

Occurrence, Probable Source, and Health Risk Assessment of Benzene, Toluene, Ethylbenzene, and Xylene Compounds in Ambient Urban Atmosphere in Ahvaz, Iran

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Background & Aims of the Study: The benzene, toluene, ethylbenzene, and xylene (BTEX) compounds are the most abundant volatile organic compounds in the urban atmosphere. This study aimed to investigate and monitor the ambient BTEX compounds in Ahvaz, Iran.

Materials and Methods: The atmospheric concentrations of the BTEX were measured using the Air Quality Monitoring Station in the center of Ahvaz. Hourly mean concentration data of the BTEX compounds from March 21, 2017, until November 21, 2017, were obtained from the environmental protection organization of Khuzestan province.

Results: Mean concentrations of the BTEX compounds were 0.80 ± 0.04 , 2.55 ± 0.10 , 0.54 ± 0.03 , and 1.26 ± 0.07 $\mu\text{g}/\text{m}^3$, respectively, and these concentrations were lower in the summer, compared to other seasons. A significant relationship between benzene and other BTEX compounds indicates that BTEX release from certain sources, such as gasoline vehicles. Moreover, the mean toluene/benzene ratio was estimated at 3.29 ± 0.84 , and this ratio shows that the highest concentrations of pollutant emissions were emitted from the activity traffic. Carcinogen risk assessment of Ahvazi people exposure to benzene showed that the mean cancer risk value for benzene exposure was 0.89×10^{-6} , which was lower than the unit cancer risk value (i.e., 1×10^{-6}). Hazard quotient's calculation showed that the mean non-carcinogenic risk values for exposure to BTEX compounds were 3.84, 0.074, 0.077, and 1.76, respectively. The mean hazard index (HI) for exposure to BTEX compounds was 5.75, which was considerably higher than the unit value of 1.

Conclusion: Based on the findings, the necessity of controlling BTEX emissions, especially benzene and identifying the sources of these compounds can be a useful tool for the management of connected control strategies.

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Background

In recent decades, the development of industries has caused severe environmental

issues, such as the emission of volatile organic compounds (VOCs) into the urban atmosphere. The VOCs are the most dangerous and important group of organic contaminants in the air (1-4). Moreover, they are known as air-

borne carbon compounds which due to their high volatility, quick evaporation and spread in the atmosphere, these compounds possess the highest emission rates after suspended particles within the environment (5, 6).

Among the majority of the air pollutants, these compounds are mostly found in the air of urban and industrial regions. Furthermore, they have turned into a critical issue of urban air quality because of their contribution to the creation of secondary aerosols and their harmful health impacts on the human body (7). These compounds as an important group of air pollutants released into the environment through various sources, namely anthropogenic and biogenic sources leading to detrimental effects. The anthropogenic sources in the urban atmosphere include vehicle exhaust emissions, combustion of fossil fuels, gasoline evaporation, the use of solvents, compressed natural gas and liquid petroleum gas leaks, petroleum refining, solid waste decomposition, and industrial processes (8, 9).

The potential biogenic sources of ambient VOCs are basically originated from the vegetation (forests) and wetlands that have the lowest contribution in urban pollution, compared to anthropogenic emissions (8, 10).

benzene, toluene, ethylbenzene, and xylene (BTEX) compounds, are the main aromatic types of VOCs that can be regarded as VOCs indices (11, 12). It is noteworthy that VOCs compounds when released into the atmosphere, cause various environmental complications. The VOCs are the major group of hydrocarbons in the atmosphere that play an important role in the physical and chemical processes of the troposphere. Therefore, the BTEX compounds can have significant effects on atmospheric chemistry (13, 14). Furthermore, hydroxyl radicals are considered to be the main atmospheric oxidant, and the VOCs compounds usually undergo varied photochemical reactions with them, which leads to the formation of proxy radicals in many cases (15). In the

presence of nitric oxide (NO), these proxy radicals quickly react with NO to form nitrogen dioxide (NO₂), and in the presence of sunlight, the NO₂ molecules react with VOCs compounds.

These photochemical reactions between BTEX and other chemical compounds, such as nitrogen oxide in the atmosphere can produce tropospheric ozone and other toxic compounds, such as peroxyacetyl nitrate, and secondary organic aerosol (13, 16). The United States Environmental Protection Agency (USEPA) considered the BTEX compounds the air poisons or hazardous air pollutants (HAPs). The HAPs are pollutants that can cause cancer or other serious health effects (17). These compounds are absorbed into the human body through different routes.

However, Inhalation is the important exposure pathway for these volatile contaminants due to the high vapor pressure of these compounds (18). The BTEX compounds are common aromatic air pollutants, and exposure to BTEX result in numerous harmful health effects. Benzene is considered the most toxic and dangerous compound among BTEX, and according to the International Agency for Research on Cancer, benzene is known as a severe carcinogenic compound for human (Group1) (19, 20) that can cause persistent bone marrow damage, aplastic anemia, acute myelogenous leukemia, and lymphoma (21, 22). Moreover, benzene adversely affects the blood-forming system and contributes to leukemia and hematological disturbances (21). Ethylbenzene is classified as possibly carcinogenic to humans (Group 2), whereas toluene and xylenes are not classifiable (Group 3) (19). Toluene is more soluble in lipid than benzene, and therefore, it can cause an increased adverse neurological effect upon exposure.

