The University of Tehran Press

Pollution

Print ISSN: 2383-451X
Online ISSN: 2383-4501

https://jpoll.ut.ac.ir/

Assessment of Carcinogenicity and Health Risks from Respiratory Exposure to BTEX Compounds at the Kermanshah Oil Depot in Iran

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Article Info

Article type:
Research Article

Article history:
Received: 28 October 2024
Revised: 18 February 2025
Accepted: 20 July 2025

Keywords:
Excess lifetime cancer risk,
NIOSH 1501,
Non-cancer hazard quotient,
Occupational exposure,
Singapore method

ABSTRACT

In the petroleum industry, oil decomposition releases volatile organic compounds that easily evaporate due to high vapor pressure, posing significant health risks to exposed workers. The aim of this study was to evaluate health risks from Benzene, Toluene, Ethylbenzene, and Xylene (BTEX) exposure among employees at the Kermanshah National Oil Products Distribution Company. BTEX sampling was conducted at six loading stations, each with two lines, over 48 hours in 8-hour shifts using NIOSH method 1501. Compounds were extracted with carbon disulfide and analyzed by gas chromatography with a Flame Ionization Detector. The risk assessment followed the Singapore method. Results showed that benzene and toluene constituted 42% and 33% of BTEX compounds in the breathing zones of active workers, while xylene and ethylbenzene accounted for 21% and 4%, respectively. The time-weighted average concentrations were: benzene at 0.51 ± 0.14 ppm, toluene at 0.28 ± 0.08 ppm, ethylbenzene at 0.05 ± 0.01 ppm, and xylene at 0.17 ± 0.05 ppm. Benzene risk ratings varied from low at station 6 to very high at station 1, line 2, and station 3, line 1. The highest carcinogenic risk from benzene was at station 3, line 1, with an excess lifetime cancer risk of 1.13×10^{-3}, while the lowest was at station 6, at 1.10×10^{-5}. Non-cancer hazard quotients for toluene, ethylbenzene, and xylene remained below 1 across all stations, indicating acceptable risk levels. The study underscores the necessity of continuous monitoring and strong regulations to mitigate BTEX emission risks in the oil industry. Enhancing measurement methods and ensuring compliance with air quality standards will protect environmental health and workforce welfare. Future research should prioritize longitudinal studies on the long-term effects of BTEX exposure.

Cite this article: Delfani, M., Mohammadi Rouzbahani, M., Choobkar, N., & Salimi, N. (2025). Assessment of Carcinogenicity and Health Risks from Respiratory Exposure to BTEX Compounds at the Kermanshah Oil Depot in Iran. *Pollution*, 11(3), 857-869.
https://doi.org/10.22059/poll.2025.384510.2623

DOI: https://doi.org/10.22059/poll.2025.384510.2623

INTRODUCTION

Air pollution is a significant environmental issue caused by harmful compounds in the atmosphere from human activities or natural processes (Shetty et al., 2023). Many workers globally are exposed to various chemicals, leading to serious health effects (Benson et al., 2021). The oil industry, covering exploration, drilling, production, and refining, negatively impacts human health and the environment, leading oil companies to undertake activities that pose health and safety risks. (Ramirez et al., 2017). In these industries, oil decomposition releases volatile organic compounds (VOCs) that readily evaporate due to their high vapor pressure, leading to widespread respiratory exposure (Feng et al., 2024).

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Health effects from chemical exposure can be acute or chronic, systemic or local, and reversible or irreversible, particularly in chemical production and use (Anderson and Meade, 2014). Benzene, toluene, ethylbenzene, and xylene (BTEX) are VOCs with similar properties. Short-term exposure can lead to skin irritation and central nervous system issues, including fatigue, headaches, dizziness, and loss of balance. Long-term exposure is associated with kidney, liver, and blood damage, as well as an increased risk of cancer-related mortality (Khajeh Hoseini et al., 2022).

To mitigate adverse side effects, it is vital to follow precautionary principles and implement control measures when using these substances, particularly due to the significant exposure faced by oil and gas workers (Benson et al., 2024). Evaluating health risks from chemical exposure is essential for managing both short-term and long-term health implications, making ongoing assessments imperative (Gwinn et al., 2017).

