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ORIGINAL ARTICLE

Evaluation of Volatile Organic Compounds Levels inside Taxis Passing through Main Streets of Tehran

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ABSTRACT

Air quality inside commuting vehicles has seldom been evaluated in Iran. Accordingly, this study investigates the levels of benzene, toluene, ethylbenzene and xylene (BTEX) during workdays characterized by heavy traffic inside taxis in Tehran- Iran between May 2009 and October 2010. The totals of 35 personal samples were collected onto solid sorbent tubes and the concentration of volatile organic compounds (VOCs) were analysed by gas chromatography technique equipped with flame ionization detector (GC/FID). The arithmetic means of personal monitoring of BTEX concentrations inside vehicles were found 72.77, 93.91, 9.90 and 4.23 ppb respectively. Exposures to BTEX during traffic flow in the evening were considerably higher than those measured in the morning. The weekdays BTEX level of inside vehicles illustrated significant differences among the studied months ($p<0.05$). The BTEX concentration ratios were estimated to be related to traffic emissions and similar for all the surveyed routes. In conclusion, the results confirmed that the emission of BTEX and their concentrations being highly associated with traffic jam as well as changes in meteorological conditions.

Keywords: *VOCs, BTEX, Taxi driver, Tehran, Iran*

INTRODUCTION

A vehicle cabin has been recognized as a microenvironment that can increase the passenger exposure to air pollutants, such as volatile organic compounds (VOCs) [1-4]. Epidemiological studies have shown a significant positive correlation between benzene, toluene, ethylbenzene and xylene (BTEX) exposure and increased carcinogenicity and toxicity to the central nervous system [5-6]. Furthermore, anthropogenic VOCs are important precursor compounds to photochemical smog and ozone and emitted largely from vehicles in urban areas [7-9]. There were several related studies about VOCs exposure on commuter and driver in the past decade [10-16]. It is interesting to note that some of these studies have reported that in-vehicle concentrations of VOCs during high traffic density periods were up to eight times higher than the corresponding ambient levels [17-18]. Since it has been recognized that volatile organic compounds such as BTEX are increased in the vehicle cabin as compared to urban areas [1, 19], taxi drivers are probably the professional category, which is most exposed to airborne pollutants. Additionally, taxi drivers spend a long time up to 12-14 consecutive hours in the urban traffic. Although there have been a few reports of outdoor pollutants in Tehran overall [20-22],

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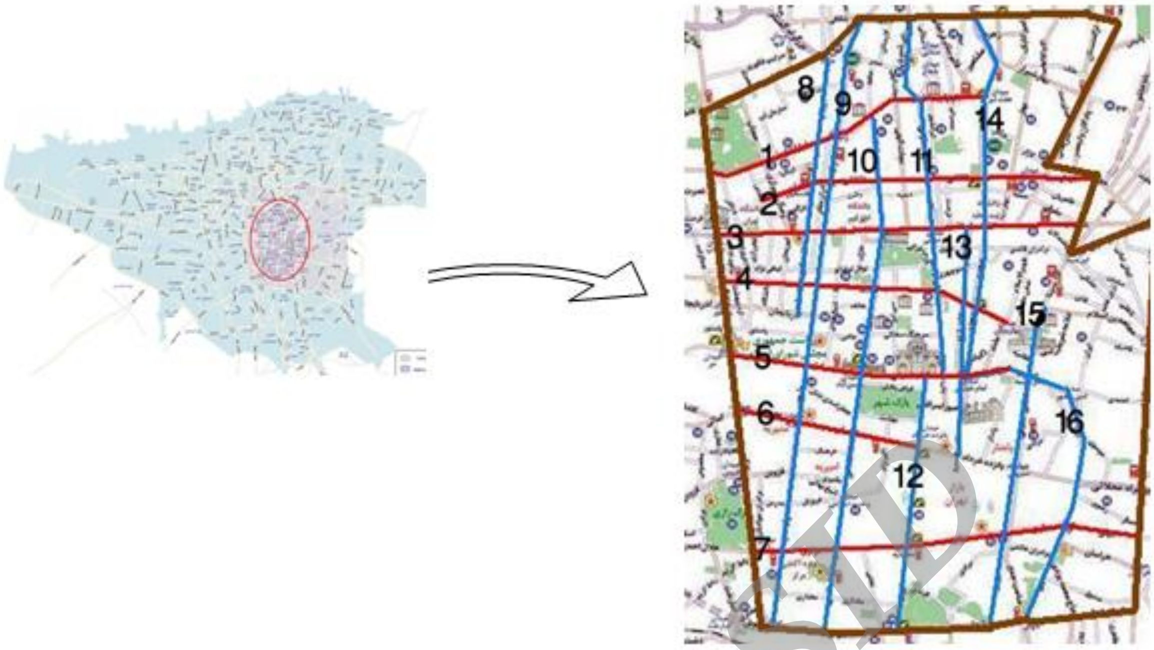

Fig 1. The study areas and the locations of measurements

there have been no reports of VOCs at exposure levels inside vehicles. Air pollutants in taxis cabin have not been examined to date, and therefore need to be addressed. This study was carried out to investigate the levels of BTEX inside taxis traveling along the major commuter routes in the metropolitan area of Tehran. The daily, monthly and seasonal distribution and differences between routes were also studied. Besides, their relation with metrological parameters and other factors were considered.