Ethylbenzene leads to brain disorders and eye irritations, and xylene can be responsible for skin inflammation and breathing problems (23, 24). Therefore, it is essential to monitor the

BTEX compounds in the atmosphere due to the fact that even at trace amounts these compounds can appear dangerous to the environment and human health (25). For this reason, these compounds are to be considered the matter of many toxicology and different health effect studies. Many researchers have conducted several studies to evaluate the concentrations of BTEX all over the world (26-35). Moreover, significant determination of the VOCs source in the atmosphere has been increased over the past few decades, and many researchers have focused on the determination of the sources of BTEX in the ambient air by estimating the ratio of these compounds and determining their correlation with each other. For instance, the ratio of toluene to benzene (T/B) has been commonly used as an index for the emission sources of contaminants (3, 4). In addition to this ratio, the ratios of ethylbenzene/benzene (Ebz/B) and xylenes/benzene (X/B) are often applied as indicators of photochemical reactivity (3, 36). Golkhorshidi et al. (2018) investigated the nature and health effects of BTEX on the population in Tehran, Iran.

Another study investigated the atmospheric BTEX concentrations and their health consequences in an ambient urban atmosphere in Kuwait (26). Similarly, Mainka and Kozielska (2016) evaluated BTEX concentrations and health risks in urban nursery schools in Gliwice, Poland. In a study by Garg and Gupta (2019), a comprehensive survey has been conducted on distribution, health risk evaluation, and ozone formation potential of BTEX emissions in the ambient air of Delhi, India.

Ahvaz is an industrial city that is located in the southwest of Iran. The number of industries, particularly oil industries, and engine vehicles are increasing following the developments and expansions within this city. Moreover, lately, dust storms in the southwestern of Iran have added a human source of air pollution to this

city (37). Accordingly, the dissemination of BTEX compounds in Ahvaz is inevitable, which raises urban air contamination and harmful effects on human health. Therefore, the assessment of BTEX concentration is essential for anticipating the ambient air quality, particularly within the middle-east cities, such as Ahvaz. In addition, the assessment of the health risk of BTEX and identification of their sources can be beneficial for the evaluation of environmental health criteria in Ahvaz. However, there remain aspects of exposure of these compounds in the different urban areas that require further research. With this background in mind, this study aimed to determine BTEX concentration and assess the associated health risk after being exposed to ambient BTEX compounds (carcinogenic and non-carcinogenic risk) in one central region of Ahvaz, Iran. Moreover, this study summarized the interspecies ratios and interrelationships among BTEX species with each other to determine their sources.

Materials & Methods

Study Area and Sampling

Ahvaz (31° 30' N, 48° 65' E) is located at the southwest portion of the urban advancement of Iran and is the capital urban area of Khuzestan province with a population of more than one million residents. Ahvaz has an area of 185 km². Industrial activities in Ahvaz and the vicinity regions continue to develop, and the city is restricted by main petroleum refineries and proximate to petrochemical industrial plants (National Iranian South Oil Company and National Iranian Drilling Company) of the country. Therefore, since Ahvaz has many industries particularly oil industries and there are a lot of motor vehicles in this city, the level of omissions of these compounds is high. Accordingly, considering the extensive use of BTEX compounds and their impacts on human

health, it is critical to sample and measure these contaminations (38, 39).

For this reason in this study, the atmospheric concentrations of BTEX were measured in the central site of Ahvaz, Iran, from March 21, 2017, until November 21, 2017, on an hourly basis (hourly data were recorded per year for each location). Furthermore, the assessment of the concentrations of BTEX compounds in the air was performed by the Air Quality Monitoring Station, which is situated in the center of Ahvaz, Iran.

In fact, since BTEX concentration data of the central site of Ahvaz were available during the study period (March 21, 2017, until November 21, 2017), this station and this period were selected as a monitoring station and study period in this city.

Data Analysis

Health Risk Assessment

Cancer and Non-cancer Risk Assessment

Risk assessment involves quality and quantity estimation of the probability occurrence and severity of harmful health effects arising from human exposure to hazards in the environment (34). The calculated compounds are regarded as carcinogens or non-carcinogen according to their toxicological information. To estimate the cancer risk of carcinogenic hydrocarbons, Lifetime Cancer Risk (LCR) index is used and defined as a possible indicator for increased risk of cancer

caused by specific exposure. In addition, Hazard Quotient (HQ) is used to estimate the risks of exposure to non-carcinogenic hydrocarbons. The HQ expresses the level of exposure to a substance that does not have any harmful effects. From this statement, it can be concluded that quantitative risk assessment is very important for VOCs, such as BTEX. Benzene has been considered a carcinogen, whereas other compounds, such as toluene, ethylbenzene, and xylene have been known as non-carcinogen. In this study, the Lifetime Average Daily Doses (LADD), the amounts of USEPA Inhalation Reference Dose (RfD), and Slope Factor (SF) were used to estimate the HQ and LCR (40).

The non-carcinogenic risk for toluene, ethylbenzene, and xylene (TEX) was estimated by utilizing RfD. Benzene cancer risks were computed by applying SF. Table 1 displays the chosen parameters used for computing inhalation lifetime cancer risk (LTCR) and HQ of BTEX compounds.

