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Indoor Levels of Volatile Organic Compounds at Households in Ulaanbaatar City

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Objectives: VOCs, or Volatile Organic Compounds, are a group of organic chemicals that can easily evaporate into the air at room temperature. They are called “volatile” because they have high vapor pressure and can readily form vapors or gases at normal atmospheric conditions. To address this knowledge gap, we aimed to assess VOC exposure and its associated health risks.
Method: Samples were collected through the adsorbent tube, followed by detachment from the solvent by organic solvents solvent or methanol, and analyzed by gas chromatographic equipment attached with a flame ionization detector (FID). We selected 150 households from the Chingeltei and Bayangol districts in Ulaanbaatar city, specifically sections 4, 5, 6, and 12, to examine the levels of indoor VOCs in this study. We used the nonparametric Mann-Whitney U test to compare medians of VOC levels for two independent groups. Kruskal-Wallis test was carried out to determine if there was any significant difference between medians of VOC levels for more than two independent groups, including the type of paint used, wooden furniture used, and construction year.
Results: We found no significant difference in benzene concentration among different types of households ($p<0.8112$). The highest benzene concentration (0.181 μg/m3) was measured in apartments and houses. Although there was no statistically significant difference between household room types, the kitchen had a higher benzene concentration than other rooms ($p<0.8156$). Factors such as household total volume, building construction year, and materials used for floors and walls did not significantly affect indoor benzene concentration. Most of the day, the benzene levels exceeded the standards set by the Indoor Air Quality Act of South Korea and the recommended levels by the Health Minister and Construction and Urban Development Minister of Mongolia. In 133 households in Ulaanbaatar city, indoor VOCs, specifically benzene concentration, exceeded the recommended level stated in Order No. A105/08 by the Health Minister and Construction and Urban Development Minister in 2017.
Conclusion: Indoor benzene concentration did not vary significantly based on household type, room type, household volume, building construction year, construction wall material, construction floor material, whether new furniture was purchased or the dwelling was repaired and painted within the last two months, proximity to major roads, or indoor smoking status.
Keywords: Air pollution, Indoor air quality, Volatile organic compounds, Benzene.

Introduction

Air pollution poses significant public health issues worldwide. It is relatively high in South East Asia, Mediterranean, and African countries [1]. Several factors affect air pollution, including mining, manufacturing, and coal burning. Besides that, cooking and vehicle engines emit harmful air pollutants to human health. At least 80 percent of the urban population lives where air pollution is regularly monitored. Even though air pollution is ubiquitous, people who live in cities of low- and middle-income countries are being exposed the most [2]. According to the WHO air quality data, 98 percent of the population in low- and middle-income countries live in polluted environments where air quality exceeds WHO air quality guidelines. In contrast, this number is decreased to 56 percent in developed countries [3]. Primary indoor air pollutants include benzene, carbon dioxide, formaldehyde, naphthalene, nitrogen dioxide, polycyclic aromatic hydrocarbons, radon, trichloroethylene, and tetrachloroethylene. Among them, benzene, formaldehyde, radon, and trichloroethylene are considered more harmful to health [4]. Numerous studies have investigated the link between air pollution caused by solid fuel combustion and acute lower respiratory infection and pneumonia in children, especially those under two years old in developing countries [5]. In at least two out of five countries worldwide, wood, coal, agricultural residues, and dung are used as a fuel in indoor environments. More than 4 million people die each year due to open combustion and solid fuel use in indoor environments. Indoor air pollution is the cause of noncommunicable diseases, including stroke, ischemic heart disease, and chronic obstructive pulmonary disease [6]. As a result of intensive research on indoor air quality since the 1970s, various air pollution sources, concentrations, health effects, solutions, and policy interventions have been implemented [7]. Environmental tobacco smoking, nitrogen dioxide, formaldehyde, radon, and other pollutants have recently been emitted from gas stoves for newly constructed buildings [8]. Volatile organic compounds (VOCs) are flammable organic substances containing carbon, oxygen, hydrogen, fluorine, and chlorine [9]. Volatile organic compounds are caused by various solvents, paints, tablets, and plastic materials that pollute indoor air and significantly affect human health. VOCs, such as benzene and formaldehyde, had been classified as group I carcinogens by the International Agency for Research on Cancer [10]. In addition, short-term exposure to VOCs can result in irritation of eyes, nose, and throat, hypersensitivity, asthma, headache, and cough. Most air pollution research has been directed to ambient air pollution. However, the air is polluted highly in community buildings [11]. The main concerns of indoor air pollution are that residents of the city spend more than 90 percent of the day in an indoor environment, and some pollutants are higher in the indoor environment than ambient, as well as difficulties in determining individual exposure to specific pollutants [12]. Therefore, it is necessary to investigate air pollution exposure and its health impacts and develop further public health policies. VOCs have been measured in indoor environments, followed by health protection interventions if their level exceeds the maximum permissible level in developed and developing countries. Despite the measurements of some pollutants such as PM2.5, nitrogen dioxide, and sulfur dioxide in indoor environments, research on exposure to VOCs has yet to be conducted in Mongolia. Hence, it is necessary to identify VOCs' direction and health risks. We aimed to assess VOC exposure and its associated health risks in Ulaanbaatar.

