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RESEARCH ARTICLE

Exposure to BTEX concentration and the related health risk assessment in printing and copying centers

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Abstract

This study was derived to investigation of BTEX (benzene, toluene, ethylbenzene, xylenes) concentrations in printing and copying centers (PCCs) in Ardabil city of Iran. Fifty-three PCCs were randomly selected from all the 136 number of PCCs and BTEX was sampled form their indoor air. The results showed that the concentration of BTEX in the indoor air PCCs is lower than the OELs (occupational exposure limit) in all cases. The obtained mean concentrations of benzene, toluene, ethylbenzene, and xylene were 93.6 ±63.2, 150.6±99.2, 34.3±16.8, and 29.5±15.2 μg/m^3 respectively. Type of printer, number of printing and copying device, and type of ventilation system had significant influence on the BTEX concentration. The mean inhalation lifetime cancer risk (LTCR) value for benzene and ethylbenzene in the indoor air of the PCCs with LaserJet and inkjet printers was 44.4 × 10^{-6} and 153.3 × 10^{-6}, and 23.4×10^{-6} and 54.2× 10^{-6}, respectively, which were higher than EPA (Environmental Protection Agency) and World Health Organization (WHO) recommended limits. The hazard quotient (HQ) of benzene in the indoor air of the PCCs with inkjet printers was >1, which indicates that the non-carcinogenic risks associated with exposure to these compounds are considerable.

Keywords Indoor air quality · VOCs · Health risk · Printing and copying centers · Air pollution

Introduction

Several researches reported emission of various air pollutant from devices such as print and copy sets and exposure of people with the pollutants like the VOCs which are mainly coming from oil and its derivatives (Jafari et al. 2019; Ongwandee et al. 2011; Tamaddoni et al. 2014). The printing and copy devices are used very regularly in work offices and houses. Hence, the employees and every users are in exposure to the emitted air pollutants from the sets. Concentrations of CO, ozone, NO, VOCs, and particulate materials are reported in printing centers (Karrasch et al. 2017; Wang et al. 2012). However, the BTEX is taken into consideration in many indoor air quality assessments regarding their health risks and very abundance emission sources (Fazlzadeh Davil et al. 2012; Hazrati et al. 2016a). One of the major sources of the BTEX is solvents and heating of organic materials. It is regular in the printing and copying devices that the ink which is an organic material and contains the solvents is heated or sprayed on the print surface; hence, it can release the BTEX to air. In the printing and copying centers, this act is very frequently done in working time and considerable concentrations of BTEX can emitted to air. The emitted BTEX cause air pollution in the working microenvironment and the around environment (Moridzadeh et al. 2020). Also, this pollution exposes the employees. The long-term exposure to BTEX can cause serious health risks (Hazrati et al. 2016b; Yousefian et al. 2018). Benzene is hematotoxic and long-term exposure to it may increase the occurrence of leukemia and aplastic anemia in humans (Rafiee et al. 2019). In 1987, International Agency for Research

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on Cancer (IARC) classified benzene as human carcinogen (group 1) (Aksoy 2017; IEPO 2012). The World Health Organization suggested no safe concentration for benzene and its concentration limit for ambient air is restricted to 5μg/m^3 in Iran (Table 1S) (IEPO 2012; WHO 2010). Besides, ethylbenzene has been grouped as a possibly carcinogenic agent to humans (group 2B) (Dehghani et al. 2019; Rafiee et al. 2018; Rostami and Jafari 2014). Abbasi et al. reported notable incremental lifetime cancer risk (ILCR) for exposure to benzene (6.49×10^{-7}–1.27×10^{-5}) and ethylbenzene (1.21×10^{-7}–2.37×10^{-6}) concentrations in ambient air of Shiraz city (Abbasi et al. 2020). Mirrezaei and Orkomi reported that cumulative risk of benzene and ethylbenzene is greater than 10^{-6} in refineries sites of Asalouyeh and the cities close to them (Mirrezaei and Orkomi 2020). The reports show that the exposure risk of them is serious in urban and industrial area. So, every exposure of them is important regarding the cumulative risk and should be controlled especially in the workplaces with potential of high concentrations and longtime exposure. Toluene, ethylbenzene, and xylenes are known neurotoxic might cause neurological disorders and symptoms such as weakness, loss of appetite, fatigue, confusion, and nausea (Zhang et al. 2012). These can cause the remarked health effects in the employees of copy and printing centers and the offices with great number of the act. Also, the cumulative cancer risk with considering remain exposure may be hazardous for the employees.

There are many printing and copying centers in each city and many people are working in this places, and these workplaces must comply with workplace regulations; however, the regulation is not well expanded in order to control of indoor air quality in such places due to less data from air quality of them especially regarding the VOCs. In this regard, determination of BTEX concentration in the printing and copying centers (PCCs), considering the influencing factors, and assessment of the related health risks is a necessary effort to expand the information about the air quality in PCCs for the future researches and legislations to have safe print and copy process.

Material and methods

Study area and data collection

The study was conducted in 2019 in Ardabil province, Iran. Fifty-three PCCs were investigated through indoor BTEX concentrations between March and September 2019. Data regarding PCC characteristics including type of printers (LaserJet or inkjet), number of active printer device (at the time of the study), ventilation systems (natural, mechanical, or both type of them), number of doors and windows, building material, and PCC area (m^2) were collected by a questionnaire administered by a researcher. Our investigators employed a checklist to collect this information based on their observations and information provided by venue owners. The characteristics of the cafes are presented in the Table 2S.

Approach to air sampling

Air samples were collected using the procedure detailed in the NIOSH Manual of Analytical Method 1501. Air sampling was carried out by SKC personal sampling pumps equipped with an adjustable low flow holder. The calibration of the pumps was performed using a defender. A flow rate of 0.2 L min^{-1} for 50 min was used for sampling the indoor air with charcoal sorbent tubes (SKC). The sampling probe was positioned at the center of the rooms at a height of 1.5 m (human breathing level) from the building floor. After completion of the sampling period, the sampling tubes were transported to the laboratory according to the manufacturer guideline, stored at −20°C and analyzed within 72 h. In addition to BTEX chemical compound sampling, atmospheric conditions (relative humidity, temperature, and wind speed) were measured using a portable anemometer and WBGT (Wet-Bulb globe temperature, ±1.8°F/1°C accuracy and 32 to 122°F (0 to 50°C) range for temperature and ±3%RH accuracy and 0–100% range for relative humidity) meter model of MK427JY.

