ISSN: 1859-2171
e-ISSN: 2615-9562 TNU Journal of Science and Technology 225(02): 91 - 98

EXPOSURE ASSESSMENT OF BTEX COMPOUNDS AMONG SAFEGUARDS IN UNDERGROUND PARKING GARAGES IN HIGH BUILDINGS IN HANOI

Vo Thi Le Ha[1], Nguyen Thu Huong[1], Nguyen Thi Thu Hang[2*], Nguyen Thi Thu Hien[1], Nghiem Trung Dung[1], Minoru Yoneda[3]
[1]*School of Environmental Science and Technology - Hanoi University of Science and Technology,*
[2]*TNU - University of Agricuture and Forest,*
[3]*Graduate School of Engineering, Kyoto University*

ABSTRACT

Multi – storey parking structures have potentially high concentrations of benzene (B), toluene (T), ethyl benzene (E) and xylene (X), as known BTEXs, which could have adverse effects on human health This study aims to estimate BTEX levels and sources and to assess the occupational health risk for safeguards in underground parking garages in high buildings in Hanoi. 27 samples were conducted using active diffusion monitors and analyzed by a GC/FID device. Health risk assessment was conducted using chronic daily intake (CDI) and slope factor (SF). Benzene, toluene and xylene were detected in all selected parking lots. In contrast, those of ethyl benzene were not detected. The mean concentrations were 16.99 $\mu g/m^3$, 200.36 $\mu g/m^3$ and 625.22 $\mu g/m^3$ for benzene, toluene and xylene, respectively. Petroleum vapor and vehicle emission were two main sources to contribute to BTEX compounds. Non- carcinogenic risks from toluene and xylene were low when values of hazard quotient (HQ) were lower than 1. Benzene showed upper-bound lifetime cancer risks that exceeded the US. EPA benchmark of one per million, exposing the moderate risk.

Keywords: *Health risk assessment; BTEX; Underground Parking; Exposure; Hanoi.*

Received: 21/02/2020; Revised: 29/02/2020; Published: 29/02/2020

ĐÁNH GIÁ PHƠI NHIỄM HỢP CHẤT BTEX ĐỐI VỚI NGƯỜI BẢO VỆ LÀM VIỆC TẠI TẦNG HẦM ĐỖ XE Ở CÁC TÒA NHÀ CAO TẦNG HÀ NỘI

Võ Thị Lệ Hà[1*], Nguyễn Thu Hương[1], Nguyễn Thị Thu Hằng[2], Nguyễn Thị Thu Hiền[1], Nghiêm Trung Dũng[1], Minoru Yoneda[3]
[1]*Viện khoa học và Công nghệ môi trường – Trường Đại học Bách khoa Hà Nội,*
[2] *Trường Đại học Nông Lâm – ĐH Thái Nguyên,*
[3]*Đại học công nghệ, Trường Đại học Kyoto, Nhật Bản*

TÓM TẮT

Hệ thống đỗ xe nhiều tầng có khả năng phát sinh các chất có nồng độ cao BTEX (Benzene (B), Toluene (T), Ethyl benzene (E) và Xylene (X)), là những chất gây ảnh hưởng xấu đến sức khỏe con người. Mục đích của nghiên cứu này là xác định nồng độ BTEX, nguồn phát sinh và đánh giá rủi ro sức khỏe đối những người bảo vệ làm việc tại các bãi đỗ xe hầm tại một số tòa nhà cao tầng Hà Nội. 27 mẫu khí được lấy chủ động và phân tích bằng GC/FID. Mô hình đánh giá rủi ro sức khỏe được sử dụng dựa trên liều lượng hấp thụ hàng ngày (CDI) và hệ số ung thư (SF). Benenze, Toluene, Xylene đã được phát hiện tại các hệ thống đỗ xe tầng hầm được khảo sát, loại trừ Ethyl Benenze. Nồng độ trung bình được phát hiện là 16,99 $\mu g/m^3$, 200,36 $\mu g/m^3$ and 625,22 $\mu g/m^3$ đối với B, T và X, tương ứng. Phát thải từ xăng dầu và khí thải động cơ là hai nguồn chính đóng góp vào phát sinh BTEX. Rủi ro không ung thư đối với Toluene và Xylene là thấp do HQ <1. Rủi ro ung thư đối với Benzene là trung bình do hệ số ung thư trọn đời vượt qua giá trị ngưỡng của EPA (10^{-6}).

