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Characteristics and health effects of BTEX in a hot spot for urban pollution

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Abstract

This study reports a spatiotemporal characterization of toluene, benzene, ethylbenzene, and xylenes concentrations (BTEX) in an urban hot spot in Iran, specifically at an bus terminal region in Shiraz. Sampling was carried out according to NIOSH Compendium Method 1501. The inverse distance weighting (IDW) method was applied for spatial mapping. The Monte Carlo simulation technique was applied to evaluate carcinogenic and non-carcinogenic risk owing to BTEX exposure. The highest average BTEX concentrations were observed for benzene in the morning (at 7:00–9:00A.M. local time) (26.15±17.65μg/m^3) and evening (at 6:00–8:00P.M. local time) (34.44±15.63μg/m^3). The benzene to toluene ratios in the morning and evening were 2.02 and 3.07, respectively. The main sources of BTEX were gas stations and a municipal solid waste transfer station. The inhalation lifetime cancer risk (LTCR) for benzene in the morning and evening were 1.96×10^{-4} and $2.49\times10^{-4,}$ respectively, which exceeds the recommended value by

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US EPA and WHO. The hazard quotient (HQ) of all these pollutants was less than 1. The results of this work have implications for public health near ‘hot spots’ such as IKBT where large populations are exposed to carcinogenic emissions.

Keywords

Risk assessment; BTEX; Spatial mapping; Hazard quotient

1. Introduction

Vehicular exhaust is one of the most important anthropogenic sources of air pollution in the ambient urban atmosphere (Bruno et al., 2008; Kalenge et al., 2013; Saxena and Ghosh, 2012; Yurdakul et al., 2013), a major constituent of which includes volatile organic compounds (VOCs) (Bruno et al., 2008; Esteve-Turrillas et al., 2007; Han et al., 2005; Jiang et al., 2017; Kim et al., 2012; Lau and Chan, 2003; Neghab et al., 2017; Özden et al., 2008; Parra et al., 2008a; Qiu et al., 2016). An important class of VOCs is the suite of BTEX (benzene, toluene, ethylbenzene, m/pxylene, and o-xylene) species, which have been the focus of many toxicological studies (Fazlzadeh Davil et al., 2011; Halliday, 2016; Hazrati et al., 2016a, 2015; Marć et al., 2016; Rad et al., 2014; Sairat et al., 2015). Ideal regions to study BTEX emissions and impacts include ‘hot spots’, which are typically urban areas where ambient levels significant exceed those of surrounding remote areas (Zhu et al., 2008). Pollution in developing countries has significantly increased in recent years and fresh emissions especially are a major health concern for large populations in these areas (Bauri et al., 2016; Hazrati et al., 2016b; Masih et al., 2016; Rad et al., 2014; Saxena and Ghosh, 2012; Tunsaringkarn et al., 2014).

BTEX is an important class of compounds owing to the abundance of these species in the ambient atmosphere, their deleterious impacts on public health, and their function in atmospheric chemistry (Alghamdi et al., 2014; Parra et al., 2008a). Their sources, including in this work’s study region, include vehicular exhaust, gas stations, industrial activity, landfill sites, municipal solid waste (MSW) stations, and combustion for domestic heating (Bruno et al., 2008; Carrieri et al., 2006; Chiriac et al., 2007, 2011; Correa et al., 2012; Durmusoglu et al., 2010; Jiang et al., 2017; Kim et al., 2008; Kountouriotis et al., 2014; Marć et al., 2016; Sairat et al., 2015; Terrés et al., 2010; Wu et al., 2006; Xiong et al., 2016). Past work has shown that more than 45% of total VOC emissions, such as for benzene and toluene, in Mexico City, the United Kingdom, and Los Angeles stemmed from gas stations, evaporation of petrol, and motor vehicle emissions (Correa et al., 2012; Durmusoglu et al., 2010). In terms of health effects, benzene is categorized as carcinogen, ethylbenzene is recognized as a potential carcinogen, while toluene and xylene are classified as Group D carcinogens or non-carcinogenic (Cancer, 2002; Demirel et al., 2014; Li et al., 2009; Tunsaringkarn et al., 2012; Von Burg, 1993). Furthermore, benzene impacts blood production, the lymphatic system, and the central nervous system (Correa et al., 2012; Duarte-Davidson et al., 2001; Moolla et al., 2015), while toluene impacts the reproductive and central nervous systems (Chen et al., 2011; Correa et al., 2012; Duarte-Davidson et al., 2001; Kalenge et al., 2013; Moolla et al., 2015; Tunsaringkarn et al., 2012). With regard to

atmospheric chemistry, photochemical reactions of BTEX pollutants can generate secondary pollutants, such as ozone and secondary aerosol via gas-to-particle conversion processes (Alghamdi et al., 2014; Bell, 2006; Crosbie et al., 2014; Demirel et al., 2014; Han et al., 2005; Kourtidis et al., 2002; Marć et al., 2014; Ng et al., 2007; Saxena and Ghosh, 2012; Sorooshian et al., 2007; Srivastava et al., 2006; Zhao et al., 2004).

The major component of gasoline is benzene, which is released from gasoline engines (Weisel, 2010). The benzene-to-toluene (B/T) ratio is often applied as an index for determining the emission sources of BTEX compounds (Buczynska et al., 2009; Cheng et al., 2016; Elbir et al., 2007; Legay et al., 2011; Parra et al., 2008b). A ratio exceeding 0.5 suggests that the source of benzene is not only related to traffic but also other sources (Jiang et al., 2017; Yurdakul et al., 2013). Moreover, B/T ratios lower than 0.5 suggest that transportation is the predominant source of BTEX (Elbir et al., 2007; Hartmann et al., 1997; Zhang et al., 2008). For instance, Hartmann et al. (1997) and Elbir et al. (2006) showed that the B/T ratio in a suburban area was about 0.16–1, while next to congested roadways, the B/T ratio was about 0.5 (Elbir et al., 2007; Hartmann et al., 1997). In addition to the B/T ratio, the xylenes/benzene (X/B) and ethylbenzene/benzene (Ebz/B) ratios are generally applied as indices of photochemical, reactivity. For example, small X/B and Ebz/B ratios (<1) suggest that sampled air masses are photochemically aged (e.g., via reactions with the hydroxyl radical) and that benzene has a relatively low reactivity as compared with ethylbenzene and xylenes; consequently, benzene can be transported to other regions without degradation (Bauri et al., 2016; Hoque et al., 2008).

The aim of this work is to investigate BTEX characteristics near a congested intercity bus terminal, including the effects of their emissions on public health. More specifically, the subsequent discussion focuses on a report of concentrations, spatial and temporal characteristics, photochemical aging, and risk assessment of BTEX in the ambient air of the Intercity Karandish Bus Terminal (IKBT) area in Shiraz, Iran. This is the first such study examining BTEX in this understudied, yet largely populated, region in the Middle East with attention geared towards spatial and diurnal trends.

2. Material and methods

2.1. Study area

Shiraz is the capital of the Fars Province in the semi-arid and southwestern part of Iran (29°36′ N, 52°32′ E). It has a population of ~ 1.8 million, based on the last census report in 2016, which qualifies it as the fifth most populated city in Iran (Statistical Centre of Iran (SCI), 2016). Shiraz covers 240km^2 of area and consists of 11 urban districts with an average population density of approximately 6890 residents per km^2 (Statistical Centre of Iran (SCI), 2016). Shiraz is one of the most polluted cities in Iran (Arfaeinia et al., 2017), with the IKBT hot spot being one of the main reasons (Statistical Centre of Iran (SCI), 2016). This area has the largest intercity bus terminal (Karandish) in the southwest of Iran. Fig. 1 shows a spatial map of Shiraz and the sampling stations. The stations were chosen based on several factors such as proximity to gas stations, level of congestion, population characteristics, and convenience for sampling. The study area is located between a longitude of 52°33′20″ and 52°34′20″ and latitudes of 29°37′20″ and 29°36′20″ (Fig. 1).

2.2. Sampling and analysis

Sampling of BTEX compounds was carried out according to NIOSH Compendium Method 1501 (Pendergrass, 2003; Schlecht and O'Conner, 1994). BTEX concentrations were measured over the duration of two hours in the morning (7:00–9:00A.M. local time) and evening (6:00–8:00P.M. local time) via active sampling (SKC, Model 222-ml/COUNT) using a charcoal glass tube at a flow rate of 0.2l per minute (Muezzinoglu et al., 2001; Pendergrass, 2003; Schlecht and O'Conner, 1994). Sampling was carried out every third day in all 18 locations. Sampling was conducted above street level (at a height of 2m). The final set of 180 samples (90 for morning and 90 for evening) was collected over four consecutive weeks in November 2016. After sampling, the charcoal tubes were tagged, covered, and stored at 4°C to minimize contamination and desorption.

Samples were analyzed within 72h after collection. Before analysis, the main and second sections of the charcoal tube were placed into two vials and BTEX compounds were extracted by adding 1ml carbon disulfide (ASTM, 1995; Hydrocarbons, 2003). The vials were subsequently shaken via ultrasonication for 20min. Next, all samples were centrifuged until a clear phase was acquired at the top of the micro tube (10min). BTEX compounds were examined using gas chromatography–mass spectrometry (GC-MS) (GC 7890N, AGILENT-MS 5975C, MODE EI). Helium was the carrier gas at 1ml/min with a split ratio of 1:5 and inlet temperature 200°C, respectively.

