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Review Article

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Air pollution by BTEX and the related health risks due to the tobacco smoke, a systematic review

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ABSTRACT

BTEX is a group of hazardous chemical compounds that include benzene, toluene, ethylbenzene, and xylene. The indoor concentration of BTEX is mostly influenced by tobacco smoking, the region within the house, and seasonal variations. This systematic review analyzed studies on BTEX concentrations in indoor air, using data from Google Scholar, Science Direct, and Springer from 2010 to 2020, and performed statistical analysis with R after thorough data extraction and evaluation. Duplicate studies were removed, and disagreements during the article selection process were resolved by a third reviewer. Out of the 1351 articles obtained from the keyword search, only 13 were eventually selected for this study. The most abundant compound found in houses among BTEX was toluene, with a concentration of 13.80±16.50 $\mu g/m^3$. The results indicated that the concentration of ΣBTEX in houses where smoking occurred was lower than in houses where no smoking occurred (18.52 vs. 27.66 $\mu g/m^3$); However, the concentration of benzene in smoking houses was higher than in non-smoking houses (7.17±9.42 vs. 2.65±3.77 $\mu g/m^3$, unpaired Wilcoxon test: $p>0.05$). The concentration of BTEX in houses was substantially lower than that in cafes (21.10±31.10 vs. 15,100±9740 $\mu g/m^3$, unpaired Wilcoxon test: $p<0.05$). The urban region had the most significant accumulation of all BTEXs, with the industrial and rural sectors following suit. The findings indicated that the average concentration of BTEX in warm months (such as spring and summer) were higher than in cold months (such as fall and winter) within houses (28.50±44.30 vs. 8.60±7.77 $\mu g/m^3$, unpaired Wilcoxon test: $p>0.05$). The findings indicated that the Cancer Risk (CR) associated with houses (3.11×10^{-6}) and cafes (3.54×10^{-3}) exceeded the permissible threshold. Moreover, the waterpipe cafes that utilized fruit-flavored tobacco had the greatest CR (4.98×10^{-3}). Furthermore, the presence of smoking, regional factors, and seasonal variations did not result in an increase in the hazard quotient (HQ) in houses beyond the acceptable thresholds. Finally, smoking, seasonal variations, and region had critical impact on indoor BTEX concentrations, and they could increase the risk of carcinogenic potential in the indoor environments.

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Review

The recognition of Indoor Air Quality (IAQ) as a significant health determinant and its association with acute and chronic health outcomes has grown in recent years [1]. Given that individuals typically allocate a substantial portion exceeding 80% of their daily lives confined indoors, this prolonged indoor exposure raises concerns regarding the potential absorption of harmful pollutants [2]. These toxic substances can infiltrate the body primarily through the respiratory system via inhalation and unintentional ingestion of dust particles prevalent in contaminated indoor environments [3]. Therefore, indoor air pollutants produced from various sources, such as infiltration from outside or indoor sources, can lead to multiple health effects, including asthma and allergy symptoms, airway irritation, decreased lung function, and other respiratory symptoms [4].

Among indoor pollutants, smoking has extensive harmful effects on the health of people living in indoor spaces due to the high and varied concentrations of air pollutants that it releases in indoor spaces. A multitude of epidemiological and experimental research findings have highlighted the intricate nature of environmental tobacco smoke. Over the past few years, there has been a noticeable trend where smoking not only takes place in residential settings but has also become more prevalent in a variety of hospitality establishments like restaurants, cafes, and bars, as well as in private homes where customers are entertained [5].

This complex mixture consists of thousands of gaseous and particulate pollutants, including those from tobacco consumption products, charcoal, and even smokers' exhaled smoke. These studies have shed light on the diverse substances present in tobacco smoke, underscoring the multifaceted composition of this environmental hazard [6]. Recent findings published by the US Surgeon General have shown that “there is no safe level of exposure to tobacco smoke not only for smokers but also for people exposed to second-hand smoke (called second-hand smoke) and even exposure to Short-term exposure can affect children and adults.” [7].