Từ khóa: *Đánh giá rủi ro sức khỏe; BTEX, đỗ xe tầng hầm; phơi nhiễm; Hà Nội.*

Ngày nhận bài: 21/02/2020; Ngày hoàn thiện: 29/02/2020; Ngày đăng: 29/02/2020

* Corresponding author. *Email: vothilehabk@yahoo.com*

https://doi.org/10.34238/tnu-jst.2020.02.2692

1. Introduction

The automobile underground parking acts as a microenvironment in which the pollutants of concern are accumulated and cause a serious health threat to people working inside. The increase in exhaust emissions, running losses and resting in a closed area and insufficient ventilation may cause the accumulation of pollutants in the underground parking. Vehicle emissions from their activity in car parks have become the main source of BTEX and other pollutants associated with health problems [1]. Personal exposure to benzene during commuting by bus, taxi, and motorcycle were apparent in Ho Chi Minh City, Vietnam, in which motorcycle drivers, petrol filling employees and street vendors were suffered from high daily exposure [2]. Accordingly, the human health effects of outdoor workers exposed to the traffic-related air pollution of BTEX were also done in Bangkok, Thai Land. These workers were mainly exposed to BTEX via the inhalation route, especially in a high level of benzene exposure in the places with traffic congestion [3]. The research in India found that workers, who exposed to VOC and CO in Indian underground parking, suffered from the cancer risk of benzene and CO exceeded the safe value of the WHO recommendation [4]. Two enclosed car parks were used for identifying the accumulation of BTEX concentrations, depended on the vehicle density and ventilation rate of the building in Athens, Greece, in which, benzene concentrations were higher than air quality limits set by NIOSH [5]. In Hanoi, published data indicated to BTEX levels indoor and outdoor, or the health risks of personal exposure to BTEX has been limited. Therefore, the main objectives of this study are to determine BTEX levels and sources and to assess their health risk for safeguards who work in underground parking lots in Hanoi.

2. Materials and methods

2.1. Sampling and analysing

The sampling campaign was carried from March to April in 2017 in underground vehicle parking lots at high buildings within Hanoi metropolis. 27 underground parking lots with different construction scale and locations in Hanoi were chosen to conduct the study. All air samples were taken following NIOSH Manual of Analytical Method 1501. Indoor and outdoor sampling was carried simultaneously by SKC samplers for 1 hour. SKC personal samplers (flow rate of 0.2 L/min) and charcoal sorbent tubes placed at stationary points at height of breathing zone (1.5 m). An In-depth interview was conducted to investigate the demographic information via questionnaires (lifetime styles, personal behaviors, numbers of vehicles and others). The results from questionnaires was used to estimate the chronic daily intake of BTEX for the safeguards to assess the potential health risk assessment.

Diffusive samplers were desorbed with 1ml carbon disulfide (CS_2 free benzene), then being shaken gently for 30 minutes. The solvent was transferred into vials and quantified by using a gas chromatograph (GC 2010-Plus, Shimadzu) equipped with FID detector using a HP-5 capillary column (30 m x 0.32 mm x 0.25 μm). Aliquots of 1 mL were injected into a capillary column. Injector and detector temperature was set at 250 ^oC and 280 ^oC, respectively. The Oven temperature was programmed at 40 ^oC for 10 min and then 8 ^oC/min to 165 ^oC.

2.2. QA/QC

Quality assurance and quality control (QA-QC) measures were implemented in the sampling and analysis procedures as well as the blanks. Precision and accuracy values are available. The majority of the samples were above the limits of detection. BTEX coefficient desorption from the charcoal tube is defined as 98% for all analyses.