Data were analyzed using the SPSS statistical software (Version 22). The relationship between target compounds were evaluated by Spearman's rho correlation coefficient. Benzene to toluene (B/T), xylenes-to-benzene (X to B), and ethylbenzene-to-benzene (Ebz to B) ratios were calculated for the morning and evening in order to evaluate photochemical aging and to determine emission sources of target compounds. Additionally, the student's *t*-test was applied to find the level of statistical significance of correlation coefficients.

2.3. Quality assurance/quality control (QA/QC)

In order to check for possible artifacts, such as breakthrough in the two sections of the charcoal tubes, analysis was done for both the primary and back-up tubes. There was no evidence of BTEX contamination in the charcoal tube sections. The recovery of analytical method was measured by spiking the charcoal tubes with 10μg of BTEX compounds. The limits of detection (LOD) were quantified as three times the standard deviation (SD) of the blank values. Limits of quantitation (LOQ) were calculated as ten times the SD of the blank values. Eighteen samples were gathered as blank samples and the concentrations ($\mu g/m^3$) of BTEX compounds in blank samples ranged from 0.00 to 0.022 for benzene, 0.00 to 0.021 for toluene, 0.00 to 0.008 for ethylbenzene and 0.00 to 0.008 for xylene. The LOD and LOQ of these components were as follows ($\mu g/m^3$): 0.021 and 0.068 (benzene), 0.022 and 0.072 (toluene), 0.008 and 0.027 (ethylbenzene), 0.012 and 0.039 (m, p-xylene) and 0.008 and 0.027 (o-xylene); also, recovery values of BTEX constituents ranged from 95.3±2.2% to 99.8±2.6% with relative SDs less than 3.5%. The calibration was achieved in six levels (0.01–60$\mu g/m^3$) of standard solutions and R^2 values of 0.998 for benzene, 0.987 for ethylbenzene, 0.989 for toluene, and 0.988 for xylene were acquired. A diagram of the steps of the procedures work are shown in Fig. 2.

2.4. Spatial distributions

ArcGIS software (Version 10.3) was used to conduct spatial analysis. The IDW interpolator method was employed to make raster layers for the average concentration of BTEX components and to show the distribution of all the targeted pollutants in the IKBT region. Subsequently, the raster calculation function was applied to overlay each layer and generate mean maps of target pollutants. The IDW model equation is as follows (Miri et al., 2016; Wang et al., 2014; Xie et al., 2011):

$$\lambda_i = \frac{Di - \alpha}{\sum_{i=1}^{n} Di - \alpha} \quad (1)$$

where λ_i is the weight of the *i* sample point, α is the weighting power, and D_i is the distance between the station *i* and uncertain point, which was variable in our study.

Higher values were allocated to values closer to the interpolated point; in this regard, Miri et al. (2016), and Shepard et al. (1968) reported that as the distance increases, the weight decreases. The number of stations used in the interpolation is *n*, which was 10 in this study.

Numerous studies have applied the IDW technique for spatial mapping of pollutants such as polycyclic aromatic hydrocarbons (PAHs) in Pennsylvania, USA (Witter et al., 2014), O_3 in northern Georgia, China, and Belgium (Bell, 2006; Hooyberghs et al., 2006; Wang et al., 2014), PM_{10} and $PM_{2.5}$ in USA and China (Wang et al., 2014; Yanosky et al., 2008), and CO, SO_2, and NO_2 in China (Wang et al., 2014). The IDW technique has been expanded in the environmental field to forecast ambient air pollutants' concentration. Furthermore, IDW is beneficial when the distribution of the computed variables is unusual.

2.5. Health risk assessment

Benzene has harmful impacts on human health and it is a suspected carcinogen (Dutta et al., 2009; EPA, 1999). In order to assess the risk to the human health created by BTEXs, the non-carcinogenic risk of target components and inhalation lifetime cancer risk (LTCR) of benzene was calculated using the data obtained in this study.

The LTCR was computed based on the following equation (Li et al., 2008; Miri et al., 2016):

$$\mathrm{LTCR} = \mathrm{CDI} \times \mathrm{CSF} \quad (2)$$

where CSF and CDI are the cancer slope factor (mg/kg-day) and chronic daily intake "air intake" (mg/kg-day), respectively. In addition, the chronic daily intake was determined by the following equation (Li et al., 2008; Miri et al., 2016):

$$CDI = (\mathrm{C} \times \mathrm{IR} \times \mathrm{CF} \times \mathrm{ED} \times \mathrm{EF})/(\mathrm{AT} \times \mathrm{BW}) \quad (3)$$

where C represents ambient concentration of pollutants (μg/m^3), CF and IR are the conversion factor (mg/μg) and the human inhalation rate (m^3/day), respectively, and ED, EF, BW, and AT are exposure duration (yr), exposure frequency (days/yr), body weight (kg), and average lifetime (yr), respectively (Li et al., 2008; Miri et al., 2016).

In order to address uncertainties in the calculations related to health risk estimates, Monte Carlo simulations were conducted using Oracle Crystal Ball 11.1.2.3 (sensitivity analysis). Table 1 displays the selected parameters utilized for risk assessment and sensitivity analysis.

Risk assessment for the non-carcinogenic of target components is represented in terms of the hazard quotient (HQ) parameter, which is expressed as the ratio of chronic daily intake (CDI) (mg/kg-day) and the reference concentration (RfC) (mg/kg-day) (Li et al., 2008; Miri et al., 2016):

$$HQ = CDI/RfC \quad (4)$$

HQ >1 indicates that the potential risk may be important, while HQ values less than and equal to one indicate is a more acceptable levek as the dose level is lower than the RfC (Demirel et al., 2014; Miri et al., 2016; Moolla et al., 2015; Tunsaringkarn et al., 2012; Zhang et al., 2012). For computing the chronic daily intake, the mean concentrations of BTEX were used. The cancer slope factor for benzene is 0.029mg/kg-day (EPA, 1999; Moolla et al., 2015) and RfD for benzene, toluene, xylenes, and ethylbenzene were 0.03, 5, 0.01, and 1mg/kg-day, respectively (EPA, 1999; Moolla et al., 2015). It should be noted that the LTCR for other BTEX species such as xylenes, toluene and ethylbenzene (TEX) cannot be calculated since there are no cancer slope factors for these pollutants (Miri et al., 2016; Moolla et al., 2015).

3. Results and discussion

3.1. BTEX concentrations

The mean and standard deviation concentrations of benzene (B), toluene (T), ethylbenzene (Ebz), m/p-xylene ((m & p)-X), and o-xylene (O-X) concentrations in the morning hours were 26.15±17.65, 12.97±7.12, 7.50±2.50, 19.34±6.49, and 23.38±8.28μg/m^3, respectively. In evening hours, the average and standard deviation concentrations for the same species were 34.44±15.63, 11.20±5.56, 6.58±1.95, 16.81±5.76, and 21.25±7.13μg/m^{-3}, respectively. These findings display that benzene was the most abundant of the four species, regardless of time of day.

Reasons for benzene being highest in concentration in this region could be linked to differences in the benzene content of the petrol in Shiraz as compared to other cities of Iran, and emissions from gas/petrol stations and the municipal solid waste (MSW) transfer station. Hence, the results of this study are in line with the findings from Mumbai (India) and Monterrey (Mexico), gasoline and CNG refueling stations in Ardabil (Iran), a gas station in Yazd (Iran), and MSW landfills in France where benzene was the most abundant among the species examined here (Chiriac et al., 2007; Hazrati et al., 2016b; Mosaddegh

Mehrjerdi et al., 2014; Srivastava et al., 2006). Moreover, Srivastava et al. (2006) and Cerón-Bretón et al. (2015) in Mumbai and in Monterrey, respectively, showed the following order of abundance: benzene >toluene >ethylbenzene >xylenes.

Fig. 3 illustrates a statistical summary of BTEX species, and total BTEX concentrations in the morning and evening. The maximum and minimum concentrations for mornings and evenings were 55.28±5.35μg/m^3 for B and 4.16±0.30μg/m^3 for T in the morning and 56.58±5.76μg/m^3 for benzene and 3.99±0.28μg/m^3 for ethylben-zene in the evening, respectively. These findings are opposite of previous studies since benzene was the most abundant as compared to other components of BTEX in ambient air (Cerón-Bretón et al., 2015; Mohamed et al., 2002; Moolla et al., 2015; Mosaddegh Mehrjerdi et al., 2014; Srivastava et al., 2006). The mean values of benzene observed by Moolla et al. (2015) (South Africa), Hazrati et al. (2016a, 2016b) (Ardabil, Iran), Mosaddegh Mehrjerdi et al. (2014) (Yazd, Iran), Mohamed et al. (2002) (United States), Srivastava et al. (2006) (Mumbai, India), and Cerón-Bretón et al. (2015) (Monterrey, Mexico) were, 313.16, 1690, 1932, 18.94, 539.95, and 55.24μg/m^3, respectively (Cerón-Bretón et al., 2015; Hazrati et al., 2016b; Mohamed et al., 2002; Moolla et al., 2015; Mosaddegh Mehrjerdi et al., 2014; Srivastava et al., 2006). A factor affecting the diurnal profile of benzene is time-dependent emissions in the vicinity of either gas stations (Kountouriotis et al., 2014; Rattanajongjitrakorn and Prueksasit, 2014) or heavily congested roadways (Correa et al., 2012; Kourtidis et al., 2002; Lin et al., 2011). In addition, the results of this study reveal that the average concentration of BTEX was more than other studies, specifically those conducted in the Tri-City area (Gdansk, Gdynia, Sopot), Poland (Marć et al., 2014), Ardabil, Iran (Hazrati et al., 2016b), and Gorakhpur, India (Masih et al., 2016). This can most likely be explained by the combination of heavy traffic, fuel quality standards, old cars, and vicinity to five gas stations in the sampling region of IKBT. In addition, previous studies reported that different refineries in Iran generate petrol with different qualities in terms of aromatic compounds (Hazrati et al., 2016b). Benzene included in gasoline varies from 1% to 5%, depending on the countries' legislation, fuel quality and season (Karakitsios et al., 2007). Consequently, BTEX compounds, especially benzene, measured in gas stations in the region of IKBT reach very high levels. An additional source of BTEX emission around IKBT is a nearby a MSW transfer station. Past work has also linked emissions from MSW landfills (MSWLF) to high levels of BTEX components (Chiriac et al., 2007, 2009, 2011; de Sá Borba et al., 2017; Durmusoglu et al., 2010; Kim et al., 2008).