The main method for evaluating risks from occupational and environmental chemicals is the risk assessment process (Heggum, 2024). This process integrates health risks into the organization's health, safety, and environmental management system, ensuring protection for all employees, contractors, and third parties. Occupational health risk assessments should be conducted for ongoing activities and changes, focusing on individuals at significant health risk. This approach streamlines the assessment process (Kamrin, 2014).

Research aimed at evaluating the potential health effects associated with exposure to VOCs has yielded inconclusive results. Jalilian et al. (2022) studied BTEX exposure at the Abadan Oil Refining Company and found that while employees were exposed to BTEX pollutants, concentrations in the breathing zone were below the Threshold Limit Value - Time-Weighted Average (TLV-TWA) recommended by the American Conference of Governmental and Industrial Hygienists (ACGIH). Additionally, Benzene was determined to pose the highest risk among the seven operating units. Alimohammadi et al. (2023) evaluated the carcinogenic and health risks of BTEX compounds in gasoline refueling stations and found that most participants had risk values within unacceptable levels, highlighting the need for corrective measures to protect employees from these risks. Kamani et al. (2023) measured BTEX pollutant levels in indoor settings such as restaurants, laundries, hair salons, and photocopying centers, finding that the average concentration of all four compounds exceeded the recommended limit of the Environmental Protection Agency (EPA). The adverse effects of VOCs can vary from minor health issues to the carcinogenic potential of specific compounds, including benzene.

This current cross-sectional study aimed to evaluate the health risks associated with exposure to BTEX among employees at the Kermanshah oil storage warehouse of Iran's National Oil Products Distribution Company.

MATERIALS AND METHODS

Research location

This descriptive cross-sectional study was conducted to assess the emissions of BTEX in the air at the oil storage of Iran's National Oil Products Distribution Company in Kermanshah (Fig. 1), located on Zan Boulevard (34°20'52"N 47°6'7" E), and evaluate the associated health risks for employees as a case study. The facility included tank truck loading stations, each with two loading lines. This research involved selecting the six loading stations under the guidance of the Ministry of Health and with the supervision of health center experts. The facility employed 104 people, divided into two groups: administrative staff working in offices away from the loading area and outdoor workers exposed to volatile organic compounds at the loading stations.

BTEX sampling and analysis

Air samples preparation

Figure 2 provides an overview of the experiment. BTEX sampling was conducted using the NIOSH (National Institute for Occupational Safety and Health) method 1501 in the loading stations with active workers. Six loading stations, each featuring two loading lines (12 in total), were monitored for 48 hours in 8-hour shifts. Since this study was designed as a cross-sectional descriptive study with a limited sampling period, the number of samples was determined based on limitations such as research costs and time constraints. Samples were collected from the workers' breathing zones, totaling 36 air samples from the 12 loading lines, with three samples taken from each line. A sampling pump (SKC Ltd, Universal 44XR Sample Pump, UK) with an adjustable flow rate below 200 ml/min was used for sampling.

Air from the sampling site was drawn through activated carbon adsorbent tubes to capture the desired compounds. The activated carbon was housed in closed glass tubes made by SKC, each measuring 7 cm in length and 4 mm in diameter, containing activated carbon separated by

Figure 1. The oil storage warehouse of the National Iranian Oil Products Distribution Company, situated in Kermanshah province, Iran (indicated by the highlighted area in orange).