2.3. Health risk assessment

The potential adverse health effect of inhalation exposure to BTEX was estimated following the four steps risk assessment of the environmental protection agency [6]. For the risk estimation, the inhalation reference concentration and cancer slope factor were obtained from IRIS (Integrated Risk Information System) and the Office of Environmental Health Hazard Assessment (OEEHA). The inhalation cancer slope factor (CSF) of benzene, ethylbenzene was 2.73×10^{-2} mg/kg.day and 3.85×10^{-3} mg/kg.day, respectively. The inhalation reference concentration (RfC) of toluene, xylene were 5 mg/m^3, 1×10^{-1} mg/m^3, respectively. The chronic daily intake (CDI), the risk index from inhalation exposure was evaluated according to the risk assessment guidance for superfund [6].

$$CDI = (CA \times IR \times ET \times EF \times ED)/(BW \times AT) \quad (1)$$

$$EC = (CA \times ET \times EF \times ED)/AT \quad (2)$$

$$\text{Cancer risk} = CDI \times CSFi \quad (3)$$

$$\text{Non cancer risk: } HI = EC/RfC \quad (4)$$

Where CA (mg/m^3) is the contaminant concentration in air, IR (m^3/h) is the inhalation rate (0.87 m^3/h) [6], BW (kg) is the body weight (58 – 75 kg) [questionnaire]; ET (h/d) is the exposure time (8 h/d for the actual working shift of the workers) [questionnaire], EF (d/y) is the exposure frequency (260 – 300 d/year) [questionnaire]; ED (y) is the exposure duration (10 years) [questionnaire] , AT (d) is the averaging time (70 year × 365 day/year = 25.550 day for cancer, and ED year × 365 day/year for non-cancer) [6]. A cancer risk value greater than 10^{-6} represents a carcinogenic risk of concern, while at or less than 10^{-6} is viewed as an acceptable level. For the non-cancer risk, an HQ value higher than 1 means an adverse non-carcinogenic effect of concern, whereas at or less than 1 means an acceptable level (of no concern) [6].

3. Results and discussions

3.1. Variation of BTEX indoor and outdoor

Indoor and outdoor BTEX concentrations measured at underground parking areas in Hanoi were presented in Figure 1 (a, b). The indoor BTEX concentrations were found in a range from 58.25 to 1232.65 $\mu g/m^3$, whereas the outdoor BTEX concentrations varied from 61.9 to 981.26 $\mu g/m^3$. The mean concentration indoor BTEX was higher than outdoor. There was poor correlation of BTEX indoor and outdoor (r=0.42). It was likely that this lage fluctuation on BTEX concentration among undergound parking slots was due to the variation of numbers of vehicles (150 vehicles to over 1000 vehicles) and types of vehicles (car and motorbikes), ventilation condition, high building status (old/new/renovated), the sampling time (weekdays or weekends). The indoor BTEX concentrations were higher than those of outdoors. The higher indoor BTEX levels in this study were found in underground parking sites with the higher number of vehicles (>1000 vehicles). Especially, the most prominent of benzene was seen at underground parking areas with a high density of fleets at new/renovated high buildings. Even the new high/renovated buildings had better ventilations than old buildings, the higher density fleet and painted wall in these buildings could release the higher indoor BTEX. Besides, the higher BTEX concentrations in some parking slots were presented at weekend due to high fleet availability. Xylene presented almost abundant in observed parking garages, accounting up 71.4 % and 76.5 % of BTEXs, whereas, the proportion of toluene was 23.37 % and 22.55 %, followed by benzene of 3.5 % and 1.57 %, for indoor and outdoor respectively. Overall, the concentration variations of BTEX compounds among underground parking sites were due to vehicle characteristics (age, emission control technology, fuel quality, or inspection, and maintenance) and parking design characteristics (ventilation type, size and maintenance) [7]. Additionally, the levels of BTEX in outdoor were dependent on vehicle emission [3, 4]. This suggests that characteristics and density of vehicles, parking characteristics might be the most important factor influencing BTEX levels [8].