3.2. The ratios between target components

3.2.1. The ratio of Benzene to toluene (B to T)—The ratio of B to T is generally utilized as an identifier for emission sources of target compounds (Hazrati et al., 2016b; Jiang et al., 2017; Masih et al., 2016; Miri et al., 2016). Table 1 compares BTEX concentrations and it various ratios in the current study versus other regions. B/T ratios in the morning and evening were 2.02±0.55 and 3.07±1.12, respectively. These high ratio values of benzene to toluene are attributed to multiple sources of benzene such as gas and petrol stations, emissions related to traffic and irregular sources, and MSW emissions that produce leachate containing BTEX (Chiriac et al., 2011; Durmusoglu et al., 2010). B/T (2.02–3.07) ratios in this study were similar to those in Orleans, France (3.22), Monterrey,

Mexico (2.48), Mumbai, India (1.55–1.78), and Yazd, Iran (2.89) (Bauri et al., 2016; Jiang et al., 2017; Mosaddegh Mehrjerdi et al., 2014; Srivastava et al., 2006). In contrast, lower ratios were observed in the region of La Plata (Argentina) (0.36) (Massolo et al., 2010), Carmen (Mexico) (0.39–0.36) (Cerón et al., 2013), Rome (Italy) (0.36), Izmir (Turkey) (0.53–0.5) (Muezzinoglu et al., 2001), and Delhi (India) (0.5–0.39) (Hoque et al., 2008). Differences in the B/T ratio between these studies is due to the diversity in the vehicular fleets, fuel formula, and industrial activities.

3.2.2. Ratios of xylenes to benzene (Xs to B) and ethylbenzene/benzene (Ebz/B)—

The mean values of the (M&P)-X to B (0.49–0.74), O-X to B (0.62–0.89), and Ebz/B (0.19–0.28) are presented in Table 1. Small X/B and Ebz/B ratios in our study suggest that the sampled air masses were photochemically aged (e.g., via reactions with hydroxyl radicals) and that benzene has a relatively low reactivity as compared with ethylbenzene and xylenes. Therefore, M&P-xylene, ethylbenzene and o-xylene could be included in photochemical reactions with hydroxyl radicals (Bauri et al., 2016; Jiang et al., 2017; Masih et al., 2016; Muezzinoglu et al., 2001). These results emphasize the findings of previous research, in which the minimum concentration of BTEX species was for ethylbenzene and xylenes (Bauri et al., 2016). In addition, higher benzene and toluene concentrations were measured in past work over the United States in line with our findings (Pankow et al., 2003). Also, the X/B ratio (0.49–0.89) in this study is comparable to Orleans, France (0.28–1.09) (Jiang et al., 2017) and Delhi, India (0.34–0.87) (Hoque et al., 2008). Moreover, X/B and Ebz/B ratios could also be indicative of air mass age (Tunsaringkarn et al., 2014). According to Jiang et al. (2017) and Hsieh et al. (2011), small X/B and Ebz/B ratios indicate that xylenes stem from transport.

3.3. Spatial analysis of BTEXs

The spatial distribution of benzene, BTEX components, and the sum of BTEX for morning and evening is shown in Fig. 4. The spatial distribution (Figs. 1 and 4) displays that the highest BTEX concentrations in the morning and evening were at points 4, 7, 16, and 17. This can be explained by proximity to several sources including IKBT, roads with heavy traffic, the MSW station, and five gas stations. In addition, the results revealed that ethylbenzene and isomers of xylene exhibited a similar distribution, while benzene, toluene, and total BTEX were different in the morning (Fig. 4a). Furthermore, spatial mapping in the evening showed that distribution of TEX species and total BTEX were similar, while benzene was different. The concentrations of benzene in sampling points 16 and 17 in the south (three gas stations) were about 1–2.2 times higher than that in sampling points 4 and 7 (two gas stations). The wind direction is mainly northerly, which is the main reason why BTEX can migrate from the petrol station and bus terminal in the north to points 16 or 17 and accumulate in the southern area. Furthermore, Parra et al. (2006) mentioned that benzene had different distribution than TEX pollutants because benzene has a relatively low reactivity with ˙OH; consequently, this pollutant can be transported to other regions without degradation. The spatial analysis indicated that BTEX levels decreased with increasing distance from strong emissions sources such as gas stations and the MSW station; this is in line with the findings of another study in Tehran, Iran (Miri et al., 2016) and in Gothenburg, Sweden (Thorsson and Eliasson, 2006).

3.4. The correlations among BTEX species

Table 2 reports on correlations between the BTEX species based on mean concentrations in both the morning and evening. There were significant positive correlations between BTEX species in the morning as well as in the evening. This result suggests that the emission sources of BTEX species are similar in both the morning and evening. Besides, Hoque et al. (2008), Rad et al. (2014), Miri et al. (2016), and Miller et al. (2010) reported that a strong correlation was obtained between BTEX compounds. Similarly, in this study a strong correlation was obtained between TEX compounds. The correlation coefficients (r) for TEX compounds were high in the morning as compared with the evening. The minimum correlation coefficient (r=0.005, P-value =0.984) was observed between benzene and m/p-xylene. This can be attributed to the various sources of BTEX species. The main source of benzene in the study region is gas stations. Nevertheless, the other sources of TEX could be related to bus traffic, gas stations, as well as the MSW station. No statistically significant differences were found between the BTEX species in the morning and evening based on the following p-values: 0.157 for benzene, 0.424 for toluene, 0.239 for ethylbenzene, 0.237 for (m+p)-xylene, 0.414 for o-xylene.

3.5. Health risk assessment

The LTCR between 1×10^{-5} and 1×10^{-6} has been regarded as “acceptable” by the WHO while the US EPA has suggested a LTCR under 1×10^{-6} (Gong et al., 2017; Miri et al., 2016). As can be observed in Fig. 5 and Table 3, the average LTCRs of benzene in the morning and evening were 1.96×10^{-4} and 2.49×10^{-4}, respectively, which exceed the recommended value by US EPA and WHO. Similar findings have been obtained by Li et al. (2014) in the ambient urban atmosphere of Beijing (China) (Li et al., 2014), in the north urban atmosphere of India (Masih et al., 2016), and by a gas station in Bangkok, Thailand (Tunsaringkarn et al., 2012) with mean LTCR values of benzene reported at 1.34×10^{-5}, $4.6\times10^{-6,}$ and 1.75×10^{-4}, respectively. In addition, different results have been obtained by Miri et al. (2016) in the ambient air in Tehran, Iran and Hu et al. (2010) in the ambient air in Nanjing, China with mean LTCR values of benzene reported at 3.93×10^{-7} and $1\times10^{-7,}$ respectively.

Results from the model simulations focused on sensitivity analysis of benzene LTCR are summarized in Fig. 5. Factors examined included body weight, inhalation rate, exposure duration, averaging time, and exposure frequency. The percentage value relevant to each variable represents the amount of the LTCR accounted for by that variable. The concentration of the pollutant had the highest positive contribution and body weight (BW) exhibited the most negative contribution to affect the average lifetime cancer risk for both the morning and evening. Furthermore, Miri et al. (2016) reported that BW was the most negative portion (−51.6%) to the average lifetime cancer risk (Miri et al., 2016).

The results of hazard quotient (HQ) are introduced in Table 3. The results of present study displayed that the hazard quotient of all BTEX pollutants are less than 1. Therefore, there is less concern about non-carcinogenic risk of these pollutants in the study area.

4. Conclusion

This study reports on ambient measurements of BTEX pollutant concentrations in the ambient urban atmosphere in the morning and evening in a busy bus terminal region of Shiraz, Iran. Spatial analysis showed revealed that BTEX levels decreased with increasing distance from the municipal solid waste (MSW) transfer station and that maximum BTEX concentrations were observed in the surrounding gas/petrol stations. High B:T ratios are attributed to emissions of traffic sources. Maximum diurnal mean concentrations of benzene were observed in the evening, while maximum levels of the ETX components were measured in the morning. The average inhalation lifetime cancer risk (LTCR) of benzene in the morning and evening exceeded the recommended value by the US EPA and WHO, while a hazard quotient (HQ) less than one indicated harmful impacts on the exposed population.

