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ORIGINAL PAPER

Assessment of air pollutants emissions due to traffic in two residential areas in Kuwait

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Abstract

This study aimed to analyze air quality in two areas in the state of Kuwait with different traffic intensities. These are the Jleeb Al-Shuyoukh district, next to two very busy main roads and the Dasman district, next to a less busy road. The study covered the years from 2012 to 2017 and included meteorological data and concentrations of NO_2, SO_2, CO, O_3 and PM_{10}. Air quality data were obtained from Kuwait's Environment Public Authority (KEPA) based on hourly measurements recorded by stationary monitoring stations. The data were statistically analyzed using the "OpenAir" software package. Results showed that northwest wind direction was predominant. In Dasman area, the CO levels did not exceed the limits defined by KEPA, while in Jleeb Al-Shuyoukh, all the air pollutants exceeded the standards few times. Jleeb Al-Shuyoukh had 2797 exceedances levels of NO_2, while Dasman had 1560 exceedances. For CO, 31 exceedances were recorded in Jleeb Al-Shuyoukh. For SO_2, there were 11 exceedances in Jleeb Al-Shuyoukh, and 6 in Dasman. For PM_{10} the exceedances were 2424 in Jleeb Al-Shuyoukh. Correlation analysis of the air pollutants revealed that there were insignificant correlations between concentrations of the five air quality parameters except for O_3 concentration that showed a strong negative correlation with NO_2 concentration ($R^2 = -0.879$). This may be due to chemical coupling of O_3 and NO_x, that makes the levels of O_3 and NO_2 inextricably linked. Busy roads around Jleeb Al-Shuyoukh seem to be a greater source of pollutants than the less busy road near Dasman area. The 3 times more traffic intensity at Jleeb Al-Shuyoukh is adversely affecting the districts air quality.

Keywords Air pollutants · Correlation analysis · Modeling · Residential areas · Traffic intensity

Introduction

Air quality continues to be a very important global issue for public health, the economy and the environment. Air pollution has adverse environmental impacts since various health diseases are caused by air emissions. Syed et al. (2013) outlined the health effects associated with ambient air pollution and examined the involvement of epigenetic modifications by interpreting the possible effects of ambient air pollution on DNA. Additionally, air pollution causes biotic and abiotic constituents in Earth's atmosphere, which damages the ecosystem (Patel et al. 2014). Analysis of air pollution emissions in cities worldwide has received much attention in recent years. Several factors have been identified to significantly affect the level and type of air pollutants. Emission levels are not the only factor that determines concentrations of air pollutants. Factors like the weather, chemical transformations in the air, and transport of pollutants from outside Europe all play a role (EEA 2013). Among 35 monitoring stations in Beijing, Chen et al. (2015) observed that $PM_{2.5}$, NO_2, CO and SO_2 were more abundant in winter and autumn. Some studies focused on modeling air pollutants dispersion.

Few studies were previously conducted in Kuwait. Al-Bassam and Khan (2004) studied the environmental impact of urban growth in Kuwait that has resulted into an unabated increase in the vehicles fleet and increasing emissions of air pollutants. Using the monitoring stations data on air quality, Alenezi and Al-Anezi (2015) examined the air quality in the Al-Mansouriya and Al-Jahra urban districts and found that road traffic is the major source of air pollutants in Al-Mansouriya district, whereas power plants and oil field affected Al-Jahra district. Other studies were carried out in

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Kuwait using mobile air quality laboratory in a residential area (Abdul-Wahab and Bouhamra 2004) revealed that non-methane hydrocarbons (NMHC), carbon monoxide (CO) and nitrogen oxides (NO_X) were high and were mostly influenced by traffic.

Air quality control and management is one of the areas that received increasing attention in recent years. In this regard, air quality assessment is the process of determining the nature of ambient air pollution using monitoring and supplementary techniques such as modeling. Air quality models and impact due to pollutant concentration assessment studies provide a tool to understand the implications of pollutant emissions which help to decide, control and manage air pollution (Kho et al. 2007). Yassin (2013) used numerical modeling of flow and dispersion of gaseous emissions from vehicle exhaust in a street canyon under changes of the aspect ratio and wind direction in Kuwait. Recently, Brohi et al. (2018) analyzed the generation of pollutants in Malaysian atmosphere using "OpenAir" software package from comprehensive R archive network. Akdi et al. (2020) studied air pollution in Ankara via time series analysis and harmonic regressions to estimate and forecast PM_{10} in air emissions.

Air pollution has become one of the major environmental issues that calls for air quality management in Kuwait due to increase in population and modern urbanization. Therefore, the present study was conducted to assess the air pollution levels in the State of Kuwait using an air dispersion model, comparing residential areas with low and high traffic intensities.

