

Ambient Air Quality Assessment of Al-Mansoriah Residential Area in the State of Kuwait

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دراسة جودة الهواء الخارجي في منطقة المنصورية السكنية بدولة الكويت

سلطان السالم، عايد الفضلي و عبدالرحمن خان

الغلامه: تمت دراسة بيانات جودة الهواء الخارجي لمنطقة المنصورية السكنية (المتضمنة لمعدلات غاز الأوزون، الميثان، مجموع الهيدروكربونات باستثناء الميثان، أول أكسيد النيتروجين، ثاني أكسيد النيتروجين، أول أكسيد الكربون، كبريتيد الهيدروجين، ثاني أكسيد الكبريت)، لتحديد كل من: (أ) عدد المخالفات الناجمة من تعدي حدود الهيئة العامة للبيئة، (ب) الأنماط الموسمية للغازات الملوثة (ج) مصادر التلوث المهيمنة على المنطقة. (د) تأثير أيام نهاية الأسبوع على غاز الأوزون، وقد تم تغطية فترة خمسة سنوات متتالية في هذه الدراسة، ما بين يناير 2000 إلى ديسمبر 2004. وقد تم تسجيل عدد من المخالفات، بما يخص غاز الأوزون. وقد تم كذلك ملاحظة تعرض سكان المنطقة لمعدلات عالية من غاز ثاني أكسيد الكبريت. وبما يخص النمط الموسمي لأكسيد الكبريت، في الفترة ما بين شهر مارس و أكتوبر (موسم انخفاض معدل التفاعلات الجوية) فقد تمت ملاحظة تفكك الغاز في الجو على الرسومات البيانية. وقد تم أيضا تحديد منطقة الشرق كمصدر رئيسي لغاز كبريتيد الهيدروجين. ومن هذه الدراسة يمكن استخلاص أن المنصورية منطقة حساسة لمجموع أكاسيد النيتروجين.

المفردات المفتاحية: أيام نهاية الأسبوع، أول أكسيد النيتروجين، ثاني أكسيد النيتروجين، مجموع هيدروكربونات باستثناء الميثان.

Abstract : Air quality data (ground level ozone (O₃), non-methane hydrocarbons (NMHC), methane (CH₄), nitrogen oxide (NO), nitrogen dioxide (NO₂), carbon monoxide (CO), hydrogen sulfide (H₂S) and sulfur dioxide (SO₂) of a Kuwaiti residential area, Al-Mansoriah, were analyzed to evaluate and determine: (a) the exceedances of air quality from permissible limits set by the Kuwait Environment Public Authority (KUEPA), (b) the diurnal patterns of air pollutants, (c) the predominant sources of airborne pollutants in the surrounding area, and (d) the "weekend effect" on ozone levels. The dataset covered the period of five consecutive years, from January 2000 to December 2004. High levels of ozone were witnessed; recording a number of exceedances. Inhabitants of Al-Mansoriah were exposed, during the period of study, to acute and chronic levels of SO₂. Concerning NMHC, the permissible limit (0.24 ppm- rolling average between 6-9 am), was violated in each of the monitoring years. NO diurnal pattern showed two distinct strong peaks during the months from October to March, in which the low solar radiation does not cause intense photochemical reactions, which lead to NO destruction. A clear H₂S source (considered as a primary one) was witnessed from Kuwait city (Sharq district). The backed up sewage lines and maintenance work coinciding with study period clearly affected Al-Mansoriah. A clear "weekend effect", in terms of difference in levels occurring during midweek and weekends, was ascertained. The analysis suggests that Al-Mansoriah residential area should be considered a NO_x sensitive region of Kuwait.

Keywords: Weekend effect, NO_x, SO₂, CO, O₃, Monthly variation, Seasonal variation

1. Introduction

Since the autonomy of Kuwait Environment Public Authority (KUEPA) from the jurisdiction of the Ministry of Health (MOH) and the recognition of its legal holding power, pollution prevention in the state of Kuwait has

been of a growing concern over urban and suburban areas. Decision makers in the state express widespread interest in controlling greenhouse gases (GHGs), volatile organic compounds (VOCs) and other airborne pollutants. Increased levels of these pollutants, besides eroding materials, are known to have deleterious effects on human health (Brunekreef and Holgate, 2002, Al-Salem and Bouhamrah, 2006), to cause injury to plants (Saitanis *et*

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al. 200; Saitanis and Karandinos, 2002), to reduce crops yield (Nali *et al.* 2002) and to negatively affect ecosystems (Bytnerowicz *et al.* 2002). Natural ecosystems adjacent to urban areas are exposed increasingly to air pollutants of urban origin. Air pollutants, particularly SO_2 , NO_2 and the major secondary photochemical oxidant O_3 are important threats to plants. Their effects comprise many physiological and biochemical changes in plants, which may result in growth reduction and yield loss, even at low levels chronic exposure. Concerning human health, tropospheric O_3 measured in urban regions and across regional airsheds, are known to affect human health (Riga-Karandinos and Saitanis, 2005).

Many researchers have been occupied with the great number of reactions and types of urban air pollutants (Wen and Lian, 2009; Fenger, 2009; Ramanathan and Feng, 2009; Gildemeister *et al.* 2007). One of the most important characteristics of urban air photochemistry is the oxidation of SO_2 and NO_2 and their conversion to particulate sulfate (SO_4^{2-}) and (gaseous and particulate) nitrates (NO_3). Moreover, the rate of the conversion of NO_x to NO_3 affects ozone formation and the fate of the NO_x in the atmosphere. NO_x is oxidized to nitric acid (HNO_3) in the atmosphere, which in turn forms NO_3 particles (Matsumoto and Tanaka, 1996). Acidification of precipitation, visibility reduction and deleterious effects on human health and plants, are all effects associated with these secondary pollutants. Such assessment of urban air quality will surely aid in the planning step of agencies concerned with green industries and keeping up with threshold and permissible limits in populated areas. Although air quality was investigated in a number of urban areas in the state of Kuwait (Al-Salem and Khan, 2006; Al-Salem *et al.* 2008a; Al-Salem *et al.* 2008b; Al-Salem *et al.* 2008c), there is insufficient or lack of information about the air pollution levels in many areas, which host a high percentage of the population of the country.