The results of this work have implications for public health near areas such as IKBT where large populations are exposed to carcinogenic emissions. One potential way to minimize exposure of large populations to high concentrations is to move an emissions hot spot, such as IKBT, which has gas stations and a MSW station, to areas outside the urban centre.

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References

Alghamdi M, Khoder M, Abdelmaksoud A, Harrison R, Hussein T, Lihavainen H, et al. Seasonal and diurnal variations of BTEX and their potential for ozone formation in the urban background atmosphere of the coastal city Jeddah, Saudi Arabia. Air Qual Atmos Health. 2014; 7:467–480.

Arfaeinia H, Kermani M, Aghaei M, Asl FB, Karimzadeh S. Comparative investigation of health quality of air in Tehran, Isfahan and Shiraz metropolises in 2011-2012. J Health Field. 2017; 1

ASTM D. 3687. Standard Practice for Analysis of Organic Compound Vapors Collected by the Activated Charcoal Tube Adsorption Method. American Society for Testing Materials; West Conshohocken PA, USA: 1995.

Bauri N, Bauri P, Kumar K, Jain V. Evaluation of seasonal variations in abundance of BTXE hydrocarbons and their ozone forming potential in ambient urban atmosphere of Dehradun (India). Air Qual Atmos Health. 2016; 9:95–106.

Bell ML. The use of ambient air quality modeling to estimate individual and population exposure for human health research: a case study of ozone in the Northern Georgia Region of the United States. Environ Int. 2006; 32:586–593. [PubMed: 16516968]

Bruno P, Caselli M, de Gennaro G, Scolletta L, Trizio L, Tutino M. Assessment of the impact produced by the traffic source on VOC level in the urban area of Canosa di Puglia (Italy). Water Air Soil Pollut. 2008; 193:37–50.

Buczynska AJ, Krata A, Stranger M, Godoi AFL, Kontozova-Deutsch V, Bencs L, et al. Atmospheric BTEX-concentrations in an area with intensive street traffic. Atmos Environ. 2009; 43:311–318.

Cancer, I.A.f.Ro.. IARC Handbooks of Cancer Prevention. Vol. 6. The Agency 6; 2002.

Carrieri M, Bonfiglio E, Scapellato ML, Maccà I, Tranfo G, Faranda P, et al. Comparison of exposure assessment methods in occupational exposure to benzene in gasoline filling-station attendants. Toxicol Lett. 2006; 162:146–152. [PubMed: 16289653]

Cerón-Bretón J, Cerón-Bretón R, Kahl J, Ramírez-Lara E, Guarnaccia C, Aguilar-Ucán C, et al. Diurnal and seasonal variation of BTEX in the air of Monterrey, Mexico: preliminary study of sources and photochemical ozone pollution. Air Qual Atmos Health. 2015; 8:469–482.

Cerón J, Ramírez E, Cerón R, Carballo C, Aguilar C, López U, et al. Diurnal and seasonal variation of BTX in ambient air of one urban site in Carmen City, Campeche, Mexico. J Environ Prot. 2013; 4:40.

Chen X, Zhang G, Zhang Q, Chen H. Mass concentrations of BTEX inside air environment of buses in Changsha, China. Build Environ. 2011; 46:421–427.

Cheng JH, Hsieh MJ, Chen KS. Characteristics and source apportionment of ambient volatile organic compounds in a science park in central Taiwan. Aerosol Air Qual Res. 2016; 16:221–229.

Chiriac R, Carre J, Perrodin Y, Fine L, Letoffe JM. Characterisation of VOCs emitted by open cells receiving municipal solid waste. J Hazard Mater. 2007; 149:249–263. [PubMed: 17826906]

Chiriac R, Carre J, Perrodin Y, Vaillant H, Gasso S, Miele P. Study of the dispersion of VOCs emitted by a municipal solid waste landfill. Atmos Environ. 2009; 43:1926–1931.

Chiriac R, Morais JDA, Carre J, Bayard R, Chovelon J, Gourdon R. Study of the VOC emissions from a municipal solid waste storage pilot-scale cell: comparison with biogases from municipal waste landfill site. Waste Manag. 2011; 31:2294–2301. [PubMed: 21778044]

Correa SM, Arbilla G, Marques MR, Oliveira KM. The impact of BTEX emissions from gas stations into the atmosphere. Atmos Pollut Res. 2012; 3:163–169.

Crosbie E, Sorooshian A, Monfared NA, Shingler T, Esmaili O. A multi-year aerosol characterization for the greater Tehran area using satellite, surface, and modeling data. Atmosphere. 2014; 5:178–197. [PubMed: 25083295]

de Sá Borba PF, Martins EM, Ritter E, Corrêa SM. BTEX Emissions from the Largest Landfill in Operation in Rio de Janeiro, Brazil. Bull Environ Contam Toxicol. 2017; 98:624–631. [PubMed: 28255609]

Demirel G, Özden, Döğeroğlu T, Gaga EO. Personal exposure of primary school children to BTEX, NO 2 and ozone in Eskişehir, Turkey: relationship with indoor/outdoor concentrations and risk assessment. Sci Total Environ. 2014; 473:537–548. [PubMed: 24388904]

Duarte-Davidson R, Courage C, Rushton L, Levy L. Benzene in the environment: an assessment of the potential risks to the health of the population. Occup Environ Med. 2001; 58:2–13. [PubMed: 11119628]

Durmusoglu E, Taspinar F, Karademir A. Health risk assessment of BTEX emissions in the landfill environment. J Hazard Mater. 2010; 176:870–877. [PubMed: 20022163]

Dutta C, Som D, Chatterjee A, Mukherjee A, Jana T, Sen S. Mixing ratios of carbonyls and BTEX in ambient air of Kolkata, India and their associated health risk. Environ Monit Assess. 2009; 148:97–107. [PubMed: 18219584]

Elbir T, Cetin B, Cetin E, Bayram A, Odabasi M. Characterization of volatile organic compounds (VOCs) and their sources in the air of Izmir, Turkey. Environ Monit Assess. 2007; 133:149–160. [PubMed: 17180406]

EPA, U. Integrated Risk Information System (IRIS). EPA. 1999

Esteve-Turrillas FA, Pastor A, de la Guardia M. Assessing air quality inside vehicles and at filling stations by monitoring benzene, toluene, ethylbenzene and xylenes with the use of semipermeable devices. Anal Chim Acta. 2007; 593:108–116. [PubMed: 17531831]

Fazlzadeh Davil M, R R, Zarei A, Feizizadeh M, Mahdavi M, Mohammadi AA, Eskandari D. A survey of 24h variations of BTEX concentration in the ambient air of Tehran. J Babol Univ Med Sci. 2011; 14:50–55.

Gong Y, Wei Y, Cheng J, Jiang T, Chen L, Xu B. Health risk assessment and personal exposure to volatile organic compounds (VOCs) in metro carriages—a case study in Shanghai, China. Sci Total Environ. 2017; 574:1432–1438. [PubMed: 27535570]

Halliday HS. Benzene Observations and Source Appointment in a Region of Oil and Natural Gas Development. 2016

Han X, Aguilar-Villalobos M, Allen J, Carlton CS, Robinson R, Bayer C, et al. Traffic-related occupational exposures to PM2.5, CO, and VOCs in Trujillo, Peru. Int J Occup Environ Health. 2005; 11:276–288. [PubMed: 16130969]

Hartmann R, Voght U, Baumbach G, Seyfioglu R, Muezzinoglu A. Results of emission and ambient air measurements of VOC in Izmir. Environ Res Forum. 1997; 78:107–112.

Hazrati S, Rostami R, Farjaminezhad M, Fazlzadeh M. Preliminary assessment of BTEX concentrations in indoor air of residential buildings and atmospheric ambient air in Ardabil, Iran. Atmos Environ. 2016; 132:91–97.

Hazrati S, Rostami R, Fazlzadeh M. BTEX in indoor air of waterpipe cafés: levels and factors influencing their concentrations. Sci Total Environ. 2015; 524:347–353. [PubMed: 25912530]

Hazrati S, Rostami R, Fazlzadeh M, Pourfarzi F. Benzene, toluene, ethylbenzene and xylene concentrations in atmospheric ambient air of gasoline and CNG refueling stations. Air Qual Atmos Health. 2016; 9:403–409.

Ho K, Lee S, Guo H, Tsai W. Seasonal and diurnal variations of volatile organic compounds (VOCs) in the atmosphere of Hong Kong. Sci Total Environ. 2004; 322:155–166. [PubMed: 15081745]

Hooyberghs J, Mensink C, Dumont G, Fierens F. Spatial interpolation of ambient ozone concentrations from sparse monitoring points in Belgium. J Environ Monit. 2006; 8:1129–1135. [PubMed: 17075619]

Hoque RR, Khillare P, Agarwal T, Shridhar V, Balachandran S. Spatial and temporal variation of BTEX in the urban atmosphere of Delhi, India. Sci Total Environ. 2008; 392:30–40. [PubMed: 18067950]

Hsu DJ, Huang HL. Concentrations of volatile organic compounds, carbon monoxide, carbon dioxide and particulate matter in buses on highways in Taiwan. Atmos Environ. 2009; 43:5723–5730.