Sample preparation and analytical method

BTEX chemical compounds were desorbed at room temperature for 30 min using 2 mL of carbon disulfide (CS_2) from each charcoal tube adsorbent. All extraction phase was performed in 5-mL screw-top glass vials while was gently shaken using an ultrasonic agitation device in desorbed time. After this stage, the extracted samples were transferred into GC vials and BTEX concentrations were determined by a gas chromatography (GC Agilent 7890) instrument equipped with a flame ionization detector (FID) using a capillary column (30 m, BD-5). One microliter of the solution was taken from the vial and injected into a capillary column. Injector and detector temperatures were set at 250 and 300 °C, respectively. Oven temperature was programmed at 40 °C for 10 min and then 10 °C/min to 230 °C (NIOSH 2003; Rezazadeh Azari et al. 2011). All chemicals and reagents used in this research were of analytical grade.

Quality control and quality assurance

All samples were stored in cold box containing ice packs to keep them cold (~4°C) immediately after sampling and during transfer

to the laboratory and then stored in laboratory fridge (4°C) until the analysis. The sampling/transferring and analysis blanking was performed along with the research procedure. In this regard, a blank sample was transferred with each group of the samples and analyzed as same as them. Also, three replicates of the extraction solvent (CS_2) were injected to GC and analyzed as the analysis and solvent blanking. Subsequently the limit of detection (LOD) was calculated (LOD=3.3×(standard deviation of the blanks/slope of the calibration curve)) (Desimoni and Brunetti 2015). Moreover, a pre-determined concentration of BTEX was introduced to the sampling charcoal tubes and the extraction procedure and the subsequent analysis were carried out as same as the samples and the recovery percent was calculated for it in three replications. The mean recovery percent for BTEX was 88 ±10%.

Health risk assessment

Exposure assessment

Carcinogenic and non-carcinogenic risks of BTEX exposure were estimated by calculation of exposure concentration (EC) and estimated daily intake (EDI) according to Eqs. 1 and 2 (Hinds WCJAT 1999; Rostami et al. 2019; Yunesian et al. 2019).

$$\mathrm{EC}\left(\frac{\mu g}{m^3}\right)=\frac{C\left(\frac{\mu g}{m^3}\right)\times \mathrm{ET}\left(\frac{h}{day}\right)\times \mathrm{ED\ (year)}\times \mathrm{EF}\left(\frac{day}{year}\right)}{\mathrm{AT\ (year)}\times 365\left(\frac{day}{year}\right)\times 24\left(\frac{h}{day}\right)} \quad (1)$$

$$\mathrm{EDI}\left(\frac{mg}{kg.day}\right)=\frac{C\left(\frac{\mu g}{m^3}\right)\times \frac{1}{1000}\left(\frac{mg}{\mu g}\right)\times \mathrm{IR}\left(\frac{m^3}{day}\right)\times \mathrm{ET}\left(\frac{h}{day}\right)\times \mathrm{ED\ (yaer)}\times \mathrm{EF}\left(\frac{day}{year}\right)}{\mathrm{AT\ (year)}\times 365\left(\frac{day}{year}\right)\times 24\left(\frac{h}{day}\right)\times \mathrm{BW(kg)}} \quad (2)$$

Table 1 Risk parameters applied to estimate non-carcinogenic and carcinogenic risk (HQ and LTCR) of BTEX

Parameter	Probability distribution		Statistical parameters	Reference
Benzene concentration (μg/m^3)	LaserJet printers	Lognormal	Mean: 41.53 SD: 22.38	This study
	Inkjet printers	Lognormal	Mean: 162.43 SD: 16.45	
Toluene concentration (mg/m^3)	LaserJet printers	Lognormal	Mean: 70.06 SD: 27.87	This study
	Inkjet printers	Beta	Minimum: 172.18 Maximum: 357.94	
Ethylbenzene concentration (mg/m^3)	LaserJet printers	Weibull	Scale: 18.05 Shap: 2.85	This study
	Inkjet printers	Lognormal	Mean: 50.79 SD: 11.73	
Xylene concentration (mg/m^3)	LaserJet printers	Beta	Minimum: 5.51 Maximum: 57.62	This study
	Inkjet printers	Minimum Extreme	Likeliest: 47.58 Scale: 6.74	
Exposure frequency (day/year)	Poisson distribution		Rate: 328.05	This study
Exposure time (h/day)	Binormal		Probability: 0.75 Trials: 15	This study
Inhalation rate (m^3/day)	NA		18.7	IRIS EPA
Body weight (kg)	NA		70	IRIS EPA
Exposure duration (year)	NA		30	IRIS EPA
Averaging time (year)	NA		25500	IRIS EPA
Inhalation unit risk (UR) (μg/m^3)$^{-1}$	NA		Benzene: 2.2×10^{-6} Ethylbenzene: 2.5×10^{-6}	IRIS EPA
Inhalation reference concentration (RfC)* (mg/m^3)	NA		Benzene: 3×10^{-2} Toluene: 5 Ethylbenzene: 1 Xylene: 1×10^{-1}	IRIS EPA IRIS EPA IRIS EPA IRIS EPA

NA not applicable

*RfD = RfC (inhalation reference concentration (μg/m^3)) × Assumed inhalation rate (m^3/day) × 1/BW (kg) [28]

