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Research Article

Benzene, toluene, ethylbenzene, and xylenes surrounding a crude oil production plant: Concentrations, health risks, and ozone formation potentials

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ABSTRACT

The global economy relies heavily on crude oil as a primary source of energy and a key component in the production of many everyday products. However, the production of crude oil can release BTEX (benzene, toluene, ethylbenzene, and xylenes) into the atmosphere, thereby contributing to air pollution and negatively affecting the health of oil workers. To improve the understanding of BTEX pollution in the vicinity of a crude oil production plant, this study examines the concentrations, health risks, and ozone formation potential of BTEX in a crude oil production plant located in Diyarbakır, Türkiye. The research employed passive samplers and chromatographic analysis to collect and analyze BTEX samples, revealing concentrations that ranged from 3.46 to 30.06 μg/m^3. Statistical analysis revealed higher concentrations of BTEX within the plant perimeter in comparison to the surrounding area, indicating the plant as a primary source of these compounds in the region. Among BTEX, toluene was identified as the dominant compound, as observed in some studies conducted in areas with heavy traffic and industrial activity. The health risk assessment indicates that the inhalation of BTEX poses negligible cancer and non-cancer risks for oil workers. Additionally, the ozone formation potential of BTEX in the Diyarbakır Plant is found to be 56.8 μg/m^3, which is generally lower than the values reported in the relevant literature. Overall, the findings suggest that monitoring and reducing emissions from crude oil production is vital for the protection of air quality and the occupational health of workers.

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INTRODUCTION

Benzene, toluene, ethylbenzene, and xylenes (collectively known as BTEX) are a group of volatile organic compounds (VOCs) that has adverse effects on human health and the environment. Researchers focus on BTEX since these compounds constitute the most abundant group of VOCs in urban air [1-3] and has been categorized as hazardous air pollutants by the United States Environmental Protection Agency [4]. BTEX emissions are pervasive in the oil industry, particularly from crude oil production plants that function as both oil collection and storage facilities prior to transfer to a refinery. To protect health and the environment, therefore, the environmental and health impacts of BTEX from these plants should be understood. In order to gain a comprehensive understanding of BTEX pollution, studies in the literature tend to focus on a number of key areas, including health risks associated with exposure, ozone formation potentials, and the concentration levels (e.g. [5-8]).

BTEX compounds can cause adverse health outcomes and contribute to the formation of tropospheric ozone. Benzene has been classified as a human carcinogen with genotoxicity [9] and has been linked to a number of other adverse health effects, including hematotoxicity, reproductive effects, decreased lymphocyte counts, nervous system disorders, and

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myelodysplastic syndrome [10-12]. Long-term exposure to toluene has been linked to permanent hearing and vision loss, mental disorders, decreased reproductive abilities, immunity disorders, neurological effects, and increased kidney weight [12, 13]. Repeated exposure to ethylbenzene has been demonstrated to result in irreversible damage to the ears and kidneys [14]. Similarly, chronic exposure to xylenes (m, p, o-xylene) has been associated with an increased risk of developing disorders by damaging the central nervous system, kidneys, and liver [15, 16]. Moreover, acute exposure to elevated concentrations of BTEX compounds may result in headaches, dizziness, ocular and nasal irritation, chest discomfort, and dyspnea [12]. In regard to ozone formation, BTEX compounds undergo a chemical reaction with nitrogen oxides in the presence of sunlight, thereby resulting in the formation of tropospheric ozone [17]. Increased tropospheric ozone slows photosynthesis by entering the plant tissues [18, 19]. This results in less carbon dioxide absorption and less oxygen release, leading to a negative impact on the Earth's climate [20]. To develop effective air quality management strategies, therefore, there is a need to ascertain the health risks associated with BTEX exposure, in addition to estimating the ozone formation potentials (OFPs).

