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ORIGINAL PAPER

Impact of fuel dispensing stations in the vicinity residential homes on the indoor and outdoor air quality

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Abstract

Worldwide, urbanization has expanded rapidly over the past two centuries that resulted in high pollution levels. Numerous fuel dispensing stations are built to serve the ever-increasing demand of consumers and are busy at all times, emitting volatile organic compounds (VOCs) and affecting the neighbouring community. VOCs comprising BTEXs (benzene, toluene, ethyl benzene and xylenes) have mutagenic and carcinogenic characteristics leading to high health risk. In this research study, the precise concentrations of these pollutants are measured in homes that neighbour fuel dispensing stations, and the associated risk of developing the described health effects are assessed. Moreover, air dispersion modelling is used to calculate meteorological data and wind rose, which indicates a north-westerly predominant wind and how pollutants move through the atmosphere. The risk of developing sensory irritation and other related health problems due to the presence of these compounds is evaluated to assess the existence of sick building syndrome in selected Kuwaiti homes near fuel dispensing stations. As a consequence of this research, the most appropriate mitigation methods are proposed to be implemented for a healthy and comfortable living for local inhabitants of the state in high-risk areas of the urban community. The distribution of BTEX compounds emitted from the fuel dispensing station is associated with the total emission and meteorological conditions. The dispersion of both NO_x and total BTEX is noticeably high at downwind locations.

Keywords Environment · BETXs · Health risk · Sensory irritants

Introduction

Air is one of the main components of our environment that has been abused by human irresponsible behaviour due to the renaissance as part of urbanization. The outdoor and indoor air pollution was rated by specialists as high risk to the environment and human health. Kuwait is an oil-producing country and has large-scale petroleum activities. Kuwait has a hot and arid climate due to its geographical location in the tropical region situated at the north-eastern corner of the Arabian Peninsula. Urbanization and fast growth have adversely affected the local air quality in almost all areas of Kuwait. The extremely dry, hot and harsh environment reaches a temperature of approximately 50 °C with prevalent dusty conditions and rapid expansion. This environment has resulted in almost all official (governmental), industrial, commercial, recreational and residential tall structures being equipped with full air conditioning and airtight environments for comfort and minimal exchange of ambient air loaded with aerosols (particulate matter) (Alenezi et al. 2012). All inhabitants spend most of their time in confined microenvironments, assuring short-term comfort with minimal consideration of health and long-term effects. Indoor air quality is of extreme importance and is strongly influenced by urban polluted air with additional local emissions emanating from volatile organics from paints, adhesives, cosmetics, insecticides, fresheners, furniture, carpets, wallpaper, other building materials, and combustion products from cooking. Extremely busy fuel dispensing stations are a major source

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of urban air pollution, and the influence of urban polluted air in the immediate neighbourhood in residential dwellings has been measured. The fuel (gasoline and diesel) consumption in the State of Kuwait is increasing gradually, as shown in the K.N.P.C. Annual Report (2012).

Many VOCs are designated hazardous air pollutants under Title III, Section 112 of the 1990 Clean Air Act Amendments. Regulatory agencies maintain full details of ambient and outdoor concentration levels of VOCs for most of the major urban areas. There is a paucity of data on indoor VOC concentrations in the non-occupational environment (Sexton et al. 2003). In the past two decades, several publications have reported the chronic health effects related to indoor air quality (Cheong and Chong 2001; Norbäck et al. 1995). Ambient air quality has a strong influence on indoor air.

Saeed et al. (1998) reported polycyclic aromatic hydrocarbon (PAH) concentration levels in dust collected from different residential areas in Kuwait for the period 1991–1996. These pollutants are anthropogenic, including the great disaster that transpired in 1991 due to the retreating army of Iraq, who torched over 600 oil wellheads. Another extensive investigation of the identification and quantification of VOCs was accomplished by Issa et al. (1998) regarding the ambient air in Kuwait.

Elkilani and Bouhamra (2001) reported that indoor concentrations of VOCs are higher than the outdoor measured concentrations due to poor infiltration of makeup air. They measured a very limited number of Kuwaiti residential homes (only 10). Elkilani et al. (2003) reported the adsorption and desorption characteristics of organic compounds into domestic carpets. VOC emissions from building materials were theoretically evaluated by Li and Niu (2005). Diffusion and partition coefficients were estimated using an inverse law.

Zabiegala et al. (2002) measured six organic compounds, that is, benzene, toluene, ethylbenzene, xylenes, butyl acetate, and (m) dichlorobenzene, in Gdansk Poland using two different techniques: permeation passive dynamic sampling with activated charcoal-filled tubes and Tenax-TA tubes indoors. The concentrations of these compounds indoors were found to be similar according to all measuring techniques, but the total hydrocarbon results revealed the presence of hydrocarbons other than those measured in the present study.

Adgate et al. (2002, 2003) reported the results for measured outdoor (O), indoor (I) and personnel (P) $PM_{2.5}$ particulates in the Minneapolis–St Paul metropolitan area for 2–15 days in spring, summer and fall of 1999. They noticed that the concentrations of $PM_{2.5}$ were $P = 19 > I = 10.7 > O = 8.6$ g/m^3. They used a passive sampling technique for VOC measurements up to ppb levels in all their programmes (Chung et al. 1999). Meininghaus et al. (2003) evaluated the risk assessment of sensory irritants in French schools. Several aldehydes, organic acids and VOCs were identified and quantified in indoor air in schools using active and passive sampling techniques. It was concluded that these measured irritants were not responsible for sickness, and a comprehensive sampling methodology was required to accomplish the risk assessment of irritants in schools.

Lai et al. (2004) completed a detailed study of personnel and microenvironment concentrations of $PM_{2.5}$, NO_2, CO and VOCs in the medium-sized town of Oxford in the UK. Thirty-seven elements and thirty organic compounds were quantified to perform the risk assessment to prioritize exposure pollutants for risk management.

O_3 levels in the troposphere are a true reflection of pollution levels, and the generation of O_3 is dependent on the concentrations of its precursors, that is, NO_x, VOCs and UV (solar radiation). Five fuel dispensing stations were selected at different locations in the State of Kuwait, and the indoor air qualities of the neighbouring homes were examined thoroughly, where all family members from infants to elders are exposed permanently. The levels of the selected pollutants BTEX and NO_x were measured using a passive sampling technique, maintaining quality control and quality assurance for 1 week.

In Kuwait, the number of cars and meteorological conditions make this research unique, and the houses in the vicinity are of a specific type with a specific number of occupants. The temperature in summer soars above 50 °C, which increases VOC concentrations due to their high vapour pressure and low boiling point. Gasoline blends and their extensive use in gas-inefficient vehicles make this research novel.