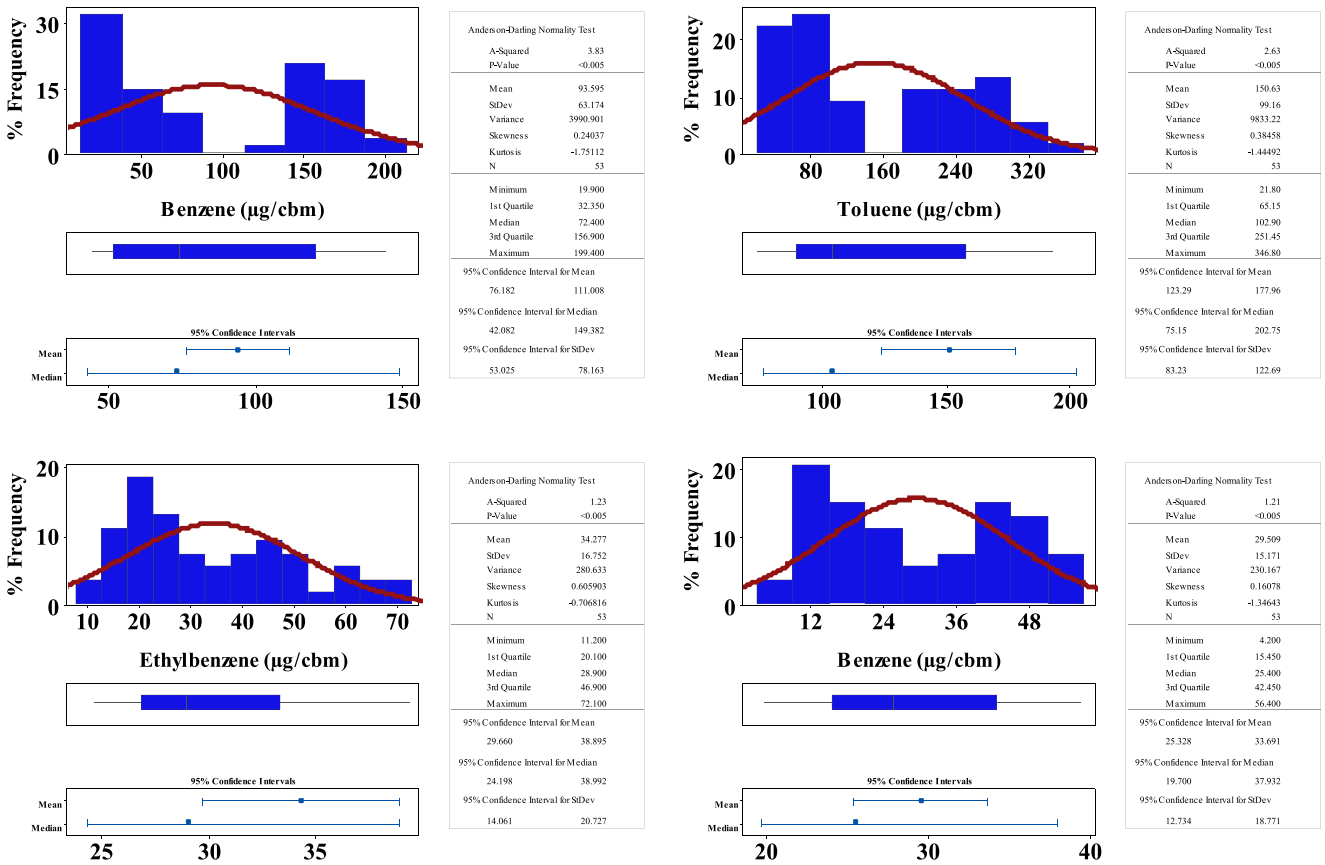


Fig. 1 Concentration of BTEX in the printing and copying centers; *X* axes are the concentrations (µg/m^3)

where *C* is BTEX concentrations in indoor air of PPCs, ET is the exposure time (h/day), ED is exposure duration (year), EF is exposure frequency (days/year), AT is averaging time, BW is body weight, and IR is inhalation rate (Baghani et al. 2018; Nabizadeh et al. 2020a; Naddafi et al. 2019a). For computing the EC and EDI, the mean concentrations of BTEX were used. The values and probability distributions of parameters in Eqs. 1 and 2 are presented in Table 1.

Carcinogenic risk assessment

Carcinogenic risks of benzene and ethylbenzene were assessed according to the methodology provided by the USEPA (USEPA 2018) as follows:

$$\mathrm{LTCR} = \mathrm{EC}\left(\frac{\mu g}{m^3}\right) \times \mathrm{UR}\left(\frac{\mu g}{m^3}\right)^{-1} \quad (3)$$

where UR is cancer unit risk. The UR of benzene and ethylbenzene are presented by the Integrated Risk Information System (IRIS) of the USEPA. The inhalation unit risk for benzene and ethylbenzene is 2.2 $\times 10^{-6}$–7.8 $\times 10^{-6}$ and 2.5×10^{-6} $(\mu g/m^3)^{-1}$, respectively ((USEPA) 2004), which were used for assessment of LTCR. Based on WHO (2010) report, LTCR values in the range of 1×10^{-5}–1×10^{-6} are considered as "an acceptable limit for humans," but the USEPA has recommended LTCR values less than 1×10^{-6} (Dehghani et al. 2018; Delikhoon et al. 2018; Golkhorshidi et al. 2019; Nabizadeh et al. 2020b).

Non-carcinogenic risk assessment

Non-carcinogenic risk of BTEX was calculated using the parameter called hazard quotient (HQ), the ratio of EDI to reference dose (RfD) using the following equation:

$$\mathrm{HQ} = \frac{\mathrm{EDI}\ \mathrm{mg/kg{-}day}\big)\big)}{\mathrm{RfD}\ (\mathrm{m/kg{-}day})} \quad (4)$$

In this study, RfC of benzene, toluene, ethylbenzene, and xylene were 3×10^{-2}, 5, 1, and 1×10^{-1} mg/m^3, respectively which were used to calculate the reference dose (RfD) for BTEX. When HQ value is above 1, the potential risk can be significant. Inversely, If HQ ≤ 1, it means as an acceptable hazard level since the