MATERIALS AND METHODS

Study site and sampling design

Tehran, the capital city of Iran, has more than 7 million inhabitants and occupies a surface area of about 780 km2 [17]. The daily urban fleet in 22 regions of municipality of Tehran comprised about 3.5 million vehicles that about 85000 of them are taxies. As shown in Fig 1, considering the extent of the study area, the main traffic routes (16 main paths) identified and selected for sampling. Thirty- five taxis providing passenger service between 16 routs in the control traffic area were recruited for this study in the period between May, 2009 and October 2010. These taxis are 1.77 years old an average and are powered by petrol fuel. In the area that consist of 7 municipality districts than 22 of them, the taxis travel on 16 free main routs: 10 of them are a linear rout traversing the central commercial and old residential districts through large trafficked roads, and six routes connecting 4 densely-populated squares across the central districts along narrow streets with many residential and commercial neighborhoods. The sampling was carried out in taxis (n=35) and the characteristics of the taxis and its drivers selected are summarized in Table 1. Six days of every months (Saturday till Thursday), approximately 10 routs were sampled during peak (9:00 to 13:00 a.m. and 16:00 to 20:00 p.m.) hours, to obtain a weekly profile for all routs. Personal samplers were placed inside the car on the passenger front seat and at the height of the driver's breathing zone. At the same time, indoor and outdoor

Table 1. Driver's age, work experience and life of vehicles produced (year)

Factors	Number	Mean.	Min.	Max	SD
Driver's age		41.54	28	66	8.01
Work experience	35	6.94	2	31	6.33
Life of vehicles produced		1.77	0	9	1.94

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Table 2. VOCs concentrations in taxis

VOCs (ppb)	Number	Mean.	Min.	Max	SD
Benzene	35	72.77	8.95	247.66	54.76
Toluene	35	93.91	53.02	203.98	38.44
Ethylbenzene	35	9.90	3.73	25.67	5.13
Xylene	35	4.23	1.4	14.36	3.74

Table 3. VOCs concentrations during day time

VOCs (ppb)	Time	Number	Mean (SD)	p-value
Benzene	Morning	18	59.45(34.94)	0.439
	Evening	17	84.61(66.55)	
Toluene	Morning	18	82.25(28.98)	0.087
	Evening	17	104.66(43.73)	
Ethylbenzene	Morning	18	8.65(4.06)	0.204
	Evening	17	11.08(5.84)	
Xylene	Morning	18	3.12(2.89)	0.522
	Evening	17	4.88(4.13)	

temperature and relative humidity were continuously recorded during the sampling campaign by research team (Using the KIMO-HD100 capable of measuring temperature and relative humidity in the range of -20 to +70°C and 5% -95% respectively). Additionally, metrological data such as wind speed, relative humidity, temperature, atmospheric conditions were registered by the automatic metrological station located in Tehran and also managed by the municipality of Tehran.

Air sampling and analysis

According to some of the similar studies [23-26], in-vehicle VOCs samples were collected by activated charcoal tubes (SKC-USA) recommended by OSHA. A calibrated personal low flow pump (222 series SKC) was used for sampling with flow of 1.9 l/min [27].

Instantaneously before sampling, both ends of the charcoal tube were opened and connected to the pump with flexible tubing. Activated charcoal tube was placed in drivers breathing zone and the air was passed through it for 3 to 4 hours. Following the sampling the charcoal tube was sealed immediately with plastic caps and collected samples were carried to the lab for analysis. For extraction of BTEX (benzene, toluene, ethylbenzene and xylene) from charcoal tubes Carbon Disulfide (CS_2) was used. BTEX samples were analysed using a gas chromatograph equipped with flame ionization detector (GC/FID). The carrier gas was helium and the analytical column was a J&W DB-5 capillary column, 30.0 m × 0.53 mm (I.D.) × 5.0 µm. The injection and detector temperatures were 150 and 200°C respectively. Also, the oven temperature program was in the beginning 45°C for 2 minutes and then increased at a rate of 25°C/min up to 65°C and 1 min hold at this temperature. Afterward 45°C per minute increase up to a temperature of 90°C and 3.5 minute stop at this temperature.