Air dispersion models are powerful tools for assessing the consequences of environmental air pollutant flows. These models are mathematical and express the pollution transport, dispersion and related processes in the atmosphere (Abdul-Wahab et al. 2011). Thus, in this study, Puff (CALPUFF) dispersion modelling was used to investigate the transport and dispersion patterns of VOCs originating from fuel stations in the neighbouring community. Indoor air quality was determined based on the results of passive samples to obtain the indoor/outdoor concentrations.

$$\text{Indoor selected pollutant level} = \text{oudoor computed levels} \; \frac{\text{indoor passive sample result}}{\text{outdoor passive sample result}}$$

Moreover, a comprehensive survey was conducted to apply a statistical model to identify health problems and correlate them to indoor air quality. Sick building symptoms (SBS) were assessed, and mitigation strategies were proposed to assist in eliminating these adverse effects in the selected homes.

Al-Awadhi (2014) used IVL passive sampler technology to measure many air pollutant gases in Kuwait City on a monthly basis for 10 locations. His results revealed that gas pollutants had low concentrations compared to the Kuwait Environment Public Authority standards for residential areas.

Recently, Kountouriotis et al. (2014) conducted a numerical investigation of VOC levels near petrol stations with their effluence and prevalent metrological parameters. Moreover, gasoline components with different properties were included in their study.

Morales Terrés et al. (2010) concluded that the air near petrol stations does not have the same concentration of VOCs as the wide-ranging city air. They explained that there is an area close to petrol stations, where the VOC concentrations are influenced by both the petrol dispensing station and the number of cars being filled.

Urbanization and expansion of new localities due to population growth have changed the landscape of developing countries. There is an annual increase of over 3% in all utilities (power, water, fuel, etc.), adversely affecting the ambient air quality. The present research project consists of comprehensive experimental work to assess the concentration levels of VOCs in the enclosed environments of residential homes near fuel dispensing stations, which strongly affect the health and performance of the population exposed to high levels of indoor pollutants. Also, the present research proposal addresses deteriorating indoor/outdoor air quality in residential homes near fuel dispensing stations. There are some publications on the air quality in urban areas, but the geographical topography of each country is different regarding associated prevalent meteorological conditions, which makes this research very relevant to address the ever-increasing pollution problem that causes health risk to residents in the immediate neighbourhood of fuel dispensing stations in Kuwait.

Materials and methods

Background

The passive sampling technique is based on the molecular diffusion of vapours. In passive sampling, pollutant gas or vapour diffuses or permeates through the selective membrane specially prepared and tested for a specific pollutant. There is always a blank sample to cancel the membrane activity and atmospheric surrounding effects during the sampling time. There is minimal active movement of the air through the sampler during sampling time. Passive samples are cost-effective and can be used in large numbers indoors, outdoors and personally for a specified time. The passive samplers were prepared, supplied and analyzed by the IVL Swedish Environmental Research Institute. The theory of the sampling technique is discussed in detail by Ferm et al. (1999, 2002, 2005).

To determine the indoor air quality, the passive samplers for BTEX and NO_x were exposed for 1 week. These samplers were specially prepared and delivered by IVL Swedish Environmental Research Institute Ltd. (Stockholm, Sweden). After exposure time of approximately 7 days, the samplers were sent back for analysis.

Site description

The air quality around fuel dispensing stations is concerning, especially that of the residential areas placed in the north-westerly wind direction from the fuel stations. To conduct the IAQ study, five fuel dispensing stations were selected in the urban area of Kuwait. Four residential areas, located 100–200 m away from the fuel station, were carefully selected based on the wind direction.

The five fuel dispensing stations selected were Farwaniya, Abdullah Al-Mubarak Al-Sabah, Saad Al-Abdullah, Hawally and Kaifan. The station selection was based on proximity to residential homes and accessibility. At each fuel station, one sampler each of BTEX and NO_x was exposed at the breathing pipe above the storage tank, and one sampler for each was placed at the dispensing station (Fig. 1). In the residential areas, one BTEX sampler was placed in the ambient air, and one sampler each of BTEX and NO_x was placed indoors in the rooms facing the fuel stations.

Sample collection and analysis

A total of 80 passive samplers were exposed in the selected locations in the five urban areas in Kuwait. Each location was selected for the measurement of BTEX and NO_x. Thirty BTEX and fifty NO_x were used to quantify the total BTEX (sum of benzene, toluene, ethyl benzene, m,p-xylene and o-xylene) and non-BTEX (sum of n-octane and n-nonane) in indoor and ambient air for a testing period of 1 week.

The samplers were sent back for accurate analysis after an exposure period of 1 week. The results for each pollutant are discussed in the following sections.

Results and discussion

Many passive samplers (BTEX and NO_x) were obtained from IVL Swedish Environmental Research Institute Ltd. and exposed for 1 week at five different fuel dispensing stations in the urban area of Kuwait. The exposed samplers were collected, sealed and sent back with the blanks to IVL Swedish Environmental Research Institute Ltd. for