Materials and methods

Study area

Kuwait is located on the north-western coast of Gulf with borders to the north with Iraq and to the south with Saudi Arabia. Its total area is about 17,820 km^2 and is mainly arid land while urban development is on the coastline. It has one of the highest GDP and the least fuel price in the world which provides an ideal opportunity for ownership of motorized vehicles (PACI 2015). The road transport is vital for the inhabitants as the sole means of transport and the motorized road vehicle fleet has grown significantly as the population increased and the economy progressed. Weather has also a major role in this issue where in long summer (lasting from April to October), temperature reaches to nearly 50 °C very often and, in short winter, it drops significantly. In general, the average temperature ranges between 7 and 46 °C throughout the year. Dust storms, humidity, and thunderstorms are general characteristics of the year's weather. Rainfall averaged about 121.7 mm/year for 5 years from 2012 to 2016.

This study considered two separate residential areas of the state of Kuwait with different traffic intensities according to Ministry of Interior of Kuwait database. These are the Jleeb Al-Shuyoukh district (Fig. 1), next to very busy main motorways (the 6th ring road and the Ghazali road) and the Dasman district, next to a less busy coastal road (the 25th Road). The Jleeb Al-Shuyoukh is a residential area with some commercial malls, shops, schools, and clinics. It is a very dense area in terms of residents and workers since it holds a population of 320,864 (7.13% of the total living population of Kuwait), and a working population of 52,411 (1.96% of the total working population of Kuwait). Most of these workers are employed by different companies around the country and are transported during working days by buses to and from Jleeb Al-Shuyoukh at the morning and at the evening. Some of the residents prefer private transportation by their own cars. Additionally, business owners tend to park their trucks in Jleeb Al-Shuyoukh and operate them for their intended businesses whenever needed. Moreover, the area is very close to Kuwait Airport (about 4 km) causing traffic throughout the day. Also it is close (about 1.6 km) to Al-Shadadiya, construction site for Kuwait University new campus, and is accessed through the segment of 6th Ring Road and Ghazali Road, next to Jleeb Al-Shuyoukh. Those circumstances make the 6th Ring Road a carrier for a large amount of traffic daily consisting of trucks, buses and private vehicles. On the other hand, for comparison, the Dasman "coastal" area is located near a relatively less busy road which is the 25th Road. Dasman has a population of 14,937 that is 0.33% of the total population of Kuwait and a working population of 470 which is 0.02% of the total working population of Kuwait.

Input data

Hourly concentrations of five air quality parameters (NO_2, SO_2, CO, PM_{10}, and O_3) along with data on wind speed and wind direction were obtained from Kuwait Environment Public Authority (KEPA) during 6 years from January 1st, 2012 to December 31st, 2017 based on three KEPA stationary air quality monitoring stations located in the areas under study. These stations are Al-Mansouriya station covering the Dasman Area and two stations (Al-Shuwaikh and Road 50) covering Jleeb Al-Shuyoukh area as shown in Fig. 2. Data on traffic intensity on roads were obtained from the traffic department of the Ministry of Interior in Kuwait. All of the air pollutant levels were measured in ppb except for PM_{10} in μg/m^3.

Fig. 1 Jleeb Al-Shuyoukh area and the two main surrounding roads

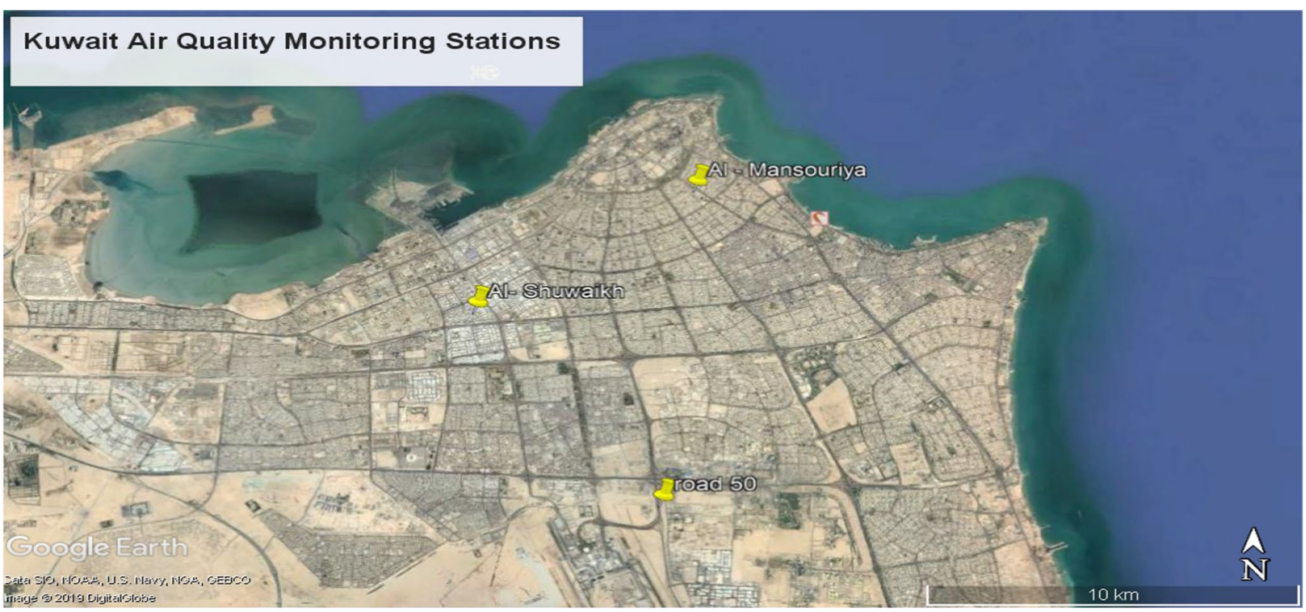


Fig. 2 Air Quality Monitoring Stations Al-Shuwaikh, Al-Mansouriya and Road 50 station