The objective of this work was to investigate the air pollution of a typical residential area in Kuwait, namely Al-Mansoriah. To this purpose we explored the air pollution levels in this area, with emphasis to ground level ozone (O_3), non-methane hydrocarbons (NMHC), methane (CH_4), nitrogen oxide (NO), nitrogen dioxide (NO_2), carbon monoxide (CO), hydrogen sulfide (H_2S) and sulfur dioxide (SO_2). The exceedances of the air quality threshold values were calculated. The diurnal profiles and the seasonal variations of these gases are studied and the relationships between each other were explored. In addition, pollution sources in the surroundings of the area under investigation were identified using a series of concentration and wind roses analyses. The so called "week-end effect", concerning the variations of ozone levels between weekdays and weekends, was also investigated.

2. Investigated Area Description

Al-Mansoriah residential area is a luxurious suburb of

the city which hosts mainly Kuwaiti residents of mid/high class (39,444 residents). Figure 1 shows the area from satellite imagery, relative to Kuwait city. Private and public transport vehicles reach a maximum of 45,000, mostly around the areas main streets.

The receptor (monitoring) point chosen for the area was above (at) the polyclinic of Al-Mansoriah situated near the area's Co-Op, which is associated with restaurants and other air polluting anthropogenic activities. These pollutants include n-CH_4 (resulting from restaurants), NO_x and CO (emissions of automobile and other burning sources) and VOCs from the gas and gasoline dispensing station. On the other hand, Al-Arabi sports club is considered one of the largest sports and family functions facility in Kuwait, in terms of children entertainment lounges and other function spaces.

Cairo St. is situated to the north side of the receptor point. It is one of the busiest streets of Kuwait especially during rush hour, linking three main residential areas together in the governorate, *ie.* Al-Mansoriah, Al-Qadisiah and Al-Daeiah. Automobile vehicles operating with gasoline are the main source of pollution associated with traffic jam in the street. Rush hours are usually between 7:30 am to 9:00 am (weekdays); and 8:00 pm to 9:30 pm (weekends).

3. Data Acquisition and Methods

The dataset of Al-Mansoriah monitoring station, used in this study, was provided from the Kuwait Environment Public Authority (KUEPA). The data cover the period from Jan 1st 2000 to Dec 31st 2004. The station is equipped with a number of air sampling devices and analyzers (ThermoTecg 08, SatCal, Al-Issa Co. Ltd.) with accuracy of order 1%, with a measuring frequency of 5 minutes (original data). Air probe was approximately 15 m above sea level. All data were stored and manipulated with *EnviroDas* data acquisition software, which did store up to three months worth of data values. Data collected by the station concerned the following pollutants: CH_4 (ppm), NMHC (ppm), CO (ppm), NO (ppb), NO_2 (ppb), H_2S (ppb), SO_2 (ppb), and O_3 (ppb). Meteorological conditions data were collected through a weather station recording the following parameters: wind speed (ms^{-1}) and direction ($^\circ$), relative humidity (%) and ambient air temperature ($^\circ\text{C}$). Data points were treated and filtered before performing any analysis. Filtration procedure was performed as indicated by (Al-Salem and Khan, 2006). NO_2 and NO values exceeding 200 ppb were excluded, in order to eliminate any automobile point source effect on data collection. Values of CH_4 levels below 1.3 ppm were also removed to avoid insertion of instrumentation signal noise. Calibration and span check points were also deleted.