Materials and Methods

Research design

The study was conducted through a cross-section design. 150 households from Chingeltei and Bayangol districts in Ulaanbaatar city were selected to characterize the indoor VOC levels in this study. Specifically, the 4th, 5th, 6th, and 12th sections were chosen from the Chingeltei district, whereas 10th, 11th, and 12th sections were selected from the Bayangol district. We recruited 31 gers, 56 houses, and 85 apartments according to the study inclusion criteria, respectively (Figure 1).

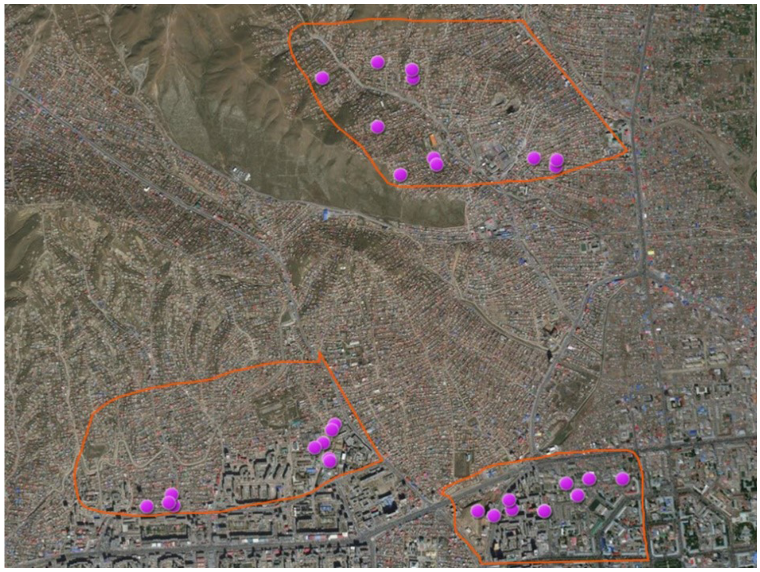

Figure 1. Geographical location of households

Sample participants

We collected air monitoring samples for VOCs solid sorbent tubes packed with 100 mg of adsorbent for 2 hours at a 200 ml/min flow rate. The pumps were calibrated to set the air flow rate. All collected samples were stored below four °C with coatings of aluminum. At least 10 percent of the samples were collected during transfer and storage as blank models to control cross-contamination.

Analytical methods

VOCs including benzene, toluene, ethyl benzene, o, and m-xylene were analyzed at "Green Crown" Laboratory of Environmental Analysis, which is accredited by ISO 17025, by the NIOSH1501 method. Samples were collected through the adsorbent tube, followed by detachment from the solvent by organic solvents solvent or methanol, and analyzed by gas chromatographic equipment attached with a flame ionization detector (FID). Pumps were calibrated before each sampling. We collected samples into the granular contained tube at 200 l/min for at least 2 hours.

Statistical analysis

We conducted statistical analyses of VOCs using STATA software version 15.0 (StataCorp LLC, Lakeway, Texas, USA) to determine environmental and human factors affecting VOC levels. Since the data was left-skewed, we used a nonparametric approach to compare median levels of benzene. Mann-Whitney test was performed to compare medians of VOC levels at a significance level of 0.05. Kruskal-Wallis test was carried out to determine if there was any significant difference between medians of VOC levels by environmental factors including type of paint used, wooden furniture used, and construction year. Multiple linear regression analysis was carried out to determine if there was a statistically significant effect on the concentration of VOC levels at households at the significance level of 0.05.

Research ethics

Ethical Approval was obtained from the Ethical Review Board of the Ministry of Health, Mongolia, on November 2, 2018 (No: C83/18/11/02).The individuals residing in gers, houses, and apartments were provided with comprehensive details about the study's goals, objectives, and significance and the intended application of the study findings for research and official purposes via an "informed consent form." The study only recruited individuals who gave their consent to participate.