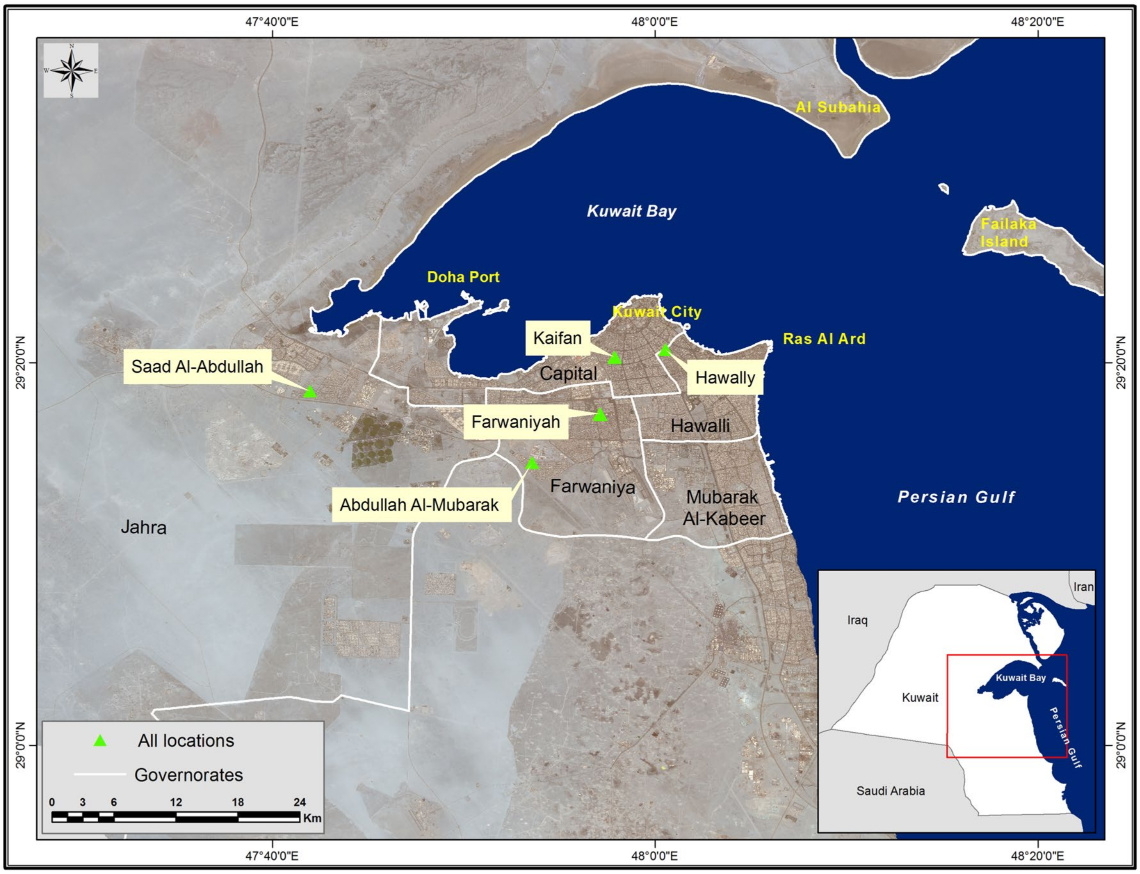


Fig. 1 Locations of the five selected urban areas in Kuwait

detailed analysis. Zabiegala et al. (2002) found that the results obtained from passive samples and from dynamic methods in all the dwellings examined indicate that no significant differences were observed in the entire sampling period. The detailed results are presented in Tables 1 and 2 and are discussed accordingly. The variations of meteorological parameters were recorded using all samples by classifying weather conditions during the 8-day sampling period. The results are shown in Table 3.

The highest concentration of total BTEX compounds in this study was found at the Hawally fuel dispensing station (Figs. 2 and 3), which is located in the commercial district of the city and has inter-nested road arteries with high congestion by light-duty vehicles resulting in elevated levels of total BTEX (405 µg m^{-3}). The weekly average concentrations of benzene, toluene, ethyl benzene and all xylenes isomers were 67, 190, 26 and 122 µg m^{-3}, respectively ("Appendix 1"). The second highest concentration of total BTEX was 122 µg m^{-3} near the breathing pipe over the fuel storage tank at this location. The dispersion of BTEX in the surrounding residential area showed high indoor and outdoor concentrations of 39 and 56 µg m^{-3}, respectively, at building no. 20 on the fourth floor of flat no. 15 (Figs. 2 and 3), which was located south-east of the fuel dispensing station and near an oil-change service station. Meteorological data were obtained, and the wind rose plot (Fig. 4) for all of Kuwait indicated north-westerly predominant wind, confirming high concentration in the downwind direction. There were exceptionally high concentrations due to the oil change facility near the fuel dispensing station, which contributed to the build-up of elevated levels of BTEX in these two above-mentioned locations.

NO_x comprising NO primary pollutant produced from the combustion process and NO_2 secondary pollutant as a result of the oxidation of NO showed the highest average concentration of 108.8 µg m^{-3} (Fig. 5) at the Hawally fuel filling point, and the peak value was 200 µg m^{-3} near residence no. 19 in the south-east direction of the fuel filling station and near the service station (Fig. 5). This location was downwind (Fig. 4) of the Hawally station, and the NO_x concentrations were similar to the TVOC concentrations. A large volume of traffic contributed to the high value of average NO_x concentration.

The second highest total BTEX levels (326 µg m^{-3}) were found at the Farwaniya fuel dispensing station, which is in the old commercial district (Figs. 2 to 3). The weekly

Table 1 BTEX concentrations at five selected fuel dispensing gas stations and few residential buildings around the stations

No.	Location		Benzene μg/m^3	Toluene μg/m^3	Ethylbenzene μg/m^3	o-Xylene μg/m^3	m + p-Xylene μg/m^3	Sum BTEX μg/m^3	Comments
Farwaniya									
1	F-GS1-BP	Fuel station 1—breathing pipe	4.9	18	3.6	4.0	11	42	
2	F-GS1-FS	Fuel station 1—fuel station	48	160	21	24	73	326	
3	F-Res3(i)	Residence 3 (mosque)	2.2	20	3.2	4.9	9.5	39	
	F-Res3(o)		2.0	6.8	1.8	1.7	5.0	17	
4	F-Res2(i)	Residence 2 (floor 1/flat no. 6)	2.6	11	6.7	8.3	25	54	
	F-Res2(o)		2.6	8.4	2.0	2.0	5.8	21	
5	F-Res4(i)	Residence 4	1.8	6.6	1.6	1.7	4.6	16	
	F-Res4(o)		2.5	6.3	1.5	1.3	3.9	15	
6	F- Res1(i)	Residence 1	2.6	8.1	1.7	1.6	5.0	19	
	F- Res1(o)		2.3	7.2	1.6	1.6	4.7	17	Painting done outside
Abdullah Al-Mubarak Al-Sabah									
1	AM-GS2-BP	Fuel station 2—breathing pipe	8.6	22	2.8	2.9	8.8	45	
2	AM-GS2-FS	Fuel station 2—filling station	19	63	8.1	9.3	28	127	
3	AM-Res6(i)	Residence 6	1.9	5.5	2.8	5.4	10	26	
	AM-Res6(o)		2.3	6.0	1.3	1.1	3.4	14	
4	AM-Res7(i)	Residence 7	2.6	7.5	1.6	1.6	4.8	18	
	AM-Res7(o)		2.5	7.4	1.5	1.4	4.1	17	Generator 30 m from the residence
5	AM-Res5(i)	Residence 5	2.3	16	12	11	16	58	
	AM-Res5(o)		2.3	5.7	1.2	1.0	3.1	13	
6	AM-Res8(i)	Residence 8	2.3	4.8	3.9	9.3	19	39	
	AM-Res8(o)		1.7	4.5	1.0	1.0	2.8	11	
Saad Al-Abdullah (Jahra)									
1	SA-GS3-BP	Fuel station 3—breathing pipe	22	75	10	12	35	155	
2	SA-GS3-FS	Fuel station 3—fuel station	39	120	15	17	53	245	
3	SA-Res9(i)	Residence 9	4.1	12	2.1	2.2	7.1	28	Indoor Diwaniya smoking
	SA-Res9(o)		4.3	13	2.5	2.7	8.2	31	
4	SA-Res10(i)	Residence 10	4.9	12	2.0	2.0	6.3	27	
	SA-Res10(o)		2.2	6.3	1.3	1.5	4.3	15	
5	SA-Res12(i)	Residence 12	3.6	9.5	1.7	2.0	5.3	22	
	SA-Res12(o)		2.9	8.6	1.6	1.8	5.2	20	
6	SA-Res11(i)	Residence 11	2.5	5.9	1.2	1.4	3.8	15	
	SA-Res11(o)		5.2	14	3.2	3.3	10	36	