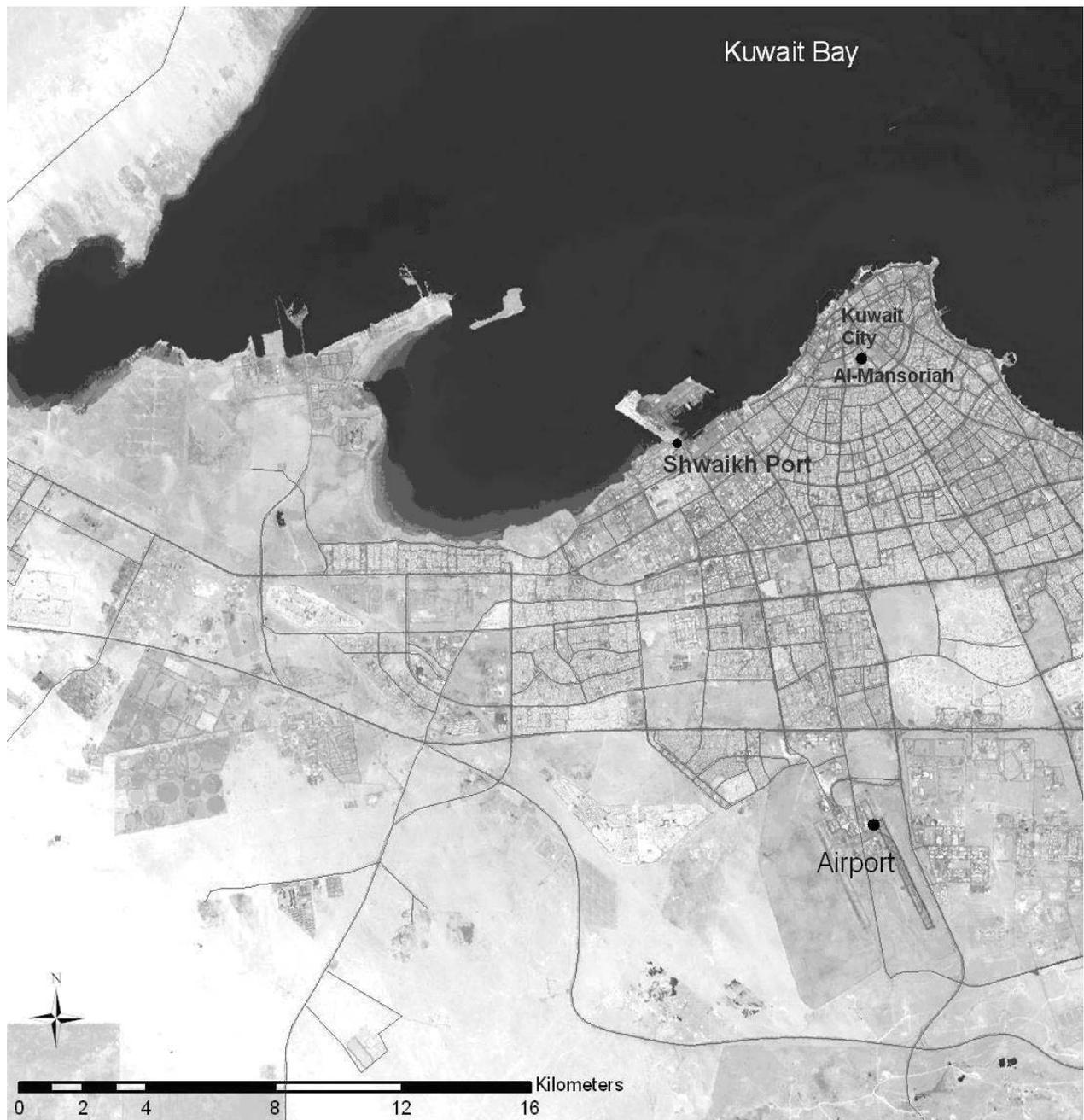


Figure 1. Al-Mansoriah residential area relative to Kuwait city. Image courtesy of satellite archives, KGIC, Kuwait Institute for Scientific Research (KISR)

4. Results and Discussions

4.1. Exceedances of Air Quality Permissible Limits/Threshold Values

In order to assess the air quality in Al-Mansoriah area, measured levels of air pollutants were compared with threshold limits specified in the rules and regulations of Kuwait Environment Public Authority (KUEPA, 2001) and the European Directive standards (EEA, 2003a; EEA, 2003b). Concerning O_3 , for the protection of both, human health and ecosystem, KUEPA rules and regulations set a permissible limit of 80 ppb as an hourly rolling (continu-

ous) average for O_3 , not to be exceeded twice in a 30 days period. Inhabitants of Al-Mansoriah were exposed to O_3 levels above the limit, but only a few days (Table 1). In 2000, six exceedances were recorded based on 8-hrs rolling averages, and one in the year 2004 (Table 1). Judging from the current dataset of Al-Mansoriah, O_3 levels should be considered potentially phytotoxic in this residential area. Investigations in other countries have shown that the nowadays ambient ozone levels can cause injury to plants. For example, (Saitanis *et al.* 2004) used plants of the ozone bioindicator Bel-W3 tobacco variety, at 28 sites around a town in Greece. In all those sites the used

Table 1. Air quality data of Al-Mansoriah in comparison with the air quality rules and regulations determined by KUEPa (kuepsa, 2001)

Pollutant	Averaging period	Permissible limit	#Exceedances/year
Ozone	8 hrs	60 (ppb)	6/2000 1/2004 6/2000 5/2001
Ozone	Hourly	80 (ppb)	1/2002 1/2003 3/2004 95/2000 48/2001
NO ₂	Daily	50 (ppb)	41/2002 93/2003 73/2004 234/2000 237/2001
NO ₂	Hourly	100 (ppb)	342/2002 259/2003 323/2004
NO ₂	Annual	30 (ppb)	5/(2000-2004) 5/2000
SO ₂	Hourly	170 (ppb)	8/2002 12/2003 17/2004
SO ₂	Annual	30 (ppb)	1/2003
SO ₂	Daily	60 (ppb)	5/2003
CO	Daily	8000 (ppb)	6/2004 120/2000
NMHC	6-9 am	0.24 (ppm)	85/2001 178/2002 172/2003 207/2004

bioindicator plants were highly injured even after one week of exposure. Similar studies, incorporating instrumental monitoring and phytodetection with ozone-bioindicator plants, have demonstrated the occurrence of ozone at potentially phytotoxic levels in other rural and forest areas in Greece (Saitanis and Karandinos, 2001; Saitanis, 2003; Saitanis *et al.* 2003).

KUEPA has not yet established any long-term objectives for ozone levels in the near future (5-15 years). Long-term objectives have been established for Europe after considering the results of the scientific experiments conducted in the framework of the UN-ECE project over several years in many European countries (Riga-Karandinos and Saitanis, 2005).

Current permissible limit in Europe, has been set to an AOT40 value of 3000 ppb*h above which direct adverse effects on trees, crops and natural vegetation may occur (Benton *et al.* 2000). AOT40 is the sum of the exceedances of the hourly ozone concentrations above the threshold of 40 ppb, during the daylight hours over a period of three months. The level of 40 ppb (80 µg/m³) of O₃ should not be considered as a lower concentration limit in Europe for biological effects, since some biological

responses may occur below that value (EEA, 2003a; EEA, 2003b). By comparison with other major European cities, Al-Mansoriah exceeded the number of permissible limit exceedances (8 hr rolling average) in the same duration of monitoring in Paris (Vardoulakis *et al.* 2002) and Aberdeen (Marr *et al.* 2007).

SO₂ levels in Al-Mansoriah were generally high, which on the other hand, risks inhabitants of acute and chronic exposure to the pollutant. The KUEPA permissible limit (30 ppb) was violated in 2003 (annual threshold) and 5 exceedances were recorded in 2003 based on daily rolling averages. This also was typical of a Greek metropolis (Volos), where levels were monitored on the basis of a rolling average as well (Riga-Karandinos and Saitanis, 2005). It was also noticed that SO₂ levels exceeded the European threshold limit for human protection reported previously (EAA, 2003a). Concerning NO₂, 279 average exceedances per year were observed during the five years of monitoring for the short term (1 hr) limit. The corresponding annual permissible limit (30 ppb) was exceeded during the monitoring period (Table 1). For carbon monoxide (CO) the limit value (8000 ppb) of a daily mean was exceeded 6 times in 2004.

Methane (CH₄) and non-methane hydrocarbons (NMHC) levels were monitored as well. KUEPA has not yet established any regulation for CH₄ in Kuwait. It has, however, set a daily permissible limit (0.24 ppm) for the period 6-9 am for NMHC. The analysis of data showed that NMHC recorded 153 exceedances (average) during the five years of monitoring. The number of exceedances increased gradually on an annual basis (Table 1).