Results

The concentration of volatile organic compounds (VOCs) was measured for a total of 150 households located in the Chingeltei and Bayangol districts. In terms of dwelling type, 19 gers, 69 apartments, and 45 houses have been selected for indoor air quality measurement in this study (Table 1).

Table 1. General characteristics of the households

Household indicators		Descriptive statistics					
		n	%	Mean	SD	Min	Max
Location							
Chingeltei district	4th section	15	24.0	0.072	0.049	0.004	0.167
	5th section	15	24.0	0.083	0.043	0.004	0.154
	6th section	15	24.0	0.061	0.064	0.004	0.284
	12th section	17	27.0	0.064	0.037	0.004	0.129
Total		62	100	0.076	0.051	0.004	0.181
Bayangol district	10th section	19	25	0.046	0.047	0.004	0.145
	11th section	26	37.5	0.087	0.047	0.004	0.181
	12th section	26	37.5	0.079	0.053	0.004	0.181
Total		71	100	0.066	0.050	0.004	0.284
Household type							
Gers		19	14.2	0.064	0.039	0.004	0.121
Apartment		69	51.8	0.071	0.048	0.004	0.181
House		45	34.0	0.065	0.049	0.004	0.181
Area, m^2							
Up to 35 m^2		27	24	0.066	0.058	0.004	0.284
35 to 70 m^2		19	17	0.057	0.054	0.004	0.181
70 to 100 m^2		18	16	0.085	0.049	0.004	0.167
100 to 150 m^2		48	43	0.070	0.051	0.004	0.181
Construction year							
Before 2000		49	51	0.058	0.044	0.004	0.180
Between 2000 and 2010		29	30	0.078	0.045	0.006	0.161
After 2010		18	19	0.054	0.042	0.004	0.130
Vicinity to main road							
Within 100 meters		81	62	0.070	0.048	0.004	0.181
Within 200 meters		24	19	0.067	0.046	0.004	0.161
Within 500 meters		24	19	0.071	0.053	0.004	0.181
Total		133	100	0.070	0.051	0.004	0.284

Characterization of indoor VOC concentration

In the analysis of indoor air volatile organic compounds, 150 samples were collected, of which 133 (88%) samples were measured as above the detection limits and included in further statistical analyses. Whereas, other volatile organic compounds such as toluene, ethylbenzene, p,m-xylene, o-xylene were measured as below the limit of detection (Table 2).

Table 2. Indoor air VOCs concentration

Volatile organic compounds	Total		Limit of detection, mg/m^3	Number of measurements reached LOD	Percentage of measurements reached LOD	IARC classification
	n	%				
Benzene	133	100	0.004-0.35	133	88%	I
Toluene	133	100	0.024-4.51	0	0%	III
Ethylbenzene	133	100	0.045-8.67	0	0%	II
p, m-xylene	133	100	0.043-0.861	0	0%	III
o-xylene	133	100	0.044-10.40	0	0%	III
Total	133	100	-	-	-	

There was no significant difference for benzene concentration among household types ($p<0.8112$) (Figure 2).

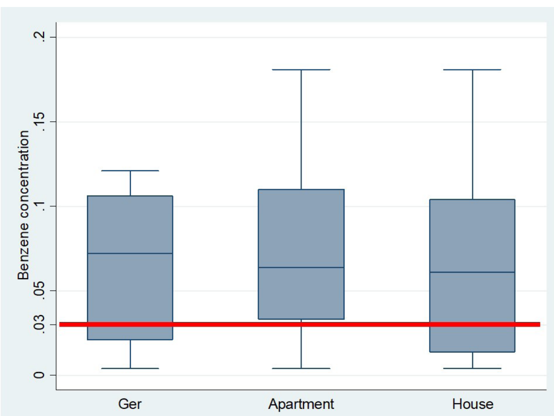

Figure 2. Indoor benzene concentration by household type

The highest concentration of benzene (0.181 μg/m3) was measured in apartments and houses. Even though we found no statistically significant difference between room type of households, benzene concentration was higher in the kitchen compared to other rooms ($p<0.8156$). In addition, household total volume, building construction year and material types of floors and wall were not significant factors for indoor benzene concentration (Table3).

