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Health risk assessment of BTEX compounds (benzene, toluene, ethylbenzene and xylene) in different indoor air using Monte Carlo simulation in zahedan city, Iran

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A R T I C L E I N F O

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A B S T R A C T

The presence of benzene, toluene, ethylbenzene, and xylene compounds (BTEX) in the breathing air outside and inside buildings is one of the most significant problems related to human health today. This study was performed to determine the concentration of BTEX pollutants in indoor environments. PhoCheck was used to detect the concentration of BTEX compounds. In this study, the concentration (BTEX pollutant) was assessed in four indoor spaces, including restaurants, laundries, hair salons, and photocopying centers. The results showed that the average concentration of all four searched compounds was higher than the recommended limit of the Environmental Protection Agency (EPA). The results of carcinogenic risk assessment by benzene and ethylbenzene compounds show 2153×10^{-4} and 913×10^{-5} respectively. The HQ values for toluene and xylene were 1.397 and 0.505, respectively, indicating that exposure to toluene alone may have adverse effects on human health, while exposure to xylene alone has no adverse effects. The hazard index (HI) for toluene and xylene pollutants was higher than one. An HI value higher than one means that the two contaminants toluene and xylene in the air we breathe may have adverse effects on human health. As a result, the necessary control measures should be taken to prevent the unfavorable effects of these two pollutants.

1. Introduction

There are growing concerns about human exposure to indoor air pollution, as people spend more than 90% of their time indoors [1]. In addition to the quantity of breathing air, the quality of breathing air is essential in both outdoor and indoor surroundings, because the low quality of breathing air can, directly and indirectly, affect people's health in the short and long term [2–4]. Nowadays, the concern related to the quality of air in indoor spaces has received more attention due to more exposure to pollutants, long contact time, especially in residential homes and work environments, less dilution, and sometimes higher concentrations of pollutants [5,6].

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So, studies by the United States Environmental Protection Agency (EPA) showed that the amount of indoor pollution is often 2 to 5 times and sometimes 100 times higher than the concentration of outdoor pollution [7]. Poor indoor air quality and the use of aromatic compounds and personal care as precursors of BTEX compounds play a major role in increasing the risk of these compounds on health. Volatile organic compounds (VOCs) such as benzene, toluene, xylene, ethylbenzene, hexane, heptane, trichloroethane, etc., are organic pollutants found in indoor environments, and their concentrations increase many times in indoor environments [8,9]. Air pollution is one of the principal environmental risk factors that can have numerous acute and chronic impacts on human health [10, 11]. These pollutants have health, carcinogenic, and teratogenic effects, so their concentration in indoor air should be determined and evaluated. The risk posed by them seems important [8,12].

Within the VOCs, benzene, toluene, ethylbenzene, and xylene, (BTEX) are present at high concentrations in many public and residential indoor environments because of their high vapor pressure [13].

The American Environmental Protection Agency has stated the Reference concentration (RfC) for benzene, toluene, ethylbenzene, and xylene as 0.03, 5, 1, and 0.1 mg/m3, respectively. Various indoor environments such as residential homes, offices, restaurants, and other public places have the potential to be affected by one or more potential sources of VOCs, such as BTEX infiltration from the outdoor air [14], use of various solvents, consumer and commercial products [15], building materials and furniture [16], heating and cooking equipment [17,18], and BTEX concentration increases in them [19].

Long-term exposure to Benzene as a hematotoxic compound increases the occurrence of leukemia and aplastic anemia in humans. Benzene is the most abundant and dangerous compound of BTEX, which is classified as a carcinogenic compound (group A) by the US Environmental Protection Agency [20].

This pollutant is detected in almost most indoor environments, and its most important indoor sources are smoking, materials used for heating and cooking, and its emission from consumer products such as paint, varnish, wax, solvent, detergents or cleaning products, etc [17,19,21]. Due to the toxicity, stability, and cumulative properties of BTEX, these compounds can have severe effects on the environment and human health. Therefore, continuous monitoring and evaluation of the health risk caused by them are one of the important health issues that should be considered [22].

The studies of Colman Lerner, Kitwattanavong, and Phatrabuddha have shown that chronic and acute respiratory diseases, nervous system problems, lung cancer, chronic and frequent headaches, allergies, asthma, and eye, nose, and throat irritation are related to exposure to VOC compounds so that it has caused health researchers to pay more attention to the air quality of indoor environments and to investigate people's exposure to VOCs [23–26]. Various studies by epidemiologists have proven a significant relationship between increased benzene concentration and aplastic anemia in children, and exposure to toluene led to a decrease in luteinizing hormone (LH) and follicle-stimulating hormone (FSH) and significantly increased the possibility of Increases abortion [27–29].There are different approaches for the measurement of volatile organic compounds in indoor air. One is used in gas sensors that have relative resistance to achieve the determination of benzene, toluene, ethylbenzene, and xylene (BTEX) with high efficiency. Disadvantages such as high cost, lack of reflection Time changes of analytes, detection limits, more influence from environmental conditions, the problem of changes related to the transfer of sample compounds to the laboratory, and the need for extraction and pre-concentration are some of the things that make the use of the PhoCheck 5000 photoionization detector device more than the methods (APCI- MS/MS made possible and recommended [30,31].