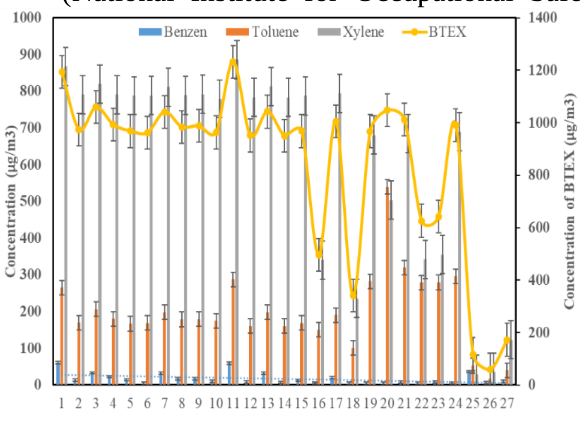
Since the concentration of ethyl-benzene was below the limit level in most cases, it was not included in the estimation for risk assessment. It can be assumed that although the mechanical ventilation systems were operating during working time in the underground parking against natural ventilation. These systems might be insufficient to disperse the BTEX emission from vehicles driving in and out in observed underground parking lots. Besides, evaporation from fuel tanks of vehicles also might be an important source of BTEX during vehicle at rest, resulting in accumulating BTEX in underground parking area [2]. The indoor mean concentrations of benzene (16.9 μg/m^3), toluene (200.36 μg/m^3) in underground parking areas in high buildings in Hanoi were lower than those of benzene (54.14 μg/m^3), toluene (209.4 μg/m^3) in shopping mall underground parking in Rio De Janeiro, Brazil in 2015, the values of xylene were much higher [8]. It should be noted that all values of BTEX indoor and outdoor were lower than the limit value for 1-hour exposure according to QCVN 06:2009/BTNMT (National Technical regulation on hazardous substances in ambient air) [9], and NIOSH (National Institute for Occupational Safety and Health), except for xylene exceeding recommended exposure limit followed by NIOSH. Additionally, the WHO (2010) guideline for indoor air quality indicated that 0.17 μg/m^3 of benzene concentration level corresponded to an increased lifetime risk of development of cancer of one in a million [10]. The presence of benzene in observed car parking lots in this research was in significant caution.

Table 1 illustrated the concentration of BTEX in other previous publications. The more accumulation of BTEX in all enclosed sites might be referred to the insufficient ventilation and further lacking light that maybe lead to difficulty in BTEX degradation. Therefore, poor indoor air quality has a detrimental effect on the safeguards who have suffered in such the indoor environment as a regular working shift.

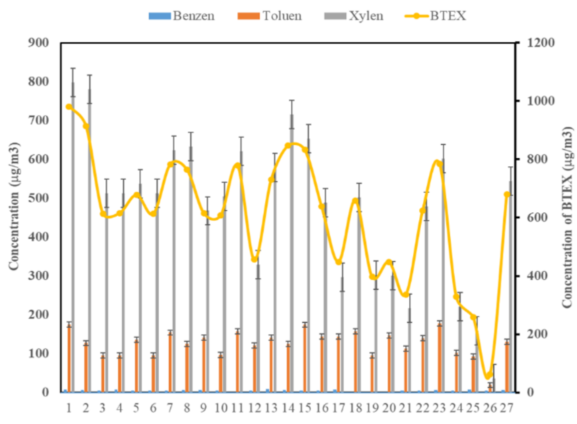
3.2. Emission sources identification

3.2.1. Indoor/outdoor (I/O) ratios of BTEX

Indoor/outdoor (I/O) ratios were also calculated for each underground garage in order to understand BTEX sources (Figure 2). If I/O value is estimated more than 1, indoor sources can be seen as the main sources, inversely, the predominance of outdoors can be referred [11]. In this work, I/O ratios for BTEX compounds were calculated and presented in figure 2.



a



b

Figure 1 (a, b). *a).Variation of BTEXT indoor and b) outdoor BTEX compounds in different parking sites in Hanoi*

Table 1. *BTEX compounds and benzene concentrations*

Indoor environments	BTEX (µg/m^3)	Benzene (µg/m^3)	References
Enclosed underground parking	1245.00	366.00	[5]
Confined parking area	428.18	54.14	[8]
Shopping mall	163.71	11.54	[11]
Car parking	151.36	15.28	[12]
Gas station	692.17	220.29	[13]
Underground parking lots	842.57	16.99	This research

