The Concentration of BTEX in the Air of Tehran: A Systematic Review-Meta Analysis and Risk Assessment

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Abstract: In the current study, the concentration of some pollutants which are categorized as volatile organic compounds (VOCs), including benzene (B), toluene (T), ethylbenzene (E), and o-xylene (o-X), in the air of Tehran was evaluated by the aid of a systematic review and meta-analysis approach. Also, the health risk for the exposed population was estimated using the recommended methods by the Environmental Protection Agency (EPA). The rank order based on their concentration in BTEX was benzene (149.18 µg/m³: 31%) > o-xylene (127.16 µg/m³: 27%) > ethylbenzene (110.15 µg/m³: 23%) > toluene (87.97 µg/m³: 19%). The ratio B/T in this study was calculated as 1.69, repressing that both stationary and mobile sources of emission can be considered as the main sources for benzene and toluene. Moreover, strong photochemical activity in Tehran was demonstrated by the high ratio of E/o-X. Meta-regression indicates that the concentration of BTEX has insignificantly (p-value > 0.05) increased over time. The BTEX compounds based on the target hazard quotient (THQ) were ordered as benzene > o-xylene > ethylbenzene > toluene. Percentile 95% of THQ due to benzene (4.973) and o-xylene (1.272) was higher than a value of 1. Percentile 95% excessive cancer risk (ECR) for benzene (1.25 × 10⁻⁶) and ethylbenzene (1.11 × 10⁻⁶) was higher than a value of 1.00 × 10⁻⁶. The health risk assessment indicated that the population of Tehran are at considerable non-carcinogenic and carcinogenic risks.

Keywords: BTEX; systematic review; meta-analysis; health risk; Tehran; air pollution; benzene; toluene
1. Introduction

The air quality in urban areas depends on different factors such as atmospheric dispersion conditions, solar radiation, meteorological factors, geographical factors, deposition, and pollutant emissions [1]. In the last few decades, with increases in urbanization and developments in human life, the issue of air pollution has attracted considerable attention [2,3]. The primary sources of air pollution in urban regions can be summarized as natural and anthropogenic sources [4,5]. In this context, air pollutants such as volatile organic compounds (VOCs), sulfur oxides (SOx), ozone (O₃), carbon oxides (COs), particulate matter (PM), nitrogen oxides (NOx), and radioactive pollutants are released from these sources [5,6].

The main sources of VOCs are anthropogenic and biogenic sources [7], including incomplete combustion in motor vehicles (fossil fuels), the petrochemical process, the fabrication of rubber and resin, solvents, and paint industries [8,9]. The presence of VOCs in a variety of forms such as toluene, benzene, ethylbenzene, and meta (m), para (p), and ortho(o) xylene in the indoor or outdoor air is important due to the consequence of non-carcinogenic risks (e.g., neurological impairment, allergy, nose and eye irritation, kidney and liver dysfunction, and heart disease) [10–12] and carcinogenic risks (e.g., lung cancer and leukemia) [13–16].

Among VOCs, benzene, as a hazardous compound with a relatively long lifetime, belongs to group 1; carcinogenic to humans [17,18]. Whilst the mutagenicity and carcinogenicity of toluene, ethylbenzene, and xylens have not been proven [19,20], they are precursors of toxic radical in the atmosphere [21]. In this regard, in addition to direct adverse health effects of BTEX, they can be classified as the main precursors of the production of secondary pollutants by photochemical reactions such as proxy acetyl nitrate (PAN) and O₃, which can endanger human health [4,22–27].

Several investigations have been performed regarding measuring the concentration of ambient BTEX around the world and also to assess the quality and quantity of air pollutants and their effects on human health [24,28–34]. In this regard, useful information considering ratios used for determining photochemical activity in the atmosphere, as well as the sources of substances such as benzene/toluene (B/T) and ethylbenzene/m, p-xylene (E/X), were provided [8].

Although Tehran, with more than nine million permanent people and three million floating people, was designed for more than 750,000 motor vehicles, more than four million motor vehicles are moving in this metropolitan [35]. Besides, several factories are located in southern Tehran, with the emission of various pollutants into the ambient air [36]. Despite a high number of conducted studies regarding the concentration and numerous emission sources for BTEX in Tehran ambient air [37–43], no systematic review and meta-analysis study has been conducted to assess the related health risks. Therefore, for the first time, in the current study, the carcinogenesis and non-carcinogenesis risks of BTEX pollutants in Tehran will be assessed by using a systematic review and meta-analysis approach.

2. Material and Methods

2.1. Strategy of Search

The search strategy was performed to obtain all citations regarding the concentration of BTEX in the air of Tehran between 2005 to 2018. The systematic review was conducted based on the Cochrane method [44] using international databases including PubMed, Scopus, and Embase, and national databases including the Scientific Information Database (SID). The following keywords were used: (a) PubMed (Medline): ((((((((((benzene[Tit/Abs]) OR toluene[Tit/Abs]) OR ethylbenzene[Tit/Abs]) OR xylene[Tit/Abs]) OR BTEX[Tit/Abs]) OR volatile organic compound[Tit/Abs])) AND (((air pollution[Tit/Abs]) OR ambient air[Tit/Abs]) OR outdoor air[Tit/Abs])) OR air pollution[MeSH Terms]) AND Iran[Tit/Abs]) OR Iran[MeSH Terms]; (b) Scopus: ((keyword (benzene) or keyword (toluene) or keyword (ethylbenzene) or keyword (xylene) or keyword (BTEX) or keyword (volatile and organic and compound))) and ((keyword (air and pollution) or keyword (ambient and air) or keyword (outdoor and air))) and (keyword (Iran)); Embase: ‘benzene’.ab,ti OR ‘toluene’.ab,ti
OR ‘ethylbenzene’:ab,ti OR ‘xylene’:ab,ti OR ‘btex’:ab,ti OR ‘volatile organic compound’:ab,ti AND ‘air pollution’/exp OR ‘air pollution’ OR ‘ambient air’:ab,ti OR ‘outdoor air’/exp OR ‘outdoor air’ AND ‘IRAN’:ab,ti. Thirteen years (1 January 2005 and 11 June 2018) was selected as the period of investigation.

2.2. Screening of Articles

The evaluation of initially retrieved articles was performed independently according to (1) title, (2) abstract, and (3) full-text of the articles [45,46]. According to the title and abstract, some articles that did not perform investigations on the concentration of BTEX in the air of Tehran were excluded.