4.2. Diurnal Patterns of the Pollutants

A good way of unraveling the dynamics and patterns of air pollutants is to examine their diurnal pattern. The average diurnal patterns of O₃, NMHC, CH₄, NO, NO₂, CO, H₂S and SO₂ levels for each month of the year were examined (Fig. 2). Significant variations were observed between the pollutants studied in both, the recorded levels and diurnal patterns. It was observed that, in Al-Mansoriah residential area, CO, NO and NO₂, exhibit the typical urban daily pattern of primary air pollutants characterized by two peaks, one in the morning and one late in the evening (Riga-Karandinos and Saitanis, 2005). This pattern coincides with the human activities (traffic, open market hours and central heating). SO₂ exhibited an unstable diurnal fluctuation. SO₂ levels have been commented to be driven not only for the emissions but also from the levels of O₃ and OH (Harrison and Perry, 1986) and the solar radiation (Riga-Karandinos and Saitanis, 2005). Khoder's (2002) results show that the oxidation processes and conversion of SO₂ to sulfate and of NO₂ to nitrate (NO₃) depend on the photochemical oxidation and that the sulfur conversion ratio increases with increasing ozone concentration.

The NO levels were higher during the months from October to March. During these months, the lower solar radiation intensity does not allow intense photochemical reactions (Riga-Karandinos and Saitanis, 2005), which would lead to NO destruction. The concentrations of NO, from April to September, were lower than during October to March months. However, during all, high and low NO months, the two typical peaks - one early in the morning and another in the evening - were present

The patterns of O₃ show a clear seasonal and diurnal variation (increased ozone levels during months from April to September and a strong daytime photochemical ozone buildup due to photooxidation of precursor gasses) showing more intense photochemical processes during the luminous hours of the days and during the high sunlight season (Fig. 2). According to (Simpson *et al.* 1995), annual cycle of ozone over mid-latitudes shows mainly two kinds of seasonal behavior, either with a broad summer maximum, generally attributed to local photochemical productions and typical of populated and industrialized areas, or with a spring maximum, of more controversial origin, typical of remote regions and associated to background conditions. The high rush-hour traffic during early morning between 7:30 am to 9:00 am (weekdays); and 8:00 pm to 9:30 pm (weekends), well before sun radiation

is strong enough to trigger photochemical reactions of ozone formation leads to ozone destruction shown in Fig. 2 as ozone decrease.

The witnessed patterns of CO were, somewhat, inverse to those of ozone. It was clear that seasonal variations of ozone affected indirectly the seasonal pattern of CO. Ozone is the photochemical precursor of hydroxyl radicals (OH) in the lower troposphere. Reaction with OH removes most gases of natural and anthropogenic origin from the atmosphere (Jockel *et al.* 2003). It is also a fact that the main mechanism for the removal of CO from the atmosphere is the reaction of OH. On the other hand, tropospheric oxidation reactions of CO in the presence of sufficient NO also lead to the production of substantial amounts of ozone. The comparison of the diurnal patterns of O₃ and CO, suggests that the depletion of O₃ and the enhancement of CO, during the non-photochemistry hours (early morning and late in the evening), come from the O₃ titration when mixed with urban emissions and simultaneously the anthropogenic release of CO. This pattern of CO may be the typical signature of urban influence (Fig. 2).

Regarding CH₄ patterns, a clear increase was witnessed in the early morning hours (5-7 am) associated with restaurants and other gas operated businesses opening hours. The same is clear for non-methane hydrocarbons (NMHC). The levels increase for both pollutants and reach their peak in the three summer break months, *ie.* July, August and September. This could be attributed to the increasing activities in luxurious areas like Al-Mansoriah in the summer time.

4.3. Wind and Pollutants' Concentrations Roses

In order to investigate the predominant sources affecting Al-Mansoriah residential area, five years mean wind rose and concentration roses for the air pollutants (O₃, NMHC, CH₄, NO, NO₂, CO, H₂S and SO₂), around the receptor point, (Al-Mansoriah polyclinic) were analyzed. Kuwait is characterized by north/northwestern winds (primary direction) contributing to over 70% of the winds around the year (Khan and Al-Salem, 2007). Figure 3 shows the 15⁰ wind speed rose executed for the period of study around Al-Mansoriah. West/west-northern and north/northwestern winds covering the corridor of wind direction between 285-3300, establish the primary wind direction with average winds exceeding 6 ms⁻¹. All wind and pollutants' concentrations' roses in this study are in a blowing form manner.

Southeastern winds could be considered as secondary winds (6 ms⁻¹) in the case of Al-Mansoriah residential area, as well as the state of Kuwait over the past 30 years (Al-Hajraf *et al.* 2005).

In the case of H₂S, the concentration rose reveals a spike value (3450- exceeding 5 ppb) in the direction of Sharq district in Kuwait city (Fig. 4). Backed up sewage and municipal work has been commenced in the period of study in which pedestrians in the district use to complain