To evaluate health risk linked with exposure to BTEX, the LADD ($\mu\text{g}/\text{kg}/\text{day}$) was calculated to measure the exposure rate to the concentrations of BTEX compounds utilizing the default amounts in Table 1 applying Equation (1) as follows.

$$\text{LADD} = [\text{C}_{\text{Exp}} \times \text{IR} \times \text{EL} \times \text{ED}] / [\text{BW} \times \text{LT}] \quad \text{Eq. (1)}$$

Where C_{Exp} , IR, EL, ED, BW, and LT are

Table 1) Risk Assessment Parameters

Summary of Default Exposure Factors		
Parameter	Default Value	Unit
Lifetime (LT)	70	Year
Body Weight, adult (BW)	70	Kg
Exposure Length (EL)	30	year
Exposure Duration (ED)	8	h/day
Inhalation Rate, adult (IR)	0.83	h/day
Slope Factor (SF)	Benzene = 0.0273	Mg/kg day
	Benzene = 0.0085	
	Toluene = 1.4	
Inhalation Reference Dose (RfD)	Ethylbenzene = 0.286	Mg/kg day
	Xylene = 0.029	

the exposure concentration of the compounds ($\mu\text{g}/\text{m}^3$), the inhalation rate (m^3/day), exposure length (day/day), the exposure duration (days), body weight (kg), and lifetime (days), respectively.

Cancer Risk Assessment

The cancer risks were calculated using the mathematical equations to characterize the number of individuals that are probably to acquire cancers because of their exposure to benzene (Yan et al. 2015) from inhalation intake. The USEPA inhalation SF taken from benzene was utilized to quantitatively assess the excess cancer risk in terms of LADD utilizing Equation (2) as follows.

$$\text{LTCR} = \text{LADD} (\mu\text{g}/\text{kg}/\text{day}) \times \text{SF} (\mu\text{g}/\text{kg}/\text{day})^{-1} \quad \text{Eq. (2)}$$

Where LADD and SF are the lifetime average daily dose ($\mu\text{g}/\text{kg}/\text{day}$) and the slope factor, respectively. The SF equals 27.3 ($\mu\text{g}/\text{kg}/\text{day}$) according to USEPA (Edokpolo et al., 2015). Therefore, if $\text{LTCR} > 1.00 \times 10^{-6}$, it represents carcinogenic effects, and if $\text{LTCR} \leq 1.00 \times 10^{-6}$, it is as "acceptable" by the World Health Organization and US EPA.

Non-cancer Risk Assessment

The HQ technique of risk characterization was applied to assess the potentially harmful health effects or non-cancer effects followed by exposure to BTEX compounds. According to the USEPA, the HQ was calculated using Equation (3).

$$\text{HQ} = \text{LADD} (\mu\text{g}/\text{kg}/\text{day}) / \text{RfD} (\mu\text{g}/\text{kg}/\text{day}) \quad \text{Eq. (3)}$$

Where LADD is the lifetime average daily dose ($\mu\text{g}/\text{kg}/\text{day}$) and RfD is the reference dose indicating a lower threshold value that has no harmful effects on human health (41). According to USEPA, if the value of HQ is less than 1, the risk is considered acceptable, and the exposed local population is said to be safe.

On the other hand, if HQ is more than or equal to 1, it displays detrimental non-carcinogenic effects and considered as not safe for human health (USEPA, 2013).

Hazard Index (HI) is calculated based on the sum of the HQs of different contaminations using Equation (4).

$$\text{HI} = \sum_{i=1}^n \text{HQ}_i \quad \text{Eq. (4)}$$

Where HQ_i is HQ of the i th pollutant.

Statistical Analysis

The descriptive data of BTEX concentration were analyzed in SPSS software (version 19.0). Moreover, the normality of the concentration distribution of these pollutants was analyzed using Shapiro-Wilk, and the correlations among the concentrations of BTEX compounds were analyzed by Pearson's correlation. In addition, a one-way ANOVA test was utilized to compare weekends and weekdays concentrations of BTEX compounds during which the normal distribution of the data was being observed. It should be noted that the excel software was used to draw diagrams.

Results

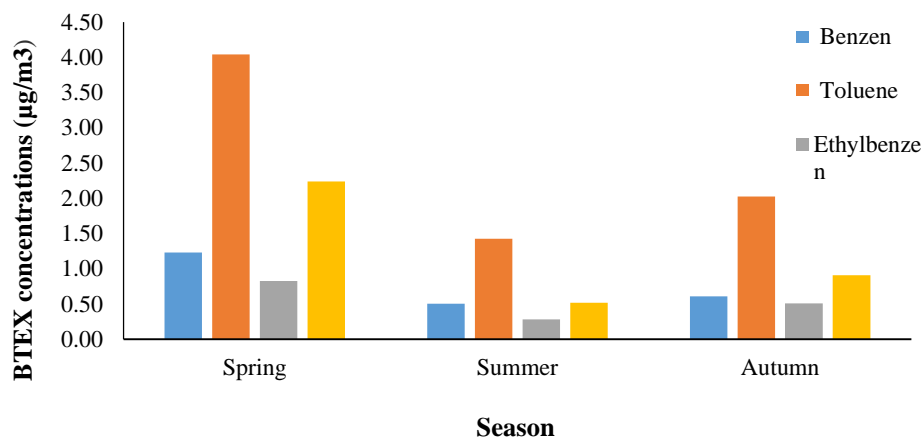
Concentration and Seasonal Variation of BTEX Compounds in Ahvaz, Iran

Table 2 tabulates the descriptive statistics of the data on BTEXs compounds concentration in Ahvaz. The mean concentrations of benzene, toluene, ethylbenzene, and xylene for all samples were 0.81, 2.56, 0.54, and 1.26 $\mu\text{g}/\text{m}^3$, respectively. The total mean of BTEX in this study was obtained at 5.17 $\mu\text{g}/\text{m}^3$.