Since inhalation exposure is the most important route for the entry of volatile compounds in the air into the human body, determining the concentration of pollutants in the air and checking the amount of exposure to them through breathing air is a suitable tool for assessing health risk (carcinogenicity and non-carcinogenicity) caused by them; the amount of risk for people in different environments is estimated based on the obtained results [15,17]. Women's hair salons, use a wide range of cosmetic products,

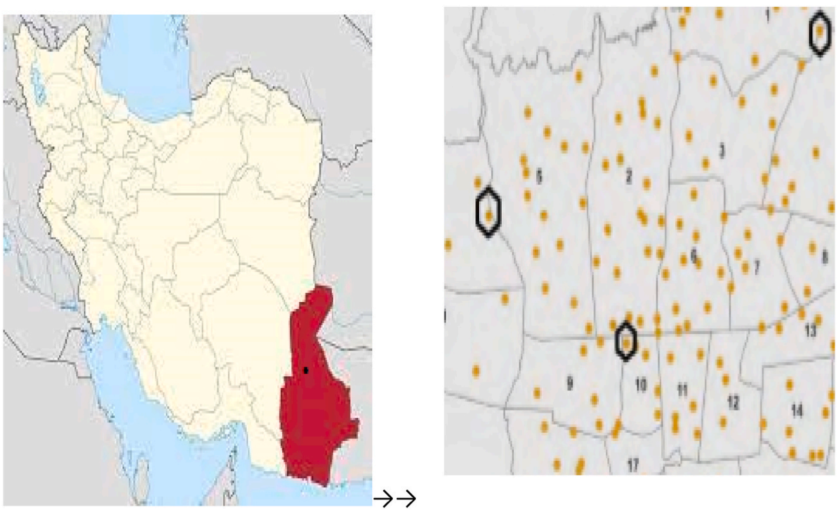

Fig. 1. Map showing the location and GIS of the study area and sampeling

including shampoo, lipstick, whitening oil and powder, hair spray, gel, mascara, perfume, rouge, creams, lotions, and cleansers, and BTEX compounds are the most important pollutants. that these cosmetic products are released in the air of beauty salons [32]. The effect of photocopiers on indoor air quality has been noticed in recent years. Laboratory and field studies have shown that about 60 VOCs may be released into room air during photocopying operations, which have been proven to be BTEX emissions [33]. Cleaning products that are used in laundry rooms release BTEX compounds into the air. Also, the presence of BTEX compounds in restaurants has been proven due to the use of detergents and chemicals. Therefore, this study was conducted with the aim of determining the concentration of BTEX compounds in the air of indoor environments, including restaurants, photocopying centers, laundries, and women's hair salons and assessing the carcinogenic and non-carcinogenic risk of exposure to these compounds. Considering the importance of these compounds in the discussion of human health, considering that the measurement of these compounds has not been performed in public places of Zahedan City, thus, this work was done for the first time its risk assessment was recognized. The innovation of this work is appropriate zoning to measure and evaluate the concentration of these compounds in different places.

2. Materials and methods

2.1. Study area

The current study is a cross-sectional descriptive study that was conducted in Zahedan city in 2013. To determine the concentration of BTEX compounds in this research, four indoor environments including photocopying centers, hairdressing salons, restaurants, and laundries were studied. The sampling points are shown in Fig. 1.

Fig. 2. PhoCheck 5000 photoionization detector device.

2.2. Measurement of BTEX concentration

BTEX concentration was measured in winter and summer. Due to the effect of different days of the week on human activities and, as a result, its effect on the amount of pollutant concentration, the concentration measurement was carried out in predetermined places for a period of one month on days that covered all working days of the week. Measuring the concentration in the studied locations was done randomly between 11:00 and 13:00 (with two repetitions) by the data-logging PhoCheck 5000 photoionization detector device having 10.6-eV ultraviolet lamp technology (Ion Science Ltd., Cambridge, England). which is shown in Fig. 2.

A PID lamp is installed inside the Phocheck device, which directly measures BTEX compounds. The limit of detection for this device for measuring BTEX compounds is 0.001 mg/L (the accuracy of the device is 0.001 ppm).

At the time of measuring the concentration of BTEX with the Phochak device, according to the instructions written in the scientific texts, it was tried to measure the concentration at a distance of 35 cm from the wall, 1 m from the floor of the environment and at three different points, and finally, the average value of the measurements was recorded at the site as the average concentration of BTEX. Due to the fact that volatile compounds are widely used in printers and photocopiers and chemicals used in hair salons and dry cleaners, these public places were taken into consideration.