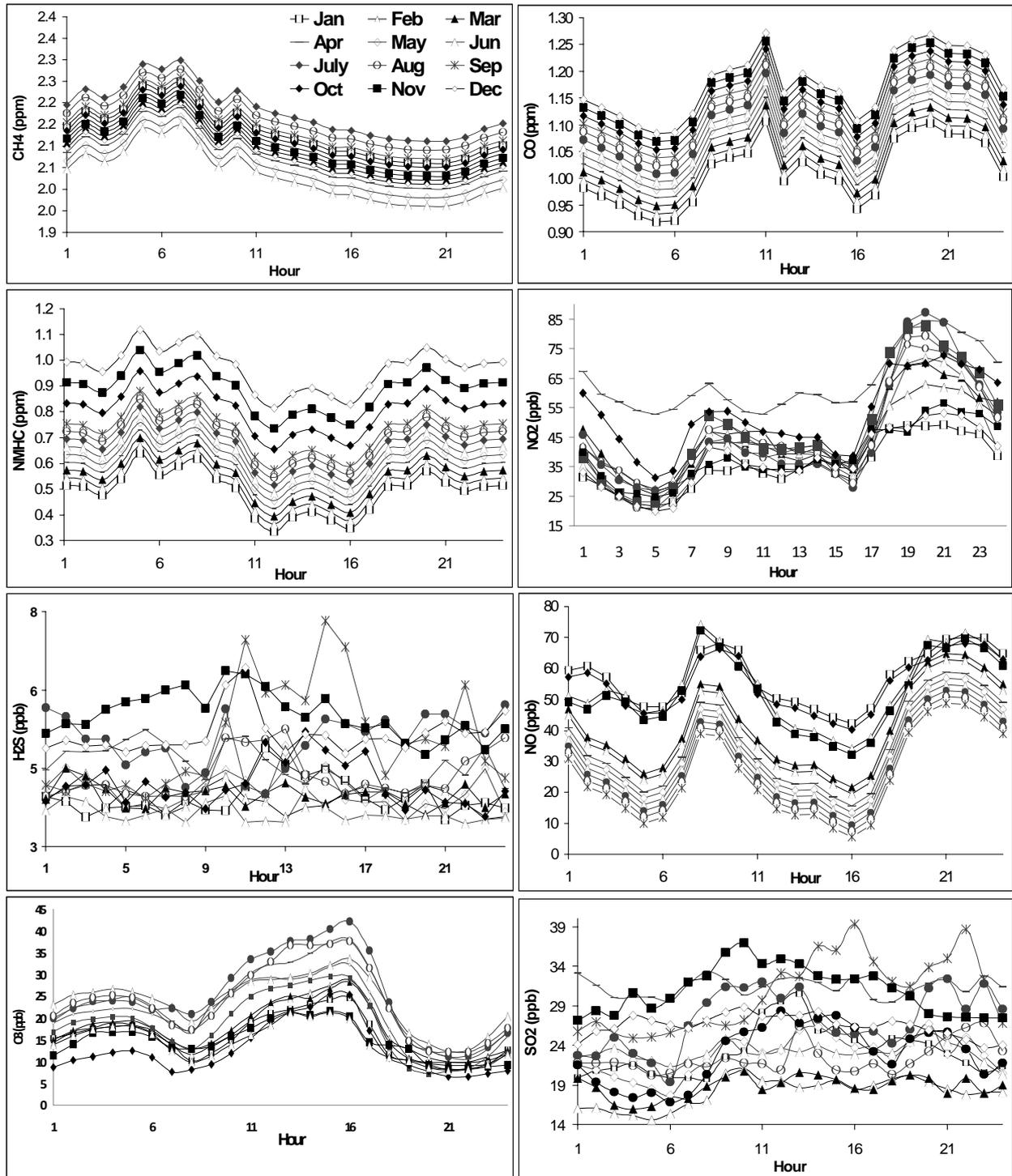


Figure 2. Plots of monthly diurnal patterns of air pollutants in Al-Mansoriah

for suffering rotten eggs odor (typical of H_2S vented or other type of emissions from municipal manholes) in Sharq. Other directions on the concentration rose when similar emission strength from wind corridors, which are typical for urban and suburban areas (Khan and Al-Salem, 2007).

Methane gas followed typical behavior in almost every case (excluding industrial sites), being uniform from all wind directions (Fig. 5). CH_4 averaged at 2 ppm, which is also typical of Kuwaiti urban areas as previously reported

in Fahaheel (Al-Salem and Khan, 2006; Al-Salem *et al.* 2008a) and Al-Riqa (Al-Salem *et al.* 2008b; Al-Salem *et al.* 2008c; Al-Salem and Al-Fadhlee, 2008). CO also showed typical urban behavior and concentration rose trend; being uniform around the receptor point and averaging about 1 ppm (Fig. 5). Daily activities in Al-Mansoriah contribute greatly to both CH_4 and CO concentration rises. Automobile emissions, dry cleaning services, gas dispensing networks and restaurant emissions; all contribute to both pollutants. Sources of these emissions

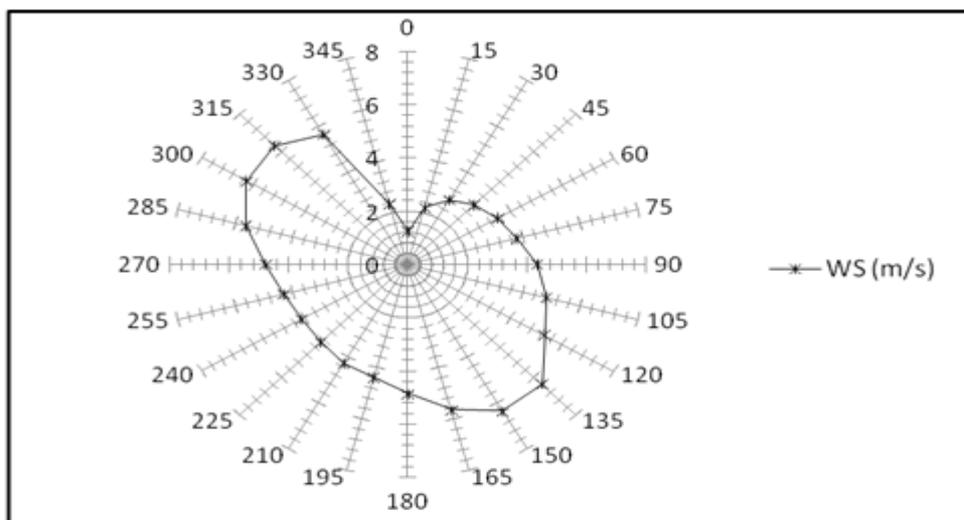


Figure 3. Plot (rose) of the average wind speed (ms^{-1}) monitored in Al-Mansoriah during the period (January 2000 to December 2004)

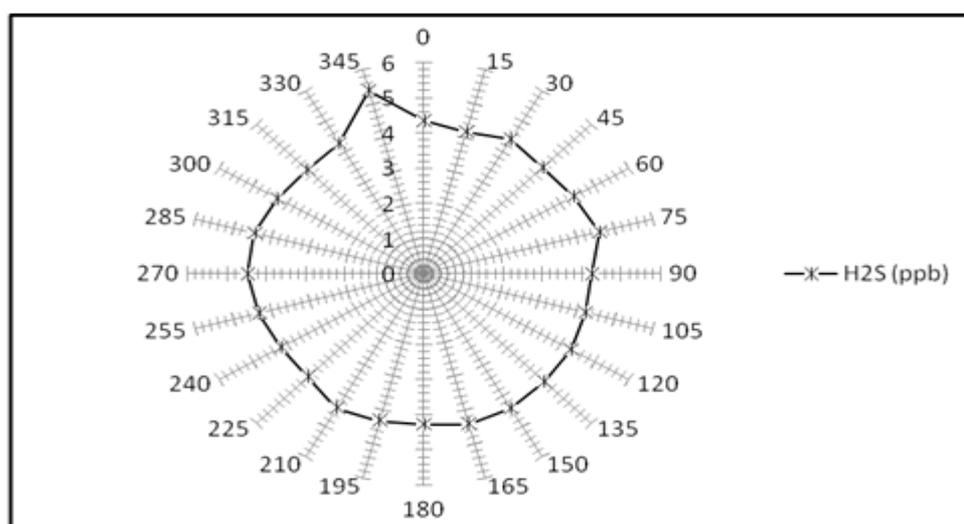


Figure 4. Plot (rose) of the average H_2S (ppb) monitored in Al-Mansoriah during the period (from January 2000 to December 2004)