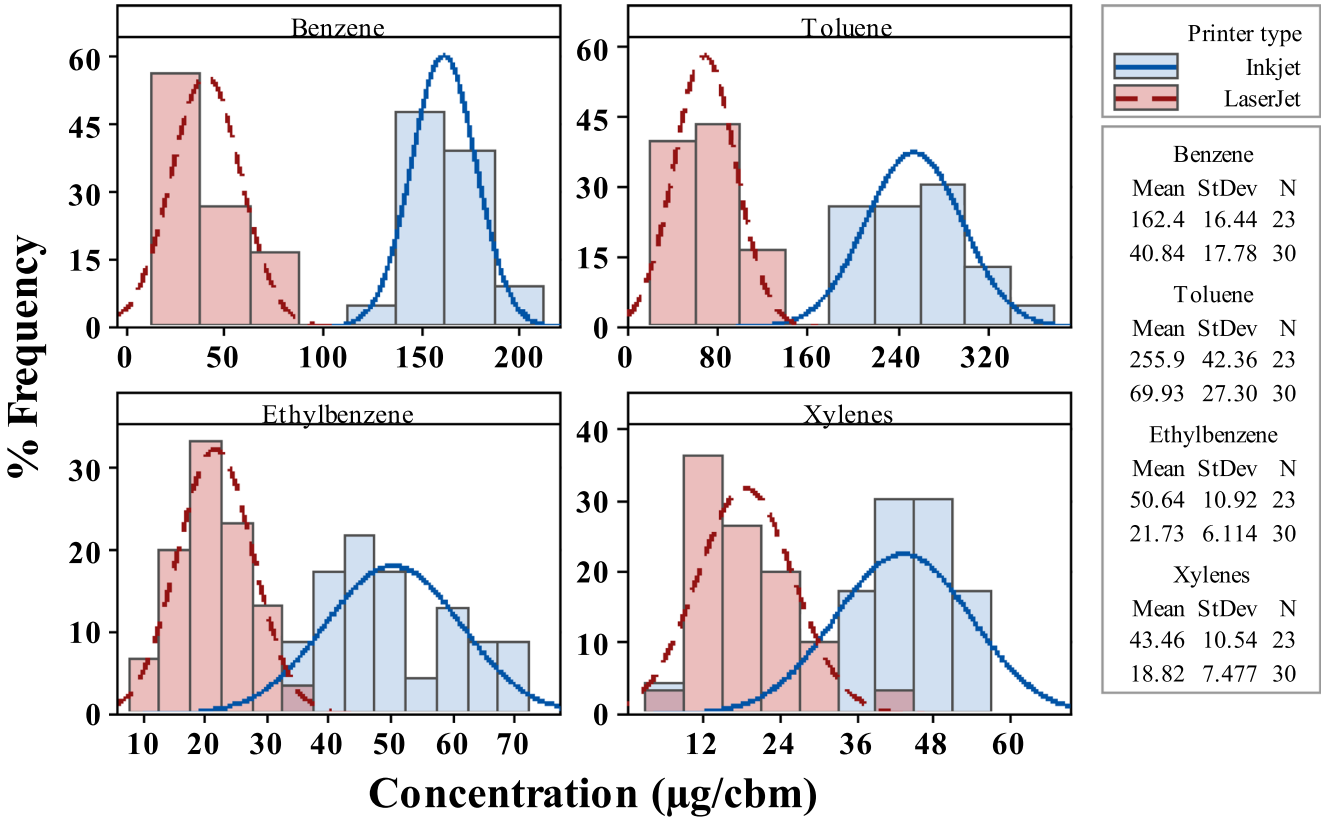


Fig. 2 Concentration of BTEX in the printing and copying centers with inkjet and LaserJet printers; *X* axes are the concentrations (µg/m^3)

dose level is lower than the reference concentration (RfC) (Heydari et al. 2019; Naddafi et al. 2019b; Rostami et al. 2020a). Risk parameters used for calculating HQ and LTCR for BTEX are presented in Table 1.

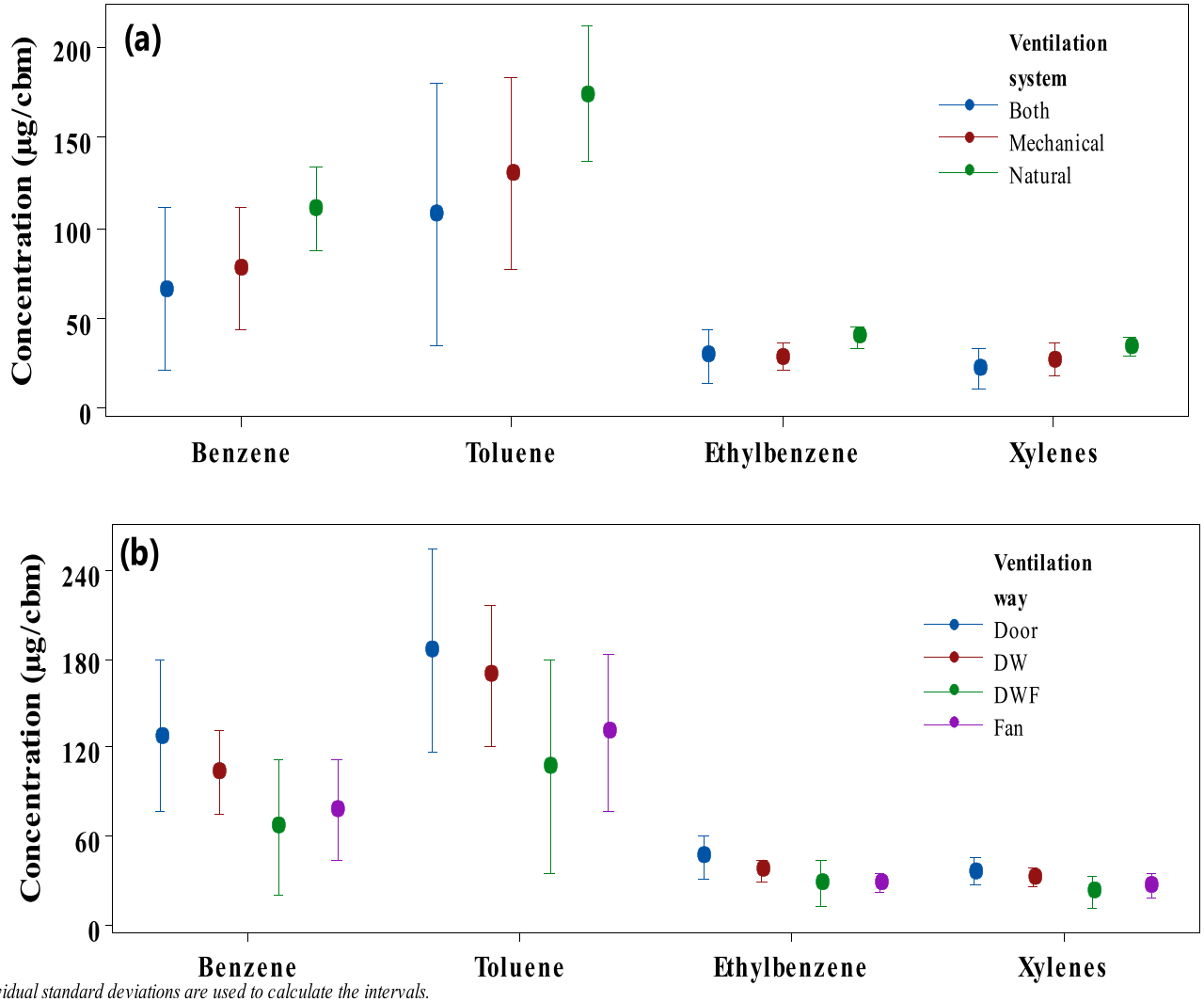
Statistical analyses

The obtained results were imported into SPSS (Vr. 16) and Minitab (Vr. 18) in order to the statistical analyses. The descriptive statistics were used to calculation of mean and SD of the results. The results were analyzed with Anderson-Darling normality test to determine that if the data in each group is obeying normal distribution or not. Given the results of this test, if the data had normal distribution then they were analyzed by normal distribution-based analyses (parametric); on the other hand, they were analyzed by nonparametric analyses. In this regard, nonparametric analysis of Mann-Whitney *U* test was used where there were two independent groups for comparison, and for cases with more groups, Kruskal-Wallis analysis was used. Spearman correlation was used for determination of correlation between the groups with nonparametric data. Partial correlation and ANCOVA were used for determination of correlation between the data groups and comparison between the groups respectively, with normalization the effect of probable confounders.