Data analysis was performed using SPSS-11.5 statistical software.

RESULTS

The statistical outcome of the individuality of subjects consist of the means of drivers' age and taxis life time also job experience participating in this investigation reviews in Table 1.

In-vehicle BTEX levels

Concentration of benzene, toluene, ethylbenzene and xylene in taxis are illustrated in Table 2. The arithmetic means of BTEX concentration in the vehicle were found 72.77, 93.91, 9.90 and 4.23 ppb respectively. So as indicated in Table 2 the highest BTEX were measured inside the vehicles was obtained from toluene while the lowest exposures were achieved for xylene.

As shown in Table 3, Independent Samples T-test did not show significant differences between the morning and evening exposure levels inside the car

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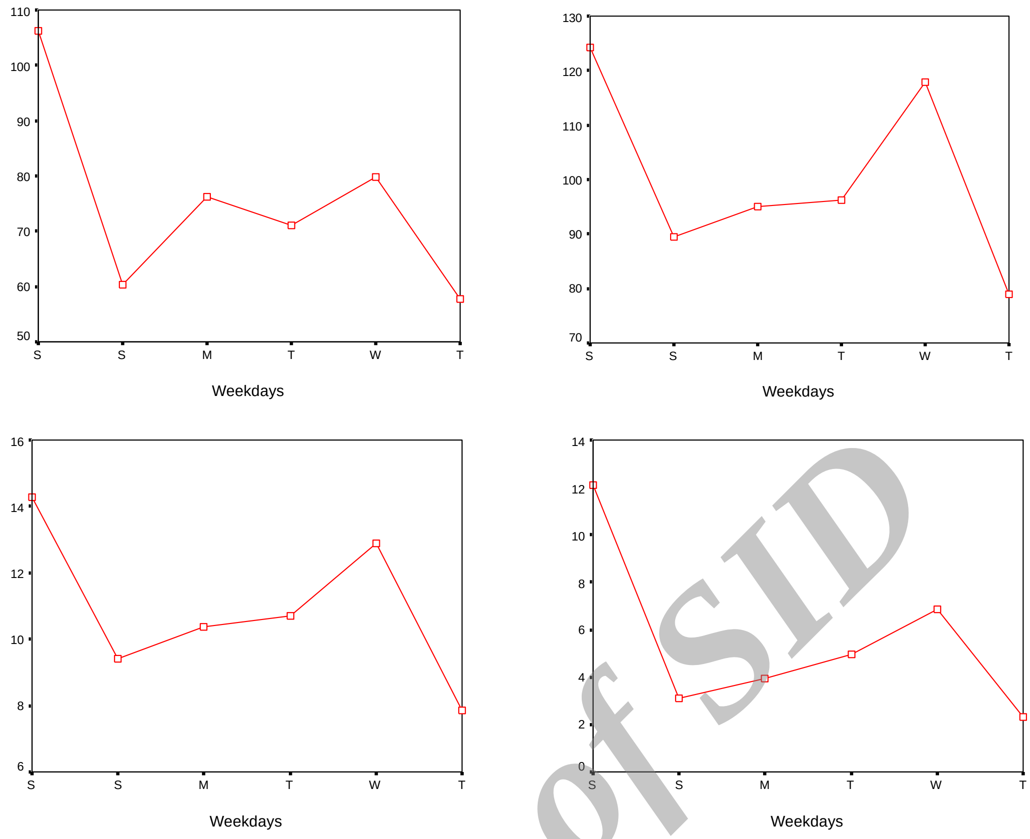

Fig 2. VOCs concentration (ppb) in taxis according to weekdays

(p>0.05). However, the obtained amounts were lower in the morning than in the evening.

BTEX level during weekdays and months

In Fig 2, VOCs concentration in taxis according to weekdays has shown. Analysis of variance test not demonstrated any significant differences between the concentrations of BTEX during weekdays (p>0.05). Unlike weekdays BTEX level inside vehicles illustrated significant differences among the studied months (p<0.05). The maximum of BTEX level was obtained in July inside the taxis cab.

Correlation between BTEX level and atmospheric conditions

Pearson correlation test illustrated significant differences between the concentrations of BTEX and atmospheric conditions contain temperature and relative humidity (p<0.05). With increasing temperature, the amount of volatile organic compounds in vehicle elevated while enhancing humidity levels had a negative effect on BTEX level.

Discussion

Concern about the health effects of elevated levels of air pollution experienced in many mega cities of both developed and developing countries is growing and motor vehicles are the major suppliers to anthropogenic pollutant releases. Obviously, exposure assessment plays as a key parameter in evaluating the risks of air pollution. Therefore, the aim of current study was to assess the in-vehicle BTEX level of taxis during 6 months in Tehran. According to the survey results, the taxis drivers' exposure to hazardous VOCs such as benzene, toluene, ethylbenzene and xylene is high level in Tehran.