Although the oil industry is an essential part of growing economies due to its energy potential and by-products, it is also a significant cause of BTEX compounds in the atmosphere. BTEX are highly volatile (each having up to 8 carbon atoms) and occur naturally in crude oil. Due to these characteristics, they can rapidly escape from crude oil during the extraction and storage phases even before the oil is transferred to refineries or industrial complexes. Accordingly, some studies focused on examining the presence of BTEX compounds in crude oil related works, including well pads, tank farms, and distribution companies. One such study used a passive sampling method to investigate the concentration of BTEX and other VOCs at two oil and natural gas production well pads and a downtown area in the United States [21]. The findings revealed that the concentrations of benzene and toluene were statistically higher at the well pad locations in comparison to those observed in downtown Denver. Similarly, another passive sampling study analyzed BTEX at a petroleum storage facility in Nigeria [22]. In the study, toluene and benzene were the dominant compounds, comprising approximately 90% of BTEX, but the concentrations of each BTEX compound remained below the chronic inhalation threshold defined by the US EPA. Another study assessed health risks for the inhalation of BTEX in various sections of a petroleum distribution company [23]. The study revealed varying levels of cumulative health risks across different sections for oil workers, ranging from possible to definite risk levels. These studies demonstrate that crude oil poses a significant threat to air quality, even prior to the refining.

Although some studies have also examined VOCs in petrochemical and refinery complexes [24-27], few have focused on BTEX (or VOCs) from crude oil production plants. In a previous study conducted within the designated study area, the concentration of the total VOCs was measured to validate an air dispersion model [28]. The aforementioned study primarily concentrated on the formulation of a modeling framework to quantify tank emissions. Consequently, it lacked the requisite depth of analysis with respect to VOCs, including the assessment of individual VOC concentrations, along with the potential health effects and the ozone formation potentials. In another study, passive sampling and chromatographic techniques were employed to analyze VOCs at two different crude oil production plants [29]. The study found that the BTEX levels in the plants are comparable to those reported in other industrial areas in the literature, and that the health risks associated with BTEX exposure are not negligible. However, the passive samplers used in the above study were situated exclusively within crude oil production plants, thereby precluding the monitoring of VOC dispersion over distances. Therefore, in general, the dispersion of BTEX from crude oil production plants and its subsequent impact on air quality and occupational health are seldom considered. Nevertheless, a comprehensive understanding of the dispersion of air pollution from industrial facilities is indispensable to the improvement of urban air quality [30-32].

The present study examines BTEX compounds emitted from a crude oil production plant to improve the understanding of air pollution and workers' health. Specifically, we sought to learn whether distance factors have any statistical significance on changes in BTEX levels and to determine how this type of plant affects air quality and occupational health in comparison to other industrial areas. To achieve this objective, passive sampling and chromatographic techniques were employed to measure BTEX within and in the vicinity of the plant. Subsequently, the BTEX concentrations within and in the vicinity of the plant were statistically compared to evaluate differences. Furthermore, the study used the Incremental Lifetime Cancer Risk, the Health Index, and maximum incremental reactivity coefficients to quantify cancer health risk, non-cancer health risk, and ozone formation potential, respectively. This study is expected to contribute to the growing body of knowledge concerning the impact of this type of plant on air quality and occupational health.

MATERIAL AND METHODS

In order to extend current knowledge regarding the impacts of crude oil-derived BTEX compounds (benzene, toluene, ethylbenzene, and xylenes) on air quality and occupational health, we deployed 48 passive samples inside and around a crude oil production plant. Following the conclusion of the sampling period, each sample was subjected to analysis using a gas chromatography equipped with a flame ionization detector and a thermal desorption system. The results of this analysis were then employed to determine the statistical changes in concentration over distance, the associated health risks, and the ozone formation potential.

Sampling Site Description

The crude oil production plant (Diyarbakır Plant) is located in southeastern Türkiye's Diyarbakir Province (Figure 1). The plant is in a rural area and 26 kilometers away from the city center. Although there is no significant vehicular activity around the plant, there are some other industrial entities within a 10-kilometer radius, including metal, furniture, textile, and food-processing facilities. During the sampling period, the average wind speed was 3.6 meters per second, and temperatures varied between 22 and 37 degrees in Celsius [33]. The routine processes at the plant entail the reception of crude oil from wells via pipeline and tank trucks, the separation of oil and water through heater treaters, tank sampling, and inter-tank transfers. The plant has a crude oil working capacity of 88,000 barrels and is comprised of 7 production tanks, 3 test tanks, and 3 heater treaters.