Results and discussions

Concentration of BTEX in the printing and copying centers

The results showed notable concentrations of BTEX in the printing and copy centers (PCC); however, the obtained concentrations were lower than the legislated limit levels for the work places. The obtained mean concentration of benzene, toluene, ethylbenzene, and xylenes were 93.6±63.2, 150.6 ±99.2, 34.3±16.8, and 29.5±15.2 µg/m^3 respectively (Fig. 1). Where the TWAs of them are 1600, 75000, 87000, and 434000 µg/m^3 respectively (ACGIH 2007; MHMEI 2012). Godoni et al. reported a range of concentration 43–84, 15–3480, 2–133, 5–459, and 2–236 µg/m^3 for benzene, toluene, ethylbnzene, m+p-xylene, and o-xylene respectively, in the offset printing plants (Godoi et al. 2009). Concentration of benzene in this study is higher than the offset printing plants but remain pollutants of the offset printing plants are higher than our findings. Also, El-Hashemy and Ali reported the concentration ranges in the small enterprises as 2.45–14.66, 81.59–955.65, 11.19–97.35, 35.66–291.88, and 3.90–28.39



Individual standard deviations are used to calculate the intervals.

Fig. 3 Concentration of BTEX in the printing and copying centers with different ventilation systems. Both: mechanical (fan) and natural; DW, door and window; DWF, door, window, and fan

µg/m^3 for BTEX in the similar order (El-Hashemy and Ali 2018). Except the xylenes, other pollutants of the small enterprises are lower than our findings, which could be due to more and continues prints or copies in the printing centers. The concentrations of BTEX in PCCs were not normally distributed (Anderson-Darling p-v<0.05 (p-value)) (Fig. 1), so it was affected by some individual factors there. On the other hand, there was strong correlation between the concentrations of BTEX (Spearman's rho, p-v<0.01), that is, a reason for the same source of them. More detailed statistics for concentration of BTEX in the PCCs are presented in Fig. 1.

Effect of printer type on BTEX concentration

The results showed that the concentration of BTEX is significantly higher in the PCCs with inkjet printers compared to the PCCs with LaserJet printers (Mann-Whitney p-v<0.01). Given the results, the mean concentration of benzene, toluene, ethylbenzene, and xylenes in the inkjet PCCs is 162.4±16.4, 255.9±42.4, 50.6±10.9, and 43.5±10.5 µg/m^3 respectively. While their mean concentrations in the LaserJet PCCs are 40.8±17.8, 69.9±27.3, 21.7±6.1, and 18.8±7.5 µg/m^3 in the same order (Fig. 2). Emission of VOCs and formaldehyde from the ink, toner, and paper is reported in previous works and it is remarked that the solvents of inkjet printers could expose the employees (Barrese et al. 2014; Indoor air quality: tackling inkjet printer fumes 2006). It is known that the solvents contain concentrations of BTEX and it can be released to air during and after the printing (Martins et al. 2016).

Effect of ventilation system on concentration of BTEX

With normalizing the results for the printer type, the results showed significant influence for type of ventilation system on concentration of BTEX in PCCs (ANCOVA p-v<0.05). Given the results, the lowest mean concentrations of BTEX

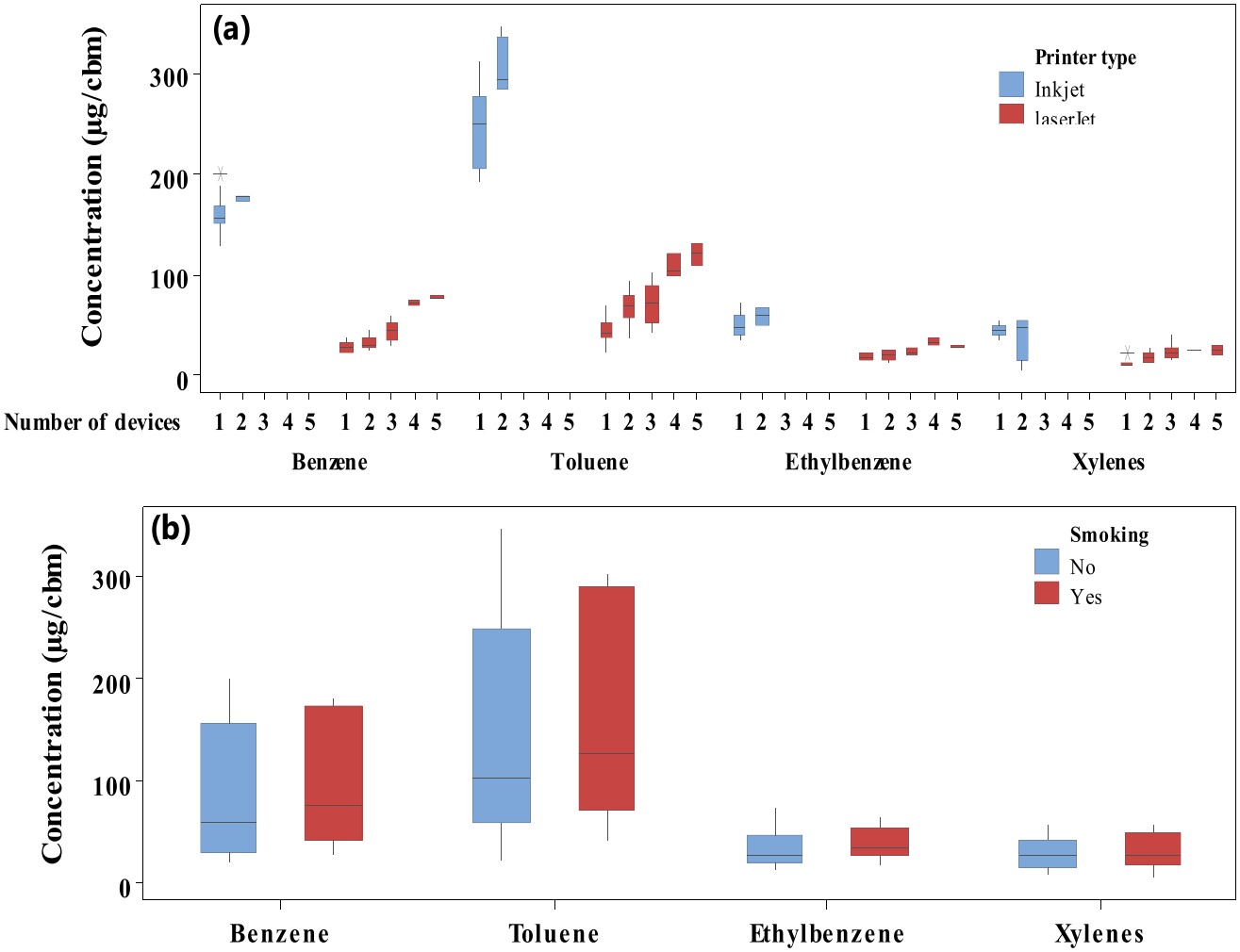


Fig. 4 Concentration of BTEX in the printing and copying centers with different number of devices (**a**) and with and without cigarette smoking (**b**)