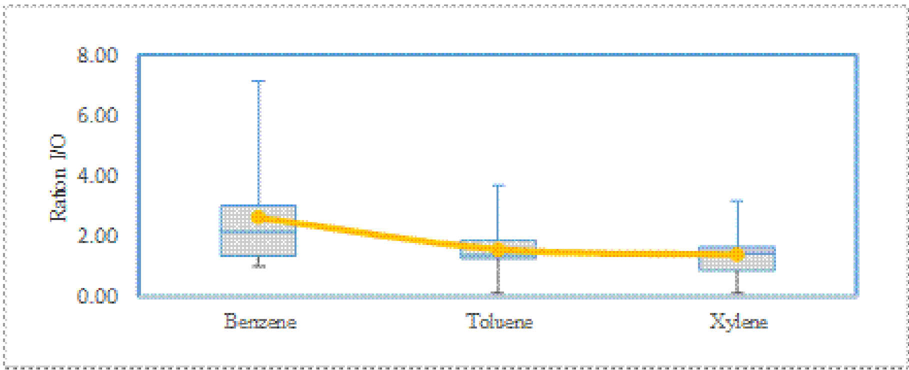


Figure 2. *I/O ratios of BTEX compounds in underground parking areas*

The results pointed out that almost I/O values of benzene, toluene, and xylene were more than 1, with average ratios of 2.62, 1.57 and 1.38 in observed underground garages, respectively. These results revealed that the concentration of indoor BTEX compounds was higher than the outdoors, which were strongly influenced by indoor sources. The higher concentrations of BTEX indoors were attributed to greater BTEX accumulation due to the unavailability of photochemical reactions in lack of light condition, less air circulation in poor ventilation conditions and confined spaces [14].

3.3.2. Diagnostic ratios

Several studies conducted in urban areas demonstrated that the ratios among BTEX are diagnostic to indicate that emissions are predominantly from vehicles [8,14]. B/T (benzene/ toluene), and X/T (xylenes/toluene) ratios can become a way of defining the main effect of vehicular emission source to indoor and outdoor air quality [8,14.15].

Table 3 illustrated B/T and X/T ratios in the internal and external air. B/T ratios in our research were lower than those in confined spaces in southern Italy and Rio de Janeiro, Brazil, whereas, X/T ratios were significantly higher [8,14]. B/T and X/T ratios were in great ability associated with those in liquid gasoline of 0.2 and 1.75, respectively [8]. Considering the vapor pressures values at 298 K, benzene is the most volatile compound, followed by toluene and xylene [8]. This means that B/T ratios should be lower than X/T and higher B/T ratios were found in enclosed spaces comparing to open spaces in our study. The B/T ratios were enhanced in underground parking garages due to non-light support.

In other previous studies, B/T ratios could also support to determine the emissions sources related to vehicular emissions. B/T ratios were recorded from 0.23-0.9, referred to as tailpipe exhaust sources in Hong Kong, Germany and China [15-17]. Also, gasoline exhaust of motorcycles or cars could be measured via B/T ratios estimated 0.3 [18]. In our study, many observed underground garages were new or renovated, toluene was incremented by volatilization from the paints as indoor sources, B/T ratio was calculated as low as 0.13. In our case, the BTEX sources could be from vehicular exhaust, fuel evaporation and volatilization of paints