Hydrocarbons, A. NIOSH Manual of Analytical Methods (NMAM). 4th. NIOSH; 2003. Method 1501.

Jiang Z, Grosselin B, Daële V, Mellouki A, Mu Y. Seasonal and diurnal variations of BTEX compounds in the semi-urban environment of Orleans, France. Sci Total Environ. 2017; 574:1659–1664. [PubMed: 27613674]

Kalenge S, Lebouf RF, Hopke PK, Rossner A, Benedict-Dunn A. Assessment of exposure to outdoor BTEX concentrations on the Saint Regis Mohawk tribe reservation at Akwesasne New York state. Air Qual Atmos Health. 2013; 6:181–193.

Karakitsios SP, Papaloukas CL, Kassomenos PA, Pilidis GA. Assessment and prediction of exposure to benzene of filling station employees. Atmos Environ. 2007; 41:9555–9569.

Kim KH, Ho DX, Park CG, Ma CJ, Pandey SK, Lee SC, et al. Volatile organic compounds in ambient air at four residential locations in Seoul, Korea. Environ Eng Sci. 2012; 29:875–889. [PubMed: 22969269]

Kim KH, Shon ZH, Kim MY, Sunwoo Y, Jeon EC, Hong JH. Major aromatic VOC in the ambient air in the proximity of an urban landfill facility. J Hazard Mater. 2008; 150:754–764. [PubMed: 17574337]

Kountouriotis A, Aleiferis P, Charalambides A. Numerical investigation of VOC levels in the area of petrol stations. Sci Total Environ. 2014; 470:1205–1224. [PubMed: 24246944]

Kourtidis KA, Ziomas I, Zerefos C, Kosmidis E, Symeonidis P, Christophilopoulos E, et al. Benzene, toluene, ozone, NO_2 and SO_2 measurements in an urban street canyon in Thessaloniki, Greece. Atmos Environ. 2002; 36:5355–5364.

Lau WL, Chan LY. Commuter exposure to aromatic VOCs in public transportation modes in Hong Kong. Sci Total Environ. 2003; 308:143–155. [PubMed: 12738208]

Legay C, Rodriguez MJ, Sadiq R, Sérodes JB, Levallois P, Proulx F. Spatial variations of human health risk associated with exposure to chlorination by-products occurring in drinking water. J Environ Manag. 2011; 92:892–901.

Li L, Li H, Zhang X, Wang L, Xu L, Wang X, et al. Pollution characteristics and health risk assessment of benzene homologues in ambient air in the northeastern urban area of Beijing, China. J Environ Sci. 2014; 26:214–223.

Li S, Chen S, Zhu L, Chen X, Yao C, Shen X. Concentrations and risk assessment of selected monoaromatic hydrocarbons in buses and bus stations of Hangzhou, China. Sci Total Environ. 2009; 407:2004–2011. [PubMed: 19101019]

Li TT, Liu ZR, Bai YH. Human cancer risk from the inhalation of formaldehyde in different indoor environments in Guiyang City, China. Bull Environ Contam Toxicol. 2008; 81:200–204. [PubMed: 18446259]

Lin CC, Lin C, Hsieh LT, Chen CY, Wang JP. Vertical and diurnal characterization of volatile organic compounds in ambient air in urban areas. J Air Waste Manag Assoc. 2011; 61:714–720. [PubMed: 21850825]

Majumdar D, Dutta C, Mukherjee A, Sen S. Source apportionment of VOCs at the petrol pumps in Kolkata, India; exposure of workers and assessment of associated health risk. Transp Res Part D: Transp Environ. 2008; 13:524–530.

Marć M, Bielawska M, Simeonov V, Namieśnik J, Zabiegała B. The effect of anthropogenic activity on BTEX, NO_2, SO_2, and CO concentrations in urban air of the spa city of Sopot and medium-industrialized city of Tczew located in North Poland. Environ Res. 2016; 147:513–524. [PubMed: 26990845]

Marć M, Namieśnik J, Zabiegała B. BTEX concentration levels in urban air in the area of the tri-City agglomeration (Gdansk, Gdynia, Sopot), Poland. Air Qual Atmosphere Health. 2014; 7:489–504.

Martins EM, Arbilla G, Bauerfeldt GF, de Paula M. Atmospheric levels of aldehydes and BTEX and their relationship with vehicular fleet changes in Rio de Janeiro urban area. Chemosphere. 2007; 67:2096–2103. [PubMed: 17257646]

Masih A, Lall AS, Taneja A, Singhvi R. Inhalation exposure and related health risks of BTEX in ambient air at different microenvironments of a terai zone in north India. Atmos Environ. 2016; 147:55–66.

Massolo L, Rehwagen M, Porta A, Ronco A, Herbarth O, Mueller A. Indoor–outdoor distribution and risk assessment of volatile organic compounds in the atmosphere of industrial and urban areas. Environ Toxicol. 2010; 25:339–349. [PubMed: 19449388]

Miri M, Shendi MRA, Ghaffari HR, Aval HE, Ahmadi E, Taban E, et al. Investigation of outdoor BTEX: concentration, variations, sources, spatial distribution, and risk assessment. Chemosphere. 2016; 163:601–609. [PubMed: 27589149]

Mohamed MF, Kang D, Aneja VP. Volatile organic compounds in some urban locations in United States. Chemosphere. 2002; 47:863–882. [PubMed: 12079081]

Moolla R, Curtis CJ, Knight J. Occupational exposure of diesel station workers to BTEX compounds at a bus depot. Int J Environ Res Public Health. 2015; 12:4101–4115. [PubMed: 25872020]

Mosaddegh Mehrjerdi MH, Tahmasebi N, Barkhordari FiroozAbadi A, Fallahzadeh H, Esmaielian S, Soltanizadeh K. The investigation of exposure to benzene, toluene, ethylbenzene and xylene (BTEX) with solid phase Microextr action method in gas station in Yazd province. ISMJ. 2014; 16:419–427.

Muezzinoglu A, Odabasi M, Onat L. Volatile organic compounds in the air of Izmir, Turkey. Atmos Environ. 2001; 35:753–760.

Neghab M, Delikhoon M, Baghani AN, Hassanzadeh J. Exposure to cooking fumes and acute reversible decrement in lung functional capacity. Int J Occup Environ Med. 2017; 8 1100-207-16.

Ng N, Chhabra P, Chan A, Surratt JD, Kroll J, Kwan A, et al. Effect of NO_x level on secondary organic aerosol (SOA) formation from the photooxidation of terpenes. Atmos Chem Phys. 2007; 7:5159–5174.

Özden, Döğeroğlu T, Kara S. Assessment of ambient air quality in Eskişehir, Turkey. Environ Int. 2008; 34:678–687. [PubMed: 18291527]

Pankow JF, Luo W, Bender DA, Isabelle LM, Hollingsworth JS, Chen C, et al. Concentrations and co-occurrence correlations of 88 volatile organic compounds (VOCs) in the ambient air of 13 semi-rural to urban locations in the United States. Atmos Environ. 2003; 37:5023–5046.

Parra M, Elustondo D, Bermejo R, Santamaría J. Exposure to volatile organic compounds (VOC) in public buses of Pamplona, Northern Spain. Sci Total Environ. 2008; 404:18–25. [PubMed: 18656247]

Parra M, Elustondo D, Bermejo R, Santamaría J. Quantification of indoor and outdoor volatile organic compounds (VOCs) in pubs and cafés in Pamplona, Spain. Atmos Environ. 2008; 42:6647–6654.

Parra M, González L, Elustondo D, Garrigó J, Bermejo R, Santamaría J. Spatial and temporal trends of volatile organic compounds (VOC) in a rural area of northern Spain. Sci Total Environ. 2006; 370:157–167. [PubMed: 16899278]

Pendergrass, S. NIOSH Manual of Analytical Methods. 3rd. National Institute of Occupational Safety and Health; Cincinnati, OH: 2003. Hydrocarbons, Method: 1501

Qiu Z, Li X, Hao Y, Deng S, Gao HO. Emission inventory estimation of an intercity bus terminal. Environ Monit Assess. 2016; 188:367. [PubMed: 27220506]

Rad HD, Babaei AA, Goudarzi G, Angali KA, Ramezani Z, Mohammadi MM. Levels and sources of BTEX in ambient air of Ahvaz metropolitan city. Air Qual Atmos Health. 2014; 7:515–524.

Rattanajongjitrakorn P, Prueksasit T. Temporal variation of BTEX at the area of Petrol station in Bangkok, Thailand. APCBEE Procedia. 2014; 10:37–41.

Sairat T, Homwuttiwong S, Homwutthiwong K, Ongwandee M. Investigation of gasoline distributions within petrol stations: spatial and seasonal concentrations, sources, mitigation measures, and occupationally exposed symptoms. Environ Sci Pollut Res. 2015; 22:13870–13880.

Saxena P, Ghosh C. A review of assessment of benzene, toluene, ethylbenzene and xylene (BTEX) concentration in urban atmosphere of Delhi. Int J Phys Sci. 2012; 7:850–860.

Schlecht P, O'Conner P. Hydrocarbon aromatics. Method. 1994:1501.

Sorooshian A, Ng NL, Chan AW, Feingold G, Flagan RC, Seinfeld JH. Particulate organic acids and overall water-soluble aerosol composition measurements from the 2006 Gulf of Mexico Atmospheric Composition and Climate Study (Go-MACCS). J Geophys Res: Atmospheres. 2007; 112

Srivastava A, Joseph A, Devotta S. Volatile organic compounds in ambient air of Mumbai—India. Atmos Environ. 2006; 40:892–903.