Analysis of data

Data analyses were conducted using the "OpenAir" R software package (Carslaw 2015) which is a model for statistical computation and graphics, and a system for data analysis and statistics. The model can undertake a wide range of analysis so that it can provide a comprehensive understanding of air pollution data. It is making it easy to carry out sophisticated analyses quickly, in an interactive and reproducible way. OpenAir functions can deal with more than one site available. The main functions in

OpenAir operate on a single data frame. This data frame for hourly measurements includes air pollutant concentrations, wind speed and wind direction. The model generates Plot Function, Wind Rose and Pollution Rose function, Percentile Rose, Polar and Time Plot functions. For the aim of this study, the model was run on the hourly concentrations data for the different criteria pollutants, totaling 306,000 hourly records. The data were compared to KEPA standards to determine how the measured concentrations of air pollutants discharged regularly from motor vehicles comply with the standards. This will help concerned authorities to take necessary air emission control measures for strict compliance with air quality standards (KEPA 2012).

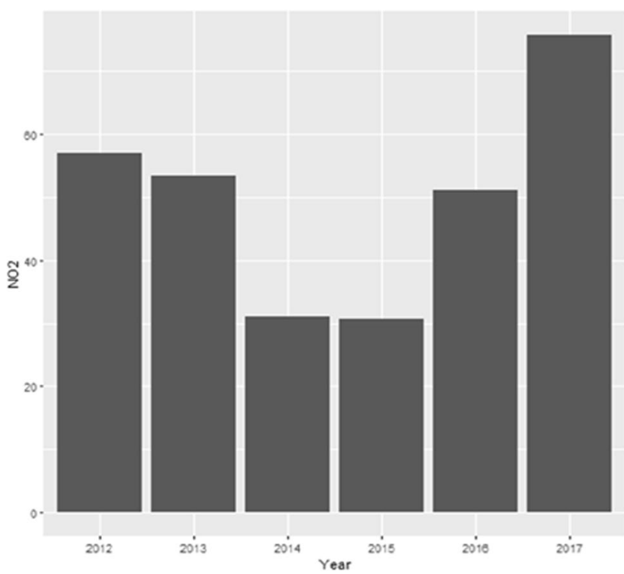


Fig. 3 Yearly averages of NO_2 concentrations at Jleeb Al-Shuyoukh area

Results and discussion

Statistical analysis

Descriptive statistics of concentrations of five air pollutants in Jleeb Al Shuyoukh, and Dasman areas, as measured hourly during the years 2012–2017 (a total of 47, 300 observations), are presented in Tables 1 and 2, respectively. Although the mean values were generally below the standards set by KEPA, the coefficients of variability were high reflecting the variations in the pollutant levels. Each air pollutant was further examined in each of the two areas considered in this study. Similar patterns were obtained for the pollutants studied. As an example, considering the NO_2 concentrations in Jleeb Al-Shuyoukh during 5 years, the yearly average values are plotted in Fig. 3 to highlight the variations in the pollutant concentration over the years, and a summary plot is shown in Fig. 4. The NO_2 concentrations had 433 exceedances to KEPA standards (100 ppb) in 2012, 667 exceedances in 2013, 241 exceedances in 2014, 309 in 2015 and 1394 in 2017, but the majority of the NO_2 readings appeared in levels below 100 ppb. The pollution rose is shown in Fig. 5. There were high levels of NO_2 in the northwest direction, which were over 100 ppb, probably due to the high traffic. The northwest direction and west direction were the highest wind direction contributors, with over 15% and 10% of the NO_2, respectively.

Traffic data are shown in Table 3. It was found that the levels of air pollutants such as NO2 and SO2 were influenced by the traffic intensity in the studied roads. The busy

Table 1 Descriptive statistics of air pollutants levels at Jleeb Al-Shuyoukh area for the period 2012–2017

Pollutant	NO_2 (ppb)	O_3 (ppb)	SO_2 (ppb)	CO (ppb)	PM_{10} (μg/m^3)
Mean	31	25	5	1011.2	199.8
SD	31	16	8	672.6	849.9
Min	1	0	1	0	0
Max	470	557	488	9880.0	75,216
CV	99.2%	66.0%	164.0%	66.5%	42.5%
KEPA Standards	100	80	170	26,000	350

Table 2 Descriptive statistics of air pollutants levels at Dasman area for the period 2012–2017