2.3. Health risk assessment

The risk assessment process is a tool outlined by the US Environmental Protection Agency for the exposure of populations to carcinogenic and non-carcinogenic toxic compounds. When a chemical is first identified and the risk assessment process is performed for it, it must go through the following 4 steps: hazard identification, exposure assessment, toxicity (dose-response) assessment, and risk characterization.

The US Environmental Protection Agency has specified reference values for all carcinogenic and non-carcinogenic substances, which are used in the risk assessment process. These reference values for oral and inhalation exposures are Reference dose (RfD) for non-carcinogenic substances and Slope factor (SOF) for carcinogenic substances, which are obtained during laboratory studies.

Since benzene and ethylbenzene are carcinogenic compounds of groups A and C, respectively, the risk of carcinogenicity was calculated for these compounds, but Hazard Quotient and Hazard Index were calculated for toluene and xylene compounds, which have non-carcinogenic health risks.

2.3.1. Non-carcinogenic risk assessment

To evaluate the health risk caused by inhalation exposure to non-carcinogenic compounds, the average daily dose (ADD) was estimated:

$$ADD = \frac{C \times CR \times EF \times ED}{AT \times BW} \tag{1}$$

In this equation, C (Concentration), CR (Contact Rate), EF (Exposure Frequency), ED (Exposure Duration), AT (Average Lifetime), and BW (Body Weight) values are the pollutant concentration in breathing air (mg.m^{-3}), the amount of air a person breathes per day (L. day^{-1}), the frequency of exposure (day.year^{-1}), the duration of exposure (year), the average lifetime (day), and the average body weight of an adult person (Kg), respectively. The Hazard Quotient (HQ) value, which is the ratio of ADD to the RfC, was calculated using the following equation.

$$HQ = \frac{ADD}{RfC} \tag{2}$$

Finally, the Hazard Index (HI) was calculated by the following equation (3) (sum of HQ values for each pollutant).

$$HI = HQ_1 + HQ_2 + HQ_3 \tag{3}$$

After calculating the Hazard Index, if its value is less than 1, it means that there is no risk of exposure to the concentration of existing BTEX compounds, and if the hazard index is greater than 1, there is a risk of exposure to the concentration of BTEX.

2.3.2. Carcenogenic risk assessment

In this study, in order to estimate the carcinogenic risk of BTEX compounds, first, according to equation (1), the value of ADD by a person was determined, and then to estimate the carcinogenic risk caused by exposure to pollutants during lifetime (ELCR = Extra

Table 1
The quantitative values used in the estimation of risk.

pollutant	RfC	SOF	source
Benzene	0.03	0.028	Agency for Toxic Substances and Disease Registry
Ethylbenzene	1	0.0038	Agency for Toxic Substances and Disease Registry
Toluene	5	–	Integrated Risk Information System
Xylene	0.1	–	Integrated Risk Information System

lifetime cancer risk), which is equal to the product of ADD and SOF, the following equation was used:

$$ELCR = ADD \times SOF \quad (4)$$

In this study, Crystal Ball software was used to analyze and simulate health risks. The default quantitative values used in the estimation of carcinogenic and non-carcinogenic risk in this research were the values suggested by the EPA, whose values are presented in Table 1.

3. Results

3.1. Concentrations of BTEX compounds

In health risk assessment processes, it is essential to determine the concentration values of the desired pollutants in the environment. In this study, the concentration values of BTEX compounds were measured in different indoor environments (restaurants, photocopy centers, laundries, and women's hair salons) in the cold winter and hot summer seasons, and their results are presented in Fig. 3(A-D) ، 4(A-D) and 5.

3.2. Results of carcinogenic risk

Since benzene and ethylbenzene are in the group of carcinogens classified by EPA, for these two pollutants, carcinogenic risk values were calculated according to equations (1) and (4) [34], and the results were obtained as ELCR and this value for benzene and ethylbenzene was equal to 2153×10^{-4} and 913×10^{-5}, respectively. On the other hand, Crystal Ball software was used to simulate the risk of carcinogenicity caused by exposure to benzene and ethylbenzene, the results of which are presented in Fig. 6.

3.3. Non-carcinogenic risk results

Toluene and xylene compounds are not in the group of carcinogenic substances classified by EPA; thus, for these compounds, HQ values were estimated according to equations (1) and (2), and finally, the HI value (sum of HQ) was calculated. The results showed that