The full text of the obtained papers was downloaded, after the abstract screening. Criteria for including articles were: (1) descriptive study on the contamination of BTEX; (2) full text available; (3) original studies; and (4) reporting of the concentration of BTEX in ambient air in Tehran. Disagreement among two of the authors was resolved by discussion; otherwise, a third author decided. A reference list of retrieved articles was also checked to obtain more articles. The required management of obtained references was carried out using EndNote X7® (Thomson Reuters, Toronto, Canada) software [46].

2.3. Data Extraction and Definitions

The collected data from each article can be summarized as sampling date, type of monitoring station, number of monitoring stations, sample size, the concentration of BTEX, the method of detection, the limit of detection, and the limit of quantitation (Table 1). BTEX represents volatile chemicals including benzene, toluene, ethylbenzene, and xylene that are emitted from crude oil, natural gas, and petroleum deposits [47]. In this regard, because of the majority of studies performed on O-xylene, it was extracted from obtained articles.

2.4. Meta-Analysis

While the heterogeneity was higher than 50%, the random effect model (REM) was used to estimate the pooled concentration of BTEX in ambient air [45,48].

The standard error (SE) of the concentration of BTEX was calculated using standard deviation and sample size (SE = SD/√n) [45]. According to the mean and standard error, the pooled concentration of BTEX was estimated [49,50]. All data were analyzed using STATA 14.0 statistical software (College Station, TX, USA). p-value < 0.05 was considered statistically significant.

2.5. Health Risk Assessment

2.5.1. Non-Carcinogenic Risk

In the current study, according to part A and B of the risk assessment manual of EPA, the exposure dose to BTEX in ambient air was estimated [51]. Dose exposure via the inhalation [exposure concentration (EC)] pathway was calculated by Equation (1) [52,53].

\[
EC = \frac{C \times ET \times EF \times ED}{ATn}
\]  

(1)
Table 1. Main characteristics included in the study.

| Sampling Date       | Type of Monitoring Station | Monitoring Station Number | Sample Size | Concentration | Method of Detection | Ref |
|---------------------|----------------------------|---------------------------|-------------|---------------|---------------------|-----|
|                     |                            |                           |             | Benzene       |                     |     |
|                     |                            |                           |             | Average       | SD                   |     |
|                     |                            |                           |             | Toluene       | Average             | SD |
|                     |                            |                           |             | Ethyl Benzene | Average             | SD |
|                     |                            |                           |             | O-Xylene      | Average             | SD |
| 23-November         | Urban                      | 1                         | 70          | 16.57         | 5.86                |     |
| 10-December         | Urban                      | 1                         | 70          | 63.24         | 11.19               |     |
| 1-December          | Urban                      | 1                         | 20          | 66            | 98                  |     |
| July                | Urban                      | 14                        | 948         | 5.32          | NM 1                |     |
| 5-April-2010        | Traffic                    | 16                        | 80          | 14.51         | 3.17                |     |
| November-2014       | Traffic                    | 1                         | 100         | 28.96         | 9.12                |     |
| March-2012          | Urban                      | 7                         | 30          | 1.056         | NM                  |     |

1 Not Mentioned.
All parameters used in this equation are presented in Table 2.

| Parameter | Define | Unit | Value | Reference |
|-----------|--------|------|-------|-----------|
| EC        | Chronic and sub-chronic exposure concentration | µg m$^{-3}$ | – | [54] |
| C         | Concentration | mg m$^{-3}$ | – | – |
| THQ       | Target Hazard Quotient | Unitless | – | [54] |
| TTHQ      | Total target Hazard Quotient | Unitless | – | – |
| IUR$_{ba}$ | Inhalation unit risk | (mg m$^{-3}$)$^{-1}$ | – | [55] |
| ECR       | Excessive cancer risk | Unitless | Benzene: 0.030 | [55] |
| RCIi      | Inhalation reference concentrations | mg m$^{-3}$ | Toluene: 5.000 | [55] |
|           |        |      | Ethylbenzene: 1.000 | |
|           |        |      | O-Xylene: 0.100 | |
| EF        | Exposure frequency | day year$^{-1}$ | 180 | [56] |
| ED        | Exposure duration | year | Adults: 24 | [57] |
| ET        | Exposure time | hour day$^{-1}$ | 24 | [52] |
| ATn       | Averaging time | days | ATn = Non-carcinogens: ED $\times$ EF days | [58] |
| IUR       | Inhalation unit risk | (µg m$^{-3}$)$^{-1}$ | Benzene = 7.80 $\times$ 10$^6$ | [55] |
|           |        |      | Ethylbenzene = 2.50 $\times$ 10$^6$ | |
| 1000      | Convert factor mg to µg | – | – | – |

The conversion of the concentration from ppb to µg/m$^3$ for benzene, toluene, ethylbenzene, and o-xylene was performed using 3.243, 0.843, 19.45, and 4.33 convert coefficients, respectively [59].

To estimate the non-carcinogenic risk of BTEX in the ambient air, the target hazard quotient (THQ) was calculated using Equation (2) [51]:

$$ \text{THQ} = \frac{\text{EC}}{\text{RfCi}} \times \frac{1000}{1000} $$  \hspace{1cm} (2)

The total target hazard quotient (TTHQ) is equal to the sum of individual THQ [60–66]. The TTHQ of BTEX was calculated by Equation (3):

$$ \text{TTHQ} = \text{THQ}_b + \text{THQ}_t + \text{THQ}_e + \text{THQ}_x $$  \hspace{1cm} (3)

When THQ and/or TTHQ is lower than or equal to a value of 1, the population are not at a significant non-carcinogenic risk [17].

2.5.2. Carcinogenic Risk

The carcinogenic risk of benzene and ethylbenzene in adults and children was estimated using Equation (4):

$$ \text{ECR} = (\text{EC} \times 1000) \times \text{IUR} $$  \hspace{1cm} (4)

The related parameters of Equations (1)–(4) are shown in Table 2.

When the ECR value of benzene and ethylbenzene is lower than 1.00 $\times$ 10$^6$, between 1.00 $\times$ 10$^6$ to 1.00 $\times$ 10$^4$, and higher than 1.00 $\times$ 10$^4$, the exposed population are at no considerable, threshold, and considerable cancer risk, respectively [54]. In the current study, the cut off point for endangering the population was a percentile of 95% (worse scenario) of THQ and ECR [65].
3. Results and Discussion

3.1. The Process of Select Papers

Among the 230 papers obtained published from 2005 to 2018 from all databases including PubMed (n = 83), Scopus (n = 66), Embase (n = 53), and SID (n = 28) in the identification step, 121 papers were excluded due to duplication. After the assessment of titles, 48 papers were regarded as unsuitable. The abstracts of 61 papers were checked, and 23 papers were excluded. Then, the full texts of the 38 papers were reviewed and finally, seven papers with 1678 samples were included in the current study (Figure 1).