Statistical Centre of Iran (SCI) I., 2016.

Terrés IMM, Miñarro MD, Ferradas EG, Caracena AB, Rico JB. Assessing the impact of petrol stations on their immediate surroundings. J Environ Manag. 2010; 91:2754–2762.

Thorsson S, Eliasson I. Passive and active sampling of benzene in different urban environments in Gothenburg, Sweden. Water Air Soil Pollut. 2006; 173:39–56.

Tunsaringkarn T, Prueksasit T, Morknoy D, Semathong S, Rungsiyothin A, Zapaung K. Ambient air's volatile organic compounds and potential ozone formation in the urban area, Bangkok, Thailand. J Environ Occup Sci. 2014; 3:130–135.

Tunsaringkarn T, Siriwong W, Rungsiyothin A, Nopparatbundit S. Occupational exposure of gasoline station workers to BTEX compounds in Bangkok. Thailand Int J Occup Environ Med. 2012; 3

Von Burg R. Toluene. J Appl Toxicol. 1993; 13:441–446. [PubMed: 8288849]

Wang L, Wang X, Nan S, Wang Q, Lu Y, Duo K. Composition and distribution characteristics of VOCs in ambient air in Zhengzhou. Environ Monit China. 2008; 24:66–69.

Wang Y, Ying Q, Hu J, Zhang H. Spatial and temporal variations of six criteria air pollutants in 31 provincial capital cities in China during 2013–2014. Environ Int. 2014; 73:413–422. [PubMed: 25244704]

Weisel CP. Benzene exposure: an overview of monitoring methods and their findings. Chem-Biol Interact. 2010; 184:58–66. [PubMed: 20056112]

Witter AE, Nguyen MH, Baidar S, Sak PB. Coal-tar-based sealcoated pavement: a major PAH source to urban stream sediments. Environ Pollut. 2014; 185:59–68. [PubMed: 24215941]

Wu BZ, Hsieh LL, Chiu KH, Sree U, Lo JG. Determination and impact of volatile organics emitted during rush hours in the ambient air around gasoline stations. J Air Waste Manag Assoc. 2006; 56:1342–1348. [PubMed: 17004688]

Xie Y, Chen T-b, Lei M, Yang J, Guo Q-j, Song B, et al. Spatial distribution of soil heavy metal pollution estimated by different interpolation methods: accuracy and uncertainty analysis. Chemosphere. 2011; 82:468–476. [PubMed: 20970158]

Xiong F, Li Q, Zhou B, Huang J, Liang G, Le Zhang, et al. Oxidative stress and genotoxicity of long-term occupational exposure to low levels of BTEX in gas station workers. Int J Environ Res Public Health. 2016; 13:1212.

Yanosky JD, Paciorek CJ, Schwartz J, Laden F, Puett R, Suh HH. Spatio-temporal modeling of chronic PM10 exposure for the nurses' health study. Atmos Environ. 2008; 42:4047–4062.

Yurdakul S, Civan M, Tuncel G. Volatile organic compounds in suburban Ankara atmosphere, Turkey: sources and variability. Atmos Res. 2013; 120:298–311.

Zhang J, Wang T, Chameides W, Cardelino C, Blake D, Streets D. Source characteristics of volatile organic compounds during high ozone episodes in Hong Kong, Southern China. Atmos Chem Phys. 2008; 8:4983–4996.

Zhang Y, Mu Y, Liu J, Mellouki A. Levels, sources and health risks of carbonyls and BTEX in the ambient air of Beijing, China. J Environ Sci. 2012; 24:124–130.

Zhao L, Wang X, He Q, Wang H, Sheng G, Chan L, et al. Exposure to hazardous volatile organic compounds, PM10 and CO while walking along streets in urban Guangzhou, China. Atmos Environ. 2004; 38:6177–6184.

Zhou J, You Y, Bai Z, Hu Y, Zhang J, Zhang N. Health risk assessment of personal inhalation exposure to volatile organic compounds in Tianjin, China. Sci Total Environ. 2011; 409:452–459. [PubMed: 21078521]

Zhou Y, Hao Z, Wang H. Health risk assessment of atmospheric volatile organic compounds in urban-rural juncture belt area. Huan jing ke xue = Huanjing kexue. 2011; 32:3566–3570. [PubMed: 22468519]

Zhu X, Fan ZT, Wu X, Meng Q, Wang S-w, Tang X, et al. Spatial variation of volatile organic compounds in a “Hot Spot” for air pollution. Atmos Environ. 2008; 42:7329–7338.

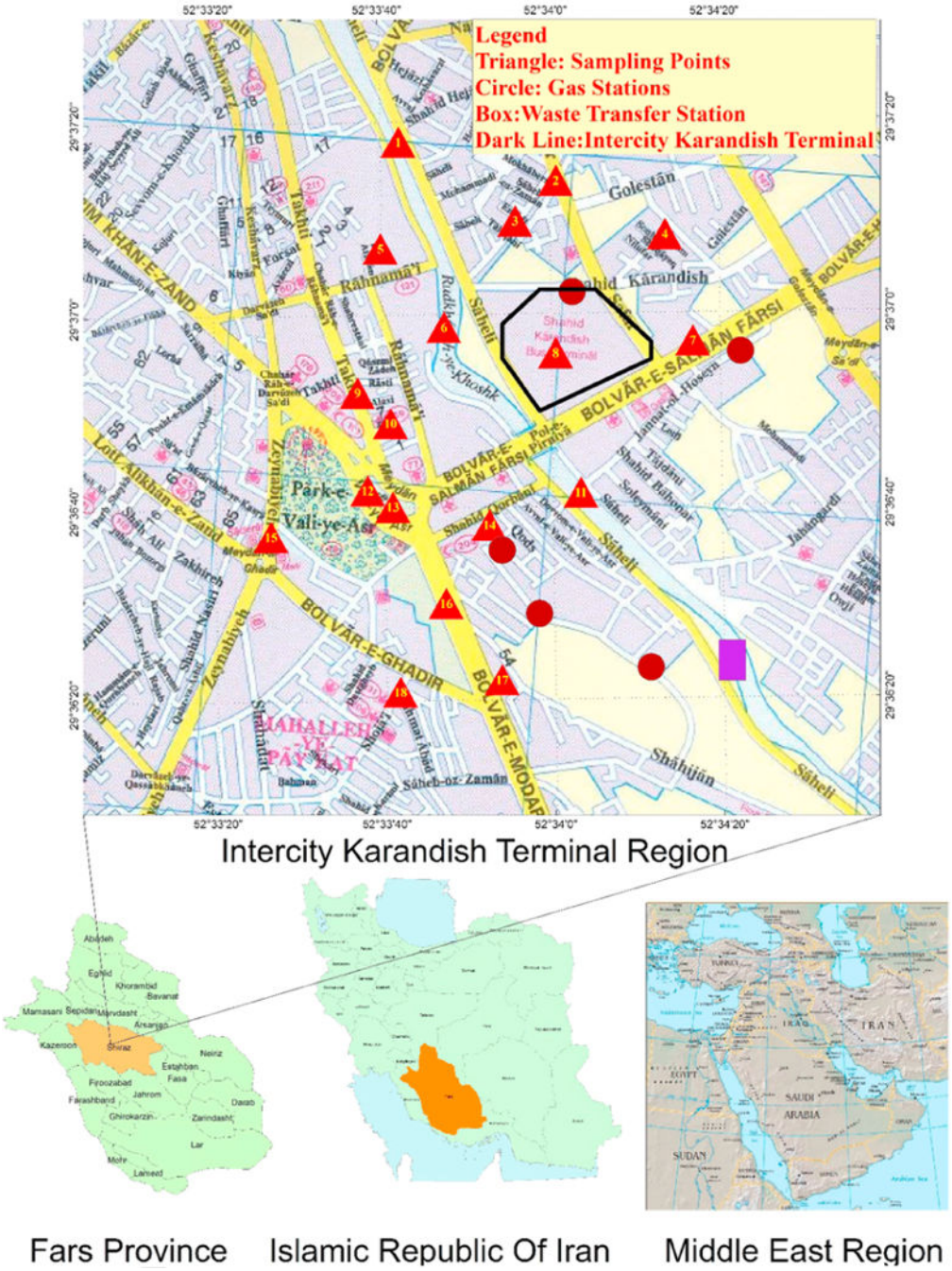

Fig. 1.
Map of the study area and air monitoring stations.

