabia City. One plausible reason for the high SO_2 emission in Fahaheel City compared to Al-Rabia City may be the differences in emission sources. Another plausible reason is the high formation of O_3 inducing the formation of SO_2 levels. A study by Khoder (2002) shows that the oxidation processes and conversion of SO_2 to sulfate depend on photochemical oxidation and that the sulfur conversion ratio increases with increasing ozone concentration. The higher O_3 concentrations in Fahaheel City may contribute to a higher conversion ratio of sulfur than in Al-Rabia, where higher values of SO_2 were observed. Moreover, downstream petroleum and petrochemical industries can both be potential causes for the increased levels of SO_2 in Fahaheel City compared to Al-Rabia City. In these facilities, chemical processes automatically release SO_2 from stacks in refineries, which eventually increase SO_2 levels in the atmosphere, which is indeed observed in this study.

In attempting to determine the most probable emission sources, a series of concentration roses for air pollutants were plotted based on hourly data for 2009 for the Fahaheel and Al-Rabia areas. Concentration roses were plotted in 16 sectors ($\pi/8$ or 22.5^o) based on the predominant wind direction, which helped identify the most probable source. The concentration roses of O_3, NO_2, CO, NMHC, and SO_2 in Fahaheel City have an identical pattern, which was also observed in Al-Rabia City. This is mainly due to the prevalent wind direction identifying the main contributors to the bulk of the concentration rose for year 2009. Thus, for the sake of brevity, only NO_2 concentration roses will be compared between Fahaheel and Al-Rabia.

Figs 3 a and b show the wind roses plotted for the residential areas of Fahaheel and Al-Rabia. The prevailing winds in both cities were strongly northwest winds (~28-32% of time) and mild south to southeasterly winds (~27-31% of time). NO_2 concentration roses for pollutants were plotted for both the Fahaheel and Al-Rabia areas, respectively, and are shown in Figs 4a and b. In the Fahaheel area (Fig.4a), NO_2 emissions directions showed similar trends to wind. The south, southwest, and southeast of Fahaheel have all the petroleum downstream facilities in addition to background concentrations resulting from inner roads, vehicle emissions, and power station emissions. Residents of Fahaheel would be susceptible to high level concentrations from petroleum downstream facilities and power station emissions when winds are blowing from the southeast direction. While, people would be vulnerable to high vehicular emissions when winds are blowing from the northwest direction. In Al-Rabia (Fig. 4b), NO_2 levels reaching 136 ppb blew from the west and 127 ppb blew from the south. Low to medium strength winds blowing from the northwest direction, where power stations is located, towards highly populated residential areas of Rabia would definitely increase pollution levels that can ultimately have detrimental impacts on the health of the people living there. The most likely emission sources in Rabia include airplanes landing and taking off from the nearby runway, main highways connecting the area to other parts of the city, and traffic emissions from the 6th highway road.

Receptor modeling is a technique that uses the chemical speciation of air pollutants collected at a receptor to gain knowledge about the contribution of potential sources to the ambient concentration of air pollutants and their chemical composition (Pandolfi *et al.*, 2008). The Chemical Mass Balance (CMB) model is among these effective receptor-oriented models that are widely used to evaluate the effects of source emissions (Hopke 1991; Mazzera *et al.*, 2001; Watson *et al.*, 2002; Samara *et al.*, 2003).

The CMB modeling procedure requires solving mass balance equations expressing measured ambient air pollutant concentrations as the sum of products