![Figure 1. The selection process of articles and inclusion.](image)

3.2. Concentration of BTEX

The pooled concentration (ppb) of benzene, toluene, ethylbenzene, and o-xylene, is demonstrated in Figure 2a–d. The pooled concentration of benzene, toluene, ethylbenzene, and o-xylene was 46.54 ppb (95% CI: 41.87–51.30 ppb), 23.65 ppb (95% CI: 19.62–27.68 ppb), 25.70 ppb (95% CI: 17.80–33.63 ppb), and 29.43 ppb (95% CI: 22.57–36.29 ppb), respectively. Also, the total BTEX concentration was measured as 125.13 ppb or 474.45 ± 29.93 µg/m$^3$. The rank order based on their contribution in BTEX was benzene (46.54 ppb or 149.18 µg/m$^3$: 31%) > o-xylene (29.43 ppb or 127.16 µg/m$^3$: 27%) > ethylbenzene (25.70 ppb or 110.15 µg/m$^3$: 23%) > toluene (23.65 ppb or 87.97 µg/m$^3$: 19%) (Figure 3).
According to our findings, the pooled concentrations of benzene (149.18 µg/m³) were higher than those in other cities around the world (Table 3). The concentration of ethylbenzene (110.12 µg/m³) in Tehran were higher than those in other cities around the world (Table 3)

The percentage of BTEX in the ambient air of Tehran was higher than many urban regions in the world. The concentration of BTEX in Tehran with other urban areas in the world is demonstrated in Figure 2.

The inversion phenomenon, which can result in higher evaporation of petrol vapors (gasoline evaporation) and emission of higher concentrations of toluene and ethylbenzene by motor vehicle

The rank order based on their total BTEX contributions in BTEX was

- toluene (23%) > o-xylene (27%) > ethylbenzene (23%) > benzene (19%).

The percentage of BTEX in the ambient air of Tehran. ES: effect size, CI: Confidence interval.

A comparison of the concentration of BTEX in Tehran with other urban areas in the world is presented in Table 3. According to our findings, the pooled concentrations of benzene (149.18 µg/m³)
and o-xylene (125.57 µg/m³) in Tehran were higher than those in other cities around the world (Table 3) [6,33,67–74] (Table 3).

The concentration of toluene in Tehran (87.97 µg/m³) was lower than that in Malaysia (Kuala Lumpur) (113.805 µg/m³) [73], but higher than other cities [6,33,67–72,74]. However, the concentration of ethylbenzene (110.12 µg/m³) in Tehran was lower than the reported value for Malaysia (Kuala Lumpur) (661.3 µg/m³) [73], but was lower than other cities (Table 3) [6,33,67–72,74].

The toluene levels in Italy (Bari) (4.76 ± 3.41 µg/m³), Canada (Sarnia) (2.88 µg/m³), Turkey (Kocaeli) (35.51 ± 39.55 µg/m³), China (Beijing) (2.21 ± 2.10 µg/m³), and Spain (Navarra) (13.26 µg/m³) were higher than other VOC compounds (Table 3) [6,67–72]; however, the concentrations of ethylbenzene in South Korea (Seoul) (80.75 µg/m³) and Malaysia (Kuala Lumpur) (661.3 µg/m³) were higher than other VOC compounds [33,73,74] (Table 3).

The concentration of BTEX in ambient air of Tehran was higher than many urban regions in the world (Table 3). The inversion phenomenon was mentioned as one of the leading causes of the high concentration of BTEX in Tehran [37,38,40,42]. It occurs in the cold seasons that cause ambient air pollutants such as VOCs to become trapped in the surface layer of the Earth, which can result in intensifying air pollution levels [37].

In addition to the inversion phenomenon, fossil fuel consumption of old vehicles, low-quality fuel, population congestion, non-standard streets, and highways, besides several factories in the south of Tehran such as iron and steel industries, are other reasons for the high level of BTEX in Tehran city [37,38,40,42].

The higher concentration of toluene and ethylbenzene in Malaysia (Kuala Lumpur) compared with Tehran is due to the higher evaporation of petrol vapors (gasoline evaporation) and emission of higher concentrations of toluene and ethylbenzene by motor vehicles [73].
Table 3. A comparison of the concentration of BTEX in ambient air of Tehran with other regions in the world (µg/m³).

| City/Country          | Sample Size | Monitoring Periods          | Benzene  | Toluene  | Ethylbenzene | O-Xylene | Method Type | Type of Source | References |
|-----------------------|-------------|-----------------------------|----------|----------|--------------|----------|-------------|---------------|------------|
| Bari/Italy            | NM¹         | April, September and October 2008 | 2.29 ± 1.59 | 4.76 ± 3.41 | 0.92 ± 0.66 | 1.3 ± 0.94 | GC/MS       | Urban         | [67]       |
| 18 areas/Canada       | NM          | September 2009 and December 2011 | 0.58     | 1.55     | 0.24         | 0.24     | GC/MS       | Urban         | [68]       |
| Aliaga/Western Turkey | 13          | 2005 and 2007               | 0.68 ± 0.68 | 1.6 ± 1.1 | 0.25 ± 0.17 | 0.16 ± 0.13 | GC/FID      | Urban         | [69]       |
| Kocaeli/Turkey        | 49          | July 2006                   | 2.26 ± 3.20 | 35.51 ± 39.55 | 9.72 ± 9.20 | 12.46 ± 12.46 | GC/FID      | Urban         | [6]        |
| Bejing/China          | 41          | 26 February and 7 March 2013 | 1.73 ± 1.68 | 2.21 ± 2.10 | 0.38 ± 0.38 | 0.19 ± 0.17 | GC/FID      | Urban         | [70]       |
| Orleans/France        | 56          | Winter 2011                 | 0.95     | 0.27     | 0.95         | 0.14     | (TD-GC–MSD) | Semi-urban    | [33]       |
| Navarra/Spain         | 932         | June 2006 to June 2007      | 2.84     | 13.26    | 2.15         | 2.63     | GC/MS       | Urban         | [71]       |
| Sarnia/Canada         | 37          | 2004–2005                   | 0.93     | 2.54     | 0.46         | 0.49     | GC/MS       | Urban         | [72]       |
| Windsor/Canada        | 42          | 2004–2005                   | 0.76     | 2.88     | 0.44         | 0.45     | GC/MS       | Urban         | [72]       |
| Kuala Lumpur/Malaysia | 28          | December 2013 and January 2014 | 58.374 | 113.805 | 661.3       | NM       | GC/MS       | Urban         | [73]       |
| Seoul/South Korea     | 8003        | 2004                        | 2.829    | 32.76    | 80.75        | NM       | GC/FID      | Urban         | [74]       |
| Present study         | 1678        | 2007–2015                   | 149.18   | 87.97    | 110.12       | 127.14   |             |               |             |