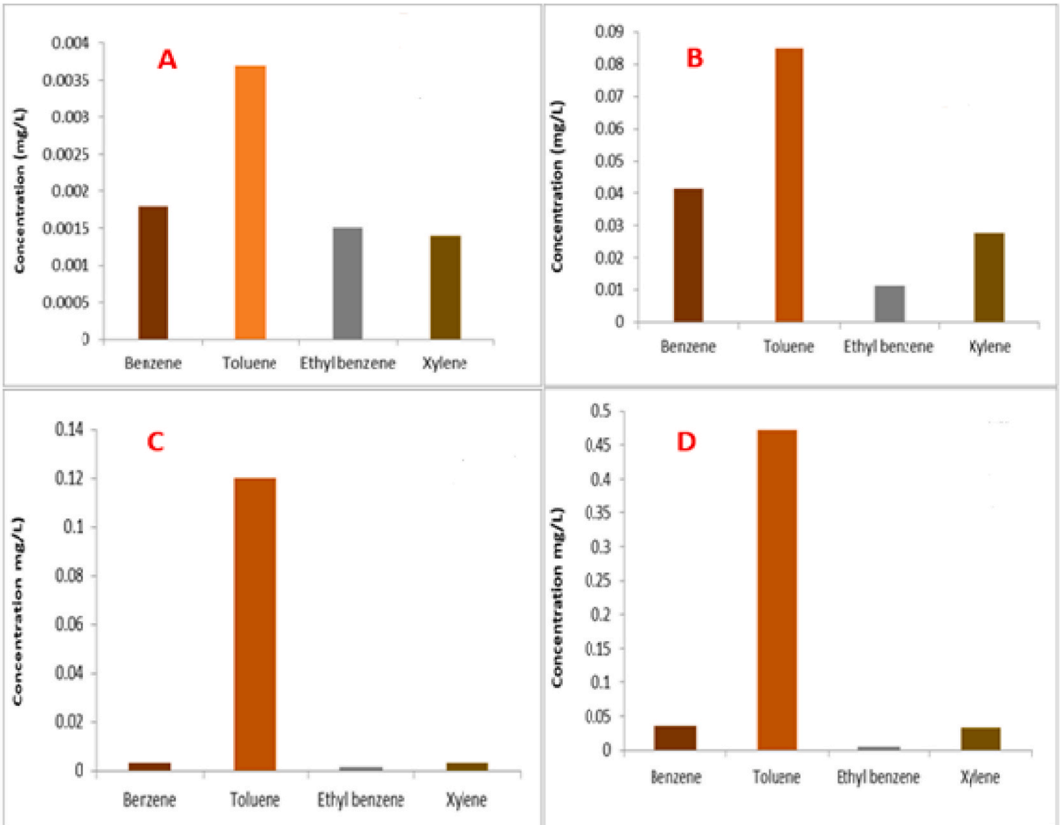

Fig. 3. Concentration of BTEX compounds in restaurants (A), photocopy centers (B), laundries (C), and women's hair salons (D) in the winter season.

the values of HQ for toluene and xylene are 1.397 and 0.505, respectively, and finally, the value of HI was 1.903. When the HQ of a pollutant for an exposed population is less than one, it means that there are no adverse health effects caused by that pollutant on humans, but if the HQ value is greater than 1, it means that the concentration of the present pollutant is more than the permissible limits, and people exposed to it are at risk to adverse health effects. , the results of which are shown in Fig. 7.

4. Discussion

As shown in Fig. 3 (A to D), the average concentration of toluene is higher than other BTEX compounds in winter in all the studied sites. The results of the analysis of variance for the average concentrations of benzene, toluene, ethylbenzene, and xylene showed that the concentrations of BTEX pollutants are significantly different from each other (p-value$<$0.05).

In addition, the concentration of this toluene compound in breathing air is higher than the standard set by the EPA. The results of this study also showed that the concentration of BTEX compounds in all the examined points is almost higher than the EPA standard; such high concentrations in indoor environments can lead to an increase in the inhalation exposure of people to such pollutants, which eventually will show its effects.

The high concentration of BTEX compounds in the indoor air of the studied locations can be affected by high urban traffic, incomplete combustion of fossil fuels in the cold season, frequent radiation inversions in the winter season, internal sources of VOCs production in the studied locations, smoking by the employees and the lack of proper ventilation system to prevent the heat loss of the workplace in the winter season. The next point is that these are the average values mentioned for BTEX compounds in the winter season, and contrary to expectations, it can be seen that the average concentration of BTEX is high, and the probable cause of this issue can be the presence of low atmospheric precipitation in this province [35,36]. The variance test showed that there is a significant difference between the concentrations of BTEX compounds in different environments (p-value$<$0.05).

Fig. 4 results show that the average concentration of benzene was measured in restaurants and photocopy centers, and the values of toluene were measured as the highest BTEX compounds for laundry centers and hair salons. In the Rostami et al. study, the concentration of BTEX print and copy centers is consistent with this study [37].