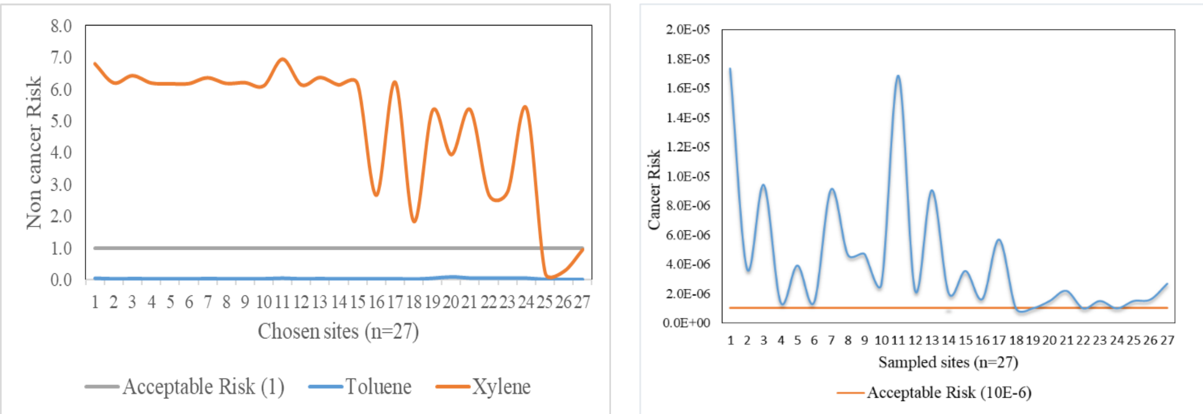
3.3. Health risk assessment for workers

The non-carcinogenic risk and carcinogenic risk was estimated in this study following the equation (1-4). Input data for health risk assessment was used from indepth interview, analysing data from sampling and EPA guildline (2009) [6]. For non-carcinogenic risk estimation as Hazard quotients (HQ) in Figure 5a, the mean value of HQ for toluene and xylene were 0.03 and 4.86, respectively. Xylene presented an unacceptable non-carcinogenic risk, suggesting neurological effects and eye irritation [6]. Toluene indicated the acceptable levels for non-cancer for target organs such as kidney effects [6]. These findings were partially consistent with previous studies, in which toluene was considered as no increased adverse health effects from inhalation exposure [11-13].

The safeguards working in underground parking garages in high buildings in our study seem to be a significant risk of developing cancer from benzene exposure via inhalation. The findings presented in Figure 5b. The overall carcinogenic risk obtained for benzene was $1.71.10^{-5}$, which exceeded the acceptable risk of 1.10^{-6} [6]. The lifetime cancer risks of benzene for safeguards in our study were lower than those found in the petrol station workers in Bangkok, Thai Lan [13]. But this study showed a higher risk for underground workers compared to workers who work in the higher parking floors in Thailand [12]. This finding implied a moderate cancer risk for safeguards working in underground parking garages associated with leukemia during inhalation by benzene [12]. In other words, the mean risk figures of $1.71.10^{-5}$ implied that the chance of developing cancer from benzene exposure among these groups of workers in 70 years of worker lifetime was 17 in 1000000. Additionally, it could be seen that the higher risks were found in underground parking sites with a higher number of vehicles (>1000 vehicles). Also, the greater carcinogenic and noncarcinogenic risks were seen in new or renovated parking garages in our study. Short sampling periods and many assumptions in calculating risk assessment should be noted as limitations of this study. However, these findings would be an important baseline data on BTEX exposure of safeguards working underground parking garages in high buildings in Hanoi metropolis.

Table 3. *Average indoor and outdoor diagnostic ratios*

Diagnostic ratio	Indoor	Outdoor	Reference
B/T	0.13	0.07	This study
X/T	3.47	3.24	This study
B/T	0.54	0.23	[14]
X/T	0.99	0.47	[14]
B/T	0.26	0.2	[8]
X/T	0.57	1.75	[8]



a *b*

Figure 5 (a, b). *Distribution of non cancer and cancer risk for benzene in the indoor air (n=27)*

4. Conclusion

The concentrations of BTEX compounds detected in the underground parking lots in our study were higher than those in outdoors. These compounds might be released into the enclosed parking from vehicle exhaust and evaporative emissions of gasoline liquid. The high values of BTEX concentrations, the ratios I/O over 1 indicated that BTEX compounds were attributed to indoor sources. Human health risk analysis through inhalation exposure to BTEX found that the safeguards working underground parking lots were suffering moderate of carcinogenic risk from benzene and unacceptable risk for xylene exposure during working shift, which should be in adequate attention.

Acknowledgement

The authors wish to acknowledge Graduate School of Global Environmental studies (GEGES), Kyoto University for financial and academic support.

REFERENCES

[1]. V. Q. Truc and N. K. Oanh , "Roadside BTEX and other gaseous air pollutants in relation to emission sources," *Atmospheric Environment*, vol. 41, no. 36, pp. 7685-7697, 2017.

[2]. N. T. Lan, N. Q Liem, and N. T. Binh, "Personal exposure to benzene of selected population groups and impact of commuting modes in Ho Chi Minh, Vietnam," *Environmental Pollution*, vol.175, pp. 56-63, 2013.

[3]. N. Kanjanasiranont, T. Prueksasit, D. Morknoy, T.Tunsaring, S. Sematong, W. Siriwong, K. Zapaung, and A. Rungsiyothin, "Determination of ambient air concentrations and personal exposure risk levels of outdoor workers to carbonyl compounds and BTEX in the inner city of Bangkok, Thailand," *Atmospheric Pollution Research*, vol. 7, no. 1, pp. 268-277, 2016.