The group of gaseous pollutants known as benzene, toluene, ethylbenzene, and xylene (commonly referred to as BTEX) has garnered significant attention in environmental research globally [8, 9]. These dangerous pollutants have been the subject of extensive studies and discussions, with researchers and scientists from various countries working diligently to better understand their impacts on air quality and human health. Outdoor air pollution, smoking, paints, adhesives, and other VOC-emitting materials found in building interiors are among the sources of BTEX in indoor environments [8]. Benzene, a colorless and highly flammable liquid compound, has gained notoriety as one of the most potent toxic chemicals within the Benzene, Toluene, and Ethylbenzene (BTE) family [10]. Also, passive smoking is one of the primary sources of non-occupational benzene exposure [11, 12]. Studies have linked prolonged and consistent exposure to this hazardous substance to serious health risks, particularly an elevated likelihood of developing leukemia and aplastic anemia among humans. Scientific studies have shown a direct correlation between long-term benzene exposure and the onset of these life-threatening hematologic disorders, raising concerns about the impacts of occupational or environmental contact with this harmful compound on public health [12]. The International Agency for Research on Cancer (IARC) has conducted extensive studies and assessments that have led to the classification of benzene as a known human carcinogen (Group 1), indicating a high level of evidence linking benzene exposure to cancer development. Additionally, the IARC classified ethylbenzene as a potential human carcinogen (Group 2B) based on suggestive but limited evidence of its carcinogenic effects in humans [13].

Over the past few decades, there has been a significant increase in public awareness of the potential health risks of secondhand smoke exposure. This increased awareness can be attributed to the widespread sharing and dissemination of scientific findings and research on the adverse health effects associated with smoke inhalation. As a result, there has been a significant change in public perception and attitude towards smoke, which forces people to adopt more cautious and conscious approaches to minimize exposure to this harmful environmental factor [14].

Numerous scientific investigations have provided diverse findings regarding the concentrations of Benzene, Toluene, Ethylbenzene, and Xylene (BTEX) compounds in various indoor and outdoor settings. As a result, there is a pressing need for a deeper understanding of the levels of BTEX present in both indoor and outdoor air environments. The gaps in current knowledge underscore the critical necessity for conducting thorough and wide-ranging research endeavors aimed at comprehensively grasping the scope and impacts of BTEX pollutants in our surroundings. This particular research endeavor is geared towards assessing and analyzing the concentrations of BTEX compounds in indoor and outdoor settings, while also delving into the various influencing factors, with a specific focus on the influence of smoking habits.

Methods

This systematic review aims to evaluate the concentration of BTEX (benzene, toluene, ethylbenzene, and xylene) compounds in indoor air, specifically within residential settings. Given the scarcity of relevant studies focused solely on residential environments, we extended our scope to include research investigating the impact of smoking on BTEX concentrations in indoor air within cafes.

To ensure a comprehensive analysis, we extensively searched three major academic databases: Google Scholar, ScienceDirect, and SpringerLink. Our search spanned studies published between 2010 and 2020, and we employed a strategic combination of keywords to capture a wide range of relevant studies that explored the relationship between smoking and BTEX levels in indoor environments.

The inclusion criteria for this review were stringent, ensuring the quality and relevance of the selected studies. We focused exclusively on original research articles published in English that examined BTEX concentrations within residential homes or cafes. We excluded studies that were abstracts, editorials, conference papers, or any form of review articles, as well as those carried out in industrial, occupational, or other settings that might introduce external factors that could influence BTEX levels. Additionally, studies investigating BTEX compounds as biomarkers, or those focused on the direct mainstream and sidestream emissions of tobacco products, were not considered for this review. This strict selection process ensures that the review accurately and focus singly examines what we know about BTEX levels in indoor air, especially when it comes to environmental tobacco smoke in homes and cafes.

After removing duplicate studies, two reviewers (A.M. and A.R.) independently evaluated the titles and abstracts of the remaining articles. In instances of disagreement, a third reviewer (R.R.) adjudicated. The third reviewer (R.R.) re-evaluated the excluded studies to ensure accuracy. Data extraction focused on pertinent details such as location, region, smoking status, type of smoking, season, and BTEX concentrations.

We performed the statistical analysis using R version 4.3.3. We conducted normality tests following a descriptive analysis for visual comparisons. We utilized the Kruskal-Wallis test and the unpaired Wilcoxon test for statistical comparisons.