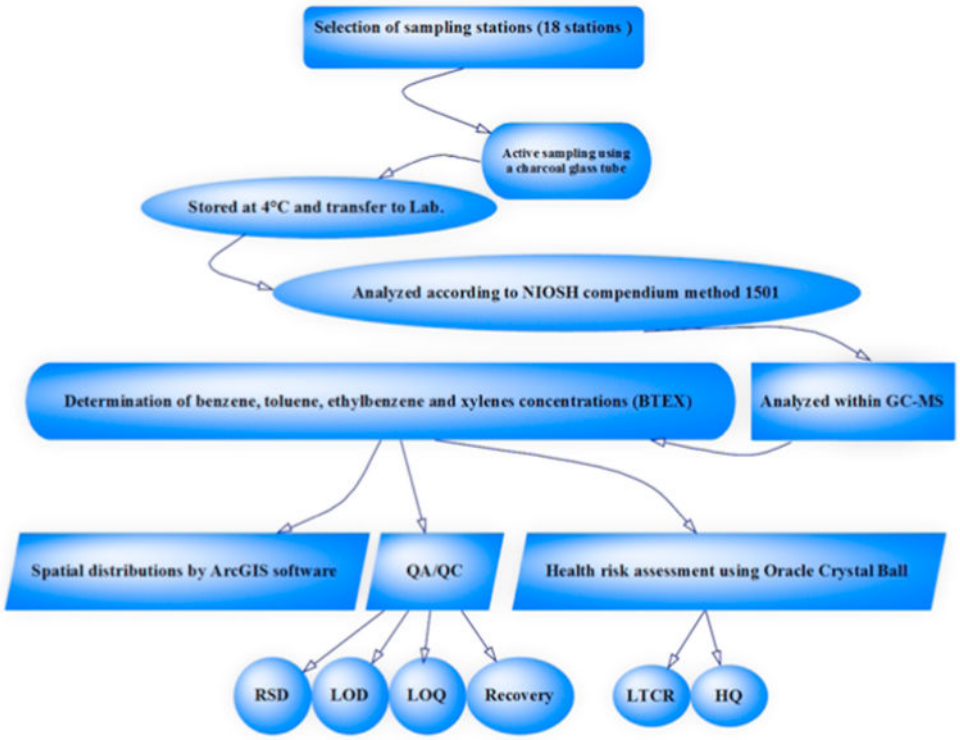

Fig. 2.
A diagram of the steps of the procedures work.

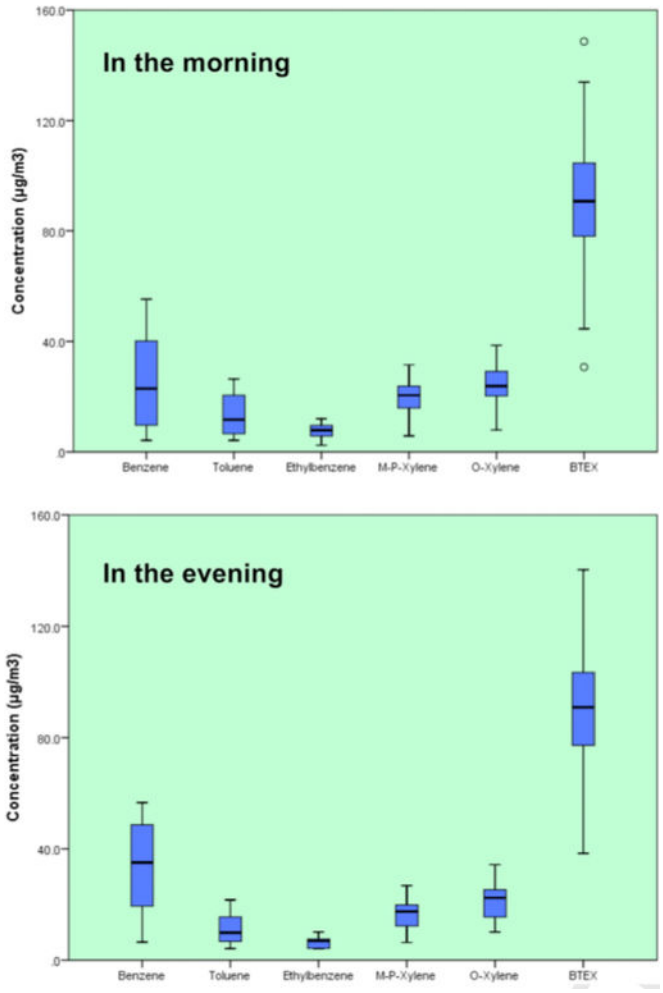

Fig. 3.

Descriptive statistics of BTEX concentrations (µgm^{-3}) in the morning (7–9A.M.) and evening (6–8P.M.).

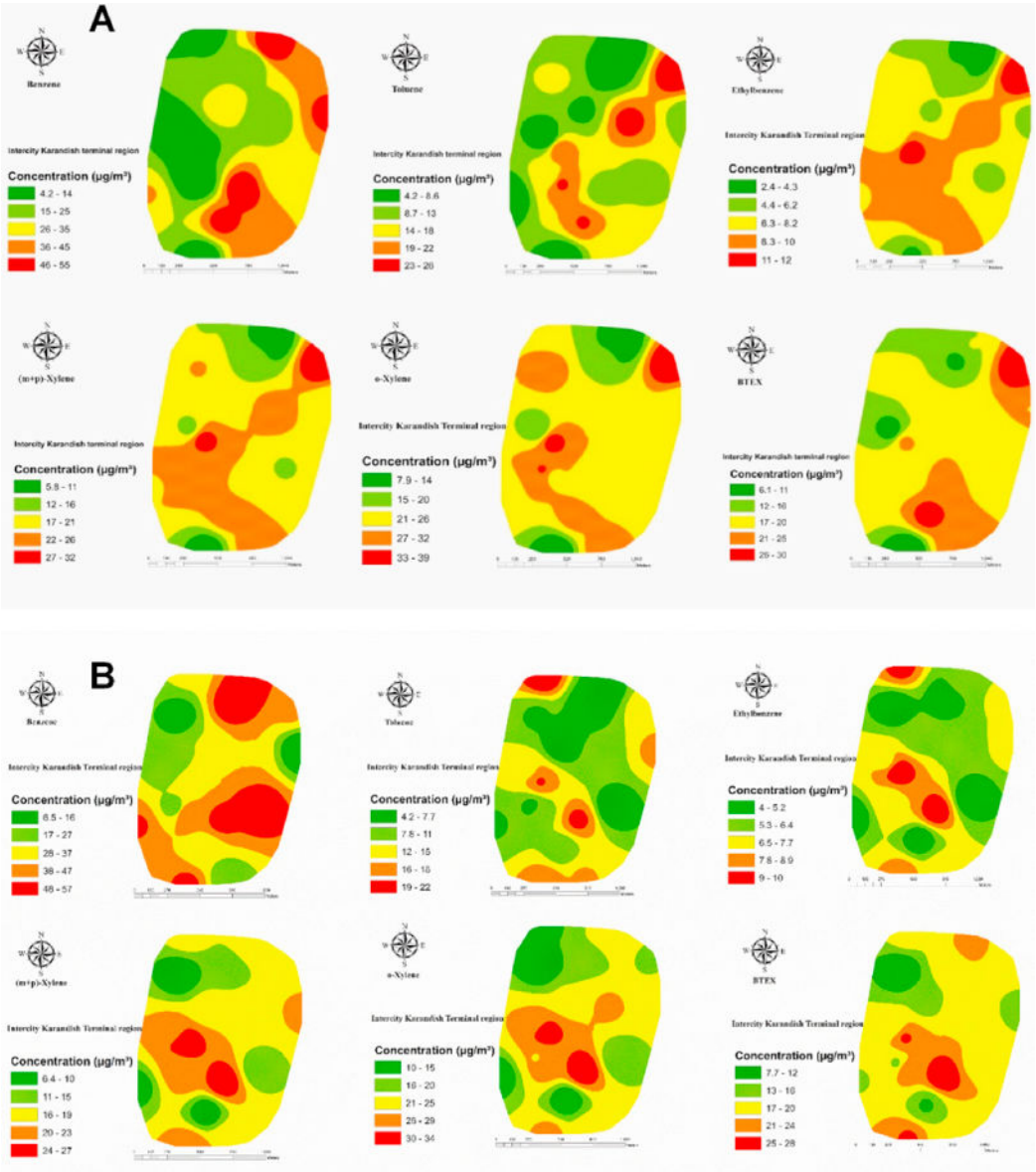

Fig. 4.

Spatial distribution of average concentrations (µg/m^3) of target components in the morning (A) and in the evening (B).