The noteworthy point in the results is that benzene, as a known carcinogenic compound in group A, is much higher than the EPA limit in restaurants and photocopy centers; therefore, the people working in the mentioned places are heavily affected by such

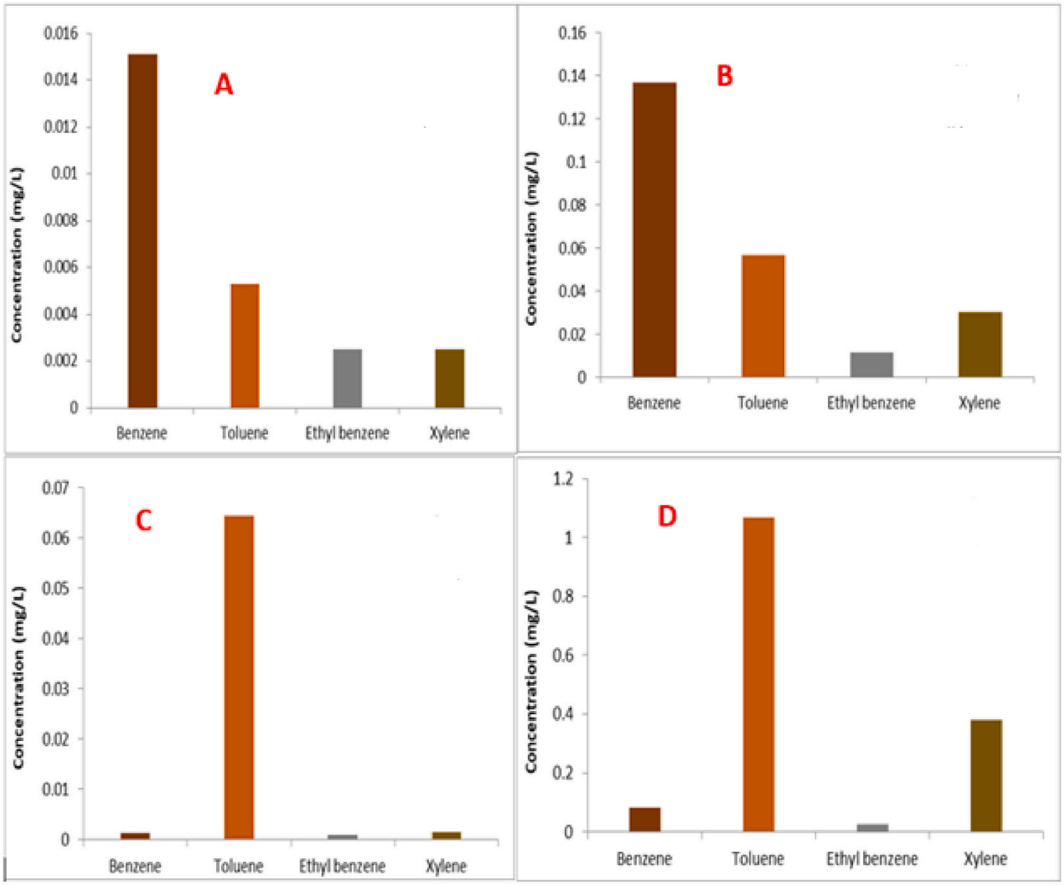

Fig. 4. Concentration values of BTEX compounds in restaurants (A), photocopy centers (B), laundries (C), and hair salons (D) in the summer season.

pollutants. In addition, because the concentration of benzene in restaurants and photocopy centers is high, the visitors to such units are also affected (especially restaurants due to the longer exposure time). Since restaurants and photocopy centers are located in crowded and high-traffic areas compared to laundries and hair salons, the high concentration of benzene in such environments can be affected by the outdoor air. In addition, due to the high consumption of fossil gas for cooking food and the lack of proper and sufficient ventilation in restaurants, a high concentration of benzene can be expected. Moreover, the use of printing solutions containing volatile compounds used and old printing devices, and ultimately the leakage of chemicals from such used and worn-out devices can justify the high concentration of benzene in photocopy centers. On the other hand, in the city of Zahedan, photocopy centers operate in very small shops, which limits the possibility of proper ventilation in such small places.

In laundry centers and women's hair salons, the amount of toluene is the highest among other BTEX compounds in the cold season of the year. Therefore, it can be concluded that the high presence of toluene in laundry centers and women's hair salons can be caused by the compounds and chemicals used in those centers [8,35,36]. The results of Baghani et al.'s study in connection with Tehran beauty salons showed that the average concentration of benzene (32.40 ± 26.38) is higher than the levels recommended by Health Canada, ANSES, and HKSAR. Among BTEX compounds, ethylbenzene (32.37 ± 62.38) has the highest concentration in the halls [38]. It is not consistent with the present study. In this study, toluene and ethylbenzene had the highest and lowest concentrations, respectively. The noteworthy point in this study is that in the summer season as well as in the cold winter season, the concentration of most BTEX compounds in all the studied environments is almost a little higher than the standard limits set by the EPA. Therefore, it seems necessary to carry out the health risk assessment process.

Fig. 5 shows that in the winter season, in restaurants, photocopying centers, laundry centers, and women's hair salons, toluene values were recorded as the highest BTEX compounds, and in the summer season, in restaurants and photocopying centers, the average concentration of benzene and for laundry centers and Women's hair salons have recorded toluene levels as the highest levels of BTEX compounds.