We thoroughly evaluated the risk assessment based on the detected BTEX concentrations. This evaluation used Eqs. 1 to 5 and Table 1 [15].

$$E = C \times IR_a \times ED_a / BW_a \quad (1)$$

$$E_Y = E \times (D/7) \times (W_k/52) \quad (2)$$

$$E_L = E_Y \times (Y_E/Y_L) \quad (3)$$

$$\text{Cancer risk(CR)}=E_L(\text{mg/kg.d})\times \text{SF(kg.d/mg)} \quad (4)$$

$$\text{Non-cancer risk (HQ)} = E_Y/\text{RfD} \quad (5)$$

where, E: daily exposure (mg/kg.d), E_Y: yearly average daily dose received (mg/kg.d), E_L: effective life time exposure (mg/kg.d), HQ: hazard quotient, and RfD; reference dose (mg/m^3).

Results

Study characterizes

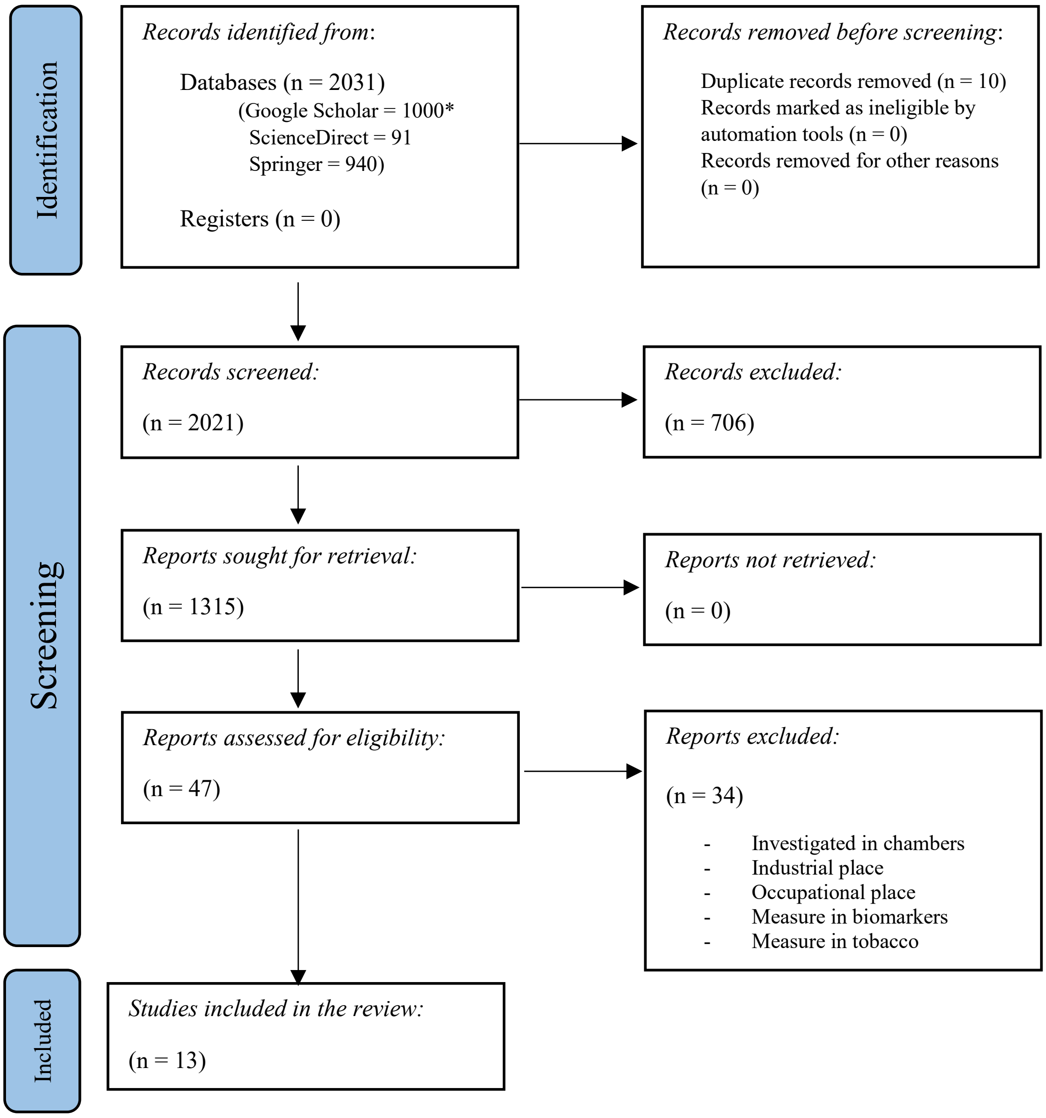
Ten articles were duplicates of 2031 studies obtained from databases, so we identified 2021 studies from databases for pre-screening. After that, 1315 articles remain for full-text screening. Ultimately, we retain 47 studies for final decision-making. We excluded 34 studies investigating BTEX in chambers, non-residential locations, or biological human samples. Thus, remain 13 studies for our analysis [8, 11, 16-26]. Fig. 1 illustrates the details of our study selection.