were seen in the PCCs which had profit of both type of mechanical (fan) and natural ventilation, while the highest mean concentrations of BTEX were owing to the PCCs with only natural ventilation (Fig. 3 a). Also, the results showed higher BTEX concentration for the PCCs which natural ventilation was only through the door, compared to the PCCs with door and window natural ventilation. And, the PCCs with fan, door, and window way ventilation had the lowest BTEX concentrations compared to remains (Fig. 3b). Air velocity in the PCCs had negative correlation with concentration of BTEX (Fig. 1S) and the air velocity was higher in the both type ventilation system (Fig. 2S); however, the correlations were not significant (Spearman's rho p-v>0.05). The effect of ventilation system on indoor concentration of air pollutants is reported in the previous researches and lower concentration of BTEX and other air pollutants is reported in the indoor environments with both type ventilation (natural and mechanical) (Fazlzadeh et al. 2015; Hazrati et al. 2015; Rostami et al. 2020b).

Effect of other influencing factors on concentration of BTEX

Among the other considered influencing factors in this research including air temperature, relative humidity, area of the PCCs, number of printing and copying devices, material of walls, smoking, material of ceiling, open area of doors and windows, and material of roof, only the number of printing and copying devices showed significant influence on the BTEX (Fig. 4a). Regarding the results, with normalizing the concentration of BTEX for type of printers, positive correlation was seen between the number of devices and BTEX in the PCCs (partial correlation p-v<0.05). This indicates that the main source of the BTEX in the PCCs is the printing and copying devices. The open area showed negative correlation with the BTEX concentrations; however, it was not significant (partial correlation p-v<0.05). Also, the concentration of BTEX in the PCCs with cigarette smoking was fairly higher than the no smoking PCCs (Fig. 4b).

Table 2 The results of carcinogenic (LTCR) and non-carcinogenic (HQ) risk assessment of BTEX

	Benzene				Toluene		Ethylbenzene				Xylene	
	LaserJet printer		Inkjet printer		LaserJet printer	Inkjet printer	LaserJet printer		Inkjet printer		LaserJet printer	Inkjet printer
	LTCR	HQ	LTCR	HQ	HQ	HQ	LTCR	HQ	LTCR	HQ	HQ	HQ
Mean	44.4E−06	0.59	153.3E−06	2.32	0.006	0.02	23.4E−06	0.01	54.2E−06	0.021	0.08	0.19
Median	37.5E−06	0.5	152.6E−06	2.31	0.005	0.019	22.9E−06	0.009	52.1E−06	0.02	0.07	0.18
SD	25.2E−06	0.34	28.8E−06	0.43	0.002	0.005	7.54E−06	0.003	15.1E−06	0.006	0.02	0.05
Min	11.4E−06	0.14	60.2E−06	0.83	0.001	0.007	5.1E−06	0.002	13.8E−06	0.006	0.01	0.06
Max	411.3E−06	2.09	281.8E−06	4.35	0.02	0.04	57.1E−06	0.023	160.8E−06	0.065	0.25	0.36
P10	23.7E−06	0.32	117.1E−06	1/78	0.001	0.015	14.1E−06	0.005	37.5E−06	0.014	0/04	0/13
P20	27.3E−06	0.36	129.1E−06	1/96	0.002	0.017	16.7E−06	0.006	41.8E−06	0.016	0/05	0/15
P30	30.6E−06	0.41	137.8E−06	2/09	0.003	0.019	18.8E−06	0.007	45.4E−06	0.018	0/06	0/16
P40	33.8E−06	0.45	145.5E−06	2/20	0.004	0.02	20.9E−06	0.008	48.7E−06	0.019	0/07	0/18
P50	37.5E−06	0.5	152.6E−06	2/31	0.005	0.021	22.9E−06	0.009	52.1E−06	0.02	0/08	0/19
P60	41.9E−06	0.56	160.1E−06	2/43	0.006	0.022	24.9E−06	0.01	55.7E−06	0.022	0/09	0/20
P70	47.4E−06	0.64	167.8E−06	2/54	0.007	0.024	27.1E−06	0.011	59.7E−06	0.024	0/10	0/21
P80	55.9E−06	0.75	177.3E−06	2/68	0.008	0.026	29.6E−06	0.012	65.2E−06	0.026	0/11	0/23
P90	72.2E−06	0.96	190.4E−06	2/89	0.009	0.028	33.4E−06	0.013	73.9E−06	0.029	0/13	0/25

Health risk assessment

Carcinogenic risks

According to the EPA guidelines, excess cancer risk of 10^{-6}–10^{-4}, above 10^{-4}, and equal to or less than 10^{-6} is considered as acceptable, high, and low risks, respectively (Wu et al. 2014). The mean LTCR of benzene and ethylbenzene in indoor air of the PCCs with LaserJet and inkjet printers are presented in Table 2 and Fig. 5. As can be seen from Table 2 and Fig. 5, the mean of LTCR for benzene in the PCCs with LaserJet and inkjet printers was 44.4 × 10^{-6} and