Sampling Campaign and Analytical Procedure

Full details of the sampling campaign, analytical analysis, and quality control procedure followed in this study can be found in a previous paper [29]. Briefly, to collect ambient BTEX samples, stainless steel passive samplers consisting of Chromosorb-106 with a 0.18 cm^2 surface area, 1.5 cm diffusion depth, and 4.8 mm inner diameter were used. The samplers were placed at eight points within the plant perimeter and sixteen points surrounding the plant (Figure 1). Sampling points numbered 1 to 8 were located within the plant perimeter, while points numbered 9 to 24 were located outside the plant, covering a 300-meter radius around it. Twenty-four samplers were placed at the sampling site from July 9 to August 9, 2024. Subsequently, these initial samplers were replaced with another twenty-four, which were deployed and left at the sampling site until September 9, 2024. Thus, a total of 48 samplers were used in the study area between July 9 and September 9, 2024. However, five samplers were lost during the sampling period. In the first month, samples from sampling points 2 and 17 were lost. In the second month, samples from sampling points 17, 22, and 24 were lost. Collected samples were carefully protected in a freezer and analyzed within a week.

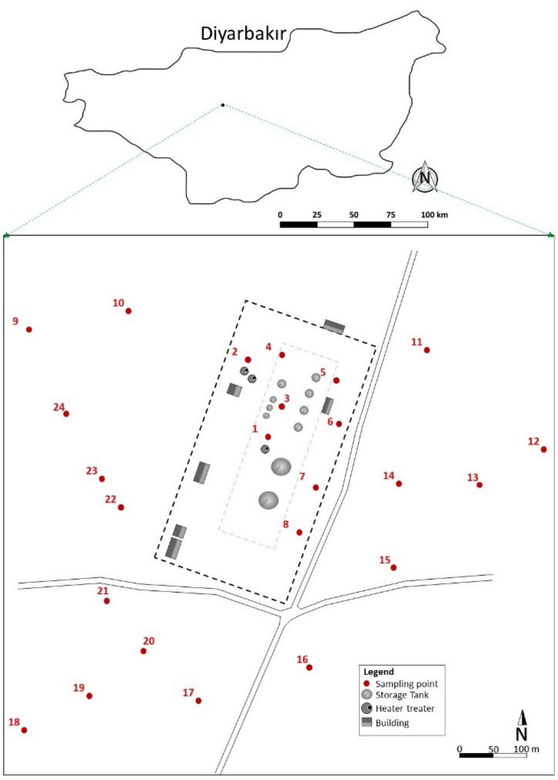

Figure 1. Study area: Diyarbakır province on the top, and Diyarbakır crude oil production plant at the bottom

The samples were analyzed using a gas chromatography equipped with a flame ionization detector (GC FID Agilent 6990) and a thermal desorption (Markes International Limited, UK) system. As a surrogate analysis, 20 µl of 1-chloro-4-fluorobenzene was used in all samples prior to extraction. The recovery percentages were between 80 and 120 for all samples, with the exception of sampling point 20 (60 % recovery) in the second month of the sampling campaign. This sample was thus removed for quality assurance. In total, 42 samples were used for further analysis. In the analysis, the analytes were thermally desorbed at 200°C for three minutes. They were transferred to a cold trap and heated to 350°C. They were subsequently sent to the GC that has two columns and FID detectors. The columns used were a DB-1 and an HP Al/S. The initial oven temperature was set to 40 °C, gradually increased to 195 °C, and maintained for 10 more minutes. The carrier gas was nitrogen, supplied at 2 ml per minute. Following the analysis, BTEX concentrations were calculated using Fick's first law of diffusion [25, 27, 34].

Five-point calibration (1-200 ng) curves with an external standard were used to calculate the limit of detection values (LODs) for benzene, toluene, ethylbenzene, and xylenes. Specifically, the LODs for these compounds were determined to be 0.05, 0.05, 0.04, and 0.035, respectively. Before conducting statistical analyses, concentrations below the LODs were adjusted to 50% of the LOD for each compound, following the methodology of previous studies [6, 21]. Field blanks were employed for quality assurance and underwent the same procedure as the field samples. The BTEX quantities detected in the blanks were all below the LODs.

Statistical Analysis

The mean concentrations of each BTEX compound, as well as the total BTEX within and outside the Diyarbakır Plant, were subjected to statistical analysis to identify significant differences. A detailed explanation of how to select an appropriate test based on the distribution of the data can be found in previous works [35-37]. In brief, the normality and equality of variances were assessed using the Shapiro-Wilk test and F-test, respectively. Subsequently, the means were statistically compared using either the Wilcoxon Rank Sum test (for non-normal distribution), Student's t-test (for normal distribution and equal variances), or Welch's t-test (for normal distribution and unequal variances).