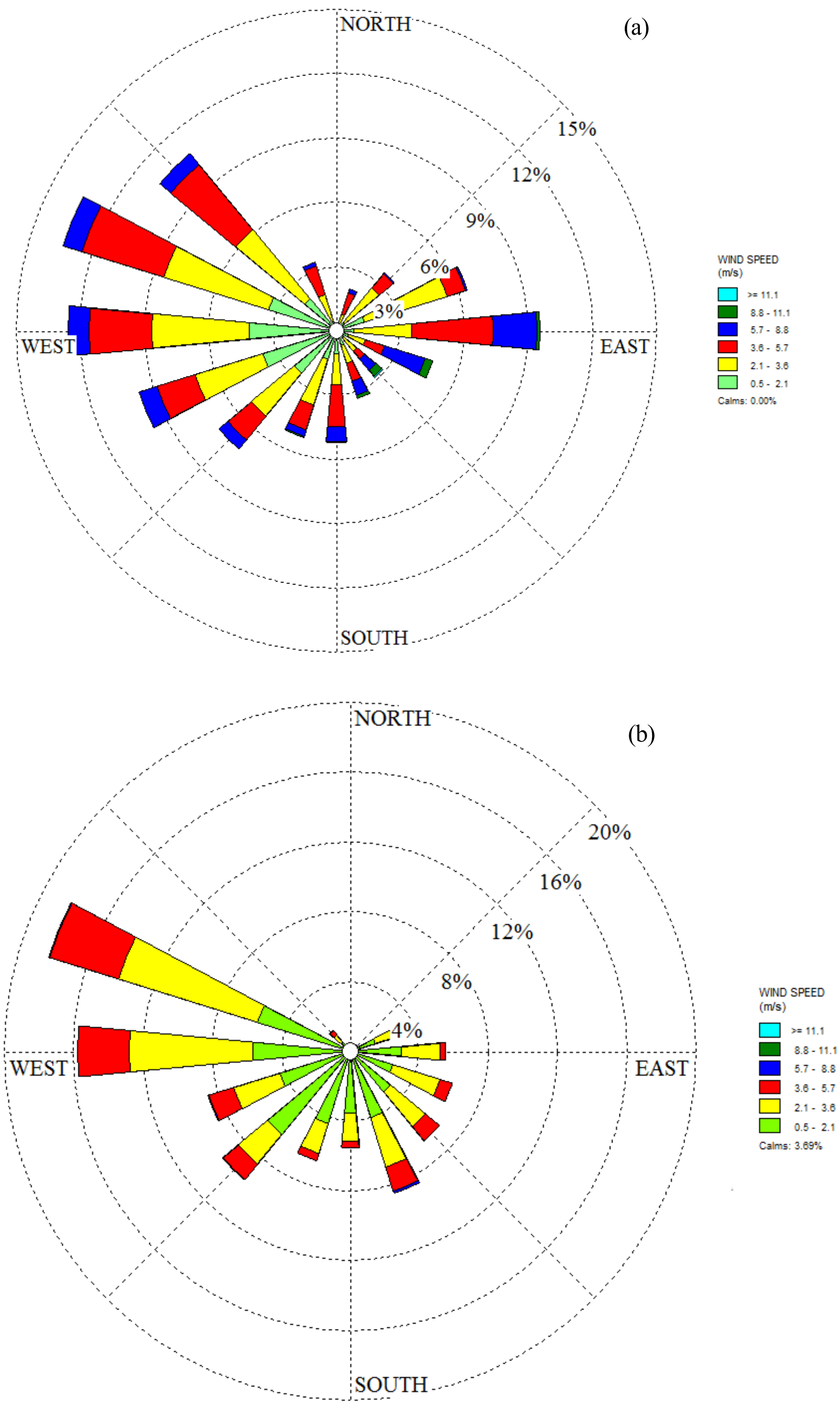

Fig. 3. Annual wind rose plot for year 2001 for (a) Fahaheel urban area, (b) Al-Rabia urban area