Pollutant	NO_2 (ppb)	O_3 (ppb)	SO_2 (ppb)	CO (ppb)	PM_{10} (μg/m^3)
Mean	64	23	8	364	200
SD	40	18	10	555	249
Min	0.26	0	0	10	2
Max	364.26	218	289	8599	3937
KEPA standards	100	80	170	26,000	350

roads around Jleeb Al-Shuyoukh seem to be a greater source of pollutants than the less busy road near Dasman area. It is evident that Jleeb Al-Shuyoukh two main roads receive about 3 times more traffic intensity than the Dasman's 25th road traffic, which is adversely impacting the Jleeb Al-Shuyoukh district's air quality. Concentrations of emission gases were reported to be maximum during early morning till afternoon hours during maximum traffic hours and were much lower at late night when vehicular density was minimum (Al-Bassam et al. 2009).

Exceedance of standards

This study also focused on determining the number of hours the monitored values exceeded the air quality standards set by KEPA as illustrated in Table 4. The percentage of hours of exceedance based on total hours of monitored data was also determined (as shown in brackets). It is to be mentioned that the total number of recorded data may differ for different air quality parameters since sensors used in the monitoring stations may not be working for some time. Generally

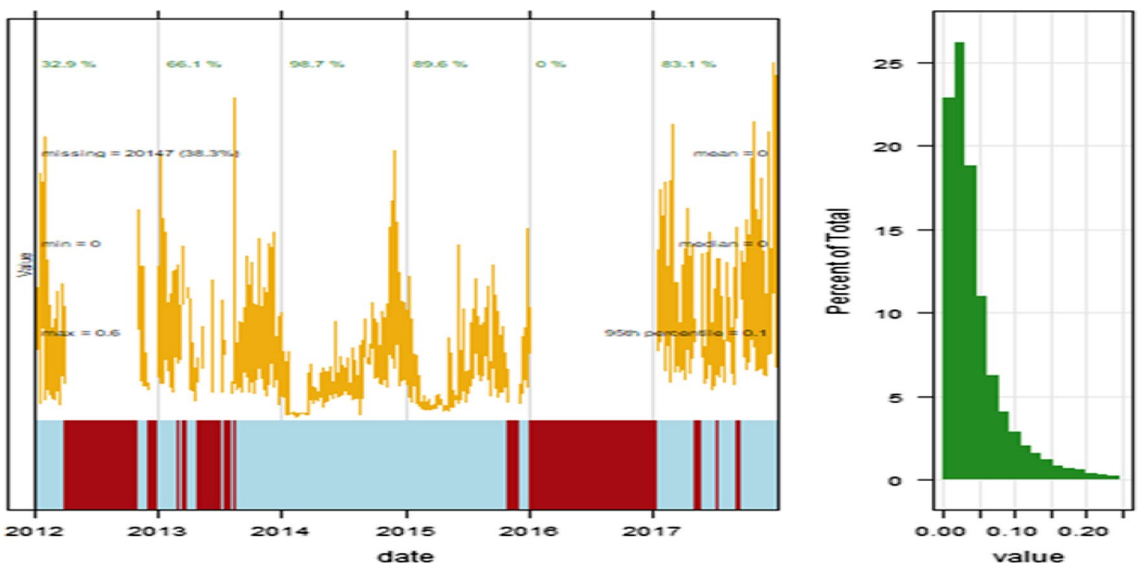
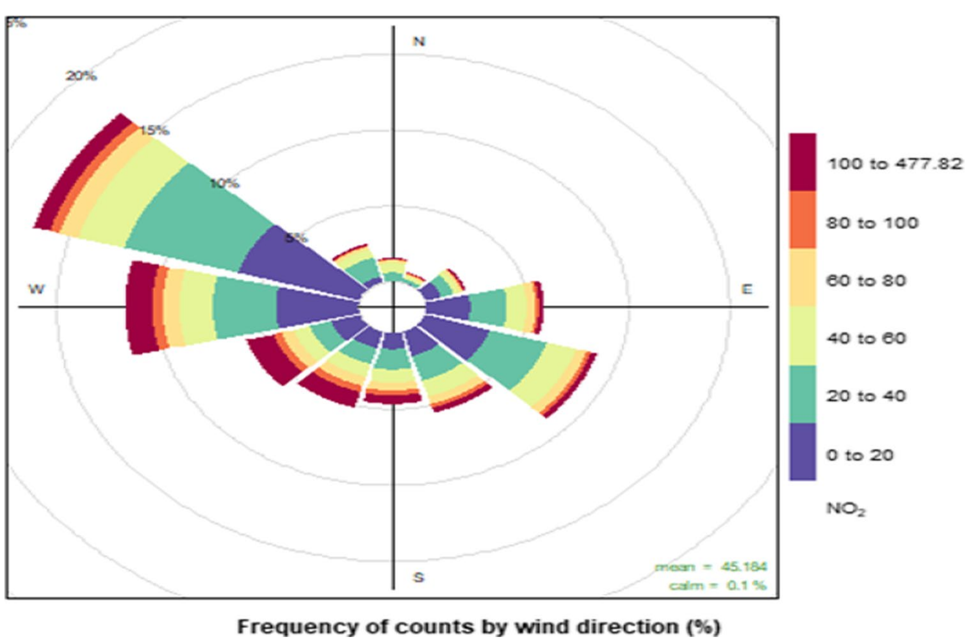