The comparison of the average concentration of BTEX compounds in the studied environments in two seasons, winter and summer, using the Kruskal-Wallis test, is shown in Table 2. The results show that in both winter and summer, the average concentration of benzene, toluene, ethylene, benzene, and xylene in restaurants, photocopy centers, laundries, and ladies' hairdressing salons show statistically significant differences (p-value <0.05). In the study by Amit Masih et al., the BTEX concentration in residential areas was 1.6 μg per cubic meter, and the highest concentration of this compound was calculated to be 56.32 μg per cubic meter in the winter season, with BTEX concentration increasing with decreasing temperature at all sites. This study also calculated the ILTCR for 10-6 benzene for residents [39]. In the Monte Carlo simulation, the concentration values are represented by 5p, 25p, 50p, 75p, and 95p, because a point, like the mean, has a high uncertainty in the health risk estimate, and this makes the health risk estimate in the simulation process can be expressed as a percentage of the probability of occurrence. As seen in Fig. 6A, for P 50, P75, and P90, the value of ELCR is equal to 3.674 E^{-5}, 4.705 E^{-5}, and 5.882 E^{-5}, respectively, and this shows that in a population of one hundred thousand people, with a probability of 90%, there are 6 cases of cancer caused by exposure to benzene.

Fig. 6B shows the distribution of carcinogenic risk for the population exposed to ethylbenzene compound. As shown, the value of ELCR in the probability of occurrences of P 50, P 75, and P90 is equal to 3.674 E^{-5}, 4.705 E^{-5}, and 5.882 E^{-5}, respectively, which indicates that with a probability of 75 and 90%, There is a possibility of occurrence of 5 and 6 cases of cancer in a population of 100,000 exposed to ethylbenzene, respectively. In the study by Amit Masih et al.

Compared to the reference value provided by EPA (safe range of 10^{-4}), it is clarified that for benzene and ethylbenzene compounds, there is almost no carcinogenic risk during 70 years of exposure to these compounds. In the study by Amit Masih et al., also calculated

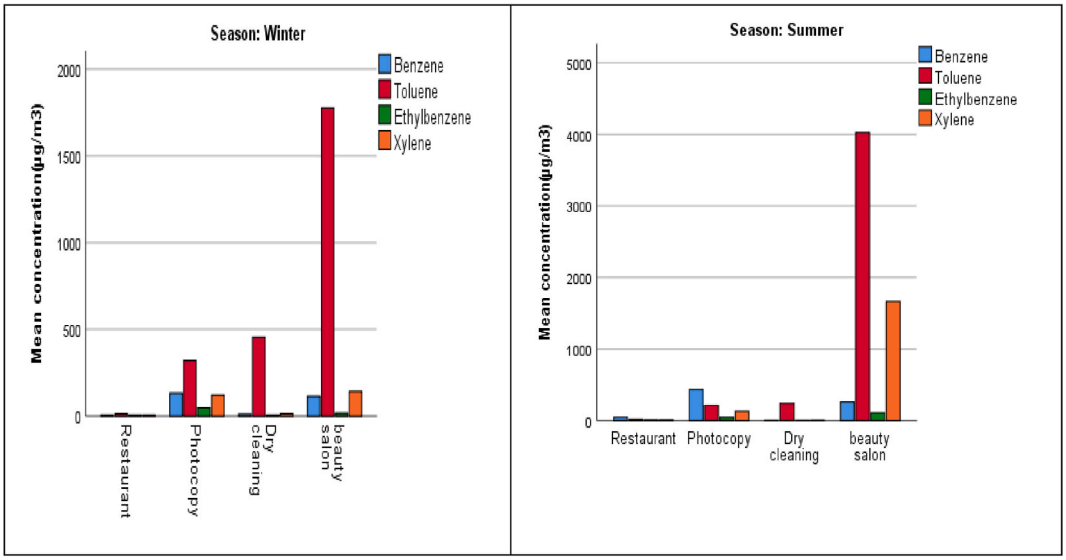

Fig. 5. The average concentration of BTEX compounds (μg/m^3) according to the investigated locations.