It is worth noting that a significant proportion, amounting to ten (76%) of included studies, were carried out specifically from the year 2015 onwards [8, 11, 18-21, 23-26], showcasing a shift towards more recent data collection. Moreover, eleven studies conducted in indoor houses [11, 16-19, 21-26], and two in indoor cafes [8, 20]. Ten of the included studies conducted in indoor houses were exclusively in urban regions [8, 11, 16, 17, 19-21, 23, 25, 26], one in industrial regions [24], one in rural and urban regions [22], and one in industrial, rural, and urban regions [18]. Eight studies investigated the concentration of BTEX exclusively in indoor non-smoking place [11, 16-18, 22, 26], two studies exclusively investigated indoor smoking places [8, 21], and three studies compared indoor smoking and non-smoking places [19, 20, 25], while one study did not mention smoking status [24]. Moreover, four studies conducted in the summer [16, 19, 24, 26], three in the winter (8, 20, 25), two comparing the summer and winter seasons [16, 22], and four not mentioning the season [17, 18, 21, 23].

Table 1. Details of risk assessment method

	Value	Unit
Concentration of the pollutant (C)	-	mg/m^3
Inhalation rate (IR_a)	0.83	m^3/h
Exposure duration (ED_a)	8	h/d
Body weight (BW_a)	70	kg
Days per week exposure (D)	6	d
Weeks of exposure (W_K)	48	week
Years of exposure (Y_E)	30	year
Years in lifetime (Y_L)	70	year
Slope factor or carcinogenic potency slope (SF)	Benzene = 0.029	kg.d/mg
Reference dose (RfD)	Benzene = 0.00855	mg/kg.d
	Toluene = 1.4	
	Ethylbenzene = 0.286	
	Xylene = 0.029	

RfD = RfC (inhalation reference concentration mg/m^3) × 20 (assumed adult inhalation rate m^3 /d) × 1/BWa (kg); based on RfCs for USEPA, IRIS (benzene = 0.03 mg/m^3, toluene = 5 mg/m^3, ethylbenzene = 1 mg/m^3, xylenes = 0.1 mg/m^3)



*Google scholar only accessed to first 100 relevant pages (from 16,900, approximately first 1000 relevant studies).

Fig. 1. The PRISMA 2020 flowchart based on our study selection

Influence of smoking on indoor BTEX concentration

Based on the results, within the houses, the rage of benzene, toluene, ethylbenzene, and xylene was 0.30 to 18.00, 3.15 to 69.7, 0.57 to 12.1, and 1.45 to 48.10 µg/m^3, respectively. The highest concentration in houses among BTEX was related to toluene (13.80±16.50 µg/m^3), followed by xylenes (7.96±12.40 µg/m^3), benzene (3.33±4.88 µg/m^3), and ethylbenzene (2.20±3.08 µg/m^3). Among the studies reported BTEX concentrations in houses, four showed the same order of concertation [17, 19, 23, 26], while three studies showed the concentration of ethylbenzene was higher than benzene [18, 22, 24].

Smoking caused a higher concentration of BTEX in houses. The findings showed that the amount of benzene in smoking houses was higher than in non-smoking houses (7.17±9.42 vs. 2.65±3.77 µg/m^3, unpaired Wilcoxon test: $p>0.05$), but the amounts of toluene, ethylbenzene, and xylene were higher in places where people didn't smoke. In this regard, Drooge et al., in a study, investigated the influence of electronic cigarettes on the concertation of VOCs in a house with no ventilation. The studies' findings showed that the effect of using electronic cigarettes on BTEX concentration in indoor environments was generally minimal [19]. While, in another study, Charles et al. showed benzene concentration in smoking houses was higher compared to non-smoking ones, but it was not significant [25].