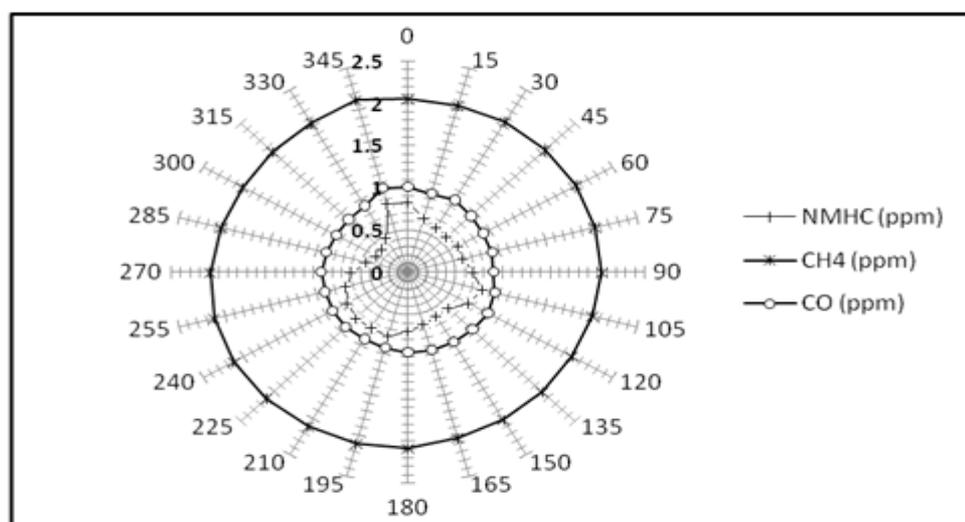


Figure 5. Plot (rose) of average CH_4 , NMHC and CO concentration rose (ppm) monitored in Al-Mansoriah during the period (from January 2000 to December 2004)

are distributed around the receptor point, which explains the trends left by both CH_4 and CO on the roses. Regarding NMHC, the concentration rose shows a peak in the emission strength in the northwestern direction (Fig. 5).

Figure 6 shows the concentration rose for NO and NO_2 gases around the receptor point. Northern winds (covering 345-150) were clearly the richest in both pollutants (exceeding 60 ppb for NO_2 and 70 ppb for NO). This direction corresponds to Kuwait city, which hosts a number of combustion sources that contribute to NO and NO_2 levels in the ambient.

Opposite to NO_x , winds blowing from northwestern and eastern directions showed higher ozone levels (Fig. 7). NO_x titration and other sets of reactions fade ozone from the lower atmosphere, which also explains the NO primary direction of north. SO_2 was present around the receptor point in an almost equal level of 25 ppb (Fig. 8).

4.4. Weekend/ Weekday Variations

During the past decade, weekend/weekday differences in levels of air pollutants (especially of O_3) have been a subject of research interest (Marr and Harley, 2002; Vandaele *et al.* 2002; Fujita *et al.* 2003, Riga-Karandinos and Saitanis, 2005). Although, weekly changes in the emissions caused by human activities are known to affect the weekly cycle of ambient pollutant concentrations, this emission-concentration relationship, in urban, suburban and rural sites, is not well elucidated as it is reflected in controversial reports (Blier and Winer, 1999; Pun *et al.* 2003). In the state of Kuwait, during the period of the study, the weekend was on Thursdays and Fridays (nowadays the weekend has shift to Fridays and Saturdays).

In weekends (Thursdays and Fridays), the emissions of anthropogenic pollutants and especially of O_3 precursors, are believed to be lower compared to those occurring during weekdays, because car traffic is lower and several polluting plants and factories may be less active or inactive. Many approaches have been used for the study of the so-called weekend effect, meaning the occurrence of increased O_3 levels and decreased NO_x during weekends in comparison to weekdays. Near constant O_3 levels, during weekdays, in the face of strong weekday/weekend variations in NO_x , should also be viewed as a weekend effect (Fujita *et al.* 2003).

After taking into account the shift in the relaxing days and the days of high anthropogenic activities in Kuwait, in comparison to the west countries, in this study, we analyzed the monthly averages of mean hourly O_3 and NO concentrations during Sunday-Tuesday vs. the corresponding concentrations on Wednesday, Thursday, Friday and Saturday, recorded in Al-Mansoriah, (Fig. 9). In Table 2, the relevant linear regression equations and the corresponding correlation coefficients are given.

Concerning O_3 , the slopes of linear regressions revealed that Wednesday concentrations were very close to those occurring in during Sun-Tue (Fig. 9; Table 2). Unexpectedly, Thursdays-Saturdays O_3 concentrations were much lower than Sun-Tue concentrations. Regarding NO, during Wednesdays and Thursday the slopes were clearly close to one indicating similar levels occurring during these two days to those occurring during Sun-Tue. On the other hand, NO levels were clearly much lower on Fridays than ones occurring during Sun-Tue (Fig. 9; Table 2). Elevated NO_x levels can always inhibit O_3 production either by NO titration of O_3 or by reaction of NO_2 and OH to form HNO_3 -nitric acid- (Riga-Karandinos and Saitanis, 2005). Synoptically, O_3 decreases more rapidly with reductions in NOx emissions, than with reductions in VOCs (Volatile Organic Compounds) in NO_x -sensitive regions (*ie.* abundant VOCs relative to NO_x). While in VOCs-sensitive regions (*ie.* abundant NOx relative to VOCs) a decrease in NO_x emissions may cause an increase in O_3 because of reduced titration or reduced formation of HNO_3 . Locations where ozone increases during weekends, while NO_x emissions are significantly lower should be considered VOCs-limited (Blanchard and Tanenbaum, 2003). Thus, in the case of Al-Mansoriah residential area, signs of being a NO_x sensitive region are very clear although NO_x levels are not always higher on weekends, suggesting a strongly influential background effect.