Health Risk Assessment and the Estimation of Ozone Formation Potential

Cancer risks associated with the inhalation of BTEX were assessed for oil workers using the Incremental Lifetime Cancer Risk (ILCR) methodology. The ILCR method is commonly used as an indicator of the potential for increased cancer risks resulting from exposure to carcinogenic pollutants [5, 6, 38]. This particular study focused on estimating the ILCR resulting from benzene inhalation, as benzene is a well-established carcinogen. The equation for estimating ILCR caused by benzene is presented below:

$$ILCR = UR\ x\ \frac{C\ x\ ET\ x\ EF\ x\ ED}{I.T} \quad (1)$$

Where UR is the unit risk for benzene ($7.8*10^{-6}$ $m^3/\mu g$) provided by the International Agency for Research on Cancer [9]. C is the measured mean concentration ($m^3/\mu g$) of benzene, and ET, EF, ED, and LT are the exposure time (8-hour workday), exposure frequency (292 workdays per year), exposure duration (25 years to retirement), and life expectancy (78.6 years) [38], respectively. After calculating the ILCR, the predicted potential for developing cancer is classified into four categories based on the following scheme: negligible risk (ILCR $<10^{-6}$), possible risk ($10^{-5}>$ ILCR $>10^{-6}$), probable risk ($10^{-4}>$ ILCR $>10^{-5}$), and definite risk (ILCR $>10^{-4}$) [8, 39].

The potential non-cancer health risks of each BTEX compound were estimated using the Health Index (HI) approach. The Health Index (HI) establishes three tiers of exposure to a substance: those posing no negative impact on health ($HI < 0.1$), those possibly having a negative impact on health ($0.1 \leq HI < 1$) and those with a definite negative impact on health ($1 \leq HI$) [40, 41]. The HI for each BTEX component was calculated using equation 2, and the total HI of BTEX was determined by summing the HI values for each individual compound.

$$HI = \frac{C \; x \; ET \; x \; EF}{RfC} \quad (2)$$

Where C represents the measured mean concentration ($\mu g/m^3$) and RfC stands for the inhalation reference concentration ($\mu g/m^3$) of a BTEX compound. The IARC provided the RfCs for benzene (30), toluene (5000), ethylbenzene (1000), and xylene (100) [9].

The average ozone formation potential (OFP) for each BTEX compound and for total BTEX was estimated using maximum incremental reactivity coefficients (MIRs). MIR is a measure of how much ozone is produced per unit of a substance introduced into the atmosphere [42]. The OFP of a compound was calculated by multiplying its concentration with the compound's MIR [6,43, 44]. The MIRs were initially designed by Carter [42] through a modeling study, and were subsequently updated by Carter [45]. The MIRs (in grams of O_3 per gram of compound) for benzene, toluene, ethylbenzene, m+p xylene, and o xylene, respectively, are 0.72, 4.8, 2.93, 7.61, and 7.44 [45].

RESULTS AND DISCUSSIONS

The Concentration of BTEX

The concentration of BTEX in the study area ranged from 3.46 to 30.06 $\mu g/m^3$, with a mean value of 10.93 $\mu g/m^3$ (Table 1). The highest concentration of BTEX was measured at sampling point 3 (30.06 $\mu g/m^3$), followed by sampling points 5 (21.83 $\mu g/m^3$) and 1 (20.83 $\mu g/m^3$). These points are located in the central region of the plant, in close proximity to the crude oil tanks (Figure 2). The lowest concentrations were observed outside of the Diyarbakır Plant perimeter at sampling points 12 (3.46 $\mu g/m^3$) and 9 (3.51 $\mu g/m^3$). More than half of the BTEX concentration was toluene, followed by xylenes, ethylbenzene, and benzene. This order of prevalence was consistent with those found in a fuel oil station in Bursa [5] and another crude oil production plant in Mardin [29].

The concentration of each BTEX in the study area can be comparable to some exposure guidelines provided by reputable environmental agencies. For example, the United States Environmental Protection Agency's (US EPA) Integrated Risk Information System provides reference concentrations for chronic inhalation of several chemicals. These reference concentrations represent the threshold concentrations below which health risks are deemed acceptable [46]. The chronic inhalation reference concentrations for benzene, ethylbenzene, toluene, and xylenes are 30, 5000, 1000, and 100 $\mu g/m^3$, respectively. In addition, the Agency for Toxic Substances and Diseases Registry (ATSDR) provides maximum risk levels for BTEX, which represent concentrations above which adverse neurological effects are likely to occur [47]. The maximum risk levels for the chronic inhalation of benzene, ethylbenzene, toluene, and xylenes are 1.28, 302.31, 435.42, and 435.39 100 $\mu g/m^3$, respectively [47]. Accordingly, the mean concentration of each BTEX in the study area was lower than the concentration of chronic inhalation standards provided by the US EPA and ATSDR.