Fig. 4 Summary plot for NO_2 at Jleeb Al-Shuyoukh area during 2012–2017

Fig. 5 Pollution rose for NO_2 at Jleeb Al-Shuyoukh area during 2012–2017



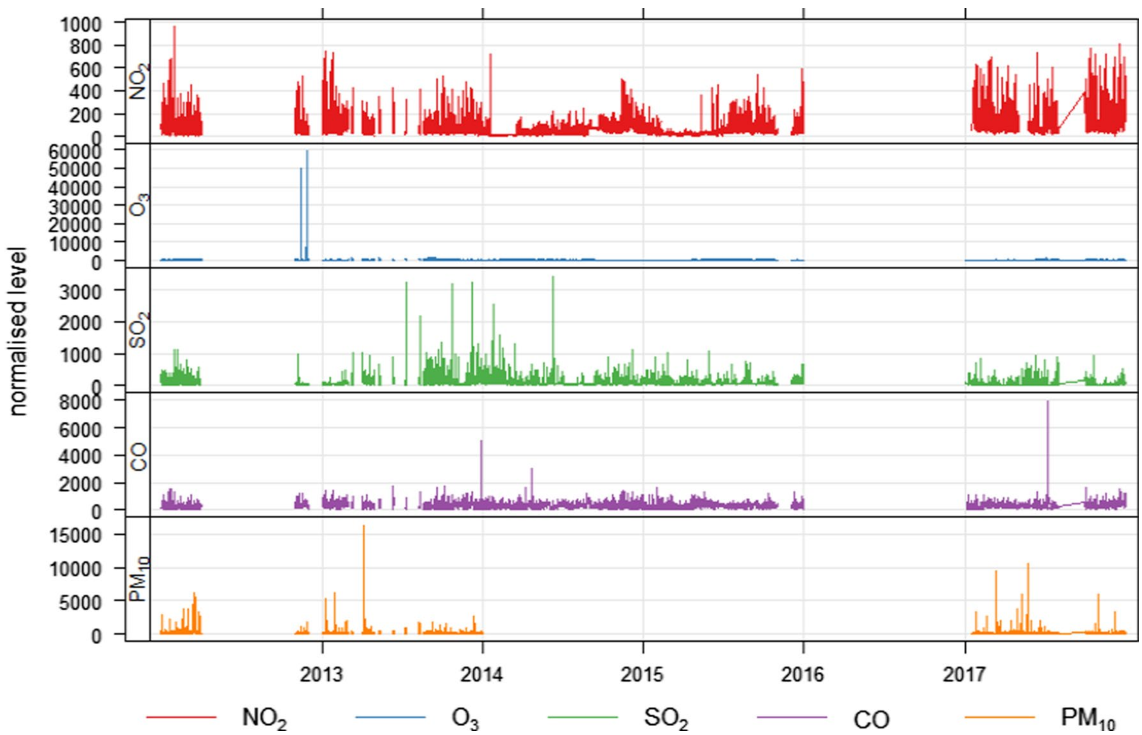


Fig. 6 Time series plot for each pollutant at Dasman area

Table 3 Number of vehicles in million per year for each main road serving the studied areas. *Source*: Ministry of Interior—Kuwait

Road	2014	2015	2016	2017
Gulf street (Dasman Area)	5,445,869	5,156,982	3,086,105	3,205,684
6th ring road (Jleeb Al-Shuyoukh area)	7,652,175	6,158,475	5,862,158	6,214,778
Ghazali road (Jleeb Al-Shuyoukh area)	6,563,214	5,485,264	4,058,156	4,854,136

Table 4 Total number of exceedances to KEPA[a] standards during the years 2012–2017

Pollutant	Total no. of exceedance hours
NO_2	Jeleeb Al-Shuyoukh: 2797 (5.91%)
	Dasman: 1560 (3.17%)
O_3	Jeleeb Al-Shuyoukh: 198 (0.42%)
	Dasman: 99 (0.20%)
SO_2	Jeleeb Al-Shuyoukh: 15 (0.03%)
	Dasman: 10 (0.02%)
CO	Jeleeb Al-Shuyoukh: 31 (0.07%)
	Dasman: 0 (0.0%)
PM_{10}	Jeleeb Al-Shuyoukh: 2424 (5.21%)
	Dasman: 2759 (5.61%)