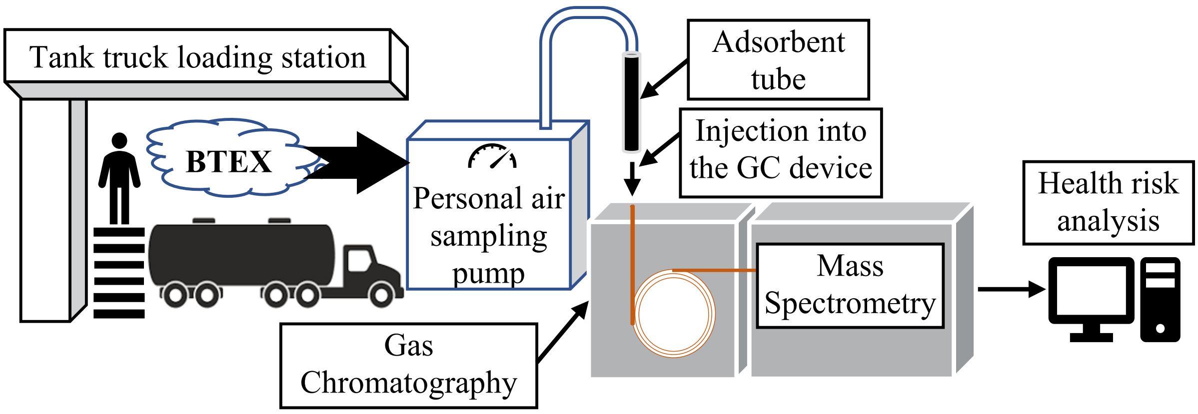

Figure 2. Summary of the experimental design

a 2 mm layer of polyurethane foam. For sampling, the pump was calibrated with a flowmeter and a double-ended adsorbent tube. The flow rate was set at 0.2 L/min, and each sampling lasted approximately 75 minutes. The sorbent tubes were positioned about 2 m above the ground level. At each sampling, the ends of the absorber tube were broken, and the tube was connected to the pump inlet according to the airflow direction indicated by an arrow. After sampling, the tubes were transported to the laboratory at IAU University of Kermanshah at a temperature of 4°C.

Chemical analysis of the air samples

To extract pollutants, the front of the adsorbent was crushed, and its contents were transferred to 2 ml vials washed with carbon disulfide (CS_2). Then, 1 ml of 99% pure CS_2 was added, and the vials were sealed with septum caps and shaken for 30 minutes. One µl of the solution was then removed using a 10 µL Hamilton syringe and injected into the gas chromatograph of the mass spectrometer (model CP3800, Variance Inc.). The extracted samples were analyzed using a gas chromatography device with a flame ionization detector (GC-FID, Agilent Technology 7890) to quantify BTEX compounds. Calibration curves were established using a standard BTEX mixture (2000 µg/ml in methanol), achieving R-squared values ≥ 0.99 across ten concentrations. The device shutdown time was 1.9-3.5 minutes, with the injection site temperature at 180°C, the initial column temperature at 30°C, and a 12-minute hold at this temperature. The temperature increased by 20°C per minute to 180°C, where it stabilized. The precision of the Method Quantitation Limit (MQL) was assessed via relative standard deviations (RSD), confirming that the RSD for each BTEX calibration level (3 replicates) did not exceed 5%. The method detection limits for each BTEX compound ranged from 0.12 to 0.16 µg/m^3, while BTEX levels in blank samples were below the limit of detection.

Health Risk Assessment

A health risk assessment for chemical exposure was conducted using the Singapore method, which incorporates measurements of BTEX compounds along with employees' exposure frequency, duration, daily and weekly working hours, and the number of shifts per week. The estimation process includes determining the Hazard Rate (HR) and the Exposure Rate Index (ERI), evaluated as follows:

Determining the degree of hazard rate

According to the method recommended by the Malaysian Department of Occupational Health, the HR (an integer value between 1 to 5) is determined according to the factors presented in Table 1. Data used in this method include information provided by organizations related to chemical hazards such as the ACGIH classification of chemicals in terms of health risks. The potential risks of chemicals can also be determined based on the classifications presented by these organizations.

Determining the degree of exposure rate index

To obtain the exposure rate index (ERI, an integer value between 1 to 5), the initial exposure rate was estimated using equation 1:

$$ER = \frac{E}{PEL} \quad (1)$$

Where ER is the exposure rate, E is the average weekly exposure rate and PEL is the permissible exposure limit. The NIOSH documents were used to estimate the PEL. ER is typically dimensionless, as both E and PEL will have the same unit of measurement.

The average weekly exposure to chemicals was determined using Equation 2:

$$E_{(\text{ppm})} = \frac{F \times D \times M}{W} \quad (2)$$

Where E represents the average weekly chemical exposure, F indicates the frequency of exposure per week, M is the exposure rate in ppm, D is the average duration of each exposure in hours, and W signifies the average weekly working hours. Finally, the ERI was assessed using the following criteria: ER < 0.1 results in ERI = 1; 0.1 ≤ ER < 0.5 results in ERI = 2; 0.5 ≤ ER < 1 yields ERI = 3; 1 ≤ ER < 2 gives ERI = 4; and 2 ≤ ER leads to ERI = 5.