Figure 1 indicates the seasonal changes of BTEX during spring, summer, and autumn in ambient air at Ahvaz, Iran. Based on these results, in spring, summer, and autumn, the concentrations of benzene were 1.23, 0.51, and 0.62 $\mu\text{g}/\text{m}^3$. Moreover, these corresponding

Table 2) Descriptive Statistics of Concentrations of BTEX in Ahvaz, Iran ($\mu\text{g}/\text{m}^3$)

BTEX	Descriptive statistic	Spring	Summer	Autumn	Total
Benzene	Max.	5.65	1.27	1.61	5.65
	Min.	0.42	0.02	0.02	0.02
	Mean	1.23 \pm 0.74	0.51 \pm 0.35	0.61 \pm 0.29	0.81 \pm 0.62
Toluene	Max.	9.98	3.18	5.17	9.98
	Min.	1	0.02	0.02	0.04
	Mean	4.04 \pm 1.59	1.43 \pm 1.04	2.02 \pm 0.97	2.56 \pm 1.72
Ethylbenzene	Max.	5.21	0.66	1.76	5.21
	Min.	0.11	0.02	0.02	0.02
	Mean	0.83 \pm 0.71	0.28 \pm 0.20	0.51 \pm 0.28	0.54 \pm 0.53
Xylene	Max.	7.25	1.39	2.67	7.25
	Min.	0.14	0.10	0.02	0.07
	Mean	2.24 \pm 1.29	0.52 \pm 0.36	0.91 \pm 0.48	1.26 \pm 1.15

**Figure 1) Seasonal BTEX concentrations ($\mu\text{g}/\text{m}^3$) in Ahvaz, Iran -a****Table 3) Descriptive statistics of weekdays and weekends variations regarding BTEX ($\mu\text{g}/\text{m}^3$)**

BTEX	Weekdays ($\mu\text{g}/\text{m}^3$)			Weekends ($\mu\text{g}/\text{m}^3$)		
	Min	Mean	Max	Min	Mean	Max
Benzene	0.40	0.82 \pm 0.51	1.33	0.32	0.80 \pm 0.41	1.78
Toluene	1.56	2.61 \pm 1.62	3.75	1.00	2.54 \pm 1.42	4.27
Ethylbenzene	0.28	0.54 \pm 0.33	0.89	0.16	0.54 \pm 0.35	1.35
Xylene	0.71	1.33 \pm 1.01	2.32	0.41	1.24 \pm 0.88	2.45

values for toluene were 4.04, 1.43, and 2.02 $\mu\text{g}/\text{m}^3$. Furthermore, ethylbenzene and xylene concentration levels were 0.83, 0.28, and 0.51 $\mu\text{g}/\text{m}^3$, as well as 2.24, 0.52, and 0.91 $\mu\text{g}/\text{m}^3$, respectively.

Concentration Variations of the BTEX on Weekdays and Weekends

The comparison between weekdays and weekends regarding the concentrations of

BTEX compounds during the period of the study was performed, and the outcome outputs were exhibited in Table 3. In general, on weekdays and weekends, the mean concentration values of benzene and toluene were 0.82 and 0.80 $\mu\text{g}/\text{m}^3$ as well as 2.61 and 2.54 $\mu\text{g}/\text{m}^3$, respectively. Moreover, these corresponding values for ethylbenzene and xylene levels were 0.54 and 0.54 $\mu\text{g}/\text{m}^3$ as well as 1.33 and 1.24 $\mu\text{g}/\text{m}^3$, respectively.

Figure 2 shows the temporal trend of benzene, toluene, ethylbenzene, xylene, and total BTEX during the weekdays and weekends in different seasons.

Source Identification and Interspecies Correlation

In this study, the mean T/B, Ebz/B, X/B, T/X, and Ebz/X ratios were calculated to distinguish between vehicular emissions and other combustion sources. Moreover, their trend during spring, summer, and autumn seasons were obtained that have been illustrated in Table 4.

The mean values of T/B, Ebz/B, X/B, T/X,

and Ebz/X ratios have been obtained at 3.18, 0.67, 1.57, 2.03, and 0.43, respectively.

Table 5 displays the relationships of the BTEX concentration compounds with each other using Pearson's correlation coefficient.