The results showed the average concentrations of benzene, toluene, ethylbenzene, and xylene within cafes were 3790±2000, 3490±3080, 2910±1830, and 6170±2140 μg/m^3. Furthermore, the xylenes had the highest concentration.

Hydari et al. showed that non-smoking cafes had a lower concentration of BTEX compared to smoking cafes (1280±NA vs. 17,820±8148.70 μg/m^3) [20]. Moreover, among smoking cafes, waterpipe cafes had a higher concentration of BTEX compared to cigarette cafes (22,210±4143.65 vs. 9040±NA μg/m^3). Furthermore, within waterpipe cafes, the concentration of BTEX in cafes that used fruit-flavored tobacco for waterpipe was higher compared to cafes that used regular tobacco for waterpipe (25,140 vs. 19,280 μg/m^3). Another study by Hazrati et al. showed the concentration of BTEX in waterpipe cafés that used fruit-flavored tobacco was 20,890 μg/m^3. The average concentration of benzene, ethylbenzene, and xylene within waterpipe cafes that used fruit-flavored tobacco were higher compared to waterpipe cafes that used regular tobacco (5335 vs. 4720, 4665 vs. 2720, and 7790 vs. 5220 μg/m^3, respectively), while the concentration of toluene within waterpipe cafes that used regular tobacco was higher compared to waterpipe cafes that used fruit-flavored tobacco (6620 vs. 5225 μg/m^3) (8). Table 2 represents the detailed concentration of BTEX in cafes and houses.

Table 2. The average concentration of BTEX in house and café (μg/m^3)

	Café		House	
	Non-smoking	Smoking	Non-smoking	Smoking
Benzene				
Mean (SD)	780 (NA)	4540 (1250)	2.65 (3.77)	7.17 (9.42)
Median [Min, Max]	780 [780, 780]	4840 [2780, 5710]	1.22 [0.30, 15.20]	2.64 [0.880, 18.00]
Toluene				
Mean (SD)	120 (NA)	4330 (2810)	14.30 (17.7)	8.30 (NA)
Median [Min, Max]	120 [120, 120]	5230 [260, 6620]	8.00 [3.15, 69.70]	8.30 [8.30, 8.30]
Ethylbenzene				
Mean (SD)	380 (NA)	3540 (1340)	2.24 (3.31)	0.57 (NA)
Median [Min, Max]	380 [380, 380]	3550 [2110, 4950]	1.15 [0.61, 12.10]	0.57 [0.57, 0.57]
Xylenes				
Mean (SD)	NA (NA)	6170 (2140)	8.47 (13.40)	2.48 (NA)
Median [Min, Max]	NA [NA, NA]	5960 [3890, 8890]	4.11 [1.45, 48.10]	2.48 [2.48, 2.48]

The average concentration of BTEX in houses was significantly lower compared to cafes (21.10±31.10 vs. 15,100±9740 μg/m^3, unpaired Wilcoxon test: $p<0.05$). Additionally, there is a significant difference between cafes and houses with different smoking statuses (Kruskal-Wallis test: $p<0.05$). Moreover, the concentration of BTEX within smoking cafes was significantly higher compared to both smoking (18,600±6830 vs. 11.00±7.76 μg/m^3; Conover-Iman test: $p<0.025$) and non-smoking (18,600±6830 vs. 22.90±34.80 μg/m^3; Conover-Iman test: $p<0.025$) (Table 3).

Influence of region on indoor BTEX concentration

The location of the house affects the indoor air quality (IAQ). The results showed houses located in urban areas had a higher concentration of BTEX (24.30±37.40 μg/m^3), followed by industrial (17.10±11.30 μg/m^3), and rural (12.70±7.90 μg/m^3). Furthermore, there is no significant difference between concentrations of BTEX in different regions (Kruskal-Wallis test: $p>0.05$). However, Villanueva et al., in a study, investigated BTEX in urban, rural, and industrial regions. The results showed the concentration of BTEX in the industrial region was higher compared to the rural region (9.07 vs. 5.75 μg/m^3), followed by the urban region (5.75 μg/m^3([18].