The mean concentration of BTEX in this study was found to be lower than that reported in several other studies (Table 2). In fact, the concentration was even 80% lower than that reported for industrial urban air in Kocaeli [26] and Shiraz [34]. There could be several factors that likely contributed to the low BTEX concentration observed in the study area. In the Diyarbakır Plant, there was no significant crude oil filling or unloading activity, resulting in less evaporation of BTEX. Furthermore, the plant is situated in a rural area, away from city traffic, indicating that there was likely a little influence on BTEX levels from mobile vehicle activities and home heating. Moreover, the relatively high wind speed during the sampling period may have also dispersed BTEX in the lower troposphere. In fact, during the sampling period of the current study, the average wind speed was higher compared to that reported for another crude oil production plant in Mardin (3.6 vs. 2.0 m/sec) [29]. Note that the mean BTEX in the Izmir and Colorado studies was slightly higher than that found in the current study. The Izmir study, which collected samples during both winter and summer seasons, may have resulted in a mean concentration that was lower due to seasonal variations in BTEX emissions [27]. In the Colorado study, BTEX has been measured in two oil and natural gas well pads located away from densely populated areas. These well pads are likely the primary BTEX sources in the area, which could explain the lower concentrations observed. In addition to these factors, the concentration of BTEX measured in any study is heavily dependent on the distance between the sampling points and the pollution source. Accordingly, any comparative analysis of air pollutants in different locations requires the consideration of a multitude of variables, including meteorological conditions, source characteristics, proximity to point sources, selected methodologies, and other pertinent factors.

Table 1. Descriptive Statistics of BTEX (µg/m^3) Compounds (n=42)

BTEX compound	Mean ± sd	Min	25th Percentile	Median	75th Percentile	max
benzene	0.65 ± 0.76	0.03a	0.03	0.37	1.04	2.91
toluene	5.58 ± 2.37	1.62	4.18	4.69	6.61	12.40
ethylbenzene	1.38 ± 1.26	0.02a	0.93	1.06	1.68	5.79
xylenes	3.32 ± 2.34	0.07	3.01	3.33	4.32	10.39
BTEX	10.93 ± 6.00	3.46	7.28	9.14	14.49	30.06