Determination of risk level and risk ranking

The risk level was calculated using the equation 3.

$$RL = \sqrt{HR \times ERI} \quad (3)$$

Where RL is risk level and HR and ERI, both on a scale of 1 to 5, are as defined above. Taking the square root of the results ensures an integer value between 1 and 5. Afterward, the RLs were ranked as follows: 1 ≤ RL < 1.7 (Negligible); 1.7 ≤ RL < 2.8 (Low); 2.8 ≤ RL < 3.5 (Moderate); 3.5 ≤ RL < 4.5 (High); and 4.5 ≤ RL ≤ 5 (Very high). This yields a risk ranking matrix summarized in Table 2.

Risk assessment of carcinogenic effects of BTEX compounds.

Carcinogenic risk assessment for BTEX compounds was conducted using the Environmental Protection Agency (EPA) method. Benzene, classified as a definite human carcinogen of category A by IARC and EPA, prompted specific carcinogenic risk evaluation, while non-carcinogenic risks for all other BTEX compounds were also assessed. To evaluate carcinogenic from exposure

Table 1. Assessment of hazard rates based on the toxic or harmful effects of chemicals

HR	ACGIH rating	Description	Example
1	A5	Materials which are known to have no adverse health effects and are not considered toxic or harmful.	Sodium chloride, Butane, Butyl acetate, Calcium carbonate
2	A4	Materials that cause skin sensitization and irritation, with reversible effects on the skin, eyes, and mucous membranes, but not severe enough to cause significant impairment.	Acetone, butane, acetic acid (10%), barium salts, etc.
3	A3	Material that are probably carcinogenic or mutagenic to humans or animals, though information is limited. This includes corrosive substances (pH <3 or 9 < pH <12) and respiratory sensitizers.	Toluene, Xylene, Ammonia, Butanol, Staldehyde, Aniline, Antimony
4	A2	Materials with heightened carcinogenic, mutagenic, and teratogenic effects on animals, include highly corrosive substances (pH <0 or pH >14).	Formaldehyde, cadmium, methylene chloride, acrylonitrile ethylene oxide
5	A1	Materials recognized for their carcinogenic, mutagenic, and teratogenic effects including highly toxic chemicals.	Benzene, benzydine, lead, arsenic, beryllium, bromine, vinyl chloride, mercury

HR: Hazard Rate; ACGIH: American Conference of Governmental and Industrial Hygienists

Table 2: Risk ranking matrix

ER \ HR	1	2	3	4	5	Guide
1	1.0	1.4	1.7	2.0	2.2	Negligible
2	1.4	2.0	2.4	2.8	3.2	Low
3	1.7	2.4	3.0	3.5	3.9	Moderate
4	2.0	2.8	3.5	4.0	4.5	High
5	2.2	3.2	3.9	4.5	5.0	Very high

to benzene, Excess Lifetime Cancer Risk (ELCR) was determined using equation 4:

$$ELCR = ADI \times CSF \tag{4}$$

where ELCR is the excess Lifetime Cancer Risk, ADI is the Average Daily Intake, and CSF refers to the Cancer Slope Factor, which quantifies the risk of cancer per unit of exposure to a chemical over a lifetime. The CSF for benzene is around 0.055 mg/kg. day. The ELCR is dimensionless, as it represents a probability or a risk estimate.

The ADI through inhalation was calculated using formula 5:

$$ADI_{(\mathrm{Mg/kg.\ d})} = \frac{CA \times IR \times ET \times ED \times EF}{BW \times AT} \tag{5}$$

where ADI is in mg/kg $_{\text{(body weight)}}$. d is as defined above, CA denotes the concentration of the pollutant in the air (in mg. m^3), IR is the ingestion rate or the number of breaths taken in 12-hour shifts of work (in m^3/d), ET is the exposure time (8 h/d), EF is the exposure frequency, ED is the exposure duration (in years), BW is body weight (in kg), and AT is the averaging time (in days). The formula ensures that exposure is calculated concerning an individual's body weight over a specific time frame. The U.S. EPA typically considers the following thresholds for carcinogenic risk:

1- A risk value greater than 1×10^{-4} indicates a high carcinogenic risk.

2- A risk value between 1×10^{-6} and 1×10^{-4} is considered to represent a low to moderate risk.