Comparison of BTEX Levels in Ahvaz, Iran, with other Cities in the World and Iran

A comparison of the mean concentrations of BTEX ($\mu\text{g}/\text{m}^3$) in the present study with the results of other studies in the different cities of the world is shown in figure 3. Moreover, figure 4 shows the comparison of the BTEX concentration levels in the present study with levels in other studies conducted in urban areas

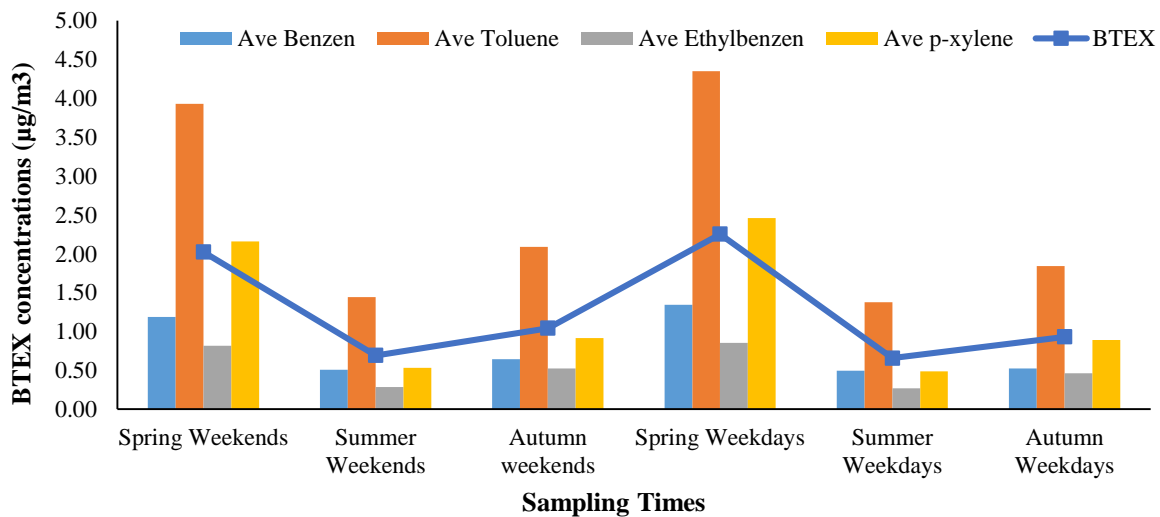


Figure 2) Temporal trend of benzene, toluene, ethylbenzene, xylene, and total BTEX in weekdays and weekends of different seasons

Table 4) Mean BTEX interspecies concentration ratios

Sampling Times	T/B	E/B	X/B	T/X	E/X
Spring	2.27	0.66	1.79	1.86	0.37
Summer	2.23	0.57	1.48	2.08	0.46
Autumn	3.25	0.81	1.42	2.33	0.58
Mean	3.18	0.67	1.57	2.03	0.43

Table 5) Correlation coefficients of the BTEX compound concentration (P<0.01)

	Benzene	Toluene	Ethylbenzene	Xylene
Benzene	1			
Toluene	0.845	1		
Ethylbenzene	0.857	0.807	1	
Xylene	0.801	0.945	0.802	1

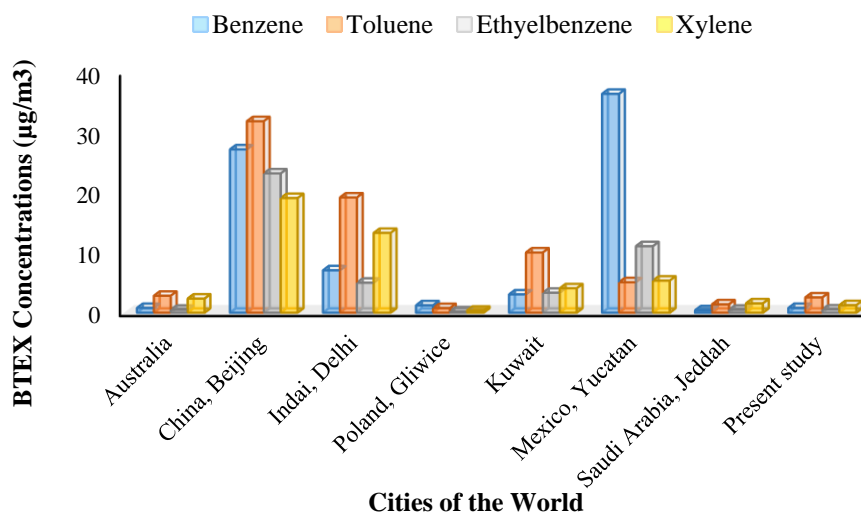


Figure 3) Comparison of BTEX concentrations in Ahvaz, Iran, with other cities across the world

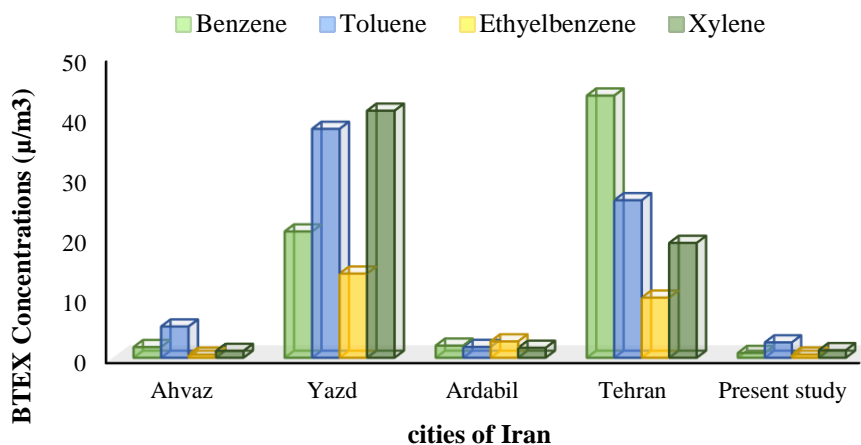


Figure 4) Comparison of BTEX concentrations in Ahvaz, Iran, with other cities in Iran