¹ Not Mentioned.
3.3. The Ratio between BTEX Compounds

The ratios of benzene/toluene (B/T) and ethylbenzene/m, p-xylene (E/X) can be used to assess the photochemical activity in the atmosphere and sources [8,75]. The ratio between BTEX compounds is the main parameter for discovering the emission sources of BTEX in the outdoor air [76,77]. The calculated B/T ratio in the range of 0.23–0.66 shows that vehicles and traffic are the main emission sources of toluene and benzene in the ambient air of Tehran [8,75,78,79]. The B/T ratio lower than this range indicates that toluene and benzene mainly originated from stationary sources. Likewise, if the B/T ratio is higher than this range, stationary (factory) and mobile (Motorcycle and car) sources are the main sources of emission [8,75]. Ratios of benzene/toluene (B/T) and ethylbenzene/o-xylene (E/o-X) in Tehran and other areas are presented in Table 4.

Table 4. Comparison of benzene/toluene (B/T) and ethylbenzene/o-xylene (E/o-X) concentration ratio in Tehran and other areas.

| Area Study              | B/T    | E/O-X  | References |
|-------------------------|--------|--------|------------|
| Guangzhou/China         | 0.35   |        | [28]       |
| Hong Kong/China         | 0.13   |        | [80]       |
| Helsinki/Finland        | 0.36   |        | [81]       |
| Munich/Germany          | 0.53   |        | [82]       |
| Louis/India             | 0.93   |        | [83]       |
| Paris/France            | 0.15   |        | [32]       |
| London/English          | 0.65   |        | [84]       |
| Seoul/South Korea       | 0.13   |        | [25]       |
| Beijing/China           | 0.71   |        | [85]       |
| Beijing/China           | 0.87   |        | [24]       |
| Bari/Italy              | 0.48   | 0.71   | [67]       |
| 18 areas/Canada         | 0.37   | 1.00   | [68]       |
| Aliaga/Western Turkey   | 0.43   | 1.56   | [69]       |
| Kocaeli/Turkey          | 0.06   | 0.78   | [6]        |
| Beijing/China           | 0.78   | 2.00   | [70]       |
| Orleans/France          | 3.49   | 6.50   | [33]       |
| Navarra/Spain           | 0.21   | 0.82   | [71]       |
| Sarnia/Canada           | 0.37   | 0.94   | [72]       |
| Windsor/Canada          | 0.26   | 0.98   | [72]       |
| Kuala Lumpur/Malaysia   | 0.51   |        | [73]       |
| Tehran/Iran             | 1.69   | 0.86   | Present study |

The B/T ratio in this study was 1.69, which was higher than 0.23–0.66, representing that the primary sources of benzene and toluene could be both stationary and mobile sources of emission. Similar to our study, the B/T ratio in ambient air in France (Orleans) and China (Beijing) was higher than the B/T ratio in this study (0.66) [24,33,70,85]. The B/T ratio in ambient air of China (Hong Kong), France (Paris), South Korea (Seoul), Turkey (Kocaeli), and Spain (Navarra) [25,32,70,71,80] was lower than 0.23, indicating that toluene and benzene mainly originated from stationary sources [8,75].

The ratio of E/X is a good indicator that indicates the degree of photochemical reactions [86,87]. A higher ratio of E/X than Spain (Navarra: 0.82), Turkey (Kocaeli: 0.78), and Italy (Bari: 0.71) shows that photochemical activity in the ambient air of Tehran is stronger than in Spain, Turkey, and Italy (Table 4) [88].

3.4. Health Risk Assessment

3.4.1. Non-Carcinogenic Risk Assessment

Non-Carcinogenic Risk BTEX compounds are presented in Table 5. Percentile 95% of THQ of benzene, toluene, ethylbenzene, and o-xylene was determined as 5.342, 0.021, 0.142, and 1.522, respectively (Table 5). The rank order of BTEX compounds based on THQ was benzene > o-xylene.
> ethylbenzene > toluene. THQ of benzene was higher than other VOC compounds because the concentration of benzene was the highest (Table 5), and also its RfC was the lowest [55].

| VOCs Compounds | C (Mean) | C (P95%) | EC (Mean) | EC (P95%) | RfCi | THQ (Mean) | THQ (P95%) |
|----------------|---------|----------|-----------|-----------|------|------------|------------|
| Benzene        | 149.178 | 160.27   | 0.149     | 0.160     | 0.03 | 4.973      | 5.342      |
| Toluene        | 87.970  | 107      | 0.088     | 0.107     | 5.00 | 0.018      | 0.021      |
| Ethylbenzene   | 110.150 | 142      | 0.110     | 0.142     | 1.00 | 0.110      | 0.142      |
| O-Xylene       | 127.160 | 152.2    | 0.127     | 0.152     | 0.10 | 1.272      | 1.522      |

Percentile 95% of THQ of benzene and o-xylene was higher than the value of 1. Also, TTHQ values based on mean and percentile 95% was 6.37 and 7.07, respectively, which were higher than a value of 1 (Figure 4). The health risk assessment shows that the residents of Tehran are at a considerable non-carcinogenic risk (THQ and TTHQ > 1 value). THQ values of benzene, toluene, ethylbenzene, and o-xylene in the China (Beijing) city were $3.2 \times 10^3$, $3.37 \times 10^4$, $3.19 \times 10^5$, and $1.5 \times 10^3$, respectively [70], which were lower than Tehran city. The lower concentration of BTEX in ambient air of China (Beijing) city (Table 3) was the main source of the lower non-carcinogenic risk when compared to Tehran city.