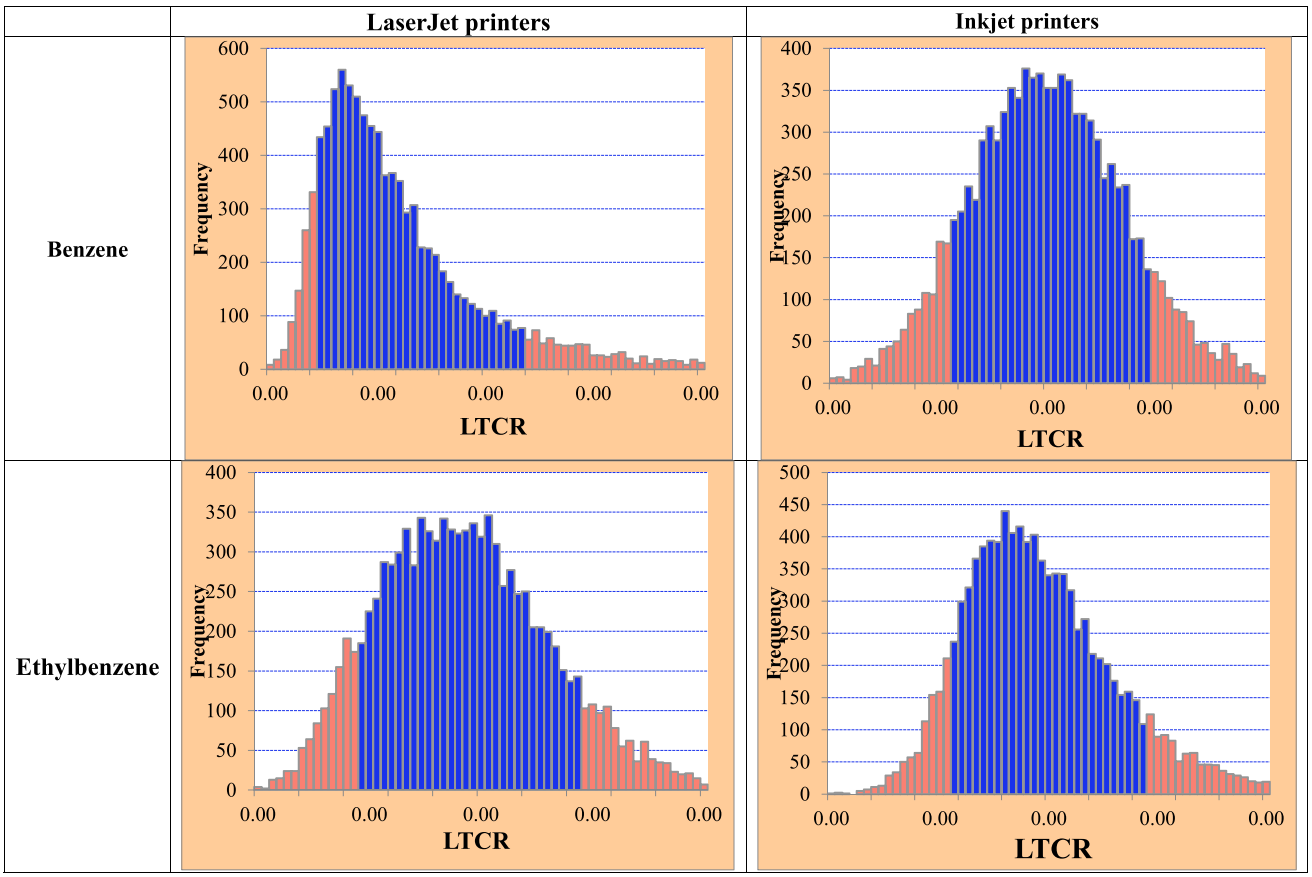


Fig. 5 Simulated LTCR values for benzene and ethylbenzene through inhalation pathway in indoor air of the PCCs with inkjet and LaserJet printers

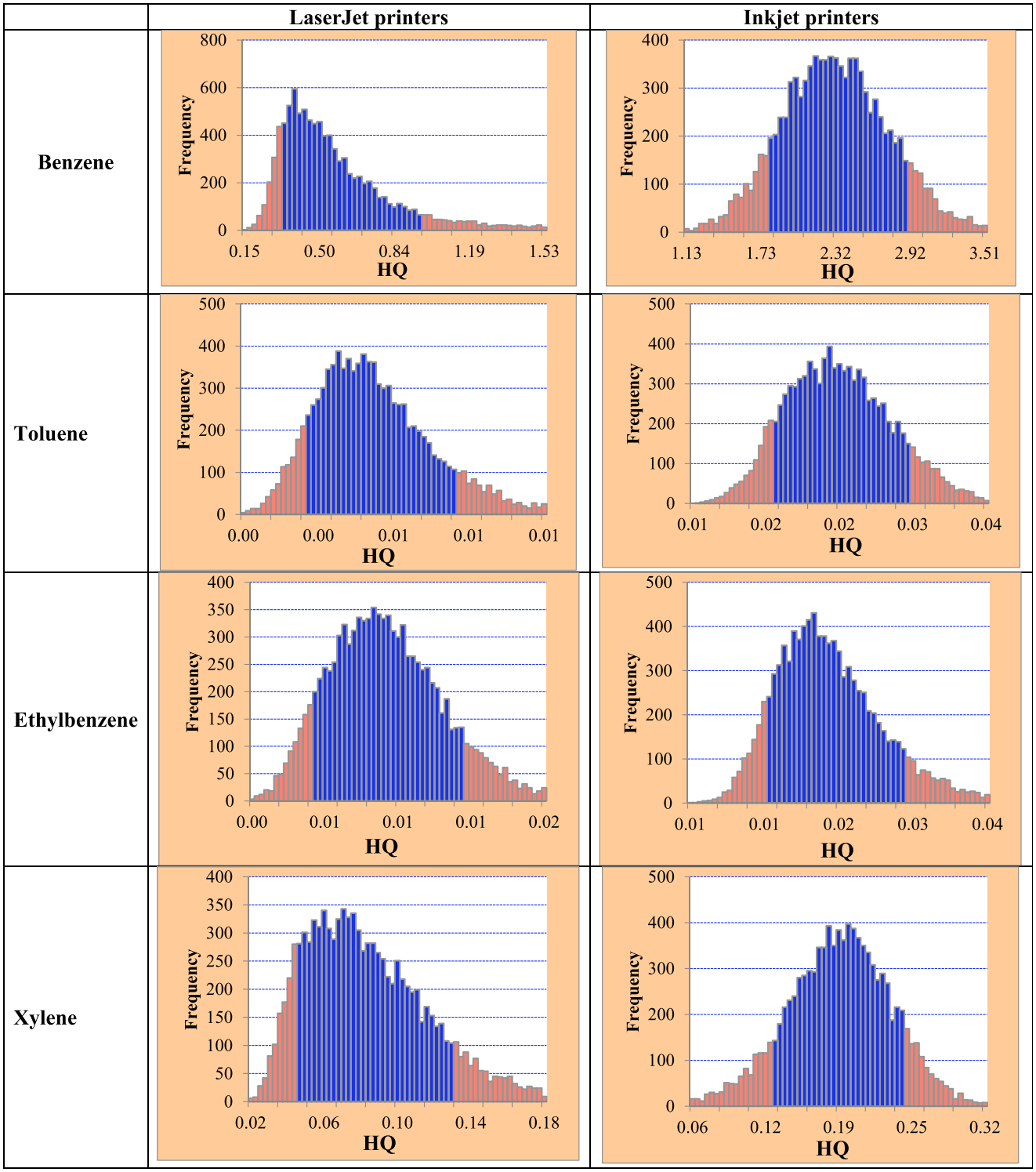


Fig. 6 Simulated HQ values for benzene, toluene, ethylbenzene, and xylene through inhalation pathway indoor air of the PCCs with inkjet and LaserJet printers