Table 6) BTEX-induced cancer risk, non-carcinogenic risk, and hazard index

	Cancer Risk		non-carcinogenic risk				Hazard index
	Benzene		Benzene	Toluene	Ethylbenzene	Xylene	
Spring	1.36×10^{-6}		5.88	0.11	0.11	3.13	9.23
Summer	0.56×10^{-6}		2.41	0.041	0.04	0.72	3.21
Autumn	0.67×10^{-6}		2.92	0.059	0.07	1.27	4.31
Total	Min.	0.02×10^{-6}	0.09	0.001	0.003	0.02	0.11
	Mean	0.89×10^{-6}	3.84	0.074	0.077	1.76	5.75
	Max.	6.26×10^{-6}	27.01	0.29	0.74	10.16	38.2

of Iran.

Health Risk Assessment

In the present study, non-carcinogenic risk due to VOCs exposure by inhalation was

evaluated through HQ. Moreover, lifetime cancer risk assessment (LCR) was utilized for benzene carcinogenic evaluation. Table 6 shows the LCR, HQ, and HI values obtained for BTEX compounds.

Discussion

The results revealed that toluene obtained the highest concentration rate among the BTEX compounds with a mean variation between 0.04 to 9.98 $\mu\text{g}/\text{m}^3$ followed by xylene (0.07- 7.25 $\mu\text{g}/\text{m}^3$), and benzene (0.02- 5.65 $\mu\text{g}/\text{m}^3$). On the other hand, ethylbenzene (0.02- 5.51 $\mu\text{g}/\text{m}^3$) was present at a lower concentration. These findings are consistent with the results of other studies conducted on BTEX compounds in which toluene had the highest concentration rate and was more abundant, compared to other BTEX concentrations in the ambient urban atmosphere (26, 30, 42, 43). In addition, these results are in line with the findings of a study conducted by Hajizadeh et al. (2014) who assessed the level of BTEX in the atmosphere of Ahvaz. According to the results of the aforementioned study, the mean concentrations of benzene, toluene, ethylbenzene, and xylenes were 1.78, 5.19, 0.51, and 1.13 $\mu\text{g}/\text{m}^3$, respectively, and toluene concentrations were higher than those of other compounds. The high concentrations of toluene and xylene can be a result of anthropogenic activities, including large use of them as solvents, fuel burning, cleaning products, and paints. Additionally, photochemical degradation of toluene and xylenes is quicker than that of benzene (44).

Based on the results, BTEX levels in the summer were lower than those in other seasons. In many previous studies, researchers observed that concentrations of BTEX compounds were lower in the summer than those in other seasons (26, 30, 33). The lowest BTEX concentration and levels in the summer can be attributed to different factors. One of the reasons for decreasing the concentration of BTEX compounds during the summer season is probably higher chemical removal reaction rates of BTEX, compared to other seasons.

Actually, in the summer, high temperatures and solar radiation with an increase in the concentration of OH radicals cause further degradation of the BTEX atmosphere, thereby contributing to the lower air concentration. In addition, this high temperature along with the long daytime can be the reason for the increased evaporation rate which is ultimately responsible for increasing the dispersion of BTEX in the atmosphere (45).

Furthermore, another acceptable reason for the decrease in the concentration of BTEX compounds in this season is probably the result of the continual dust storms in Khuzestan province which has a dry and semi-dry climate the same as other regions. These dust storms eliminate BTEX compounds from the air in the summer period, thereby reducing their concentrations (26). The low BTEX concentration in other seasons, compared to summer, maybe due to the reduced photochemical degradation and or washing out of atmospheric BTEX followed by precipitation and thunderstorms (46). Rainfall could transfer BTEX species from the atmosphere to the earth's surface into the water or soil (47). Rad et al. (2014) reported that the minimum concentration of BTEX compounds in the air in Ahvaz was related to the summer (September 2012) with a mean concentration of 7.05 $\mu\text{g}/\text{m}^3$. In this study, the maximum level of these pollutants in the winter was attributed to the higher stability of the atmosphere in this season, and the reason for minimum level in the summer was expressed due to more sunlight and high temperatures contributing to faster removal of BTEX by OH radicals in summer than in winter (48). However, these results were not consistent with the findings of a study performed by Yaghmaien et al. (2019) to compare the health risk of BTEX exposures from landfills, composting units, and leachate treatment plants, as well as a study carried out by Omid et al. (2019) to evaluate the risk of

professional exposure to VOCs in the rendering plant of a poultry slaughterhouse.

According to the findings, there is no significant difference between weekdays and weekends in terms of the concentration of all BTEX compounds in the studied period ($P > 0.05$). This lack of difference can be due to the short duration of the study. The results of other studies have shown that BTEX concentrations during weekdays (i.e., rush hour and traffic) were higher than those on the weekends; however, this result is not consistent with the findings of the present study. This can be attributed to more population densities and larger volumes of traffic on weekdays, compared to weekends (49, 50). Moreover, as shown in figure 2, the levels of BTEX compounds were higher during the weekdays and weekends in spring, compared to two seasons of autumn and summer. The reason could be explained using this fact that in the spring, Ahvaz has a more favorable climate than summer, and the volume of traffic is high in this season. Additionally, the results of a study by Asadifard and Masoudi (2018) on the assessment of status and prediction of carbon monoxide as an air pollutant in Ahvaz, Iran, indicated that based on the seasonal concentrations, the highest amounts were in the spring. This is because CO is elevated by increasing traffic in this season.