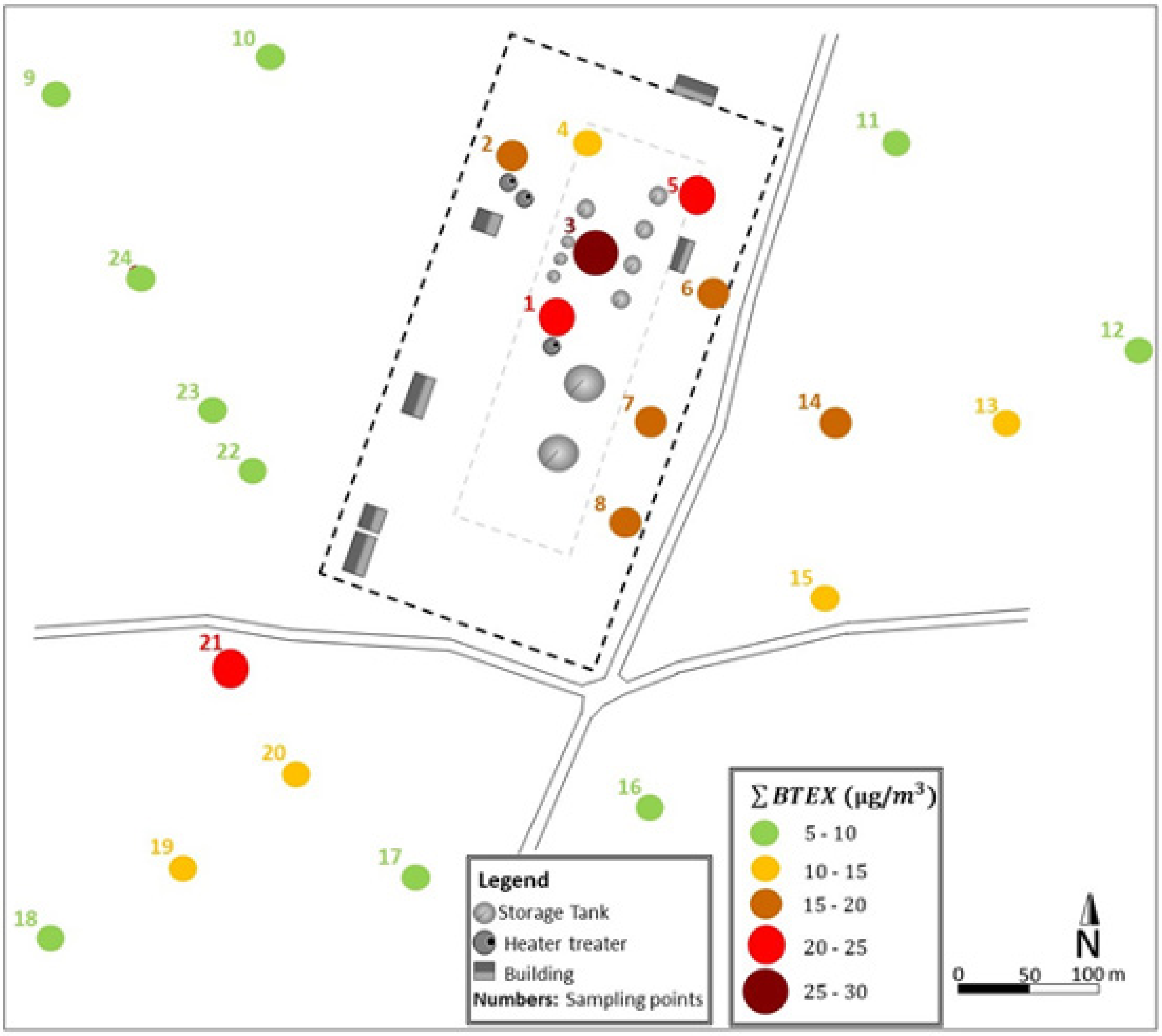

Figure 2. The spatial distribution of ΣBTEX concentrations (µg/m3) in the Diyarbakır Plant and the surrounding area. Two samples were analyzed at each sampling point. The concentration values depicted at each sampling point represent the highest value of the two

Table 2. The concentration (μg/m³) of BTEX reported by some studies around the world

Sampling area	Location	Sampling durationa	The mean concentration of ΣBTEX (μg/m³)	Reference
Around an industrial city	Shiraz, Iran	14 days	112.8	[34]
Around an industrial city	Kocaeli, Türkiye	7 days	96.82	[26]
Crude oil production plant	Diyarbakir, Türkiye	30 days	38.06	[29]
Crude oil production plant	Mardin, Türkiye	30 days	31.87	[29]
Fuel oil station	Bursa, Türkiye	14 days	28.5	[5]
Crude oil and natural gas production well pad	Colorado, USA	14 days	16.03	[21]
Petroleum refinery and petrochemicals complex	Izmir, Türkiye	7 days	12.35	[27]
Crude oil production plant	Diyarbakir, Türkiye	30 days	10.93	this study

[a]Only studies that used passive sampling and chromatographic methods were included for methodological consistency

The Comparison of BTEX Levels Inside and Outside the Diyarbakır Plant

The BTEX concentrations, both individually and as a whole, were found to be statistically different between the two means within a 95% confidence interval (Table 3). The Wilcoxon rank sum test was used to compare the means, as the concentrations of each BTEX compound outside the plant does not follow a normal distribution according to the Shapiro-Wilk normality test (p-values < .05). Specifically, the total concentration of BTEX inside the plant was higher than that measured outside the plant by a factor of 1.7. Additionally, BTEX concentrations within the plant exhibited a relatively wide distribution compared to the surrounding area (Figure 3). This indicates that the concentration of BTEX resulting from crude-oil related activities rapidly disperses and dilutes once the BTEX emission exits the plant area. This could be due to the fact that the elevated emission episodes within the plant are not so frequent, thus preventing BTEX concentration from accumulating in the surrounding area. Examples of these episodes include tanker truck loading/unloading, inter-tank transfers, tank turnovers, overhaul for tank maintenance, and so forth.