Table 1 (continued)

No.	Location		Benzene μg/m³	Toluene μg/m³	Ethylbenzene μg/m³	o-Xylene μg/m³	m + p-Xylene μg/m³	Sum BTEX μg/m³	Comments
Kaifan									
1	K-GS4-BP	Fuel station 4—breathing pipe	14	45	5.8	7.1	20	92	Sampler on lamp post near breathing pipe
2	K-GS4-FS	Fuel station 4—filling station	48	150	17	19	58	292	
3	K-Res14(i)	Residence 14 (tyre and puncture)	13	80	15	19	53	180	
	K-Res14(o)		2.7	11	2.4	2.8	8.0	26	
4	K-Res15(i)	Residence 15 (stage/hall)	2.1	7.8	1.2	1.3	3.5	16	
	K-Res15(o)		6.9	25	2.9	2.9	8.5	46	
5	K-Res16(i)	Residence 16 (nursery)	2.6	7.2	1.4	1.4	4.2	17	
	K-Res16(o)		2.4	7.5	1.6	1.7	5.0	18	
6	K-Res13(i)	Residence 13	–	–	–	–	–	–	
	K-Res13(o)		2.4	6.1	1.4	1.4	4.1	15	
Hawally									
1	H-GS5-BP	Fuel station 5—breathing pipe	17	59	8.0	9.2	28	122	
2	H-GS5-FS	Fuel station 5—filling station	67	190	26	30	92	405	
3	H-Res20(i)	Residence 20 (floor 1/flat no. 4)	5.2	18	2.9	3.3	9.5	39	Oil-change station (Garage) 10 m from residence
	H-Res20(o)		7.1	25	4.3	5.0	15	56	
4	H-Res17(i)	Residence 17 (floor 4/flat no. 10)	2.2	6.4	2.3	2.2	5.5	19	
	H-Res17(o)		2.1	5.1	1.3	1.5	4.2	14	
5	H-Res19(i)	Residence 19 (floor 4/flat no. 15)	4.8	14	2.4	2.6	7.6	31	Oil-change station (Garage) 10 m from residence
	H-Res19(o)		3.7	13	2.6	3.0	8.7	31	
6	H-Res18(i)	Vacant	–	–	–	–		–	
	H-Res18(o)	Vacant							
7	J-ResNaw(i)	Nawaf Residence Jahra/Doha	1.2	9.3	14	27	56	108	
	J-ResNaw(o)		6.3	14	2.7	2.8	8.4	35	

average concentrations of benzene, toluene, ethyl benzene and all xylenes isomers were 48, 160, 21 and 97 μg m^{-3}, respectively ("Appendix 1"). These elevated levels were due to road traffic emissions contributing to the build-up of BTEX. The dispersion of BTEX in the surrounding residential area showed high levels in residence no. 2 on the first floor flat no. 6 (54 μg m^{-3}) and residence no. 3 (mosque) (39 μg m^{-3}) (Figs. 2 and 3), which were located south-east (downwind) of the fuel station. The average outdoor concentration of total BTEX was 17.7 μg m^{-3}, reflecting uniformity in the ambient air around the fuel dispensing station. NO_x showed the highest concentration of 130 μg m^{-3} at the filling point, followed by a concentration of 83 μg m^{-3} at dwelling no. 1, west of the fuel station (Fig. 5). The average

Table 2 NO_x concentrations at five selected gas stations and few residential buildings around the gas stations

No.	Location		NO_2 μg/m^3 STP	NO μg/m^3 STP	NO_x as NO_2 μg/m^3 STP	Comments
Farwaniya						
1	F-GS1-BP	Fuel station 1—breathing pipe	11	22	45	
2	F-GS1-FS	Fuel station 1—filling station	55	49	130	
3	F-Res3(i)	Residence 3 (mosque)	32	26	72	
4	F-Res2(i)	Residence 2	58	8	71	
5	F-Res4(i)	Residence 4	41	11	57	
6	F- Res1(i)	Residence 1	69	9	83	
Abdullah Al-Mubarak Al-Sabah						
1	AM-GS2-BP	Fuel station 2—breathing pipe	45	37	102	
2	AM-GS2-FS	Station 2—filling station	44	24	81	
3	AM-Res6(i)	Residence 6	35	15	58	
4	AM-Res7(i)	Residence 7	28	11	45	
5	AM-Res5(i)	Residence 5	45	20	75	Sampler fell
6	AM-Res8(i)	Residence 8	19	12	37	
Saad Al-Abdullah (Jahra)						
1	SA-GS3-BP	Fuel station 3—breathing pipe	44	24	81	Sampler fell
2	SA-GS3-FS	Fuel station 3—filling station	45	16	70	
3	SA-Res9(i)	Residence 9	58	101	212	Indoor Diwaniya smoking
4	SA-Res10(i)	Residence 10	34	11	51	
5	SA-Res12(i)	Residence 12	49	15	72	Sampler fell
6	SA-Res11(i)	Residence 11	42	9	56	
Kaifan						
1	K-GS4-BP	Fuel station 1—breathing pipe	45	43	111	
2	K-GS4-FS	Fuel station 1—filling station	45	22	79	
3	K-Res14(i)	Residence 14 (tyre and puncture)	61	23	96	
4	K-Res15(i)	Residence 15 (stage/hall)	39	21	72	
5	K-Res16(i)	Residence 16 (nursery)	45	13	65	
6	K-Res13(i)	Residence 13	–	–	–	
Hawally						
1	H-GS5-BP	Hawally fuel station 5—breathing pipe	54	33	105	
2	H-GS5-FS	Hawally fuel station 5—fuel station	55	27	96	
3	H-Res20(i)	Residence 20—floor 1/flat no. 4	33	16	58	
4	H-Res17(i)	Residence 17—floor 4/flat no. 10	49	23	85	
5	H-Res19(i)	Residence 19—floor 4/flat no. 15	93	70	200	
6	H-Res18(i)	Vacant				
7	J-ResNaw(i)	Nawaf residence Jahra/Doha	31	19	59	

NO_x concentration was 76.19 μg m^{-3}, reflecting uniformity generated by the large volume of road traffic in and around this fuel station.