3- A risk value less than 1×10-6 is generally deemed acceptable, indicating a low carcinogenic risk (Zhao et al., 2023).

Risk assessment of non-carcinogenic effects of BTEX compounds

Non-carcinogenic risk for BTEX compounds was quantified using the equation 6:

$$\mathrm{HQ} = \frac{ADI}{RFC} \tag{6}$$

where HQ is the non-cancer Hazard Quotient, and RFC is the reference concentration value (mg/kg. day) set by the US EPA. As both the ADI and RFC are expressed as concentrations, the HQ is unitless. An HQ of ≤1 indicates no significant non-carcinogenic risk to humans, while an HQ >1 indicates a high and unacceptable risk (Moradnia et al., 2024).

Statistical analysis

The normality of the data distribution was assessed using the Kolmogorov-Smirnov test, along with an analysis of skewness. Spearman's correlation coefficient was used to check the relationship between the concentrations of BTEX compounds. The significance level of the tests was considered as $P < 0.05$.

RESULTS AND DISCUSSION

Petroleum product loading stations are specialized facilities designed for the safe and efficient handling of liquid petroleum products in warehouses. Employees near these stations are often exposed to volatile organic compounds, especially benzene, toluene, ethylbenzene, and xylene, which can present serious health risks, including carcinogenic effects, respiratory problems, and potential organ damage. (Saeedi et al., 2024). BTEX health risks depend on factors such as the type and concentration of compounds in breathing zones, indoor air quality, exposure levels, emission sources, and individual health susceptibility (Kamani et al., 2023). Therefore, estimating these compounds' concentrations and assessing their potential health risks is crucial for evaluating the short-term and long-term impacts on exposed employees (Shetty et al., 2023).

The results obtained from the measurement of BTEX compound concentrations in the breathing zones of active workers at the oil product loading stations within the Kermanshah oil storage warehouse are summarized in Table 1 and Fig. 3. The findings reveal that benzene and toluene constituted 42% and 33% of the BTEX compounds, respectively, while xylene and ethylbenzene represented 21% and 4%, respectively. Furthermore, the time-weighted average concentrations (calculated over an 8-hour work shift) were as follows: benzene at 0.51 ± 0.14 ppm, toluene at 0.28 ± 0.08 ppm, ethylbenzene at 0.05 ± 0.01 ppm, and xylene at 0.17 ± 0.05 ppm. The data presented in Table 1 indicate that the average exposure to benzene has exceeded the occupational exposure limit (OEL) established by the American Conference of Governmental and Industrial Hygienists (ACGIH). In contrast, the concentrations of toluene, ethylbenzene, and xylene remained below their respective OELs. These findings are consistent with the research conducted by Heibati et al. (2017), Salama et al. (2021), Alimohammadi et al. (2023), Latif et al. (2019), Jalilian et al. (2022), Garg et al. (2019) which measured BTEX

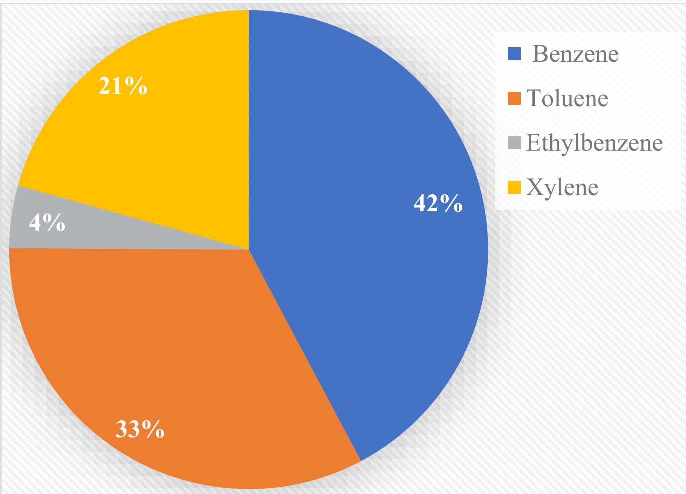

Figure 3. Percentage of BTEX compounds in the air of oil storage warehouse of National Oil Products Distribution Company of Kermanshah

Table 3. BTEX compound levels (ppm) in the air of the National Oil Products Distribution Company's oil storage warehouse of Kermanshah

BTEX compound	Mean ± StD (ppm)	ACGIH-TWA (ppm)
Benzene	0.51 ± 0.14	0.5
Toluene	0.28 ± 0.08	20
Ethylbenzene	0.05 ± 0.01	20
Xylene	0.17 ± 0.05	100

ACGIH-TWA: American Conference of Governmental and Industrial Hygienists-Time Weighted Average (an 8-hour work shift).