The mean BTEX concentration within the plant (14.8 μg/m³) and in the surrounding area (8.77 μg/m³) is relatively low in comparison to the levels reported in other industrial regions, with the exception of a refinery and petrochemical complex in Izmir (Table 2). These values are also below the threshold level recommended by the US EPA and the ATSDR, as discussed in the second paragraph of the preceding section. However, these findings do not necessarily indicate that crude oil production plants are not a source of air pollution or do not contribute significantly to BTEX emissions. As has been previously documented, this type of plant can present an equal level of air pollution and public health risks as other industrial facilities [29]. Furthermore, the statistical results in the current study imply that the Diyarbakır Plant is the primary source of BTEX in the region, given that the BTEX level within the 300-meter radius around the plant was found to be significantly lower than that within the plant perimeter. Therefore, should the plant capacity increase or the intensity of crude oil-related activities rise, it may contribute significantly to air pollution. Consequently, to reduce the impact of air pollution from this type of plant, it is essential to implement regular monitoring and take the necessary precautions when needed, regardless of the BTEX level.

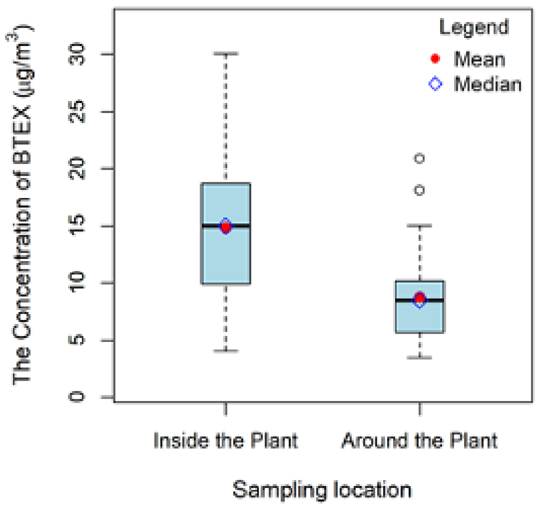

Figure 3. Box plot comparison of BTEX concentrations inside and around the plant

Table 3. The mean concentration of each BTEX, along with the p-values calculated by comparing the measured mean concentrations (μg/m^3) inside and outside the Diyarbakır Plant

	Mean concentration (μg/m^3)		Wilcoxon rank sum test
	Inside the plant (n=15)	**outside the plant (n=27)**	**p-value[a]**
benzene	1.07	0.42	0.001
toluene	7.03	4.77	0.021
ethylbenzene	2.13	0.97	0.026
xylene	4.59	2.61	0.017
BTEX	14.80	8.77	0.003

[a]If the p-value is less than the significance level (0.05), it can be concluded that the two means are statistically different from each other.

Health Risks and Ozone Formation Potentials

We assessed cancer and non-cancer health risks associated with the inhalation of BTEX using the Incremental Lifetime Cancer Risk (ILCR) and the Health Index (HI) approaches, respectively. The results showed that the exposure to benzene resulted in an ILCR of 4.3x10^{-7}, which is classified as having a negligible risk level for cancer [8, 39]. Furthermore, the total health index (HI) for BTEX (the sum of the HI values for each BTEX compound) was less than 0.1, indicating a negligible risk level according to the non-cancer risk classification [40, 41]. This finding is consistent with the comparison of BTEX concentrations to the chronic inhalation standards provided by the US EPA [46] and ATSDR[47]. According to health risk assessment and international standards, therefore, the BTEX level in the plant poses a negligible risk to oil workers.

The Ozone Formation Potential (OFP) of BTEX in the Diyarbakır Plant was 56.8 μg/m^3. The measured OFP of BTEX in this study was lower than that found in some industrial complexes (166.4 – 245.9 μg/m^3) [29, 44, 48] and urban areas (217.5 – 932.7 μg/m^3) [7, 8, 49, 50] worldwide. However, it was slightly higher than the OFP measured in an urban settlement (43.6 μg/m^3) in Nigeria [51]. Regarding the contribution percentages of BTEX compounds, toluene accounted for 47.1% of the total OFP, making it the highest contributor, followed by xylene (45.5%), ethylbenzene (6.6%), and benzene (0.8%). This order of prevalence is consistent with findings in other studies conducted in the vicinity of the oil industry (e.g. [29, 48]). Thus, the OFP estimations suggest that the Diyarbakır Plant is a typical facility with crude oil-related activities in terms of the OFP pattern of BTEX, yet it contributes less BTEX pollution than an average industrial plant.