The Abdullah Al-Mubarak area is a newly constructed residential area, and its fuel dispensing station had the highest fuel sale among the five selected stations during the period of study (Table 4). The total BTEX concentration was 127 μg m^{-3} at the filling point (Figs. 2 and 3), and the weekly average concentrations of benzene, toluene, ethyl benzene and all xylenes isomers were 19, 63, 8.1 and 37.3 μg m^{-3}, respectively ("Appendix 1"). These elevated levels were due to road traffic emissions contributing to the build-up of BTEX. The dispersion of BTEX in the surrounding residential area showed high levels in dwelling no. 5 (58 μg m^{-3}) and dwelling no. 8 (39 μg m^{-3}) (Figs. 2 and 3), which were located south-west of the fuel station. The small deviation from the previous two filling stations might be attributed to the obstruction in the downwind direction. The average concentration of total BTEX was 24.5 μg m^{-3}, reflecting uniformity in the ambient air around the fuel dispensing station.

Table 3 Weather conditions during 8-day sampling period

Day	Weather condition	Temperature (°C)
Day 1	Rain in the evening and night	23–26
Day 2	Rain in the morning and afternoon; cloudy all day	23–26
Day 3	Cloudy	23–26
Day 4	Bright and sunny	23–26
Day 5	Bright and sunny	23–26
Day 6	Rainy day and cloudy	23–26
Day 7	Heavy rain and windy	23–26
Day 8	Slight drizzle and cloudy	23–26

NO_x showed the highest concentration of 102 µg m^{-3} at the storage tank near the breathing pipe, followed by a concentration of 81 µg m^{-3} at the filling point (Fig. 5). The average NO_x concentration was 66.40 µg m^{-3}, due to a moderate flow of road traffic. The NO_x concentrations near residential dwellings no. 5 and 8 were 75 and 37 µg m^{-3}, respectively ("Appendix 2"), south-west of the fuel station. The slight change in the direction from the two previous sites could be attributed to some building obstruction.

Saad Abdullah is an extension of the Al-Jahra residential governorate and a newly constructed residential area, and the fuel dispensing station had moderate fuel sales during the period of study. The total BTEX concentration was the highest (245 µg m^{-3}) at the filling point (Figs. 2 and 3), and the weekly average concentrations of benzene, toluene, ethyl benzene and all xylenes isomers were 39, 120, 15 and 70 µg m^{-3}, respectively ("Appendix 1"). These elevated levels were due to road traffic emissions contributing to the build-up of BTEX. The dispersion of BTEX in the surrounding residential area showed high levels in dwelling no. 11 (36 µg m^{-3}) and dwelling no. 9 (31 µg m^{-3}) (Figs. 2 and 3), which were located north-west of the fuel station. The high value of BTEX was not consistent with the downwind direction due to obvious obstruction altering the flow of natural wind. The average concentration of total BTEX was 24.3 µg m^{-3}, reflecting uniformity in the ambient air around the fuel dispensing station. NO_x showed the highest concentration of 212 µg m^{-3} at dwelling no. 9, followed by 81 µg m^{-3} at the breathing pipe of the fuel storage tank (Fig. 5). The average NO_x concentration was 90.3 µg m^{-3}, due to the large flow of road traffic in the area. The NO_x concentrations near residential dwellings no. 11 and 12 were 56 and 72 µg m^{-3}, respectively, north-west of the station, similar to BTEX but with a deviation from the previous locations due to physical obstruction of some constructed buildings.

Kaifan is a central residential locality in the capital (Al-Asema) governorate and the oldest constructed residential area, and the fuel dispensing station had moderate fuel sales during the period of study (Table 4). The total BTEX concentration was the highest (292 µg m^{-3}) (Figs. 2 and 3) at the filling point, and the weekly average concentrations of benzene, toluene, ethyl benzene and all xylenes isomers were 48, 150, 17 and 77 µg m^{-3}, respectively ("Appendix 1").

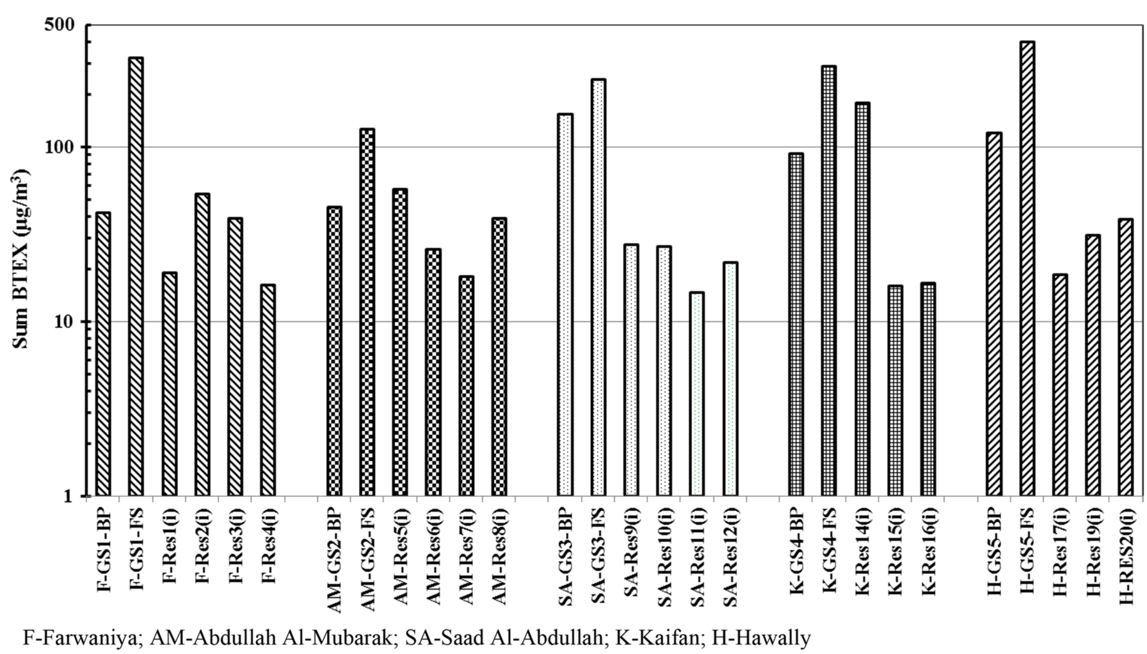


Fig. 2 Concentration of the sum of BTEX compounds at various gas stations and indoor residential areas. *F* Farwaniya; *AM* Abdullah Al-Mubarak, *SA* Saad Al-Abdullah, *K* Kaifan, *H* Hawally