[4]. S. Dhawan, A. J. Sebastian A. J and S. John. "Health Risk Assessment of Workers in Underground Parking Due to Exposure to CO and VOC," *International Journal of Engineering Technology Science and Research*, vol. 5, no. 1, pp. 1388-1391, 2018.

[5]. A. P. Soldatos, E. B. Bakeas and P. A. Siskos "Occupational exposure to BTEX of workers in car parkings and gasoline service stations in Athens, Greece," *Fresenius Environmental Bulletin*, vol. 12, no.9, pp. 1064-1070, 2003.

[6]. United States Environmental Protection Agency (US EPA), *Risk Assessment Guidance for superfund Volume 1: Human Health Evaluation Manual*, (Part F, Supplemental Guidance for inhalation Risk Assessment)"- EPA-540-R-070-002; EPA: Washington, DC, USA, 2009.

[7]. F. Borhani and A. Noorpoor. "Cancer Risk Assessment Benzene, Toluene, Ethylbenzene and Xylene (BTEX) in the Production of Insulation Bituminous," *Environmental Energy and Economic Research*, vol. 1, no. 3, pp. 311-320, 2017.

[8]. B. P Castro, G. M. Souza, G. F. Bauerfeldt, J. D. Fortes and E. M. Martins, "Assessment of the BTEX concentrations and reactivity in a confined parking area in Rio de Janeiro, Brazil," *Atmospheric Environment*, vol. 104, pp. 22-26, 2015.

[9]. Ministry of Natural Resources and Environment, *QCVN 06: 2009/BTNMT– National Technical Regulation on Hazadous Substances in Ambient Air – QCVN 06: 2009/BTNMT*, 2009.

[10]. WHO, *Selected Pollutants, WHO Guidelines for indoor air Quality*, WHO Regional Office for Europe, Copenhagen, 2010.

[11]. H. Guo, S. C. Lee, and W. M. Li, "Source characterization of BTEX in indoor microenvironments in Hong Kong," *Atmospheric Environment*, vol. 37, no. 1, pp. 73-82, 2003.

[12]. W. Loonsamrong, N. Taneepanichskul, S. Puangthongthub and T. Tungsaringkarn, "Health Risk Assessment and BTEX Exposure among Car Park Workers at a Parking Structure in Bangkok, Thailand," *Journal of Health Research*, vol. 29, no. 4, pp. 285-292, 2015.

[13]. M. Kitwattanavong, T. Prueksasit, D. Morknoy, T. Tunsaringkarn T and W. Siriwong W., "Health risk assessment of petrol station workers in the inner city of Bangkok, Thailand, to the exposure to BTEX and carbonyl compounds by inhalation - Human and Ecological Risk Assessment," *International Journal*, vol. 19, no. 6, pp.1424-1439, 2012.

[14]. G. Gennaro, P. R. Dambruoso, A. D.Gilio, A. Marzocca and M. Tutino, "Indoor and Outdoor Volatile Organic Compounds Monitoring in a Multi-Storey Car Park," *Environmental Engineering & Management Journal (EEMJ)*, vol. 7. no. 7. pp. 1563-1570, 2015.

[15]. H. Guo, S. C. Zoua, W. Y. Tsai, L. Y.Chan and D. R. Blake, "Emission characteristics of nonmethane hydrocarbons from private cars and taxis at different driving speeds in Hong Kong,"

Atmospheric Environment, vol. 45, no. 16, pp. 2711-2721, 2011.
[16]. T. Schmitz, D. Hassel and F. J. Weber, “Determination of VOC - components in the exhaust of gasoline and diesel passenger cars,” *Atmospheric Environment*, vol. 34, no. 27, pp. 4639-4647, 2000.
[17]. Q. He , Y. Yan , H. Li, Y. Zhang, L. Chen and Y. Wang, “Characteristics and reactivity of volatile organic compounds from non-coal emission sources in China,” *Atmospheric Environment*, vol. 115, pp. 153-162, 2015.
[18]. Y. Zhang, X. Wang, Z. Zhang. S. Lü, M. Shao, F.S . Lee and J. Yu, “Species profiles and normalized reactivity of volatile organic compounds from gasoline evaporation in China,” *Atmospheric Environment*, vol. 79. pp. 110-118, 2013.