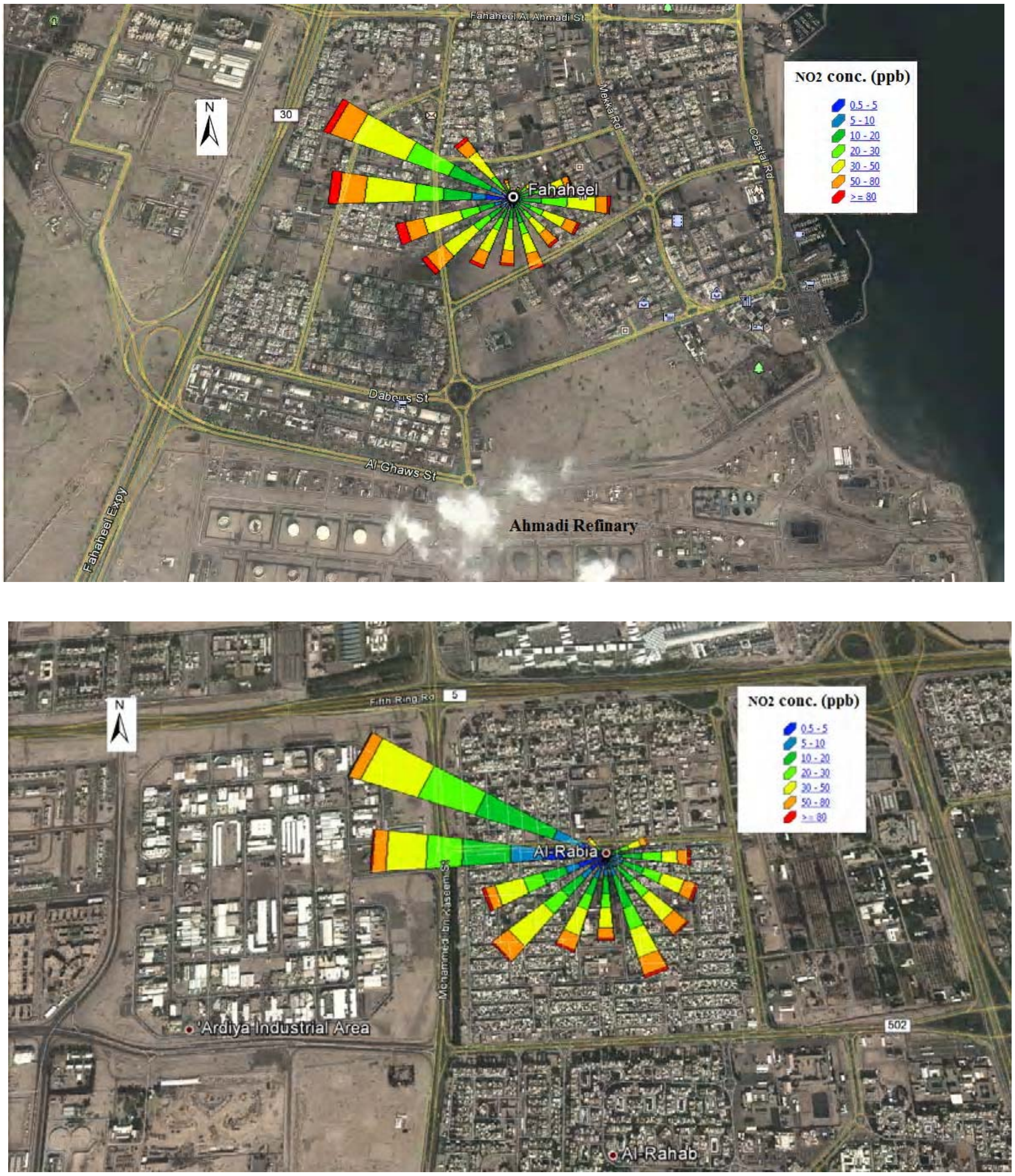

Fig. 4. Annual NO_2 (ppb) accumulated concentration rose plotted for the year 2009 for (a) Fahaheel urban area, (b) Al-Rabia urban area

between the source contributions and the air pollutant abundances in the source emissions. Equation 1 is used in the CMB model to express the relation between the concentrations of chemical species measured at the receptor point and chemicals emitted from the source.

$$\Delta C_i = \Sigma F_{ij} - S_i \quad (1)$$

Where ΔC_i is the difference in concentration of chemical compound i at the receptor point; F_{ij} is the fraction of concentration of species i starting from source j; and S_i is the concentration of pollutant i at the receptor point. To ease the analysis part of the constructed CMB model, the sector's position distribution around both Fahaheel and Al-Rabia (receptor points) were identified and are shown in Table 2.

In addition to air pollutant abundances in the source emissions, wind speed and its direction are considered in the CMB model to estimate their

Table 2. Position distribution around outdoor data collection point in Fahaheel and Al-Rabia urban areas

Fahaheel City	
Position in degrees	**Source**
0-135	Commercial area
136-255	Refineries, petroleum, and petrochemical industries
256-300	Oil production facilities (Burgan)
301-360	Traffic line sources (Highway), gas stations, and sports clubs
Al-Rabia City	
300-130	Commercial area
130-170	Refineries, petroleum and petrochemical industries
Others	Traffic line sources (Highway), gas stations, and sports clubs

percentage contribution. The contribution of wind speed to the source was estimated with the following equation

$$\%WS_i = (k_i / K) \times 100 \quad (2)$$

Where $\%WS_i$ is the percentage contribution of wind speed with respect to source i; k_i is the summation of wind speed points collected with respect to source i in (m/s); and K is the total summation of wind speed points in (m/s) excluding calm periods.