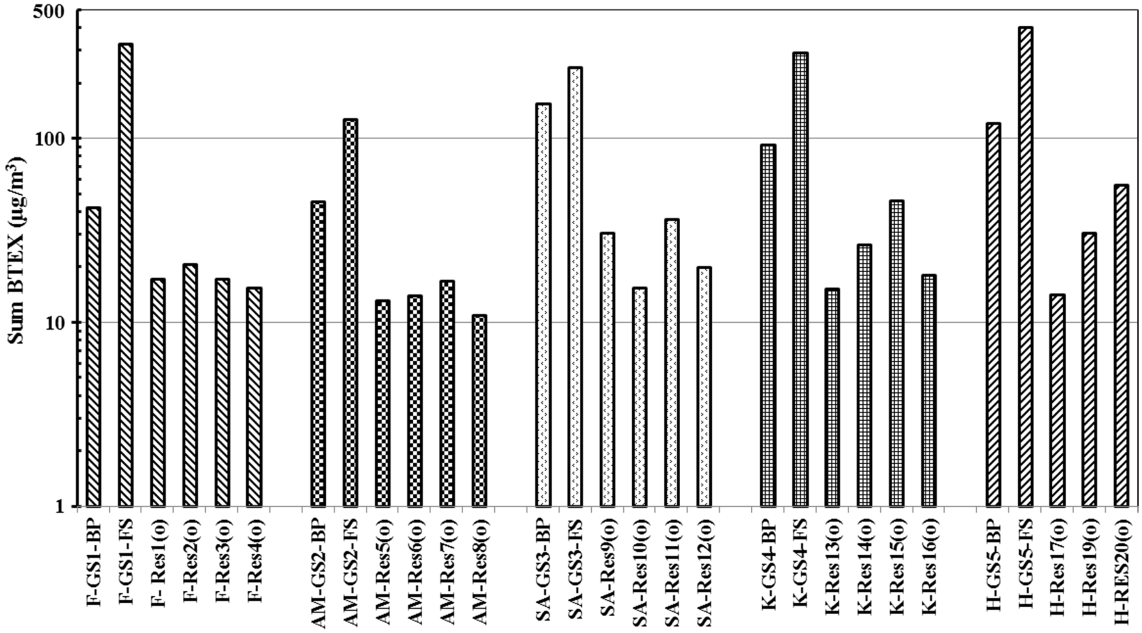


Fig. 3 Concentration of the sum of BTEX compounds at various gas stations and outdoor residential areas