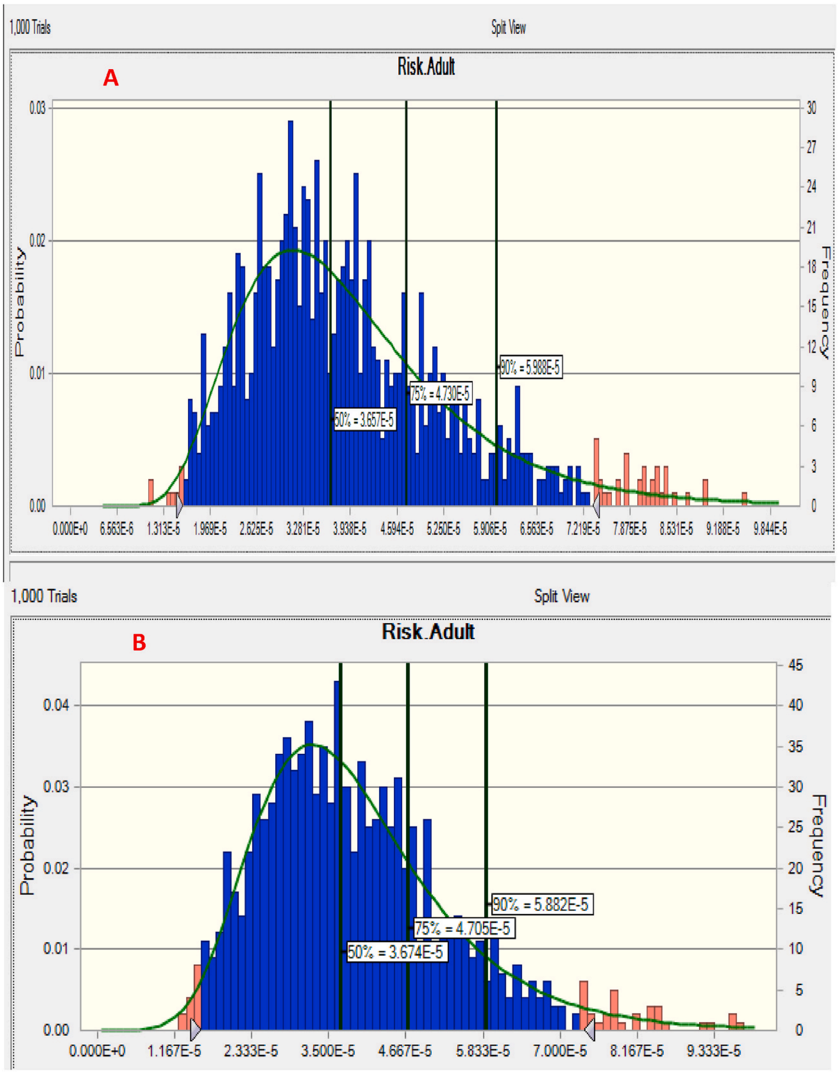

Fig. 6. Simulation results of carcinogenicity risk in the population exposed to benzene (A) and ethylbenzene (B).

the ILTCR for 10^{-6} benzene for residents. Therefore, since the average concentrations presented for benzene and ethylbenzene are higher than the permissible range of the EPA, the presence of non-carcinogenic effects is possible and it is recommended that proper control measures should be taken. On the other hand, the results of the sensitivity analysis show that body weight, pollutant concentration, and the amount of inhaled air respectively have the greatest effect on risk distribution, which is consistent with the results of other researchers who have studied BTEX compounds [39–41].

According to the HQ values obtained for toluene and xylene and their comparison, it was found that the HQ value of toluene alone (even without considering the HQ value of xylene) is higher than one, and it indicates that due to the high concentration of toluene in inhaled air, this pollutant can have harmful effects on human health. While the amount of HQ related to xylene is less than one, it means that it does not have an adverse health effect on its own. The HI value obtained from the sum of the HQ related to the studied pollutants is higher than one for toluene and xylene. The HI value greater than 1 indicates that the two toluene and xylene pollutants in the breathing air of the people exposed in this study can have adverse effects on human health.

Considering that the risk assessment using HQ and HI is a number, the health risk caused by toluene and xylene was also presented as a risk distribution by Monte Carlo simulation.

Fig. 7 represents the risk distribution for exposure to toluene and xylene. Fig. 7A shows that there is a probability of risk caused by toluene for the exposed population with a 95% confidence interval, and in simpler terms, the concentration of toluene is high enough in inhaled air so that there is a potential for non-carcinogenic adverse effects for 90% of the exposed population.

Fig. 7B also shows the risk distribution for the population exposed to xylene. According to this figure, it can be concluded that the average concentration of xylene is low so that the risk factor for 95% of the exposed population will not have adverse effects and is within the safe range. In similar studies that have been conducted on BTEX compounds in outdoor urban environments and indoor