[a]Kuwait Environment Public Authority (2012)

speaking, the concentrations levels of the five parameters were below the KEPA air quality standard levels most of the time. However, the total number of hours of exceedance was higher for NO_2, O_3 and PM_{10} as compared to SO_2 and CO. Also, the number of exceedances for Dasman area was much lower than those for Jleeb Al-Shuyoukh area that accommodates 3 times traffic density as compared to Dasman. This is important for air quality control and management by KEPA. Moreover, each of the five air pollutants was compared to KEPA and other regulatory agencies guidelines for comparison in each of the 6 years studies as shown in Table 5. Air quality standards of British Columbia province in Canada was used in the comparison since such standards are more complete and most recent (2020). During the study period covering the years from 2012 to 2017, the pollutants exceeded the KEPA and other regulatory agencies guidelines a few times. The highest hourly NO_2 concentration exceedance of KEPA standards was 2489 times in 2015 at Jleeb Al-Shuyoukh district while its concentration recorded less exceedance of 705 times in 2013. Ozone (O_3) hourly

Table 5 Yearly exceedance of air quality parameters against KEPA and other regulatory agencies guidelines

Pollutant	Authority	Req. time (hours)	Standard	Area	2012	2013	2014	2015	2016	2017
NO_2	KEPA[a]	1	100 ppb	Jleeb Al-Shuyoukh	NA	332	64	2489	NA	197
				Dasman	66	705	103	88	NA	NA
	WHO[b]	1	106.3 ppb	Jleeb Al-Shuyoukh	NA	119	40	2126	NA	159
				Dasman	40	609	82	58	NA	NA
O3	British Columbia[c]	1	82 ppb	Jleeb Al-Shuyoukh	47	11	21	37	61	NA
				Dasman	6	33	45	6	NA	NA
	KEPA	1	80 ppb	Jleeb Al-Shuyoukh	51	17	23	42	62	NA
				Dasman	6	37	50	6	NA	NA
SO_2	KEPA	1	170 ppb	Jleeb Al-Shuyoukh	1	9	0	1	2	NA
				Dasman	2	8	0	0	0	0
	WHO	1	133.59 ppb	Jleeb Al-Shuyoukh	2	10	2	5	4	0
				Dasman	0	7	0	1	NA	NA
CO	USEPA	1	35,000 ppb	Jleeb Al-Shuyoukh	0	0	0	0	0	26
				Dasman	0	0	0	0	NA	0
	British Columbia	1	13,000 ppb	Jleeb Al-Shuyoukh	0	0	0	0	0	32
				Dasman	0	0	0	0	NA	0
	KEPA	1	26,000 ppb	Jleeb Al-Shuyoukh	0	0	0	0	0	31
				Dasman	0	0	0	0	0	NA
PM_{10}	KEPA	24	350 μg/m^3	Jleeb Al-Shuyoukh	1487	874	NA	NA	761	411
				Dasman	889	570	NA	NA	NA	111
	WHO	24	50 μg/m3	Jleeb Al-Shuyoukh	8024	7964	NA	NA	8563	5595
				Dasman	7027	7034	NA	NA	NA	NA

[a]Kuwait Environment Public Authority (2012)

[b]World Health Organization (2018)

[c]British Columbia (2020)

concentrations exceeded the KEPA 62 times in Jleeb Al-Shuyoukh area in 2016, whereas exceedance was only 50 times in Dasman area in 2014. It is to be noted that both short-term and long-term exposure to ozone cause important health effects (Bowman, 2013). Ozone also plays a role in climate directly in climate change and indirectly through the carbon cycle as a phytotoxin (ibid). SO_2 and CO levels exceeded the KEPA guidelines very few times only. There were many daily average PM10 that exceed the daily regulatory limit. The highest PM10 levels were recorded in Jleeb Al-Shuyoukh (1487 exceedances) in 2012 and in Dasman (889 exceedances) in the same year since more frequent sand storms occurred in that year.

NO_2 originates primary from the heating of fuel (Ul-Haq and Salmam 2015) and as is it is known, the NO2 level increases with increase in traffic (Zhang et al. 2007) as observed in Jleeb Al-Shuyoukh area. Despite the lower traffic intensity in Dasman area, the northwest direction was the most influential wind direction in the NO_2 concentration, as well as in the concentration of all the pollutants registered in this area. It is noticed that concentration of PM10 is the highest in summer months and reduces to almost 50% in winter months. This is not only due to traffic but meteorological weather conditions, with dusty weather in summer and rainy in winter. Moreover, heavy vehicles, buses, and trucks contribute a lot to the PM_{10} concentrations. Apparently the effect of dust storms on levels of PM_{10}, which equally affect both districts, was reflected in almost similar percentages of exceedances in both districts as presented in Table 4. It is clear that the concentrations of NO_2, CO, SO_2 and PM_{10} are much higher in a commercial/residential area such as Jleeb Al-Shuyoukh reflecting the high traffic activity as compared to the Dasman residential area.