The reduction of anthropogenic emissions during weekends is expected to reduce proportionally equally anthropogenic VOCs (AVOCs) and NO_x . In addition to the above-discussed role of VOCs in the "weekend effect", it is the high early morning rush-hour traffic on weekends that allow ozone concentrations to rise from a significantly lower concentration and therefore reaching lower overall weekend concentrations.

A number of studies demonstrate a wide range in the weekday/weekend O_3 behavior. Marr and Harley (2002) suggest that NO_x concentrations are consistently lower on weekends relative to weekdays by approximately 30–40%, while VOC changes are less pronounced (approximately 10%). The explanation of weekday/weekend variation, due to NO_x reduction, is supported by a wide range of analyses of ambient data and several photochemical studies, while changes in the timing and location of emissions and meteorological factors play smaller roles in weekend O_3 behavior (Heuss *et al.* 2003; Riga-Karandinos and Saitanis, 2005). Analyses of ambient air quality data and emissions forecasts for weekdays and weekends may improve considerably our understanding of the effects of control strategies and of future changes in emissions on future ambient O_3 concentrations.

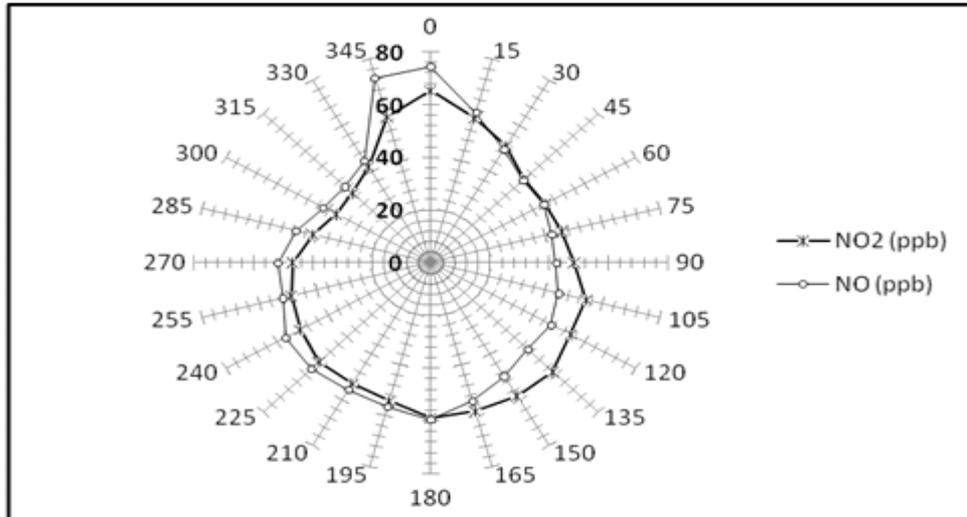


Figure 6. Plot (rose) of average NO and NO₂ concentration rose (ppb) monitored in Al-Mansoriah during the the period (from January 2000 to December 2004)

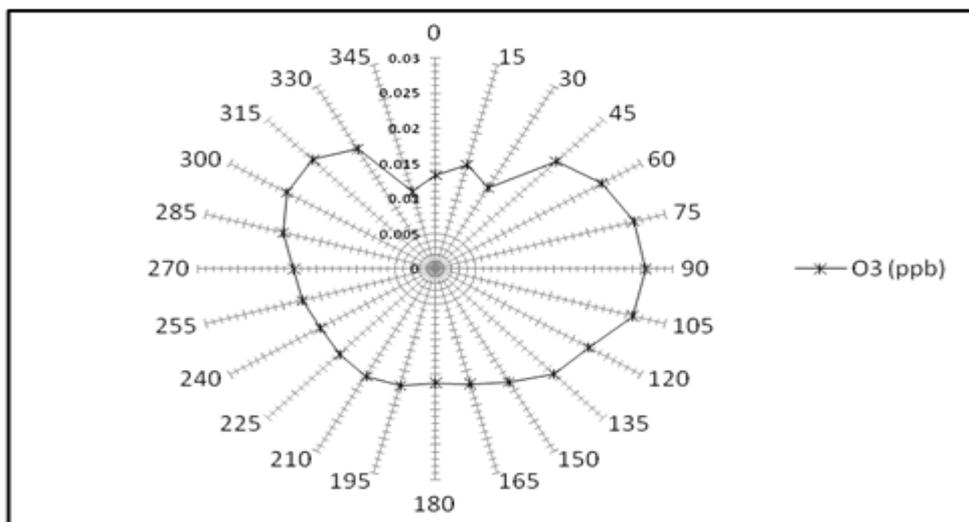


Figure 7. Plot (rose) of average O₃ concentration rose (ppb) monitored in Al-Mansoriah during the period (from January 2000 to December 2004)

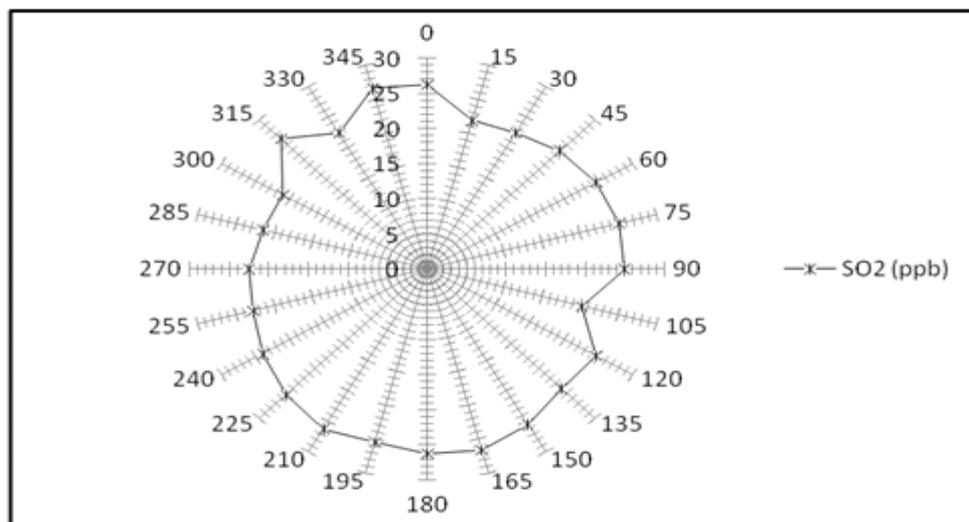


Figure 8. Plot (rose) of average O₃ concentration rose (ppb) monitored in Al-Mansoriah during the period (from January 2000 to December 2004)