After comparing the mean ratios of T/B, Ebz/B, X/B, T/X, and Ebz/X in the different seasons, it was revealed that all of these ratios, except for X/B were highest in autumn, and the lowest ratios included T/B, Ebz/B, and X/B in the summer; however, the lowest ratios of T/X and Ebz/X were in the winter.

In the same line, Masih et al. (2018) reported that the highest T/B ratio was observed in the course of monsoon season (2.38 and 3.85) followed by summer (2.32 and 3.33) and winter (1.31 and 1.61). In this study, the mean ratios of T/B in the spring, summer, and autumn were 2.27, 2.23, and 3.25, respectively, expressing

the significance of vehicular traffic emissions as the major source of BTEX emissions in this region.

Due to the fact that benzene and toluene are gasoline components, they can be released into the atmosphere through automobile exhausts (51). The T/B ratio with a range of 1.50-4.30 is regarded as a well-known and important indicator of the traffic emissions (4, 13), and the mean ratio of this component in this study is within this range.

The single BTEX species undergo photochemical degradation with different reaction rates; therefore, the ratios of the different types of BTX compounds are usually utilized to obtain information about the characteristics of the atmosphere and also to provide data regarding different emission sources of these pollutants in the ambient air (52). For this reason, the interspecies ratio of BTEX species has been widely used as an identifier of emission source in previous studies in this field by various researchers (53, 54).

The T/B ratio is more widely used in different studies, compared to other ratios. Furthermore, higher values of the X/B ratio indicate emissions from a vicinity source, whereas lower amounts illustrate photochemical aging of the air mass. In this study, the X/B ratios were lower than the T/B ratios. This may be attributed to xylene degradation faster than that of toluene (55). Among the most important factors affecting the T/B ratio, one can name photochemistry, meteorology, and emissions (56). Prior studies announced that increasing traffic volume, industrial activities, and other urban sources in denser regions cause increases in the ratio of B/T (26, 27, 33). Moreover, the ratio value of T/X that is close to one is an indicator of the emissions of traffic sources, and these ratios increase in the areas with higher sources of pollution (9, 27, 52). Therefore, in this study, considering that the T/B, T/X, and X/B ratios have the highest rates relative to other ratios, vehicular

emissions were the major pollution source of BTEX compounds in this city.

Based on the results, there was a positive and statistically significant correlation between all BTX compounds with one another. The T/X ($r=0.94$) and Ebz/B ($r=0.85$) had the highest correlation coefficient, and this strong Pearson's correlation shows probable common sources of these compounds.

Other studies were conducted by Rad et al. (2014), Hajzadeh et al. (2018), Masih et al. (2018), Yaghmaien et al. (2019), and AL-HARBI (2019) reported significant relative relationships among the individual BTEX compounds. They proposed that the significant relationship between Ebz/B and two species of xylene and benzene indicates that the compounds were originating from similar sources. On the other hand, due to the fact that benzene is frequently caused by urban traffic, it can be used as an index for BTEX species in the urban region (57). In other words, the strong correlation between benzene and other compounds indicates that these compounds could be originated from gasoline vehicles and stations (58).

In this study, the concentrations of BTEX compounds in Ahvaz, Iran were calculated and also compared with the number of concentrations of these compounds in some cities across the world (13, 26, 27, 36, 59-61). Figure 3 illustrates the comparison of the mean concentrations of BTEX ($\mu\text{g}/\text{m}^3$) in the present study with the results of other studies. Accordingly, the mean concentrations of BTEX ($\mu\text{g}/\text{m}^3$) in the present study are different from those in other studies. As shown in figure 3, the highest levels of BTEX concentration were reported in China (Beijing) ($B=27.2$, $T=31.9$, $E=23.2$, and $X=19.1\mu\text{g}/\text{m}^3$) and Mexico (Yucatan) ($B=36.45$, $T=5.08$, $E=11.08$, and $X=5.35\mu\text{g}/\text{m}^3$). On the other hand, the lowest levels of these compounds were found in Poland (Gliwice) followed by Saudi Arabia (Jeddah) ($B=1.24$, 0.41 ; $T=0.78$, 1.4 ; $E=0.22$,

0.49 , and $X=0.33$, 1.56 , respectively). The mean BTEX concentration in the present study ($B=0.8$, $T=2.55$, $E=0.54$, and $X=1.26\mu\text{g}/\text{m}^3$) was similar to those in Australia ($B=0.8$, $T=2.83$, $E=0.49$, and $X=2.36\mu\text{g}/\text{m}^3$); however, these values were higher than those in Poland (Gliwice) and Saudi Arabia (Jeddah) but lower than those in other countries.