The order of BTEX compounds in urban areas showed toluene had the highest concentration (18.10±20.40 μg/m^3), followed by xylene (10.90±16.70 μg/m^3), benzene (4.39±5.63 μg/m^3), and ethylbenzene (2.76±4.17 μg/m^3). In industrial and rural regions, the concentration of ethylbenzene was higher compared to benzene. In this vein, Villanueva et al. conducted a study to investigate BTEX compounds in industrial regions [24]. The results showed that, among BTEX compounds, toluene had the highest concentration (12.00 μg/m^3), followed by xylene (7.80 μg/m^3), ethylbenzene (3.40 μg/m^3), and benzene (1.90 μg/m^3). Table 4 depicts the BTEX concentration in the houses of different areas.

Table 3. Comparison between cafes and house with different smoking status (Bonferroni method)

	Non-smoking cafes	Smoking cafes	Non-smoking house
Smoking cafes	-0.44 1.000	-	-
Non-smoking house	1.76 0.281	4.12 **0.001***	-
Smoking house	1.95 0.195	3.61 **0.005***	0.69 1.000

Table 4. The average concentration of BTEX in the houses of different areas (μg/m³)

	Industrial	Rural	Urban
Benzene			
Mean (SD)	1.35 (0.778)	0.760 (0.651)	4.39 (5.63)
Median [Min, Max]	1.35 [0.800, 1.90]	0.760 [0.300, 1.22]	2.27 [0.500, 18.0]
Toluene			
Mean (SD)	8.45 (5.02)	6.39 (3.59)	18.1 (20.4)
Median [Min, Max]	8.45 [4.90, 12.0]	6.39 [3.85, 8.93]	11.6 [3.15, 69.7]
Ethylbenzene			
Mean (SD)	2.16 (1.75)	1.34 (0.544)	2.76 (4.17)
Median [Min, Max]	2.16 [0.920, 3.40]	1.34 [0.950, 1.72]	1.15 [0.570, 12.1]
Xylenes			
Mean (SD)	5.13 (3.78)	4.20 (3.11)	10.9 (16.7)
Median [Min, Max]	5.13 [2.45, 7.80]	4.20 [2.00, 6.40]	4.111.45, 48.1]

Table 5. The average concentration of BTEX compounds in different season (μg/m³)

	Summer	Winter
Benzene		
Mean (SD)	2.65 (4.76)	1.85 (0.704)
Median [Min, Max]	0.880 [0.300, 15.2]	1.92 [0.930, 2.64]
Toluene		
Mean (SD)	15.7 (21.3)	11.1 (7.56)
Median [Min, Max]	8.00 [3.15, 69.7]	11.1 [5.71, 16.4]
Ethylbenzene		
Mean (SD)	2.55 (3.96)	1.04 (NA)
Median [Min, Max]	0.935 [0.570, 12.1]	1.04 [1.04, 1.04]
Xylenes		
Mean (SD)	8.86 (16.0)	3.86 (NA)
Median [Min, Max]	2.47 [1.45, 48.1]	3.86 [3.86, 3.86]

Influence of season on indoor BTEX concertation

Season is one of the factors that could affect indoor air quality. The results showed, within houses, the average concentration of BTEX in warm month (e.g. spring and summer) was higher compared to the cold month (e.g. fall and winter) (28.50±44.30 vs. 8.60±7.77, unpaired Wilcoxon test: $p>0.05$). Both seasons had the same order of BTEX compounds, with toluene having the highest concentration and ethylbenzene having the lowest (Table 5). In this way, Xu et al. showed that seasonal variations could affect BTEX concentrations(22). The results showed that toluene and ethylbenzene had significant differences between summer and winter ($p<0.05$); however, benzene and xylene did not show significant differences ($p>0.05$). Additionally, Héroux et al., in a study, showed seasonal variations could not be significantly different in the concentration of BTEX compounds [16].

Table 6. The cancer risk (CR) of houses and cafes

	House		Cafes			
	Non-smoking	Smoking	Non-smoking	Cigarette	Regular tobacco	Fruit-flavored tobacco
Cancer risk	2.47×10^{-6}	6.69×10^{-6}	7.28×10^{-4}	2.59×10^{-3}	4.40×10^{-3}	4.89×10^{-3}

Table 7. The non-cancer risk (HQ) of houses and cafes

	House		Cafes			
	Non-smoking	Smoking	Non-smoking	Cigarette	Regular tobacco	Fruit-flavored tobacco
Non-cancer risk	2.47×10^{-6}	6.69×10^{-6}	7.28×10^{-4}	2.59×10^{-3}	4.40×10^{-3}	4.89×10^{-3}

Risk assessment

We evaluated the risk of exposure to different concentrations of BTEX in various places. The results showed the cancer risk (CR) of both houses (3.11×10^{-6}) and cafes (3.54×10^{-3}) was greater than the acceptable limit (10×10^{-6}) (8). Furthermore, the highest CR was related to the waterpipe cafes that used fruit-flavored tobacco (4.98×10^{-3}) (Table 6).