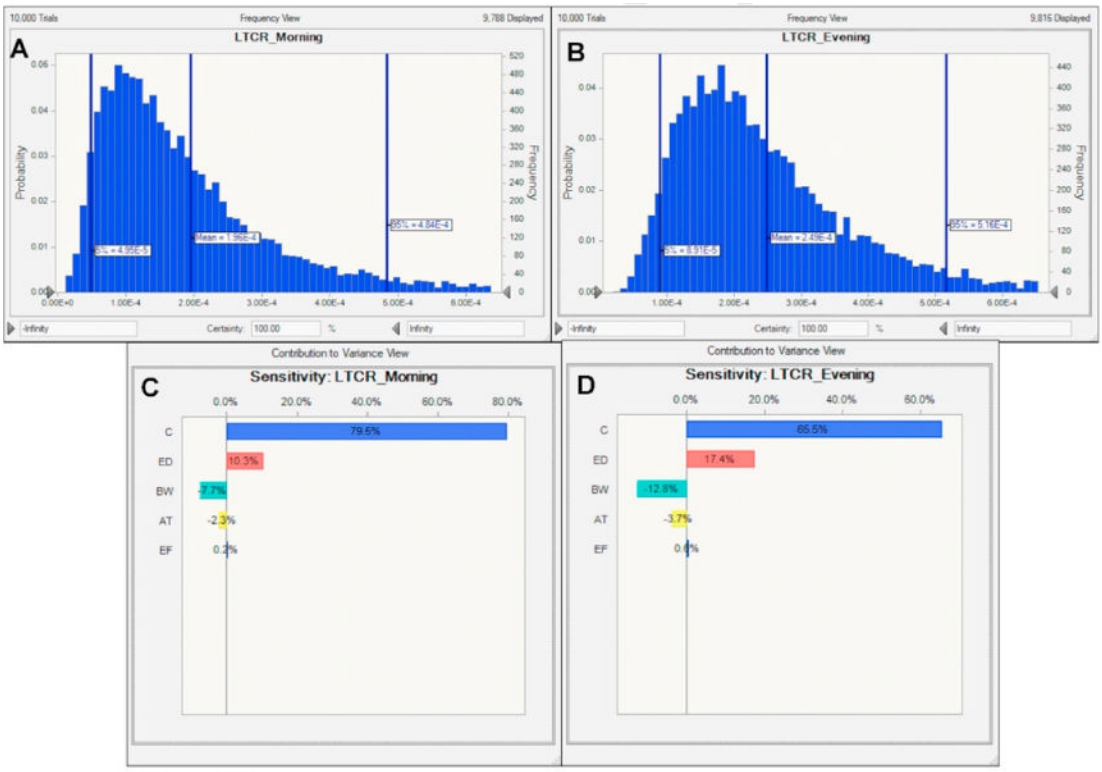

Fig. 5.

Forecasted possibility of LTCR for benzene in the morning (A) and evening (B) and sensitivity analysis of LTCR model for benzene in the morning (C) and evening (D), (C: concentration of the pollutant, IR: inhalation rate, ED: Exposure duration, BW: body weight, AT: Averaging time, and EF: Exposure frequency).

Table 1

Risk parameters employed for Monte Carlo simulations and comparison of BTEX concentrations and B/T, (M+P)-X/B, O-X/B, and Ebz/B ratios in the current study and other studies.

Description	**Parameters**	**Units**	**Value**		**Refs.**
Body weight	BW	kg	71 ± 13.6		(Miri et al., 2016; Moolla et al., 2015)
Inhalation rate	IR	m^3 day^{-1}	15–20		(Demirel et al., 2014; Moolla et al., 2015; Tunsaringkarn et al., 2012; Zhang et al., 2012)
Exposure duration	ED	yr	70		(Miri et al., 2016; Moolla et al., 2015; Zhou et al., 2011a)
Averaging time	AT	days	25,500		(Demirel et al., 2014; Miri et al., 2016; Tunsaringkarn et al., 2012)
Exposure frequency	EF	days yr^{-1}	350–365		(Demirel et al., 2014; Miri et al., 2016; Tunsaringkarn et al., 2012; Zhou et al., 2011a)
B/T, (M+P)-X/B, O-X/B, and Ebz/B ratios					
B/T ratio	**(M+P)-X/B ratio**	**O-X/B ratio**	**Ebz/B ratio**	**City**	**Ref.**
2.01	0.84	0.89	0.28	Shiraz, Iran-in the morning	This study
3.07	0.49	0.62	0.19	Shiraz, Iran-in the evening	This study
1.55–1.78	–	–	0.004–0.005	Mumbai, India	(Srivastava et al., 2006)
2.89	–	–	0.07	Yazd, Iran	(Mosaddegh Mehrjerdi et al., 2014)
2.48	–	–	0.12	Monterrey, Mexico	(Cerón-Bretón et al., 2015)
1.05	–	–	0.21	Zhengzhou, China	(Wang et al., 2008)
1.11	–	–	1.35	Ardabil, Iran	(Hazrati et al., 2016b)
0.56	–	–	0.24	Gorakhpur, India	(Masih et al., 2016)
0.09	1.16	0.83	1.42	Tainan and Taipei, Taiwan	(Hsu and Huang, 2009)
0.69	–	–	0.4	Gdansk, Poland	(Marć et al., 2014)
0.75	–	–	0.36	Gdynia, Poland	(Marć et al., 2014)
0.75	–	–	0.20	Sopot, Poland	(Marć et al., 2014)
0.19	0.54	0.40	0.51	Hong Kong, Japan	(Ho et al., 2004)
0.23	9.45	2.72	3.27	Rio de Janeiro, Brazil	(Martins et al., 2007)
0.07	1.5	0.53	1.08	Seoul, Korea	(Kim et al., 2012)
0.27	1.01	0.18	0.38	Ankara, Turkey	(Yurdakul et al., 2013)
3.22	0.07	0.02	0.03	Orleans, France	(Jiang et al., 2017)

Table 2

Spearman's correlation coefficients (r) between target compounds.

Pollutant		Benzene	Toluene	Ethylbenzene	m/p-xylene	o-xylene
Morning						
Benzene	r	1.000				
	P-value					
Toluene	r	0.055	1.000			
	P-value	.828				
Ethylbenzene	r	0.007	0.799**	1.000		
	P-value	.977	0.000			
m/p-xylene	r	0.055	0.844**	0.963**	1.000	
	P-value	.829	0.000	0.000		
o-xylene	r	0.069	0.754**	0.841**	0.926**	1.000
	P-value	.785	0.000	0.000	0.000	
In the evening						
Benzene	r	1.000				
	P-value					
Toluene	r	0.251	1.000			
	P-value	.316				
Ethylbenzene	r	0.127	0.799**	1.000		
	P-value	.616	0.000			
m/p-xylene	r	0.005	0.608**	0.880**	1.000	
	P-value	.984	0.007	0.000		
o-xylene	r	0.127	0.404	0.740**	0.917**	1.000
	P-value	.616	0.097	0.000	0.000	

** Correlation is significant at the 0.01 level.

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Table 3

Comparison of the results of health risk assessment in the current and other related studies.

HQ and LTCR		Benzene	Toluene	Ethylbenzene	M/P-xylene	O-xylene	Reference	Ref.
HQ	**Mean**	8.71×10^{-1}	2.59×10^{-3}	7.50×10^{-3}	1.93	2.33	Shiraz, Iran	This study, in the morning
	SD	5.88×10^{-1}	1.42×10^{-3}	2.50×10^{-3}	6.49×10^{-1}	8.05×10^{-1}		
LTCR		2.77×10^{-7}	–	–	–	–		
HQ	**Mean**	1.14	2.24×10^{-3}	6.58×10^{-3}	1.68	2.12	Shiraz, Iran	This study, in the evening
	SD	5.21×10^{-1}	1.11×10^{-3}	1.95×10^{-3}	5.76×10^{-1}	6.93×10^{-1}		
LTCR		3.35×10^{-7}	–	–	–	–		
HQ	**Mean**	4.37×10^{-2}	1.06×10^{-3}	1.75×10^{-3}	4.45×10^{-2}	1.65×10^{-2}	Tehran, Iran	(Miri et al., 2016)
	SD	7.32×10^{-3}	3.70×10^{-4}	8.06×10^{-4}	1.17×10^{-2}	5.01×10^{-3}		
LTCR		3.93×10^{-7}	–	–	–	–		
HQ	**Mean**	0.29	8×10^{-3}	5×10^{-3}	7×10^{-2}		Ardabil, Iran	(Hazrati et al., 2016b)
	SD	0.22	7×10^{-3}	4×10^{-3}	6×10^{-2}			
LTCR		7.1×10^{-5}	–	–	–	–		
HQ	**Mean**	7.74×10^{-1}	2.17×10^{-2}	2.01×10^{-2}	4.72×10^{-1}		Kolkata, India	(Majumdar et al., 2008)
LTCR		9.66×10^{-5}	–	–	–	–		
HQ	**Mean**	1.57×10^{-1}	2.39×10^{-2}	3.29×10^{-3}	8.06×10^{-3}	3.53×10^{-3}	Beijing, China	(Zhang et al., 2012)
LTCR		4.19×10^{-5}	–	–	–	–		
HQ	**Mean**	0.38	5×10^{-3}	9×10^{-3}	2×10^{-3}		Bangkok, Thailand	(Tunsaringkarn et al., 2012)
LTCR		8.71×10^{-5}	–	–	–	–		
HQ	**Mean**	5.73×10^{-2}	1.08×10^{-3}	1.19×10^{-3}	2.09×10^{-2}	5.32×10^{-3}	Northeastern urban area of Beijing, China	(Li et al., 2014)
LTCR		1.34×10^{-5}	–	–	–	–		
HQ	**Mean**	–	–	–	–	–	Tianjin, China	(Zhou et al., 2011a)
LTCR		2.18×10^{-5}	–	–	–	–		
HQ	**Mean**	9.43×10^{-2}	2.30×10^{-2}	2.0×10^{-3}	5.61×10^{-2}	–	Hangzhou, China	(Li et al., 2014)
LTCR		9.43×10^{-6}	–	–	–	–		
HQ	**Mean**	1.58×10^{-1}	–	1.69×10^{-2}	7.76×10^{-3}	–	Urban-rural juncture belt area in Beijing, China	(Zhou et al., 2011b)
LTCR		2.21×10^{-5}	–	–	–	–		

HQ: hazard quotient; ILTCR: integrated lifetime cancer risk.

The values of RFC in this study for benzene, toluene, ethylbenzene, m/p-xylene, and o-xylene were 30, 5000, 1000, 10, 10μg/m^3, respectively (EPA, 1999; Moolla et al., 2015).