Relationship between pollutants

Correlation analysis was conducted among the pollutant concentrations in Dasman area. The results of a time series plot are presented in Fig. 6, where the data were analyzed in R environment and the matrix plot was constructed using "corrplot" package. Besides the small correlation coefficient for most of the pollutants, showing no linear relationship between the variables, but, presenting a moderate correlation between them. Meanwhile, O_3 had a

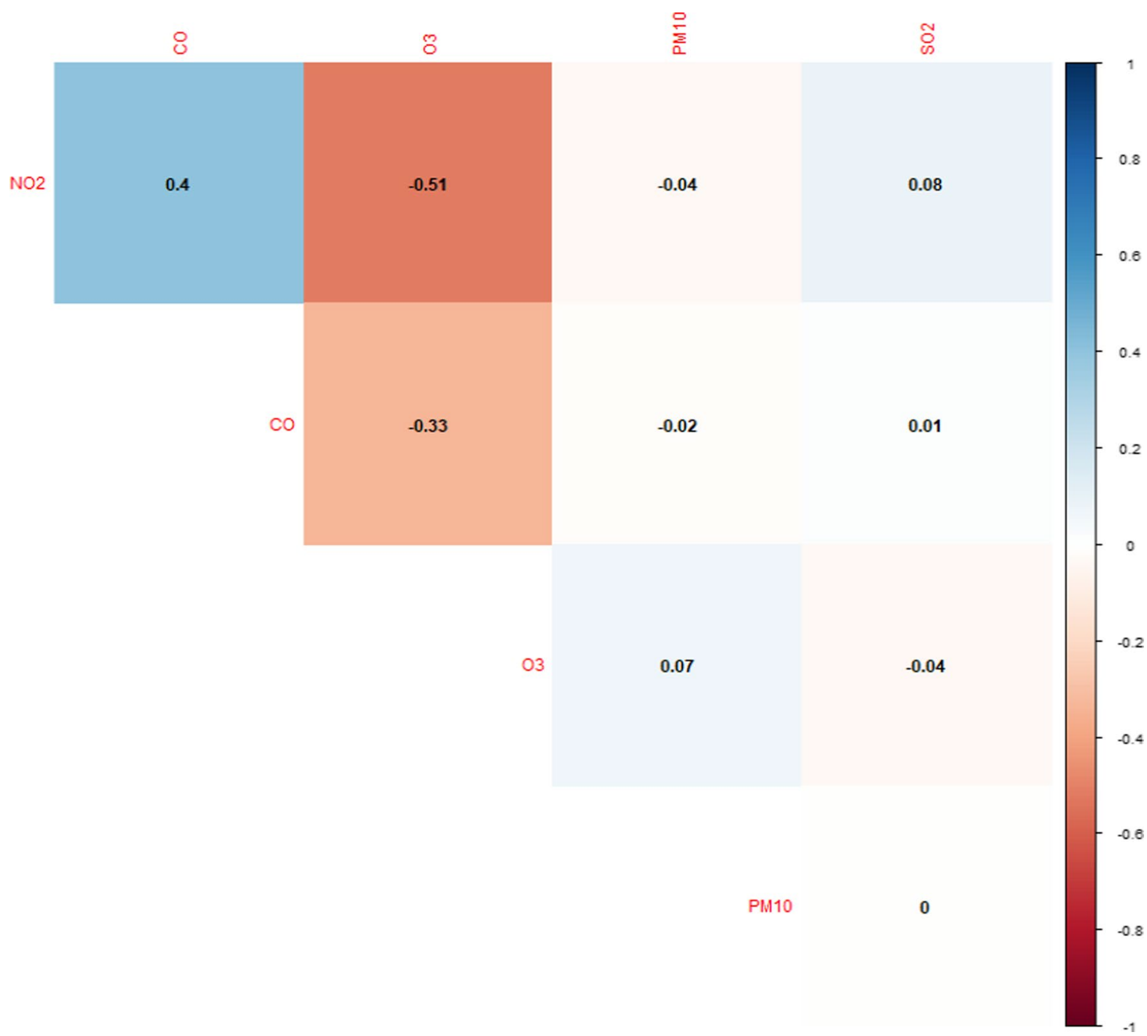


Fig. 7 Pearson's correlation matrix for the pollutants for Dasman area

good negative relationships with NO_2 (− 0.61) and a weak relationship with CO (− 0.33).

A correlation analysis was conducted among the NO_2, O_3, SO_2, CO and PM_{10} concentrations in Dasman area. The results are presented in Fig. 7. The data were analyzed by CORREL, which is an option for the Excel software and plotted using OpenAir software. There was a high negative correlation between O_3 and NO_2 ($R^2 = -0.879$), but weak positive correlation between CO and NO_2 ($R^2 = 0.4$) and weak negative correlation between CO and O_3 ($R^2 = -0.33$). NO_2 and PM_{10} with ($R^2 = 0.189$). Meanwhile, SO_2 and PM_{10}, as the value of the proportional correlation between them was (R^2 – 0.011). Similarly, the proportional correlation between SO_2 and NO_2 was insignificant, with ($R^2 = 0.066$). O_3 was not correlated with PM_{10} ($R^2 = 0.077$).