![Figure 4. TTHQ of BTEX in ambient air due to inhalation exposed population.](image)

3.4.2. Carcinogenic Risk Assessment

The result of the carcinogenic risk assessment of benzene and ethylbenzene is presented in Table 6. Percentile 95% ECR of benzene and ethylbenzene was $1.25 \times 10^6$ and $1.11 \times 10^6$, respectively (Table 6). Also, percentile 95% ECR of benzene and ethylbenzene was higher than the value of $1.00 \times 10^6$. In this context, the population of Tehran is at considerable carcinogenic risk. These outcomes of the health risk assessment show that strict monitoring needs to be performed to control the concentration of BTEX in ambient air in Tehran city and BTEX standards should be revised as soon as possible.
Table 6. Carcinogenic risk due to the inhalation of benzene and ethylbenzene.

| VOCs Compounds | EC (Mean) | EC (P95%) | IUR | ECR (Mean) | ECR (P95%) |
|----------------|-----------|-----------|-----|------------|------------|
| Benzene        | 0.149     | 0.160     | 7.80 × 10^6 | 1.16 × 10^6 | 1.25 × 10^6 |
| Ethylbenzene   | 0.110     | 0.142     | 2.50 × 10^6 | 8.59 × 10^7 | 1.11 × 10^6 |

4. Conclusions

In the current study, the concentration of BTEX in Tehran ambient air was estimated based on a systematic review and meta-analysis approach and the non-carcinogenic and carcinogenic risks in the exposed population were estimated. The rank order of BTEX based on their concentration was benzene > o-xylene > ethylbenzene > toluene. The primary sources of benzene and toluene in ambient air of Tehran include both mobile and stationary sources of emission. Also, strong photochemical activities in the ambient air of Tehran were assumed. A health risk assessment based on the worse scenario (Percentile 95% THQ and ECR) indicated that the population of Tehran are at considerable non-carcinogenic and carcinogenic risks. Therefore, to reduce the health risks of BTEX, emission reduction plans should be implemented.

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References

1. Al-Dabbous, A.N.; Kumar, P. Number and size distribution of airborne nanoparticles during summertime in Kuwait: First observations from the Middle East. *Environ. Sci. Technol.* 2014, 48, 13634–13643. [CrossRef] [PubMed]
2. Bouarar, I.; Wang, X.; Brasseur, G.P. *Air Pollution in Eastern Asia: An Integrated Perspective*; Springer: Berlin, Germany, 2017; Volume 16.
3. Cecchi, L.; Annesi-Maesano, I. News on Climate change, air pollution and allergic trigger factors of asthma. *J. Investig. Allergol. Clin. Immunol.* 2018, 28, 91–97.
4. Ghozikali, M.G.; Heibati, B.; Naddafi, K.; Kloog, I.; Conti, G.O.; Polosa, R.; Ferrante, M. Evaluation of chronic obstructive pulmonary disease (COPD) attributed to atmospheric O₃, NO₂, and SO₂ using Air Q Model (2011–2012 year). *Environ. Res.* 2016, 144, 99–105. [CrossRef] [PubMed]
5. Lin, R.-T.; Christiani, D.C.; Kawachi, I.; Chan, T.-C.; Chiang, P.-H.; Chan, C.-C. Increased risk of respiratory mortality associated with the high-tech manufacturing industry: A 26-Year study. *Int. J. Environ. Res. Public Health.* 2016, 13, 557. [CrossRef] [PubMed]
6. Pekey, B.; Yılmaz, H. The use of passive sampling to monitor spatial trends of volatile organic compounds (VOCs) at an industrial city of Turkey. *Microchem. J.* 2011, 97, 213–219. [CrossRef]
7. Sarkhosh, M.; Mahvi, A.H.; Zare, M.R.; Fakhri, Y.; Shamsolahi, H.R. Indoor contaminants from hardcopy devices: Characteristics of VOCs in photocopy centers. *Atmos. Environ.* 2012, 63, 307–312. [CrossRef]
8. Hoque, R.R.; Khillare, P.; Agarwal, T.; Shridhar, V.; Balachandran, S. Spatial and temporal variation of BTEX in the urban atmosphere of Delhi, India. *Sci. Total Environ.* 2008, 392, 30–40. [CrossRef] [PubMed]
9. Sharma, S.; Goel, A.; Gupta, D.; Kumar, A.; Mishra, A.; Kundu, S.; Chatani, S.; Klimont, Z. Emission inventory of non-methane volatile organic compounds from anthropogenic sources in India. *Atmos. Environ.* 2015, 102, 209–219. [CrossRef]
10. Kim, H.; Bernstein, J.A. Air pollution and allergic disease. *Curr. Allergy Asthma Rep.* 2009, 9, 128–133. [CrossRef] [PubMed]

11. Seaton, A.; Godden, D.; MacNee, W.; Donaldson, K. Particulate air pollution and acute health effects. *Lancet* 1995, 345, 176–178. [CrossRef]

12. Thurston, G.D.; Burnett, R.T.; Turner, M.C.; Shi, Y.; Krewski, D.; Lall, R.; Ito, K.; Jerrett, M.; Gapstur, S.M.; Diver, W.R. Ischemic heart disease mortality and long-term exposure to source-related components of US fine particle air pollution. *Environ. Health Perspect.* 2016, 124, 785. [PubMed]

13. Saalberg, Y.; Wolff, M. VOC breath biomarkers in lung cancer. *Clin. Chim. Acta* 2016, 459, 5–9. [CrossRef] [PubMed]

14. Carlos-Wallace, F.M.; Zhang, L.; Smith, M.T.; Rader, G.; Steinmaus, C. Parental, in utero, and early-life exposure to benzene and the risk of childhood leukemia: A meta-analysis. *Am. J. Epidemiol.* 2015, 183, 1–14. [CrossRef] [PubMed]

15. Masih, A.; Lall, A.S.; Taneja, A.; Singhvi, R. Exposure profiles, seasonal variation and health risk assessment of BTEX in indoor air of homes at different microenvironments of a terai province of northern India. *Chemosphere* 2017, 176, 8–17. [CrossRef] [PubMed]

16. Partovi, E.; Fathi, M.; Assari, M.J.; Esmaeili, R.; Pourmohamadi, A.; Rahimpour, R. Risk assessment of occupational exposure to BTEX in the National Oil Distribution Company in Iran. *Chronic Dis. J.* 2018, 4, 48–55.

17. International Agency for Research on Cancer (IARC). *Agents Classified by the IARC Monographs*; IARC: Lyon, France, 2011; Volume 1–102.