Leakage from the engine evaporates; domestic sources of VOCs inside automobiles such as interior decoration and nearness to the exhaust of other vehicles determined to be the main factors of high levels of pollutants in cars.

Vehicles low-speed in heavy traffic in crowded streets of Tehran and lack of adequate air ventilation inside the cab can cause traffic-related air pollutants accumulation in vehicle.

Other studies have investigated exposure to air pollutants within the vehicles and have reported different results according to the auto manufacturing technologies, atmospheric conditions, economic situation and other reasons in their study [23-24,28-31].

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Table 4. Mean in-vehicle concentration of BTEX for the present and other studies

Study	Year	Location	Subject	Measure Unit	Pollutant	
Current study	2010	Iran-Tehran	Taxi	ppb	Benzene	72.77
					Toluene	93.91
					Ethylbenzene	9.90
					Xylene	4.23
Chan [10]	2002	China-Hong Kong	Taxi	μg/m³	Benzene	33.6
					Toluene	108.5
					Ethylbenzene	20.3
					m-p, Xylene	26
					O, Xylene	17.2
Hsu [38]	2009	Taiwan-Taipei	Bus	μg/m³	Benzene	6.6
					Toluene	74.1
					Ethylbenzene	9.4
					m-p, Xylene	7.7
					O, Xylene	5.5
Bahrami [23]	2007	Iran-Hamedan	Taxi	ppm	Benzene	0.31
Bahrami [24]	2008	Iran-Hamedan	Taxi	ppm	Xylene	0.24
Chertok [31]	2004	Australia-Sydney	Car	ppb	Benzene	12.29
					Toluene	28.76
					Ethylbenzene	4.38
					Xylene	19.91
Xlanglu [30]	2005	Peru-Trujillo	Taxi	μg/m³	Benzene	8.4
					Toluene	37.3
					Ethylbenzene	4.6
					Xylene	27.6
Balanay [28]	2009	Philippines-Manila	Jeepney	μg/m³	Benzene	55.6
					Toluene	196.6
					Ethylbenzene	17.9
					m-p, Xylene	72.5
					O, Xylene	88.5

Although BTEX levels showed no statistically significant differences but the evening levels were higher than the morning levels. Commute restrictions for cars during morning rush hours resulted in a low density of vehicles which may be considered as the major reason for this. As are illustrated in Fig 2, in Saturdays as the first day of the week there is very heavy traffic and therefore, pollution levels are extremely high.

According to the obtained results, the temperature increases with increasing the amount of VOCs showing a positive and direct correlation. The highest exposure level was related to the warmest months. In this case, internal sources of VOCs may also need to be considered as a contributing factor [32]. It is noteworthy to comment on drivers' exposure assessment during different months of the year. Further, evaluation of VOCs levels during whole mounts of the year is required.

According to the definition of the United States Environmental Protection Agency (US EPA), and typically regards VOCs as organic compounds having vapor pressure exceeding 0.1 mmHg at standard conditions (20 ºC and 760mmHg) [33], as well as with considering domestic sources of VOCs in the vehicle cabin such as sealants, carpet, leather, *etc* [13,34] increased levels of these compounds within the car's cabin are not unexpected with increasing temperature. For example Wan-Kuen and his colleagues in their study, reported higher BTEX levels inside the vehicle in warm season than the cold season [35].

Compared to other studies

The average level of exposure to BTEX was measured 72.77, 93.91, 9.90 and 4.23 ppb respectively in current study. As is clear from Table 4, various studies have reported different results. Multiple causes can be considered like: motor vehicles' technology, Traffic situation, sampling method, environmental state, type of fuel, *etc* [36-37].

CONCLUSION

Vehicular exhaust is the major responsible for health effects related to air contaminants and the high increase in vehicles and these emissions, many cities of both developed and developing countries are harshly

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polluted. Although the amount of VOCs obtained in this study is less than occupational recommended limit [39-40] but it should be noted that the limit values are for 8 hours per day and 40 hours exposure in week. Whereas drivers spend more time in vehicles polluted cabin. Also, occupational limit value not considered mix effect of pollutant [36]. So, in this study looks the amount of taxi drivers' exposure as one of the important working populations who exposed to high level of pollution was assessed. The results of current investigation illustrated that high level of exposure to VOCs are encountered in taxis. Therefore, it seems drivers are more susceptible group suffering from exposure to traffic-related pollutants. Although passengers spend moderately little time commuting, they might also receive considerable exposures throughout traveling periods. In conclusion, traffic volume and climate situations can be considered as effective factors of exposure in the cab.

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