The negative relationship between O_3 and NO_2 levels obtained in this study can be explained as follows. Owing to the chemical coupling of O_3 and NOx (= NO + NO_2), the levels of O_3 and NO_2 are inextricably linked. Consequently, any resultant reduction in the level of NO_2 is invariably accompanied by an increase in the level of O_3 (Clapp and Jenkin 2001).

Correlation analysis

Dasman area

A Pearson's correlation matrix was presented among NO_2, CO, O_3, SO_2 and PM10 concentrations in Dasman area as shown in Fig. 7. There was a positive correlation between NO_2 and CO ($R^2 = 0.4$). The proportional positive correlation between NO_2 and SO_2 was insignificant ($R^2 = 0.08$). Similarly, between CO and SO_2 ($R^2 = 0.01$) and between

O3 and PM10 ($R^2 = 0.04$), there were insignificant positive correlations. Meanwhile, O_3 had a good negative correlation with NO_2 ($R^2 = -0.61$) and less correlation with CO ($R^2 = -0.33$). The correlation between NO_2 and PM_{10} was insignificant ($R^2 = -0.04$) as well as between O_3 and SO_2 ($R^2 = -0.04$). There was no correlation between PM_{10} and SO_2.

Jleeb Al-Shuyoukh area

Similarly, a Pearson's correlation matrix was plotted among NO_2, CO, O_3, SO_2 and PM_{10} concentrations in Jleeb Al-Shuyoukh area, and the results showed a good positive correlation between NO_2 and CO ($R^2 = 0.61$), as well as between CO and SO_2 ($R^2 = 0.23$). The proportional positive correlation between CO_2 and SO_2 was insignificant ($R^2 = 0.13$). Similarly, between CO and PM_{10} ($R^2 = 0.02$), there was an insignificant positive correlation. Furthermore, O_3 showed a strong negative correlation with NO_2 ($R^2 = -0.78$) and with CO ($R^2 = -0.41$). The proportional negative correlation between NO_2 and PM_{10} was insignificant ($R^2 = -0.05$) as well as between O_3 and SO_2 ($R^2 = -0.02$). This was also true for the correlations between O_3 and PM_{10} ($R^2 = -0.02$) and between SO_2 and PM_{10} ($R^2 = -0.02$).

Overview

The diurnal variations of the five air pollutants showed that the concentrations of pollutants in both 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 ozone concentration is highly correlated with NO_2 emissions. The NO_2 and SO_2 levels were greater in the summer than in winter due to increased activities in summer. The results confirm that road traffic is a major source of air pollution in both districts, but in comparison, Jleeb Al-Shuyoukh district showed by far more air pollutant levels since it has more internal roads, commercial activities, and heavy motor vehicles such as trucks and buses. Moreover, Jleeb Al-Shuyoukh district is more closer to power plants, industrial activities, and petroleum oil refineries. On the other hand, Dasman district is strictly a residential area with far less traffic and is located far from industrial areas.

Conclusion and recommendations

In this study, the concentrations of air pollutants such as O_3, NO_2, CO, SO_2, and PM_{10} were analyzed in two areas with different levels of traffic density, one of which is surrounded by two main roads "motor ways" (Jleeb Al-Shuyoukh area) and the other is close to a less busy road (Dasman area), in the state of Kuwait for the period 2012–2017. Thousands of hourly readings were collected, analyzed by "OpenAir" software package, for descriptive statistics and were compared to local (KEPA) and international agencies standards. The concentrations levels of the five parameters were below the KEPA air quality standard levels most of the time. However, regarding the O_3, in the heavy traffic area, there were 867 hourly readings that exceeded the hourly KEPA standards, whereas there were 98 readings that exceeded the KEPA standards in the less traffic area. The main cause of the increasing air pollutant levels in the Jleeb Al-Shuyoukh is likely to be the close proximity to the two busy main motorways. Similar to O_3, the emission of vehicles likely impacted the NO_2 levels, leading to 7169 and 1545 readings above the KEPA standard in Jleeb Al-Shuyoukh and Dasman, respectively. Apparently, the high traffic intensity at Jleeb Al-Shuyoukh is adversely affecting the district's air quality. Correlation analysis of the five air pollutants revealed that there were insignificant correlation between concentrations of the different parameters except for O_3 concentration that showed a strong negative correlation with NO_2 concentration ($R^2 = -0.879$). This may be due to chemical coupling of O_3 and NOx ($= NO + NO_2$), that makes the levels of O_3 and NO_2 inextricably linked. Consequently, any resultant reduction in the level of NO_2 is invariably accompanied by an increase in the level of O_3. It is clear that the concentrations of NO_2, CO, SO_2 and PM_{10} are much higher in a commercial/residential area such as Jleeb Al-Shuyoukh reflecting the 3 times higher traffic activity as compared to the Dasman residential area. It is recommended to enforce more strict regulations and introduce vehicle exhaust emission measurements while licensing vehicles to travel on roads in Kuwait. Also to control travel hours of heavy vehicles and trucks on motorways surrounding residential districts as to reduce air pollutant levels.

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