18. Heshmati, A.; Ghdimi, S.; Khaneghah, A.M.; Barba, F.J.; Lorenzo, J.M.; Nazemi, F.; Fakhri, Y. Risk assessment of benzene in food samples of Iran’s market. *Food Chem. Toxicol.* 2018, 114, 278–284. [CrossRef] [PubMed]

19. Mansha, M.; Saleemi, A.R.; Naqvi, J.H. Status and spatial visualization of toxic pollutants (BTEX) in urban atmosphere. *Adv. Chem. Eng. Sci.* 2012, 1, 231. [CrossRef]

20. Holmes, C.; Atkinson, D.; Jaffer, J.; Sigman, C.; Thompson, K.; Kelsey, M.; Kraybill, H.; Munn, J. Evaluation and classification of the potential carcinogenicity of organic air pollutants. *J. Environ. Sci. Health Part A* 1982, 17, 321–389. [CrossRef] [PubMed]

21. Possanzini, M.; Di Palo, V.; Gigliucci, P.; Scianò, M.C.T.; Cecinato, A. Determination of phase-distributed PAH in Rome ambient air by denuder/GC-MS method. *Atmos. Environ.* 2004, 38, 1727–1734. [CrossRef]

22. Guimarães, E.D.F.; do Rego, E.C.; Cunha, H.; Rodrigues, J.M.; Figueroa-Villar, J.D. Certified reference material for traceability in environmental analysis: PAHs in toluene. *J. Braz. Chem. Soc.* 2014, 25, 351–360. [CrossRef]

23. Henze, D.; Seinfeld, J.; Ng, N.; Kroll, J.; Fu, T.-M.; Jacob, D.J.; Heald, C. Global modeling of secondary organic aerosol formation from aromatic hydrocarbons: High-vs. low-yield pathways. *Atmos. Chem. Phys.* 2008, 8, 2405–2420. [CrossRef]

24. Xie, X.; Shao, M.; Liu, Y.; Lu, S.; Chang, C.-C.; Chen, Z.-M. Estimate of initial isoprene contribution to ozone formation potential in Beijing, China. *Atmos. Environ.* 2008, 42, 6000–6010. [CrossRef]

25. Na, K.; Kim, Y.P.; Moon, K.C. Diurnal characteristics of volatile organic compounds in the Seoul atmosphere. *Atmos. Environ.* 2003, 37, 733–742. [CrossRef]

26. Zhang, Y.; Mu, Y.; Liu, J.; Mellouki, A. Levels, sources and health risks of carbonyls and BTEX in the ambient air of Beijing, China. *J. Environ. Sci.* 2012, 24, 124–130. [CrossRef]

27. Murena, F. Air quality nearby road traffic tunnel portals: BTEX monitoring. *J. Environ. Sci.* 2007, 19, 578–583. [CrossRef]

28. Barletta, B.; Meinardi, S.; Simpson, I.J.; Zou, S.; Rowland, F.S.; Blake, D.R. Ambient mixing ratios of nonmethane hydrocarbons (NMHCs) in two major urban centers of the Pearl River Delta (PRD) region: Guangzhou and Dongguan. *Atmos. Environ.* 2008, 42, 4393–4408. [CrossRef]

29. Grosjean, D. In situ organic aerosol formation during a smog episode: Estimated production and chemical functionality. *Atmos. Environ. Part A Gen. Top.* 1992, 26, 953–963. [CrossRef]

30. Song, Y.; Shao, M.; Liu, Y.; Lu, S.; Kuster, W.; Goldan, P.; Xie, S. Source apportionment of ambient volatile organic compounds in Beijing. *Environ. Sci. Technol.* 2007, 41, 4348–4353. [CrossRef] [PubMed]

31. Lu, S.; Liu, Y.; Shao, M.; Huang, S. Chemical speciation and anthropogenic sources of ambient volatile organic compounds (VOCs) during summer in Beijing, 2004. *Front. Environ. Sci. Eng. China* 2007, 1, 147–152. [CrossRef]
32. Gros, V.; Sciare, J.; Yu, T. Air-quality measurements in megacities: Focus on gaseous organic and particulate pollutants and comparison between two contrasted cities, Paris and Beijing. C. R. Geosci. 2007, 339, 764–774. [CrossRef]
33. Jiang, Z.; Grosselin, B.; Daële, V.; Mellouki, A.; Mu, Y. Seasonal and diurnal variations of BTEX compounds in the semi-urban environment of Orleans, France. Sci. Total Environ. 2017, 574, 1659–1664. [CrossRef] [PubMed]
34. Liu, K.; Zhang, C.; Cheng, Y.; Liu, C.; Zhang, H.; Zhang, G.; Sun, X.; Mu, Y. Serious BTEX pollution in rural area of the North China Plain during winter season. J. Environ. Sci. 2015, 30, 186–190. [CrossRef] [PubMed]
35. Iranian Students News Agency (ISNA). 2017. Available online: https://www.isna.ir/news/96063118066/ (accessed on 1 February 2018).
36. Soleimani, M.; Amini, N. Source Identification and Apportionment of Air Pollutants in Iran. J. Air Pollut. Health 2017, 2, 57–72.
37. Davil, M.F.; Naddafi, K.; Rostami, R.; Zarei, A.; Feizizadeh, M. A mathematical model for predicting 24-h variations of BTEX concentrations in ambient air of Tehran. Int. J. Environ. Health Eng. 2013, 2, 4.
38. Mohseni Bandpai, A.; Yaghoubi, M.; Hadei, M.; Salemi, M.; Shahsavani, A. Concentrations of Criteria Air Pollutants and BTEX in Mehrabad International Airport. J. Mazandaran Univ. Med. Sci. 2018, 28, 76–87.
39. Asadollahfardi, G.; Mehdinejad, M.; Mirmohammadi, M.; Asadollahfardi, R. Predicting Atmospheric Concentrations of Benzene in the Southeast of Tehran using Artificial Neural Network. Asian J. Atmos. Environ. (AJAE) 2015, 9, 12–21. [CrossRef]
40. Atabi, F.; Mirzahosseini, S.A.H. GIS-based assessment of cancer risk due to benzene in Tehran ambient air. Int. J. Occup. Med. Environ. Health 2013, 26, 770–779. [CrossRef] [PubMed]
41. Asadi, M.; Mirmohammadi, M. Experimental study of benzene, toluene, ethylbenzene, and xylene (BTEX) contributions in the air pollution of Tehran, Iran. Environ. Qual. Manag. 2017, 27, 83–93. [CrossRef]
42. Dehghani, M.H.; Sanaei, D.; Nabizadeh, R.; Nazmara, S.; Kumar, P. Source apportionment of BTEX compounds in Tehran, Iran using UNMIX receptor model. Air Qual. Atmos. Health 2017, 10, 225–234. [CrossRef]
43. Miri, M.; Shendi, M.R.A.; Ghaffari, H.R.; Aval, H.E.; Ahmadi, E.; Taban, E.; Gholizadeh, A.; Aval, M.Y.; Mohammadi, A.; Azari, A. Investigation of outdoor BTEX: Concentration, variations, sources, spatial distribution, and risk assessment. Chemosphere 2016, 163, 601–609. [CrossRef] [PubMed]
44. Higgins, J.P.; Green, S. Cochrane Handbook for Systematic Reviews of Interventions; John Wiley & Sons: Hoboken, NJ, USA, 2011; Volume 4.
45. Khaneghah, A.M.; Fakhri, Y.; Raeisi, S.; Armoon, B.; Sant’Ana, A.S. Prevalence and concentration of ochratoxin A, zearalenone, deoxynivalenol and total aflatoxin in cereal-based products: A systematic review and meta-analysis. Food Chem. Toxicol. 2018, 118, 830–848. [CrossRef] [PubMed]
46. Khaneghah, A.M.; Fakhri, Y.; Sant’Ana, A.S. Impact of unit operations during processing of cereal-based products on the levels of deoxynivalenol, total aflatoxin, ochratoxin A, and zearalenone: A systematic review and meta-analysis. Food Chem. 2018, 268, 611–624. [CrossRef] [PubMed]
47. Dehghani, M.; Fazlzadeh, M.; Sorooshian, A.; Tabatabaei, H.R.; Miri, M.; Baghani, A.N.; Delikhooon, M.; Mahvi, A.H.; Rashidi, M. Characteristics and health effects of BTEX in a hot spot for urban pollution. Ecotoxicol. Environ. Saf. 2018, 155, 133–143. [CrossRef] [PubMed]
48. Kuroki, T.; Watanabe, Y.; Teranishi, H.; Izumiya, S.; Amemura-Maekawa, J.; Kura, F. Legionella prevalence and risk of legionellosis in Japanese households. Epidemiol. Infect. 2017, 145, 1398–1408. [CrossRef] [PubMed]
49. Quan, H.; Zhang, J. Estimate of standard deviation for a log-transformed variable using arithmetic means and standard deviations. Stat. Med. 2003, 22, 2723–2736. [CrossRef] [PubMed]
50. Higgins, J.; White, I.R.; Anzures-Cabrera, J. Meta-analysis of skewed data: Combining results reported on log-transformed or raw scales. Stat. Med. 2008, 27, 6072–6092. [CrossRef] [PubMed]
51. United States Environmental Protection Agency (USEPA). Risk Assessment Guidance for Superfund. In Part A: Human Health Evaluation Manual; Part E, Supplemental Guidance for Dermal Risk Assessment; Part F, Supplemental Guidance for Inhalation Risk Assessment, Volume I. 2011. Available online: http://www.epa.gov/oswer/riskassessment/human_health_exposure.htm (accessed on 20 April 2011).
52. Environmental Protection Agency (EPA). Risk Assessment Guidance for Superfund; Volume I: Human Health Evaluation Manual (Part A); EPA/540/1-89/002; USEPA: Washington, DC, USA, 2004.
53. Environmental Protection Agency (EPA). Soil Screening Guidance Technical Background Document; EPA/540; Office of Solid Waste and Emergency Response: Washington, DC, USA, 1996; p. 95.