Table 4. Spearman's correlation coefficient between BTEX compounds measured in the air sample of Kermanshah Oil Company warehouse

	Benzene	Toluene	Ethylbenzene
Toluene	0.97**	1	
Ethylbenzene	0.86**	0.91**	1
Xylene	0.75**	0.78**	0.78**

** correlation is significant at 0.01 probability level concentrations in the worker's breathing zone within facilities associated with the oil industry. In comparison to heavier compounds, such as xylene and ethylbenzene, benzene demonstrates a rapid evaporation rate attributable to its relatively high vapor pressure and lower molecular weight (Nourmoradi et al., 2012). Consequently, in our study, benzene was found to be the predominant component of the concentration of BTEX compounds.

The Smirnov-Kolmogorov test indicated that the data distribution did not conform to a normal distribution. Consequently, Spearman's rank correlation coefficient was employed to examine the relationships among the measured BTEX compounds. The results revealed a strong, positive, and statistically significant correlation among all BTEX compounds ($p < 0.01$). The most pronounced correlation was observed between benzene and toluene; thus, an increase in benzene levels corresponded with an increase in toluene levels in the air at the study site, and vice versa. Similarly, Allahabady et al. (2022), and (Cruz et al., 2020) reported comparable findings.

Despite the strong correlation observed between benzene and toluene, the findings suggest that the health risks associated with benzene are greater than those linked to toluene. This disparity can be primarily attributed to the classification of benzene as a known carcinogen, which is associated with various health risks, including leukemia. In contrast, toluene, although toxic, exhibits lower reactivity due to the presence of the electron-donating methyl group, which diminishes the likelihood of forming carcinogenic compounds (Tulebekov et al., 2023). Furthermore, benzene's tendency to metabolize harmful substances further contributes to its elevated risk in comparison to toluene (Saeedi et al., 2024).

The findings of the health risk assessment concerning BTEX compounds are presented in Tables 5 to 8. The mean weekly exposure to benzene ranged from 0.026 ppm at station 6, line

Table 5. Health risk of Benzene in the operational units of the Kermanshah National Oil Products Distribution Company's storage warehouse

LS	Line	E (ppm)	HR	ER	ERI	RL	RR
1	1	0.74	5	1.48	4	4.47	High
	2	1.02	5	2.04	5	5.00	Very high
2	1	0.17	5	0.34	2	3.16	Moderate
	2	0.26	5	0.52	3	3.87	High
3	1	2.05	5	4.10	5	5.00	Very high
	2	0.33	5	0.66	3	3.87	High
4	1	0.26	5	0.52	3	3.87	High
	2	0.03	5	0.06	1	2.24	Low
5	1	0.24	5	0.48	2	3.16	Moderate
	2	0.26	5	0.52	3	3.87	High
6	1	0.03	5	0.05	1	2.24	Low
	2	0.03	5	0.05	1	2.24	Low

LS: loading station; E: average weekly exposure; HR: hazard rate (see table 1), ER: exposure rate; ERI: exposure rate index; RL: risk level; RR: risk ranking

Table 6. Health risk of Toluene in the operational units of the Kermanshah National Oil Products Distribution Company's storage warehouse

LS	Line	E (ppm)	HR	ER	ERI	RL	RR
1	1	0.88	3	8.80×10^{-3}	1	1.73	Low
	2	0.92	3	9.20×10^{-3}	1	1.73	Low
2	1	0.17	3	1.70×10^{-3}	1	1.73	Low
	2	0.18	3	1.80×10^{-3}	1	1.73	Low
3	1	1.94	3	1.94×10^{-2}	1	1.73	Low
	2	0.33	3	3.30×10^{-3}	1	1.73	Low
4	1	0.24	3	2.40×10^{-3}	1	1.73	Low
	2	0.17	3	1.70×10^{-3}	1	1.73	Low
5	1	0.11	3	1.10×10^{-3}	1	1.73	Low
	2	0.13	3	1.30×10^{-3}	1	1.73	Low
6	1	0.043	3	4.30×10^{-4}	1	1.73	Low
	2	0.038	3	3.80×10^{-4}	1	1.73	Low