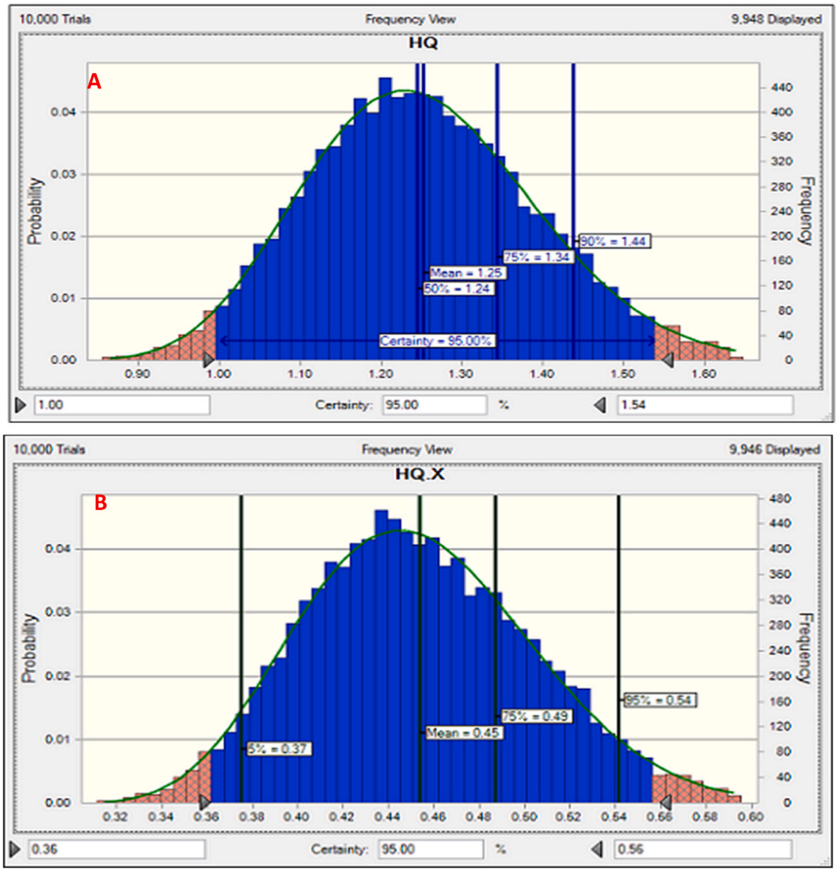

Fig. 7. Simulation results of the non-cancer risk of the population exposed to toluene (A) and xylene (B).

Table 2
Comparison of the average concentration of BTEX compounds (μg/m^3) in the investigated environments.

location	winter				summer			
	Benzene	Toluene	ethylbenzene	Xylene	Benzene	Toluene	ethylbenzene	Xylene
Restaurants	5.75	13.94	6.51	6.08	43.24	19.97	10.86	10.86
Photocopy centers	132.58	320.70	48.63	120.72	436.39	213.30	48.63	131.14
Laundries	10.22	453.73	6.08	13.90	4.15	242.32	3.91	6.51
Women's hair salons	114.69	1776.10	17.37	142.43	2622.83	4025.90	112.03	1665.28
p-value	0.001	0.001	0.006	0.001	0.008	0.001	0.002	0.001

environments, the average toluene concentration was higher than usual, but the HI value was reported to be less than 1. While, in the present study, the obtained HI was about 1.9. In the study by Amit Masih et al., The HI value was estimated to be less than 1 at all sites. The amount of non-carcinogenic risk in this study is higher than that of Amit Masih et al. [39]. In the study that Ghaffari et al. focused on measuring the concentration of BTEX (benzene, toluene, ethylbenzene, and xylene) in the air of different areas and indoor and outdoor environments of Bandar Abbas, Iran. The levels of all BTEX compounds were higher in the winter period. And the cancer risk of benzene exceeded the recommended level of 1.0E. −06 and it was found that the concentration ratio of BTEX inside the beauty salon is more than 1 [42]. This study is in perfect agreement with our work.

5. Conclusion

Volatile organic compounds, especially BTEX, including benzene, toluene, xylene, and ethylbenzene, are dangerous organic pollutants in the air of indoor environments, whose concentration levels increase many times in indoor environments, and long-term exposure to these pollutants can cause carcinogenic, teratogenic, and non-carcinogenic effects on human health. Therefore, it is very necessary to measure and evaluate the health risk and their control methods in the air of indoor environments. In this study, to determine the concentration and assess the health risk of BTEX compounds, four indoor environments including photocopy centers, hair salons, restaurants, and laundries were studied, and the BTEX concentrations were evaluated in two seasons, i.e., winter and summer. The results showed that the average concentration of the four target pollutants is higher than the limits suggested by the EPA. The health risk assessment for carcinogenic compounds showed that benzene and ethylbenzene have no carcinogenic risk during the human lifetime, with a confidence of 95%, the risk of cancer occurrence in the exposed population is lower than the confidence limit. However, for the non-carcinogenic risk, the HQ values for toluene and xylene were calculated as 1.397 and 0.505, respectively, which shows that exposure to toluene alone can have adverse health effects, while exposure to xylene alone does not have adverse health effects. The results showed that the values of HQ for toluene and xylene are 1.397 and 0.505, respectively, and finally, the value of HI was 1.903. When the HQ of a pollutant for an exposed population is less than one, it means that there are no adverse health effects caused by that pollutant on humans which indicates that there is a health risk (non-carcinogenic) related to exposure to these two pollutants in the breathing air, and they will show their adverse effects in the long term; the outcomes received as ELCR and this value for benzene and ethylbenzene were equal to 2153 × 10-4 and 913 × 10-5, respectively therefore, necessary control measures should be taken to prevent the harmful effects of these two pollutants.

Author Contribution statement

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2-Performed the experiments; Marzieh Baniasadi.
3-Analyzed and interpreted the data; Leili Mohammadi, Ali Azari and Shahla Rayegannakhost.
4-Contributed reagents, materials, analysis tools or data; Hossein Moein.
5-Wrote the paper ; Hossein Abdipour.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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