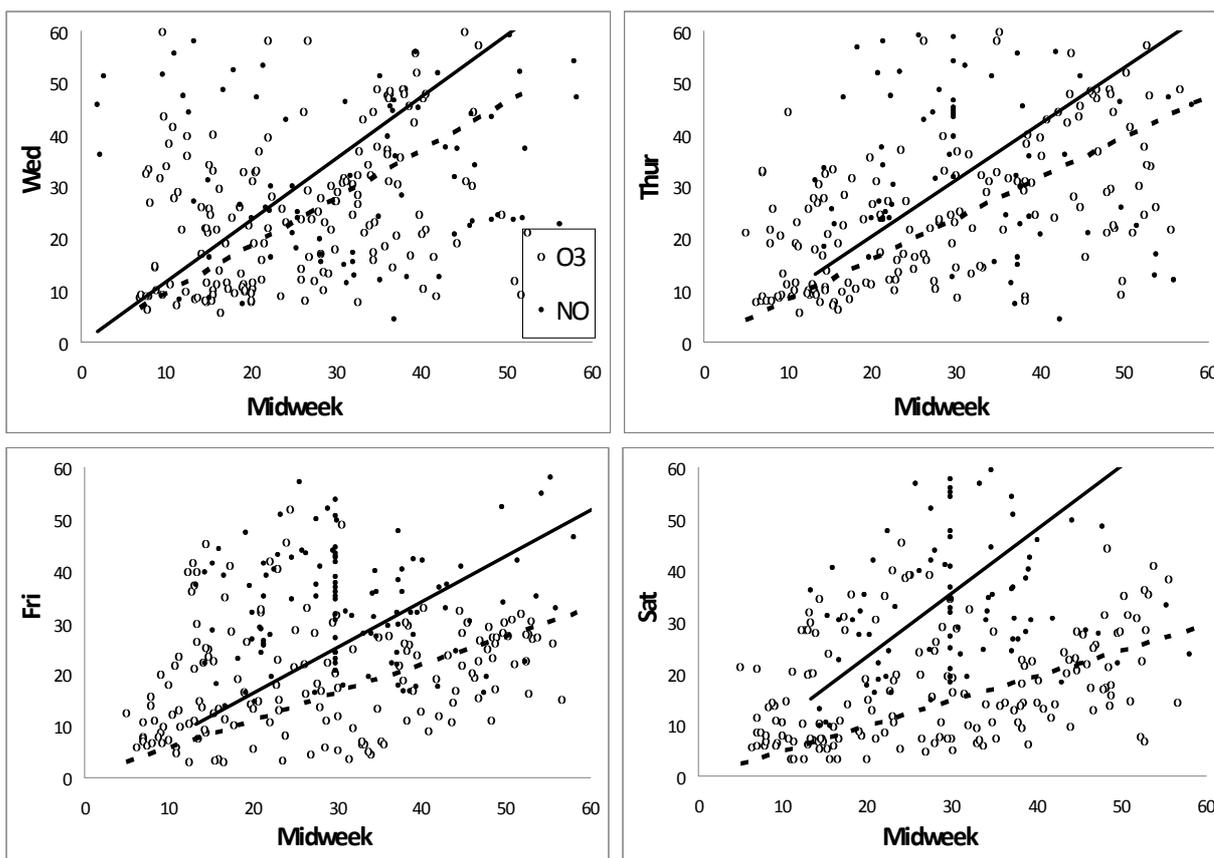


Figure 9. Regression plots of the monthly averages of the mean hourly ozone (dashed line) and NO (solid line) concentrations during midweek (Sun-Tues) vs. the corresponding concentrations of the rest of the week

Table 2. Regression equations of mean hourly ozone concentrations during (Sun-Tues) vs. the corresponding mean hourly ozone concentrations on Wednesday, Thursday, Friday, and Saturday (X)

Day/ (Pollutant)	Regression Equation	Correlation Coefficient (r)
Wednesday/ O ₃	$Y = 0.91X$	$r = 0.28$
Wednesday/ NO	$Y = 1.02X$	$r = 0.24$
Thursday/ O ₃	$Y = 0.78X$	$r = 0.40$
Thursday/ NO	$Y = 0.97X$	$r = 0.87$
Friday/ O ₃	$Y = 0.54X$	$r = 0.64$
Friday/ NO	$Y = 0.77X$	$r = 0.67$
Saturday/ O ₃	$Y = 0.48X$	$r = 0.46$
Saturday/ NO	$Y = 1.12X$	$r = 0.54$

5. Conclusions

After analyzing the dataset obtained for Al-Mansoriah residential area, a number of exceedances were recorded, violating KUEPA permissible limits of air quality. Concerning the exceedances of O₃, there were no exceedances violating annual or daily limits. However, inhabitants of Al-Mansoriah were exposed to acute SO₂ levels. Recorded NO₂ annual, daily and hourly

exceedances in the five years of monitoring. The diurnal patterns of the studied pollutants were investigated and revealed a seasonal variation in ozone levels. An inverse pattern was witnessed for CO. On the other hand, methane patterns showed an increase in the early morning hours associated with the anthropogenic activities in the area.

Series of concentration roses were executed around the receptor point (*ie.* polyclinic) to determine the influential pollution sources around Al-Mansoriah. Methane and CO showed typical urban area patterns, while NO and NO₂ concentration roses revealed a primary source situated in northern wind corridor (covering 345-150). Weekend effect analysis revealed that the area under investigation was a NO_x sensitive one. The causes of the weekend O₃ effect are probably the weekend/weekday differences in NO_x emissions and the complex non-linear photochemistry of ozone. The data of this study would be useful for future comparisons, after the operation of the new infrastructures at Kuwait city (Sharq district), which certainly will cause changes in pollutants levels. It is obvious that, for future air quality management strategies, the development of accurate, temporally and spatially resolved day-of-week emission inventories, including separate inventories for weekends can promote a better understanding.

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