153.3 × 10^{-6}, respectively. Also, mean LTCR calculated for ethylbenzene in indoor air of the PCCs with LaserJet and inkjet printers were 23.4×10^{-6} and 54.2× 10^{-6}, respectively. The LTCR values of both benzene and ethylbenzene found in the present study exceeded the acceptable limits established by the USEPA (1×10^{-6}) and WHO (1×10^{-5}).

Moreover, 90th percentiles of LTCR for benzene and ethylbenzene in the PCCs with LaserJet and inkjet printers were 72.2× 10^{-6} and 190.4× 10^{-6} and 33.4× 10^{-6} and 73.9× 10^{-6}, respectively, which were also higher than WHO and USEPA recommended limits, implies high risk due to benzene and ethylbenzene inhalation exposure for employees of PCCs.

The LTCR values in PCCs with LaserJet printers are 3 times higher than of PCCs with inkjet printers. The high values of LTCR found for benzene and ethylbenzene in the present study in PCCs with inkjet printers could be attributed to the high concentrations of these two carcinogenic pollutants, which were mostly originated from used solvents. Therefore, to reduce the carcinogenic risks related to benzene and ethylbenzene exposure in these areas, it is vital to manage the solvent consumption properly in PCCs.

Furthermore, the evidence from the epidemiological studies indicates that long-term exposure to benzene and ethylbenzene has shown an increased risk of leukemia, aplastic anemia, cancer of the blood-forming organs, and neurological disorders (Bahadar et al. 2014; Gamberale et al. 1978; Janitz et al. 2017; Seifi et al. 2019). There might be other carcinogens including heavy metals, PAHs, and aldehydes in indoor air of PCCs regarding the presence of their sources such as the inks and solvents. These pollutants were not considered in this study. In this line of research, further advance in information about the indoor air quality of such places is needed to more complete exposure risk assessments.

Non-carcinogenic risks

Table 2 and Fig. 6 show the calculated mean HQ of BTEX in indoor air of PCCs. As shown in Table 2, the mean HQ value for benzene, toluene, ethylbenzene, and xylenes in indoor air of the PCCs with LaserJet printers was 0.59, 0.006, 0.01, and 0.08, respectively. Also, the mean of HQ for benzene, toluene, ethylbenzene, and xylene in the indoor air of PCCs with inkjet printers was 2.32, 0.02, 0.021, and 0.19, respectively. Benzene also had the highest non-cancer HQ followed by ethylbenzene, xylene, and toluene. According to USEPA and WHO guidelines, HQ values higher than 1 are unacceptable exposure conditions with notable chronic non-cancer risks for the exposed population's target organs. In the present study, the mean HQ of benzene in the indoor air of PCCs with inkjet printers was > 1, indicating an unacceptable high non-carcinogenic risk for employee's health in PCCs. The estimated HQ values for employee's PCCs with inkjet printers were remarkably higher than those with LaserJet printers mainly due to high concentrations of these pollutants in solvent. Therefore, controlling strategies such as enhancement of the personal protection, improvement of the ventilation system, and reduction in releasing from other sources should be adopted along with the promotion of preventive health decisions against cancer and non-cancer effects of these pollutants.

Conclusions

This research provides the data on the concentration of BTEX in indoor air of PCCs with LaserJet and inkjet printers for the first time in Iran. Also, the health risk due to human exposure to BTEX was investigated. In the fortune of the results and the raised disruptions above, it can be concluded that the concentration of BTEX in the PCCs is not exceeded the work places' limit levels of short-time exposure and time weighted average guidelines. However, the concentrations showed notable exceeded cancer risk for benzene and ethylbenzene and unacceptable non-carcinogenic hazard for the inkjet PCCs, on the employees in a long-time exposure. The concentration of BTEX is significantly influenced by the type of device and the inkjet devices emit higher concentrations of BTEX compared to the LaserJet. Given the results, the printing and copying devices are the major sources of BTEX in the PCCs. The concentration of BTEX is notably affected by the ventilation system as the combination of natural and mechanical ventilation showed considerably lower concentrations of BTEX in PCCs and it can be suggested as a simply available method to efficiently reduction of BTEX levels and the related health effects in PCCs. Also, the ventilation requirements can be included in obligatory characteristics of such places beside the prohibition of smoking where the air treatment facilities are not applicable or reasonable.

The average LTCRs for benzene and ethylbenzene in indoor air of PCCs with LaserJet printers were 44.4E−06 and 23.4E−06, respectively. Also, these values in PCCs with inkjet printers were 153.3E−06 and 54.2E−06, respectively, which exceed the limit value by the USEPA and WHO. The mean of HQ for benzene in PCCs with inkjet printers was < 1, but this value for TEX in PCCs with inkjet printers and for BTEX in PCCs with LaserJet printers was > 1 which corresponds an unacceptably high risk for human health in employees. Results of this research show that the estimated LTCRs and HQ values for employees in the PCCs with inkjet printers were remarkably higher than the PCCs with LaserJet printers.

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Authors contribution Behzad Saranjam and Mehdi Fazlzadeh participated in the conceptualization and design of the research and supervised the work. Amin Babaei-Pouya and Leila Rastgho involved in data collection. Malek Abazari and Roohollah Ghasemi are responsible for analysis and interpretation of data. Roohollah Rostamy and Behzad Saranjam wrote the first draft of manuscript. Mehdi Fazlzadeh Contributet to final editing of manuscript. All authors have read and approved the final paper as submitted.

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Data Availability The data used and analyzed during the current study are available from the corresponding author upon reasonable request.

Declarations

Ethical consideration The protocol was approved by the Institutional Review Board of Ardabil University of Medical Sciences (Approval ID: IR.ARUMS.REC.1398.232).

Consent to participate Not applicable.

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