Moreover, the results showed only the CR of rural regions was within the acceptable limit (7.09×10^{-7}), while the CR of urban and industrial regions was greater than the acceptable limit (4.09×10^{-6} and 1.26×10^{-6}, respectively). Furthermore, the winter season showed lower CR compared to the summer; however, they were greater than the acceptable limit (1.73×10^{-6} and 2.47×10^{-6}, respectively).

Additionally, the results showed the non-cancer risk (HQ) for houses was lower than acceptable limit 1 (5.11×10^{-2}) (8), while for cafes it was greater than acceptable limit (5.02×10). Furthermore, non-smoking cafes and all types of smoking cafes showed higher HQ than the permission limit (Table 7).

Additionally, smoking, region, and seasonal variation could not increase HQ in homes beyond the permissible limits.

Conclusion

The results illustrated that smoking in indoor environments could increase the concentration of benzene, toluene, ethylbenzene, and xylenes (BTEX); however, it's very dependent on various factors, such as the type of smoking tool (e.g., cigarette, electronic cigarette, waterpipe, etc.). In general, people may be exposed to more BTEX concentration in public places like cafes than in houses. Our results indicated that all types of cafes posed a potential cancer risk to people, whereas houses fell within an acceptable threshold. The region of the houses is critical to determining indoor BTEX concertation. Different concentrations of BTEX in outdoor areas of each region are one of the important factors that could affect the indoor concertation of BTEX in each region. Our results indicated that only rural houses were free from any potential cancer risks. Moreover, seasonal variations could affect indoor air quality, but there is potential for cancer risk in both the summer and winter seasons.

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Competing interests

The authors, Ali Momen, Arezo Rezaei, and Roohollah Rostami certify that they have no affiliation with or financial interest in the subject matter or materials discussed in this research.

Author's Contributions

Roohollah Rostami contributed to the conception and design of the study, while all authors participated in material preparation. Data management was undertaken by Ali Momen and Roohollah Rostami, and the initial manuscript draft was collectively written by all authors. Statistical analysis was conducted by Ali Momen, and study administration was overseen by Roohollah Rostami. Finally, all authors reviewed and approved the final manuscript.

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Ethical considerations

"Ethical issues (Including plagiarism, Informed Consent, misconduct, data fabrication and/ or falsification, double publication and/ or submission, redundancy, etc) have been completely ob-served by the authors."

References

1. Carlsen L, Bruggemann R, Kenessov B. Use of partial order in environmental pollution studies demonstrated by urban BTEX air pollution in 20 major cities worldwide. Science of the total environment. 2018;610:234-43.

2. Petry T, Vitale D, Joachim FJ, Smith B, Cruse L, Mascarenhas R, et al. Human health risk evaluation of selected VOC, SVOC and particulate emissions from scented candles. Regulatory Toxicology and Pharmacology. 2014;69(1):55-70.

3. Harrad S, Hazrati S, Ibarra C. Concentrations of polychlorinated biphenyls in indoor air and polybrominated diphenyl ethers in indoor air and dust in Birmingham, United Kingdom: implications for human exposure. Environmental science & technology. 2006;40(15):4633-8.

4. Mitchell CS, Zhang J, Sigsgaard T, Jantunen M, Lioy PJ, Samson R, Karol MH. Current state of the science: health effects and indoor environmental quality. Environmental health perspectives. 2007;115(6):958-64.

5. Hoffman SJ, Tan C. Overview of systematic reviews on the health-related effects of government tobacco control policies. BMC public health. 2015;15:1-11.

6. Rodgman A, Perfetti TA. The chemical components of tobacco and tobacco smoke: CRC press; 2008.

7. United States. Public Health Service. Office of the Surgeon General. The health consequences of involuntary exposure to tobacco smoke: a report of the Surgeon General. US Department of Health and Human Services, Public Health Service, Office of the Surgeon General; 2006.

8. Hazrati S, Rostami R, Fazlzadeh M. BTEX in indoor air of waterpipe cafés: Levels and factors influencing their concentrations. Science of the total environment. 2015;524:347-53.