The CMB model serves as an effective-variance least-squares solution to the linear combination of the product of the source contribution and its concentration (Watson *et al.*, 1984).

A linear objective function (Eq. 3) is also used in the CMB model to match the concentrations at the major sources (receptor points) considered. Equation 3 represents the total cumulative concentration of a pollutant to be matched.

$$LF = \sum_{j=1}^{m}\sum_{i=1}^{n} C_i.WS_i.SC_i - \sum_{i=1}^{n} C_i.WS_i.SC_i \quad (3)$$

Where L.F. is the linear function set to match the percentage contribution of each source; C_i is the concentration of airborne chemical i at a certain source or receptor point; $\%WS_i$ is the percentage wind speed contribution at a certain wind direction range for source i; $\%SC_i$ is the percentage source contribution for a source I; i represents pollutants; and j sources.

The source apportionment results from the CMB analysis, based on the measured concentration of air pollutants from the Fahaheel and Al-Rabia areas are briefly compared in Table 3.

According to the presented results in Table 3, petroleum refineries and petrochemical industries (petroleum downstream facilities) account collectively for 69% of the total air pollutants in Fahaheel City.

Table 3. %source contribution in Fahaheel and Al-Rabia urban areas based on CMB model results averaged over the period of the study

Source	Fahaheel (% source contribution)	Al-Rabia (% source contribution)
Petroleum downstream facilities	69	-
Petroleum upstream facilities	3	-
Highway (Traffic)	17	79
Area's commercial	6	13
Miscellaneous sources	5	8

This indeed was expected due to the geographical location of Fahaheel City, which is bounded by petroleum refineries and petrochemical industries in the southern part. The lowest source contribution to total air pollutants in Fahaheel City was the upstream facilities of the Greater Burgan area (petroleum upstream facilities), which only contributed 3% of total air pollutants. This is possibly due to the far distance and strong winds, which ultimately disperse gaseous pollutants away from the selected urban area. As for Al-Rabia City, highway (traffic) was found to contribute the most (79%) to air pollutants, compared to 17% in Fahaheel City. Again, the high contribution of highway (traffic) in Al-Rabia City is truly expected. Al-Rabia City is an urban community surrounded by the main arteries of a road network that is intensely influenced by traffic pollution. It is bounded by the 5th and 6th ring roads from the north and south, respectively, and in the east, a highway connects Kuwait port to the rest of the city. These road networks around Al-Rabia City are characterized by traffic congestion, which is the ultimate source of air pollution.

Applying the CMB model enhances our knowledge about emission sources in Fahaheel and Al-Rabia. Such an approach would definitely help local authorities to pay more attention toward these sources in order to reduce human health impacts by these air pollutants as there is consensus in previous epidemiological studies about their human health effects.

CONCLUSIONS

Diurnal and seasonal variations of NO_2, O_3, CO, non-methane hydrocarbons (NMHC), and SO_2 of two urban cities, Fahaheel and Al-Rabia, were compared in this study for the entire year of 2009. Regarding diurnal patterns, it is apparent that almost all measured pollutants exhibited two peaks: one in the morning and another in the afternoon. These peaks, which occurred during associated peak hours in the two cities, originated from various activities (schools, open stores, traffic, restaurants and markets, and central heating). However, there were significant differences in the magnitude (values) of air pollutants between the two cities. In terms of exceedances of the Kuwait Environment Public Authority's (KUEPA) air quality threshold values, the number of exceedances in Fahaheel City was as follows: 320 for NO_2, 3 for O_3, 3 for CO, 1227 for NMHC, and 15 for SO_2. This compares with 43 for NO_2, 10 for O_3, 4 for CO, 1039 for NMHC, and none for SO_2 in Al-Rabia City. To identify the most probable sources of air pollution concentration, roses were plotted for annual durations for both Fahaheel and Al-Rabia. The contribution of each prevalent source was quantified using the Chemical Mass Balance (CMB) model. The major emission sources in Fahaheel were petroleum downstream facilities and highway traffic, which accounted for 69% and 17%, respectively. In Al-Rabia City, highway traffic and the area's commercial area accounted for 79% and 13%, respectively.

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