LS: loading station; E: average weekly exposure; HR: hazard rate (see table 1), ER: exposure rate; ERI: exposure rate index; RL: risk level; RR: risk ranking

2, to 2.05 ppm at station 3, line 1. Likewise, the mean weekly exposure to toluene varied from 0.038 ppm at station 6, line 2, to 1.94 ppm at station 3, line 1. This observation is consistent with the strong correlation identified between benzene and toluene. The highest average weekly exposure to ethylbenzene, measured at 0.28 ppm, was recorded in the first line of the fifth loading station, whereas the lowest exposure, at 0.0067 ppm, was observed in the second line of the fourth loading station. Additionally, the highest concentration of xylene exposure, measured at 1.03 ppm, was recorded in line 1 of station 3, whereas the lowest concentration, at 0.028 ppm, was noted in line 1 of station 2. The health risk assessment revealed that the risk ranking for benzene ranged from low at loading station 6 (for both lines) to very high at loading station 1 (line 2) and loading station 3 (line 1). In contrast, the risk ranking for the other three compounds remained consistently low across all sampling locations (Tables 5 to 8). This result was in agreement with Jalilian et al. (2022) who reported that benzene had the highest risk ranking in operating units of Abadan Oil Refining Company, Iran, while toluene, ethylbenzene, and xylene had a very low risk.

The findings of the risk assessment concerning the non-carcinogenic and carcinogenic effects of BTEX compounds are presented in Table 9. According to the data provided in this table, the carcinogenic risk associated with benzene exposure for workers in loading stations 1, 2, and 3 surpasses the maximum permissible limit established by the United States Environmental Protection Agency (US EPA). In contrast, the risk levels for the other three loading stations remained within the acceptable range. The workers at loading station 3, line 1, were exposed to the highest carcinogenic risk associated with benzene, quantified at 1.13×10^{-3}, whereas loading station 6 exhibited the lowest risk, measured at 1.10×10^{-5}. The non-carcinogenic risk levels

Table 7. Health risk of Ethylbenzene in the operational units of the Kermanshah National Oil Products Distribution Company's storage warehouse.

LS	Line	E (ppm)	HR	ER	ERI	RL	RR
1	1	0.17	3	8.50×10^{-3}	1	1.73	Low
	2	0.15	3	7.50×10^{-3}	1	1.73	Low
2	1	0.12	3	6.00×10^{-3}	1	1.73	Low
	2	0.14	3	7.00×10^{-3}	1	1.73	Low
3	1	0.26	3	1.30×10^{-2}	1	1.73	Low
	2	0.28	3	1.40×10^{-2}	1	1.73	Low
4	1	0.0089	3	4.45×10^{-4}	1	1.73	Low
	2	0.0067	3	3.35×10^{-4}	1	1.73	Low
5	1	0.028	3	1.40×10^{-3}	1	1.73	Low
	2	0.026	3	1.30×10^{-3}	1	1.73	Low
6	1	0.016	3	8.00×10^{-4}	1	1.73	Low
	2	0.019	3	9.50×10^{-4}	1	1.73	Low

LS: loading station; E: average weekly exposure; HR: hazard rate (see table 1), ER: exposure rate; ERI: exposure rate index; RL: risk level; RR: risk ranking

Table 8. Health risk of Xylene in the operational units of the Kermanshah National Oil Products Distribution Company's storage warehouse

LS	Line	E (ppm)	HR	ER	ERI	RL	RR
1	1	0.59	3	2.95×10^{-2}	1	1.73	Low
	2	0.58	3	2.90×10^{-2}	1	1.73	Low
2	1	0.0028	3	1.00×10^{-4}	1	1.73	Low
	2	0.0035	3	2.00×10^{-4}	1	1.73	Low
3	1	1.03	3	5.15×10^{-2}	1	1.73	Low
	2	0.29	3	1.45×10^{-2}	1	1.73	Low
4	1	0.26	3	1.30×10^{-2}	1	1.73	Low
	2	0.29	3	1.45×10^{-2}	1	1.73	Low
5	1	0.087	3	4.40×10^{-3}	1	1.73	Low
	2	0.063	3	3.20×10^{-3}	1	1.73	Low
6	1	0.0086	3	4.00×10^{-4}	1	1.73	Low
	2	0.0069	3	3.00×10^{-4}	1	1.73	Low

LS: loading station; E: average weekly exposure; HR: hazard rate (see table 1), ER: exposure rate; ERI: exposure rate index; RL: risk level; RR: risk ranking

Table 9. Risk of carcinogenic and non-carcinogenic BTEX compounds at six loading stations in the oil storage warehouse of the National Oil Products Distribution Company in Kermanshah.