54. United States Environmental Protection Agency (USEPA). Regional Screening Levels (RSLs)—Generic Tables. USEPA 2011b. 2017. Available online: http://www.epa.gov/region9/supersite/prg/index.html (accessed on 16 July 2017).

55. United States Environmental Protection Agency (USEPA). Regional screening level (RSL) Summary Table (TR = 1E−6, HQ = 1). Available online: https://www.epa.gov/risk/regional-screening-levels-rsls-generic-tables (accessed on 25 June 2013).

56. Zheng, N.; Liu, J.; Wang, Q.; Liang, Z. Health risk assessment of heavy metal exposure to street dust in the zinc smelting district, Northeast of China. Sci. Total Environ. 2010, 408, 726–733. [CrossRef] [PubMed]

57. United States Environmental Protection Agency (USEPA). Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites; Peer Review Draft, OSWER 9355; USEPA: Washington, DC, USA, 2001; pp. 4–24.

58. Ferreira-Baptista, L.; De Miguel, E. Geochemistry and risk assessment of street dust in Luanda, Angola: A tropical urban environment. Atmos. Environ. 2005, 39, 4501–4512. [CrossRef]

59. UK-Air, Conversion Factors between ppb and µg m⁻³ and ppm. 2014. Available online: https://uk-air.defra.gov.uk/.../0502160851_Conversion_Factors_Between_ppb_and_p (accessed on 20 May 2014).

60. De Miguel, E.; Iribarren, I.; Chacon, E.; Ordóñez, A.; Charlesworth, S. Risk-based evaluation of the exposure of children to trace elements in playgrounds in England. Chemosphere 2007, 66, 505–513. [CrossRef] [PubMed]

61. Lim, H.-S.; Lee, J.-S.; Chon, H.-T.; Sager, M. Heavy metal contamination and health risk assessment in the vicinity of the abandoned Songcheon Au–Ag mine in Korea. J. Geochem. Explor. 2008, 96, 223–230. [CrossRef]

62. Shahrbabki, P.E.; Hajimohammadi, B.; Shoebt, S.; Elmi, M.; Yousefzadeh, A.; Conti, G.O.; Ferrante, M.; Amirahmadi, M.; Fakhri, Y.; Khanezhah, A.M. Probabilistic non-carcinogenic and carcinogenic risk assessments (Monte Carlo simulation method) of the measured acrylamide content in Tah-dig using QuEChERS extraction and UHPLC-MS/MS. Food Chem. Toxicol. 2018, 118, 361–370. [CrossRef] [PubMed]

63. Ghasemidehkordi, B.; Malekirad, A.A.; Nazem, H.; Fazilati, M.; Salavati, H.; Shariatifar, N.; Rezaei, M.; Fakhri, Y.; Khanezhah, A.M. Concentration of lead and mercury in collected vegetables and herbs from Markazi province, Iran: A non-carcinogenic risk assessment. Food Chem. Toxicol. 2018, 113, 204–210. [CrossRef] [PubMed]

64. Fakhri, Y.; Mohseni-Bandpei, A.; Conti, G.O.; Ferrante, M.; Cristaldi, A.; Jeihooni, A.K.; Dehkordi, M.K.; Alinejad, A.; Rasoulzadeh, H.; Mohseni, S.M.; et al. Systematic review and health risk assessment of arsenic and lead in the fished shrimps from the Persian Gulf. Food Chem. Toxicol. 2018, 113, 278–286. [CrossRef] [PubMed]

65. Rahmani, J.; Alipour, S.; Miri, A.; Fakhri, Y.; Riahi, S.M.; Keramati, H.; Moradi, M.; Amanidaz, N.; Pouya, R.H.; Bahmani, Z.; et al. The prevalence of aflatoxin M1 in milk of Middle East region: A systematic review, meta-analysis and probabilistic health risk assessment. Food Chem. Toxicol. 2018, 118, 653–666. [CrossRef] [PubMed]