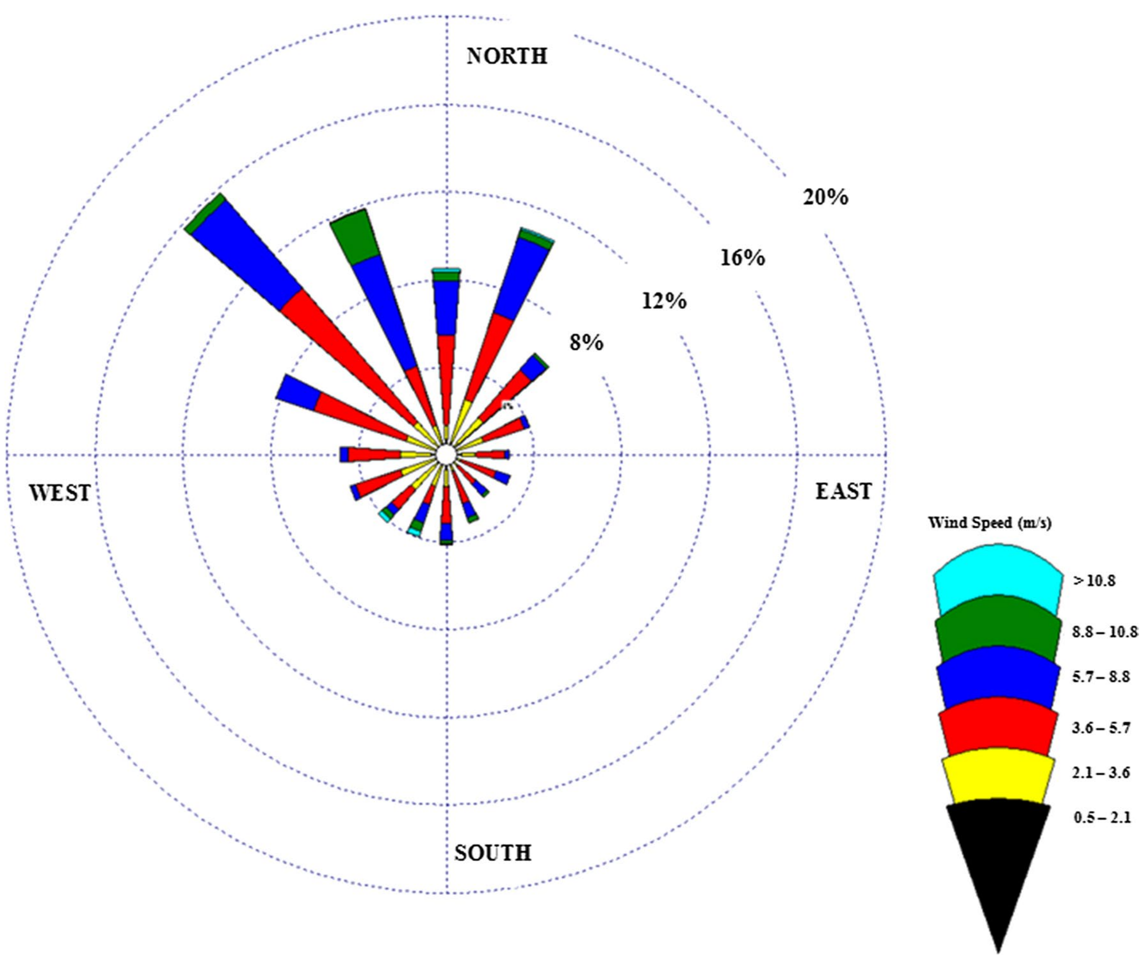


Fig. 4 Wind rose for the State of Kuwait

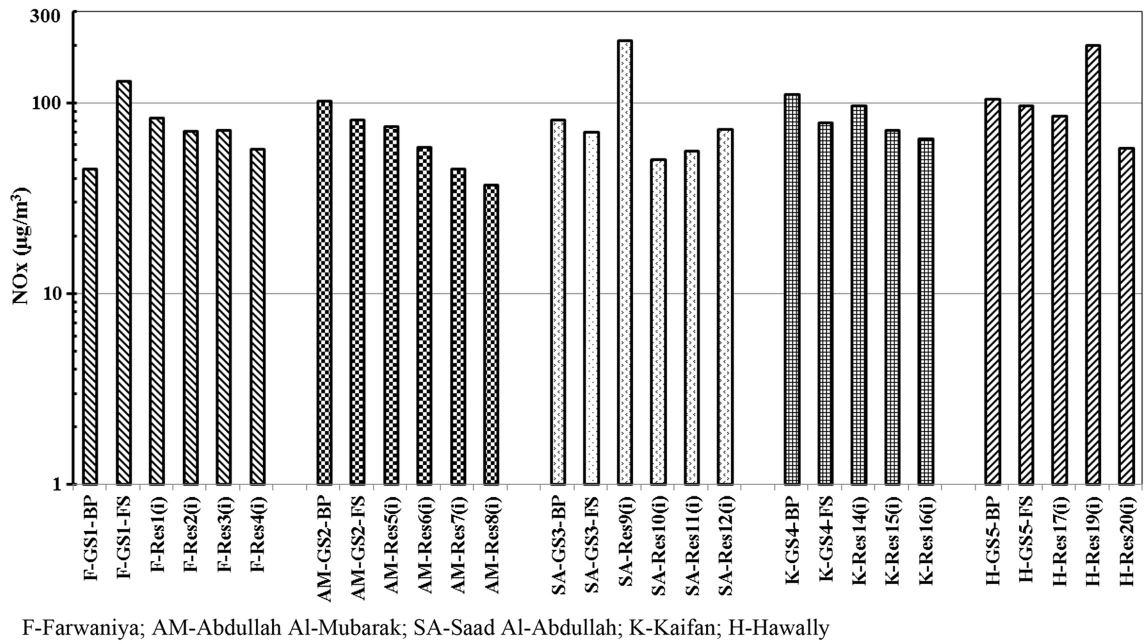


Fig. 5 Concentration of NO_x as NO_2 compounds at various fuel dispensing stations and indoor residential areas. *F* Farwaniya; *AM* Abdullah Al-Mubarak, *SA* Saad Al-Abdullah, *K* Kaifan, *H* Hawally

Table 4 Weekly sale of fuel and number of cars fuelled at the five selected fuel dispensing stations from 18 to 25 March 2017

Fuel station	Premium fuel (L)	Super fuel (L)	Total amount of fuel (L)	No. of cars			
				1 week	1 day	1 h	10 min
Farwaniya	305,771	584,731	890,502	14,842	2120	88	15
Abdullah Al-Mubarak Al-Sabah	510,870	416,556	927,426	15,457	2208	92	15
Saad Al-Abdullah (Jahra)	292,150	584,214	876,364	14,606	2087	87	14
Kaifan	306,208	373,680	679,888	11,331	1619	67	11
Hawally	405,130	325,861	730,991	12,183	1740	73	12

These elevated levels were due to road traffic emissions contributing to the build-up of BTEX. The dispersion of BTEX in the surrounding residential area showed high levels in dwelling no. 14 (180 µg m^{-3}) and dwelling no. 15 (46 µg m^{-3}) (Figs. 2 and 3), which were located east and south-east of the fuel station, respectively The average concentration of total BTEX was 45.5 µg m^{-3} in the ambient air around the fuel dispensing station, with one spike at building 14 with a tyre shop. NO_x showed the highest concentration of 111 µg m^{-3} at the breathing pipe of the fuel storage tank, followed by 96 µg m^{-3} at building no. 14 with the tyre shop (Fig. 5). The average NO_x concentration was 84.4 µg m^{-3}, reflecting moderate traffic flow. The other NO_x concentrations were 79 and 96 µg m^{-3} at the fuel filling dispensing station and dwelling no. 14, respectively (Fig. 5), north-west of the fuel dispensing station, showing deviation from the previous locations due to physical obstruction of some construction.

Two-way ANOVA without replications was applied to TVOCs and the NO_x and I/O ratio of TVOC data separately. The results of the variations are tabulated in Table 5. The calculated value of F is greater than $F_{critical}$, rejecting the null hypothesis for samples around the fuel dispensing station and confirming the significant variance among different locations around any fuel dispensing station with a very low probability value. The second row depicts F as being less than the $F_{critical}$, accepting the null hypothesis for different fuel dispensing stations. The variance values were similar among all fuel dispensing stations irrespective of the location.

Two-way ANOVA without replication was applied to NO_x data and the I/O ratio of TVOCs. The ANOVA results revealed no change in variance among the samples around the fuel dispensing station or between different filling stations. The null hypothesis was accepted for both NO_x and the I/O ratio of TVOCs, indicating similarity among different

Table 5 Two-way ANOVA results without replication for TVOCs, NO_x and I/O ratio of TVOC values

Source of variation	SS	df	MS	F	*P* value	F crit
ANOVA—application to total VOC concentrations						
Samples around fuel station	284,277.6	9	31,586.4	16.83	2E − 10	2.15
Fuel stations	13,316	4	3329	1.77	0.155,511	2.63
Error	67,560.4	36	1876.678			
Total	365,154	49				
ANOVA—application to NO_x concentrations						
Samples around fuel station	8054.7	5	1610.9	0.94	0.478	2.71
fuel stations	4275.1	4	1068.8	0.62	0.652	2.87
Error	34,353.7	20	1717.7			
Total	46,683.5	29				
ANOVA—application to indoor/outdoor TVOC levels						
Samples around fuel station	3.36	3	1.12	0.34	0.798	3.49
Fuel stations	6.61	4	1.65	0.5	0.738	3.26
Error	39.77	12	3.31			
Total	49.74	19				

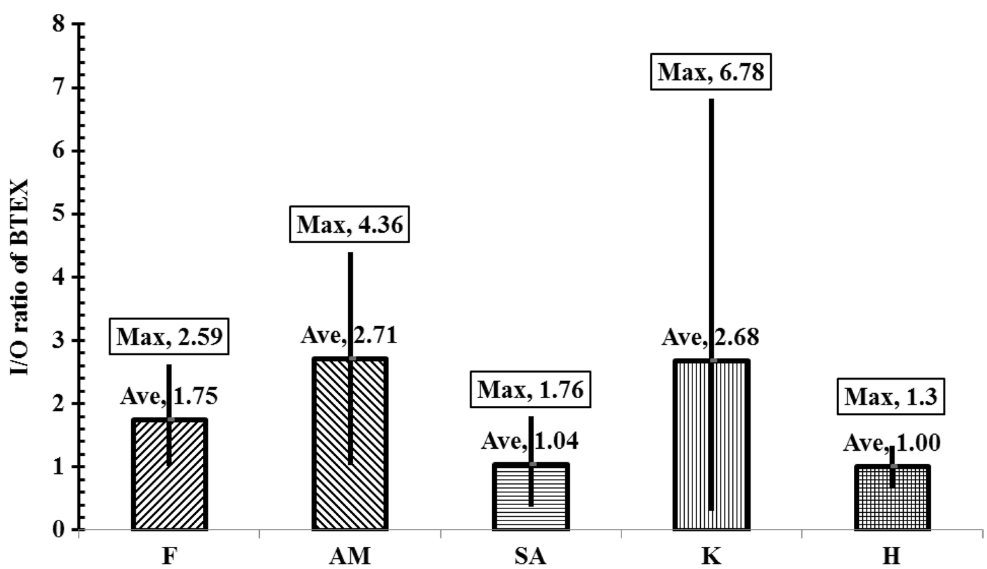


Fig. 6 Indoor/outdoor ratio concentration of sum of BTEX compounds at various residential areas