Loading station	ELCR for Benzene	HQ for BTEX compounds		
		Toluene	Ethylbenzene	Xylene
1	4.07×10^{-4}	4.40×10^{-2}	1.70×10^{-2}	5.90×10^{-3}
2	8.80×10^{-4}	6.40×10^{-2}	2.10×10^{-2}	7.80×10^{-3}
3	1.13×10^{-3}	9.70×10^{-2}	2.60×10^{-2}	1.03×10^{-2}
4	1.43×10^{-5}	1.20×10^{-2}	3.65×10^{-2}	2.60×10^{-3}
5	1.21×10^{-5}	6.50×10^{-3}	2.22×10^{-2}	6.30×10^{-4}
6	1.10×10^{-5}	1.00×10^{-2}	5.00×10^{-3}	1.50×10^{-3}

ELCR: Excess Lifetime Cancer Risk; HQ: non-cancer Hazard Quotient
An HQ > 1 indicates a high and unacceptable risk. The U.S. EPA's maximum acceptable carcinogenic risk value is 1×10^{-4}.

for toluene, ethylbenzene, and xylene remained below 1 across all examined loading stations, signifying an acceptable risk threshold. Among the four BTEX compounds, benzene represents the most significant risk as a hazardous pollutant due to its pronounced acute and chronic toxicity. Consequently, it is imperative to implement comprehensive measures for monitoring, controlling, and mitigating its health impacts. Similar results were also reported by Rahimpoor et al. (2022), Mohammadi et al. (2020), and Maleki et al. (2022). The study by Dehghani et al. (2018) highlighted a significant carcinogenic risk associated with benzene and ethylbenzene, as well as non-carcinogenic risks related to benzene and xylene. Mohammadi et al. (2020) concluded that benzene is the most significant compound impacting public health. Al-Harbi et al. (2020) reported an increased cancer risk among workers exposed to elevated concentrations of benzene and ethylbenzene. Nevertheless, reports indicate that in industries associated with non-petroleum air pollution, for example, beauty salons (Baghani et al., 2018; Ebrahimi et al., 2023), printing industry (Alabdulhadi et al., 2019) the concentration of BTEX in the workers' breathing zone was found to be within the acceptable limits.

CONCLUSIONS

Employees in oil companies are frequently exposed to BTEX compounds. Given the serious risks associated with benzene exposure, control measures for this chemical are prioritized over the other compounds. Benzene and toluene accounted for the highest percentage of volatile compounds in workers' breathing areas.

1- Benzene's risk rating varied from low to very high, whereas the other three BTEX compounds consistently rated low at all stations.
2- The carcinogenic risk of benzene at loading stations 1, 2, and 3 surpassed the US EPA maximum limit.
3- Non-carcinogenic risk levels for toluene, ethylbenzene, and xylene were below 1 at all loading stations.

The study's risk assessment recommends prioritizing corrective and preventive measures at three levels: engineering, management, and personal protective equipment. Fluctuations in BTEX concentrations suggest that regulatory measures and monitoring must be adaptable to varying emission rates. Spatial assessments reveal the need for targeted monitoring, particularly in areas like loading zones, which show higher BTEX levels. The study emphasizes the importance of continuous monitoring and strong regulatory frameworks to mitigate BTEX emission risks in the oil industry. Enhancing measurement methods and ensuring compliance with air quality standards will better protect environmental health and workforce welfare. Future research should prioritize longitudinal studies to clarify the long-term effects of BTEX exposure.

GRANT SUPPORT DETAILS

The present research did not receive any financial support.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy have been completely observed by the authors.

LIFE SCIENCE REPORTING

No life science threat was practiced in this research.

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