66. Yousefi, M.; Shemshadi, G.; Khorshidian, N.; Ghasemzadeh-Mohammadi, V.; Fakhri, Y.; Hosseini, H.; Khanezhah, A.M. Polycyclic aromatic hydrocarbons (PAHs) content of edible vegetable oils in Iran: A risk assessment study. Food Chem. Toxicol. 2018, 118, 480–489. [CrossRef] [PubMed]

67. Caselli, M.; de Gennaro, G; Marzocca, A; Trizio, L; Tutino, M. Assessment of the impact of the vehicular traffic on BTEX concentration in ring roads in urban areas of Bari (Italy). Chemosphere 2010, 81, 306–311. [CrossRef] [PubMed]

68. Xu, J.; Szyszkwiczow, M.; Jovic, B.; Cakmak, S.; Austin, C.C.; Zhu, J. Estimation of indoor and outdoor ratios of selected volatile organic compounds in Canada. Atmos. Environ. 2016, 141, 523–531. [CrossRef]

69. Civan, M.Y.; Elbir, T.; Seyfioglu, R.; Kuntasal, Ö.O.; Bayram, A.; Doğan, G.; Yurdakul, S.; Andiç, Ö.; Müezzinoğlu, A.; Sofuoglu, S.C.; et al. Spatial and temporal variations in atmospheric VOCs, NO₂, SO₂, and O₃ concentrations at a heavily industrialized region in Western Turkey, and assessment of the carcinogenic risk levels of benzene. Atmos. Environ. 2015, 103, 102–113. [CrossRef]

70. Gao, J.; Zhang, J.; Li, H.; Li, L.; Xu, L.; Zhang, Y.; Wang, Z.; Wang, X.; Zhang, W.; Chen, Y.; et al. Comparative study of volatile organic compounds in ambient air using observed mixing ratios and initial mixing ratios taking chemical loss into account—A case study in a typical urban area in Beijing. Sci. Total Environ. 2018, 628, 791–804. [CrossRef] [PubMed]
71. Parra, M.; Elustondo, D.; Bermejo, R.; Santamaria, J. Ambient air levels of volatile organic compounds (VOC) and nitrogen dioxide (NO\textsubscript{2}) in a medium size city in Northern Spain. *Sci. Total Environ.* **2009**, *407*, 999–1009. [CrossRef] [PubMed]

72. Miller, L.; Xu, X.; Wheeler, A.; Zhang, T.; Hamadani, M.; Ejaz, U. Evaluation of missing value methods for predicting ambient BTEX concentrations in two neighbouring cities in Southwestern Ontario Canada. *Atmos. Environ.* **2018**, *181*, 126–134. [CrossRef]

73. Hosaini, P.N.; Khan, M.F.; Mustaffa, N.I.H.; Amil, N.; Mohamad, N.; Jaafar, S.A.; Nadzir, M.S.M.; Latif, M.T. Concentration and source apportionment of volatile organic compounds (VOCs) in the ambient air of Kuala Lumpur, Malaysia. *Nat. Hazards* **2017**, *85*, 437–452. [CrossRef]

74. Nguyen, H.T.; Kim, K.-H.; Kim, M.-Y. Volatile organic compounds at an urban monitoring station in Korea. *J. Hazard. Mater.* **2009**, *161*, 163–174. [CrossRef] [PubMed]

75. Buczynska, A.J.; Krata, A.; Stranger, M.; Godoi, A.F.L.; Kontozova-Deutsch, V.; Bencs, L.; Naveau, I.; Roekens, E.; Van Grieven, R. Atmospheric BTEX-concentrations in an area with intensive street traffic. *Atmos. Environ.* **2009**, *43*, 311–318. [CrossRef]

76. Kerbachi, R.; Boughedaoui, M.; Bounoua, L.; Keddam, M. Ambient air pollution by aromatic hydrocarbons in Algiers. *Atmos. Environ.* **2006**, *40*, 3995–4003. [CrossRef]

77. Khoder, M.I. Ambient levels of volatile organic compounds in the atmosphere of Greater Cairo. *Atmos. Environ.* **2007**, *41*, 554–566. [CrossRef]

78. Perry, R.; Gee, I.L. Vehicle emissions in relation to fuel composition. *Sci. Total Environ.* **1995**, *169*, 149–156. [CrossRef]

79. Barletta, B.; Meinardi, S.; Rowland, F.S.; Chan, C.-Y.; Wang, X.; Zou, S.; Chan, L.Y.; Blake, D.R. Volatile organic compounds in 43 Chinese cities. *Atmos. Environ.* **2005**, *39*, 5979–5990. [CrossRef]

80. Ho, K.; Lee, S.; Guo, H.; Tsai, W. Seasonal and diurnal variations of volatile organic compounds (VOCs) in the atmosphere of Hong Kong. *Sci. Total Environ.* **2004**, *322*, 155–166. [CrossRef] [PubMed]

81. Hellen, H.; Hakola, H.; Laurila, T. Determination of source contributions of NMHCs in Helsinki (60 N, 25 E) using chemical mass balance and the Unmix multivariate receptor models. *Atmos. Environ.* **2003**, *37*, 1413–1424. [CrossRef]

82. Rappenglück, B.; Fabian, P. Nonmethane hydrocarbons (NMHC) in the greater Munich area/Germany. *Atmos. Environ.* **1999**, *33*, 3843–3857. [CrossRef]

83. Singh, H.B.; Salas, L.J.; Cantrell, B.K.; Redmon, R.M. Distribution of aromatic hydrocarbons in the ambient air. *Atmos. Environ.* (1967) **1985**, *19*, 1911–1919. [CrossRef]

84. Derwent, R.; Middleton, D.; Field, R.; Goldstone, M.; Lester, J.; Perry, R. Analysis and interpretation of air quality data from an urban roadside location in central London over the period from July 1991 to July 1992. *Atmos. Environ.* **1995**, *29*, 923–946. [CrossRef]

85. Liu, Y.; Shao, M.; Zhang, J.; Fu, L.; Lu, S. Distributions and source apportionment of ambient volatile organic compounds in Beijing city, China. *J. Environ. Sci. Health* **2005**, *40*, 1843–1860. [CrossRef] [PubMed]

86. Atkinson, R.; Arey, J. Gas-phase tropospheric chemistry of biogenic volatile organic compounds: A review. *Atmos. Environ. Part A Gen. Top.* **1990**, *24*, 1–41. [CrossRef]

87. Yassaa, N.; Brancaleoni, E.; Fratoni, M.; Ciccioni, P. Isomeric analysis of BTEXs in the atmosphere using β-cyclodextrin capillary chromatography coupled with thermal desorption and mass spectrometry. *Chemosphere* **2006**, *63*, 502–508. [CrossRef] [PubMed]