9. El-Hashemy MA, Ali HM. Characterization of BTEX group of VOCs and inhalation risks in indoor microenvironments

at small enterprises. Science of the Total Environment. 2018;645:974-83.

10. Saxena P, Ghosh C. A review of assessment of benzene, toluene, ethylbenzene and xylene (BTEX) concentration in urban atmosphere of Delhi. International Journal of the physical Sciences. 2012;7(6):850-60.

11. Fustinoni S, Campo L, Satta G, Campagna M, Ibba A, Tocco MG, et al. Environmental and lifestyle factors affect benzene uptake biomonitoring of residents near a petrochemical plant. Environment international. 2012;39(1):2-7.

12. Yadav J, Reddy C. Degradation of benzene, toluene, ethylbenzene, and xylenes (BTEX) by the lignin-degrading basidiomycete Phanerochaete chrysosporium. Applied and environmental microbiology. 1993;59(3):756-62.

13. Organization Wh, Cancer IAfRo, Humans IWGotEoCRt. IARC monographs on the evaluation of carcinogenic risks to humans: World Health Organization; 2004.

14. Momen A, Rostami R. The heavy metals in human body fluids related to the tobacco smoke: a systematic review. Tobacco and Health. 2023;2(1):15-22.

15. Hazrati S, Rostami R, Fazlzadeh M. BTEX in indoor air of waterpipe cafés: Levels and factors influencing their concentrations. Science of The Total Environment. 2015;524-525:347-53.

16. Héroux M-E, Clark N, Van Ryswyk K, Mallick R, Gilbert NL, Harrison I, et al. Predictors of indoor air concentrations in smoking and non-smoking residences. International journal of environmental research and public health. 2010;7(8):3080-99.

17. Chin JY, Godwin C, Parker E, Robins T, Lewis T, Harbin P, Batterman S. Levels and sources of volatile organic compounds in homes of children with asthma. Indoor air. 2014;24(4):403-15.

18. Villanueva F, Tapia A, Lara S, Amo-Salas M. Indoor and outdoor air concentrations of volatile organic compounds and NO2 in schools of urban, industrial and rural areas in Central-Southern Spain. Science of the Total Environment. 2018;622:222-35.

19. Van Drooge BL, Marco E, Perez N, Grimalt JO. Influence of electronic cigarette vaping on the composition of indoor organic pollutants, particles, and exhaled breath of bystanders. Environmental Science and Pollution Research. 2019;26:4654-66.

20. Heydari G, Ranjbar Vakilabadi D, Kermani M, Rayani M, Poureshgh Y, Behroozi M, et al. Load characteristics and inhalation risk assessment of benzene series (BTEX) pollutant in indoor air of Ghalyan and/or cigarette cafes compared to smoking-free cafes. Environmental Pollutants and Bioavailability. 2020;32(1):26-35.

21. Tirler W, Settimo G. Incense, sparklers and cigarettes are significant contributors to indoor benzene and particle levels. SciELO Public Health; 2015. p. 28-33.

22. Xu J, Szyszkowicz M, Jovic B, Cakmak S, Austin CC, Zhu J. Estimation of indoor and outdoor ratios of selected volatile organic compounds in Canada. Atmospheric environment. 2016;141:523-31.

23. Su F-C, Mukherjee B, Batterman S. Determinants of personal, indoor and outdoor VOC concentrations: an analysis of the RIOPA data. Environmental research. 2013;126:192-203.

24. Villanueva F, Tapia A, Amo-Salas M, Notario A, Cabanas B, Martínez E. Levels and sources of volatile organic compounds including carbonyls in indoor air of homes of Puertollano, the most industrialized city in central Iberian Peninsula. Estimation of health risk. International journal of hygiene and environmental health. 2015;218(6):522-34.

25. Charles SM, Jia C, Batterman SA, Godwin C. VOC and particulate emissions from commercial cigarettes: analysis of 2, 5-DMF as an

ETS tracer. Environmental science & technology. 2008;42(4):1324-31.

26. Hazrati S, Rostami R, Farjaminezhad M, Fazlzadeh M. Preliminary assessment of BTEX concentrations in indoor air of residential buildings and atmospheric ambient air in Ardabil, Iran. Atmospheric environment. 2016;132:91-7.