Moreover, the comparison of the BTEX concentration amounts in the present study with those in other studies in urban areas of Iran showed some differences in terms of mean concentrations of BTEX (1, 9, 28, 30). The highest values of BTEX concentration were calculated in Yazd ($B=21$, $T=38$, $E=14$, and $X=41\mu\text{g}/\text{m}^3$) and Tehran ($B=43.5$, $T=26.2$, $E=10$, and $X=19.1\mu\text{g}/\text{m}^3$). The mean BTEX levels in the present study ($B=0.8$, $T=2.55$, $E=0.54$, and $X=1.26\mu\text{g}/\text{m}^3$) were similar to those in a study conducted by Rad et al. (2014) in Ahvaz ($B=1.78$, $T=5.19$, $E=0.51$, and $X=1.13\mu\text{g}/\text{m}^3$). Variation in BTEX concentration in different cities can be ascribed to the particular characteristics of the studied cities, major city activities, and also differences related to vehicles, including vehicle manufacture quality, fuel combination, the concentration of aromatic compounds in fuels, traffic density, diversity and number of industries, atmospheric conditions, sampling points, and sampling periods (30, 62).

According to the findings of a definitive risk assessment analysis, the mean, minimum, and maximum cancer risks of benzene were 0.89×10^{-6} , 0.02×10^{-6} , and 6.26×10^{-6} , respectively. Based on these results, the mean and minimum carcinogenic risks values of the exposure to benzene are 0.89×10^{-6} and 0.02×10^{-6} , respectively, which represents lower cancer risks of benzene, compared to unit cancer risk value (i.e., 1×10^{-6}). However, the maximum cancer risk values for benzene were observed more than 1.00×10^{-6} as the limit set by USEPA. The limits of carcinogenic risks have been categorized to some classes, such as

deterministic ($>1 \times 10^{-4}$), probabilistic (1×10^{-5} - 1×10^{-4}), conceivable (1×10^{-6} - 1×10^{-5}), and admissible risks ($<1 \times 10^{-6}$) (63). In the present study, the minimum and mean benzene LTCR were lower than 1×10^{-6} ; accordingly, benzene can be defined as an acceptable risk. However, the maximum cancer risk values for benzene (6.26×10^{-6}) is exceeded 1.00×10^{-6} and can be considered a possible risk. The minimum, mean, and maximum HRs of benzene (0.09, 3.84, and 27.01), toluene (0.001, 0.074 and 0.29), ethylbenzene (0.003, 0.077 and 0.74) and xylene (0.02, 1.76 and 10.16) were also summarized in Table 6.

For non-carcinogenic risks, the HRs should be less than 1 to indicate an insignificant risk (64). Therefore, based on the HR values of these compounds, mean and maximum HR for benzene and xylene exceeded this limit which indicated a deterministic health hazard for people of this city. Concerning the non-carcinogenic hazard for toluene and ethylbenzene, none of the HRs were higher than 1.00; therefore, they cannot be considered a threat to human health. The sum of minimum, mean, and maximum HRs (HI) of all compounds were 0.11, 5.75, and 38.2, respectively. Therefore, the mean and maximum values of HI (the cumulative HR) exceeded 1 which showed a definite health risk. Overall, the results of this study indicate the need for controlling BTEX emission, especially benzene, and monitoring this city. Hadei et al. (2018) evaluated the risks of BTEX compounds and formaldehyde in Tehran, Iran. The results of their study showed that based on a health risk assessment, the carcinogenic risks of benzene and formaldehyde were more than 1×10^{-4} indicating a definite risk. In the same vein, Omidi et al. (2019) evaluated the probable risk of occupational exposure to VOCs in the rendering plant of a poultry slaughterhouse in Iran. Based on the results, the measured HQ values for whole compounds were more than 1,

and the LCR values for carcinogenic compounds showed that the risk of benzene-induced cancer is higher than the maximum admissible level presented by USEPA. Furthermore, the results of a study by Hajizadeh et al. (2018) who assessed the health risk of BTEX in Yazd, Iran, showed that though the values of the non-cancer risk of BTEX were within the permissive recommended range, there was a cancer risk due to high levels of benzene in the air.

Conclusion

This study was conducted to determine the concentrations of BTEX compounds and assess the health risk of these pollutants (carcinogenic and non-carcinogenic) for the residents in Ahvaz, Iran during a year in spring, summer, and autumn. Out of the BTEX compounds, toluene was the most abundant followed by xylene, benzene, and ethylbenzene in the course of the study period. The Σ BTEX indicated differences among seasons in which the highest concentrations of the BTX were in the winter followed by autumn and summer. This is due to more sunlight and higher temperatures in the summer which produce higher chemical removal reaction rates, thereby eliminating these pollutions from the atmosphere.

After comparing weekdays and weekends in terms of the concentration of BTEX compounds, no significant difference was observed in this regard during the study period ($P > 0.05$). The B/T and X/E ratios indicated that vehicular emissions were the major pollution source of BTEX compounds in this city. The cancer risk for benzene in this study was lower than the provided value by USEPA. In addition, the HQ of the BTEX indicated that the non-carcinogenic risk for benzene and xylene was higher than the acceptable limit expressing the potential for adverse health

effects. However, the HQ for toluene and ethylbenzene were lower than the recommended levels. Therefore, it is essential to determine a major source of air pollutants which can be a suitable tool for the management and implementation of related control strategies. Accordingly, the findings declare the need for controlling BTEX emissions (mainly benzene and Xylene) and source identification of the air pollutants, particularly B and X, which can be a useful tool for the management and implementation of associated control strategies.

Footnotes

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Conflict of Interest

The authors declared no conflict of interest.

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