filling stations and samples around the fuel dispensing station. NO_x and I/O TVOC values reflected road traffic in general rather than the sales patterns of individual fuel dispensing stations.

Figure 6 shows the average indoor/outdoor ratio (I/O) of various residential areas around the selected fuel dispensing stations. At residence no. 14 in Khaitan, an I/O ratio of 6.8 can be seen, thus indicating high levels of indoor BTEX. This result is in agreement with Elkilani and Bouhamra (2001) as reported that indoor concentrations of VOCs are higher than the outdoor measured concentrations. These high levels are due to the presence of many vehicles in this location, which is a centrally located service station in the area. The next highest I/O ratios of 4.4 and 2.6 were seen at residence no. 5 in Abdullah Al-Mubarak and residence no. 2 in Farwaniya, respectively. These high levels of BTEX are due to an internal source, which could be from internal refurbishing or renovation of the house. An average I/O ratio of 1.02 was seen in the residential areas of Saad Al-Abdullah and Hawally, indicating an equal dispersion of BTEX in these regions. The total VOCs concentrations not only depended on the outdoor income but also the building characteristics to several extents (Langer et al. 2016).

The high average concentrations of NO_x, such as 108.68, 90.3 and 84.4 μg m^{-3}, in areas such as Hawally, Saad Al-Abdullah and Kaifan, respectively, reflect the large volume of traffic in these areas. An internal residential Diwaniya (traditional gathering area) with casual cigarette smoking at residence no. 9 contributed to the high NO_x concentration of 212 μg m^{-3} in the Saad Al-Abdullah area. Residence no. 19 in Hawally showed an exceptionally high NO_x concentration of 200 μg m^{-3} which was due to it being south-east of the fuel filling station and near an oil service station. Alenezi and Al-Anezi (2015) confirmed that in the State of Kuwait, the concentration of NO_2 is strongly influenced by on-road mobile source emissions and the higher concentration of NO_2 can be recognized in the downtown areas.

Conclusion

Passive sampling technique has been used to measure BTEX and NO_x in five fuel dispensing stations and four surrounding residential homes for each station for exposed of 1 week.

The highest concentration of total BTEX compounds was found at the Hawally fuel dispensing station, which is located in the old part of the city, is very central and is almost always congested with light-duty vehicles. Fuel dispensing was not that high, but elevated levels of total BTEX (405 μg m^{-3}) indicated emissions from neighbouring road traffic. The distribution of BTEX compounds emitted from the filling station was associated with the total emission and meteorological conditions.

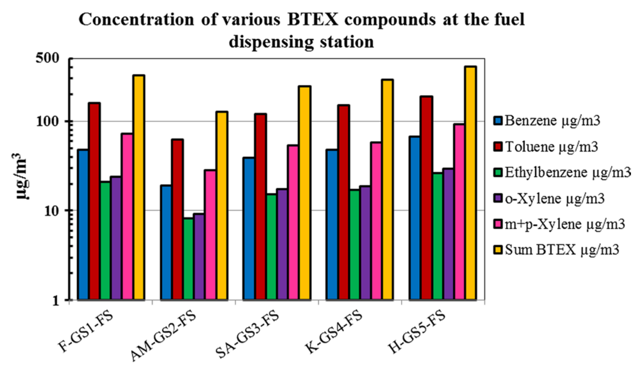
The dispersions of both NO_x and total BTEX were noticeably high at a downwind location. The highest NO_x concentration was not at the fuel dispensing station but in indoor flat no. 15, near residence no. 19, on the fourth floor downwind of the fuel filling station and near a car service station where road traffic contributed to the build-up of this value. The ambient NO_x concentration was high above the fuel storage near the breathing pipe. The dispersion of NO_x was almost uniform, resulting in an average value of 76.3 μg m^{-3}.

The results of two-way ANOVA application without replication to total BTEX showed insignificant variance among the different fuel stations but significant variance among the different sites of each fuel station. The result of two-way ANOVA applied to NO_x and I/O ratio of total BTEX concluded insignificant variance among the different fuel dispensing stations and among the different sampling sites for each fuel dispensing station. The null hypothesis was accepted.

This research project was an initial assessment of air pollution levels around fuel dispensing stations in urban localities. A comprehensive study with health risk assessment of the people living in the neighbouring residential dwellings is of high importance. The study should not be restricted to BTEX but should be conducted for all VOCs, including aliphatic, aromatic, oxygenated and halogenated compounds.

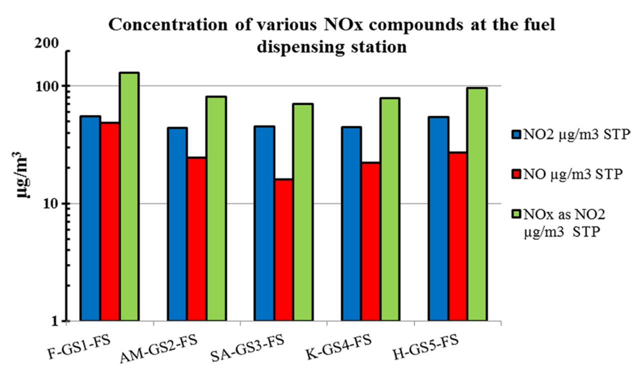
Acknowledgements The authors are grateful to the Public Authority for Applied Education and Training (PAAET) for funding this project (TS-14-002).

Appendix 1: Concentration of various BTEX compounds at selected fuel dispensing stations in Kuwait



F-Farwaniya; AM-Abdullah Al-Mubarak; SA-Saad Al-Abdullah; K-Kaifan; H-Hawally

Appendix 2: Concentration of various NO_x compounds at selected fuel dispensing stations in Kuwait



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