The Ozone Formation Potential (OFP) of BTEX in the Diyarbakır Plant was measured at 56.8 μg/m³, which is notably lower than values reported in some industrial complexes worldwide, ranging from 166.4 to 245.9 μg/m³ [29, 44, 48] and urban areas, with a broader range of 217.5 to 932.7 μg/m³ [7, 8, 49, 50]. However, it was slightly higher than the OFP measured in an urban settlement in Nigeria, which was 43.6 μg/m³ [51]. The lower OFP of BTEX in the Diyarbakır Plant might partly be due to the dry climate, since ambient concentrations of BTEX are typically lower in dry weather compared to wet or rainy weather [52]. Furthermore, the study area features open geographic characteristics and a lower urban density, which facilitate better dispersion of pollutants. This is in contrast to more densely populated urban areas or those with geographical barriers that trap pollutants [49, 50]. Regarding the contribution percentages of BTEX compounds, toluene accounted for 47.1% of the total OFP, making it the highest contributor, followed by xylene (45.5%), ethylbenzene (6.6%), and benzene (0.8%). This order of prevalence is consistent with findings in other studies conducted in the vicinity of the oil industry (e.g. [29, 48]). Thus, the OFP estimations suggest that the Diyarbakır Plant is a typical facility with crude oil-related activities in terms of the OFP pattern of BTEX, yet it contributes less BTEX pollution than an average industrial plant.

Limitations

Some shortcomings of the study should be kept in mind when interpreting the findings. The application of passive sampling over a 30-day period is not sufficient for the capture of peak concentrations, as it represents a weighted average. This may result in an inability to accurately assess acute BTEX exposure. This acute exposure can cause workers to become unconscious or even die at very high concentrations [53], which could be addressed in future studies using active sampling methods. The 30-day sampling approach, however, is useful for estimating health risks associated with chronic exposure. In addition, the range of atmospheric pollutants resulting from crude oil-related activities extends beyond those of the BTEX group. Nevertheless, BTEXs are of particular concern to researchers because they are hazardous to public health and the environment, and they are the primary representatives of VOCs, which consist of hundreds of species [54]. The BTEX analysis in this study thus provides insight into the potential for air pollution associated with crude oil-related activities, which can serve as a basis for developing emission management strategies. We thus recommend future studies to address other air pollutants in the oil and gas industry. Such pollutants include but not limited to toxic metals, particulates, nitrogen oxides, sulfur oxides, methane, polycyclic aromatic hydrocarbons, and carbon monoxide.

CONCLUSIONS

The analysis of BTEX compounds can help to improve knowledge regarding the air pollution impacts of crude oil-related activities. In particular, the determination of BTEX concentration levels, along with the associated ozone formation potentials and health risks, serves as a valuable indicator of the impacts of industrial settings on air pollution and occupational health. In the present study, BTEX passive samples were collected in and around a crude oil production plant and subsequently analyzed using chromatographic techniques. The BTEX concentrations observed within the plant were comparable to those documented in a few suburban areas, yet generally lower than those reported for other industrial regions. Among the BTEX compounds, toluene was the dominant compound in nearly all samples, which is consistent with observations in other industrial and urban areas with heavy traffic. Similarly, the highest to lowest contributors to ozone formation were toluene, xylenes, ethylbenzene, and benzene. This pattern is sometimes observed in the oil industry and urban air. The health risk assessment suggests that the potential for cancer and non-cancer health risks associated with BTEX exposure was negligible for oil workers. The findings also indicate a statistically significant higher concentration within the plant compared to the surrounding area. This could mean that the plant is a significant source of BTEX in the region, yet the BTEX emissions from it are rapidly diluted in relatively short distances. These results represent the impacts of a relatively small-sized (88,000 barrels) crude oil production plant on air quality and occupational health. These findings represent the BTEX characteristics of a modest-sized (88,000 barrels) crude oil production plant. The BTEX level in the plant might be below the threshold for concern, yet it still requires regular monitoring.

The impacts of crude oil on air quality underscore the importance of monitoring and mitigating emissions from the production, processing, and use of this essential resource. Our approach could be applied to other industrial facilities located near a residential area to assess air pollution and potential health risks associated with both occupational and public health. Based on the findings of this study, we recommend that the oil industry be subjected to regular monitoring, even in instances where the plants of the industry emit air pollutants that fall below the established international air quality limits. Additionally, governments and production companies should implement mitigation strategies to reduce air pollution caused by the oil industry. Such strategies include, but are not limited to, enhanced monitoring, vapor control systems, improved maintenance practices, and employee training and awareness [12, 55-57]. These precautions would serve to limit the air pollution impacts of the oil industry.

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DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

USE OF AI FOR WRITING ASSISTANCE

Not declared.

ETHICS

There are no ethical issues with the publication of this manuscript.

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