Table 3. Indoor benzene concentration by household indicators

Characteristics	Benzene concentration, mg/m^3					p-value	Percentage exceeded than "Indoor Air Quality Act of South Korea[1]" ($0.030 mg/m^3$)
	N	Mean	SD	Min	Max		
Household type							
Ger	19	0.064	0.039	0.004	0.121	0.8112	68%
Apartment	69	0.071	0.048	0.004	0.181		76%
House	45	0.065	0.049	0.004	0.181		73%
Total	133	0.079	0.048	0.004	0.284		75%
Room type							
Kitchen	25	0.072	0.056	0.004	0.181	0.8156	68%
Living room	69	0.070	0.046	0.004	0.181		81%
Bedroom	19	0.061	0.050	0.004	0.180		68%
Ger	18	0.062	0.039	0.004	0.121		66%
Total	131	0.070	0.051	0.004	0.284		75%
Household volume							
Up to 35 m^2	27	0.066	0.058	0.004	0.284	0.3869	66%
35 to 70 m^2	19	0.057	0.054	0.004	0.181		68%
70 to 100 m^2	18	0.085	0.049	0.004	0.167		83%
100 to 150 m^2	48	0.070	0.051	0.004	0.181		73%
Total	112	0.069	0.053	0.004	0.284		72%

In terms benzene concentration influencing factors, there was no significant difference by building construction year (p<0.0974), construction wall material (p<0.6313), floor material (p<0.7780), HEPA air purifier usage (p<0.8015), window opening frequency (p<0.9381), respectively (Table 4).

Table 4. Indoor benzene concentration by household indicators

Characteristics	Benzene concentration, mg/m^3						p-value	Percentage exceeded than "Indoor Air Quality Act of South Korea[1]" (30 $\mu g/m^3$)
	N	(%)	Mean	SD	Min	Max		
Building construction year								
Before 2000	49	49	0.058	0.044	0.004	0.180	0.0974	69%
2000-2010	29	30	0.078	0.045	0.006	0.161		83%
After 2010	18	21	0.054	0.042	0.004	0.130		61%
Total	96	100	0.063	0.044	0.004	0.180		72%
Construction wall material								
Concrete	84	66	0.076	0.055	0.004	0.284	0.6313	77%
Wood	10	8	0.074	0.041	0.004	0.145		90%
Brick	9	7	0.055	0.035	0.004	0.113		77%
Block	12	9	0.054	0.052	0.004	0.156		58%
Ger	13	10	0.061	0.039	0.004	0.112		69%
Total	128	100	0.071	0.051	0.004	0.284		75%
Construction floor material								
Parquet	73	58	0.070	0.047	0.004	0.181	0.7780	77%
Linoleum	27	22	0.058	0.040	0.004	0.143		70%
Wood	2	2	0.058	0.014	0.048	0.069		100%
Carpet	22	18	0.073	0.061	0.004	0.181		68%
Total	124	100	0.068	0.048	0.004	0.181		74%
HEPA air purifier usage								
Yes	32	25	0.070	0.057	0.004	0.181	0.8015	72%
No	96	75	0.068	0.045	0.004	0.181		75%
Total	128	100	0.068	0.048	0.004	0.181		74%
Window opening frequency per day								
Do not open	53	42	0.070	0.047	0.004	0.181	0.9381	75%
Once	55	44	0.068	0.050	0.004	0.181		75%
Two times or more	18	14	0.066	0.046	0.004	0.145		72%
Total	126	100	0.069	0.048	0.004	0.181		75%

There was no significant difference either the house hold bought a new furniture or have had repaired and painted their dwellings for last 2 months (p<0.9406), by vicinity to main road (p<0.9378), indoor smoking (p<0.3657), cooking frequency (p<0.8322), use of cleansing products (p<0.3095), respectively (Table 5).

Table 5. Indoor benzene concentration by environmental factors and human activities

Characteristics	Benzene concentration, mg/m³						p-value	Percentage exceeded than "Indoor Air Quality Act of South Korea" (30 µg/m³)
	N	(%)	Mean	SD	Min	Max		
Either buying new furniture or have had repaired and painted their dwellings for last 2 months								
Yes	19	14	0.071	0.048	0.004	0.156	0.9406	68%
No	114	86	0.070	0.051	0.004	0.284		76%
Total	133	100	0.070	0.051	0.004	0.284		75%
Vicinity to main road								
Within 100 m	81	62	0.070	0.048	0.004	0.181		74%
Within 200 m	24	19	0.067	0.046	0.004	0.161	0.9378	75%
Within 500 m	24	19	0.071	0.053	0.004	0.181		75%
Total	129	100	0.071	0.051	0.004	0.284		74%
Indoor smoking								
Yes	18	14	0.067	0.048	0.004	0.145	0.3657	84%
No	112	86	0.078	0.045	0.004	0.181		72%
Total	130	100	0.068	0.048	0.004	0.0181		74%
Cooking frequency per day								
Once	25	20	0.066	0.010	0.004	0.180		72%
Two times or more	98	80	0.068	0.004	0.004	0.181	0.8322	74%
Total	123	100	0.068	0.004	0.004	0.181		74%
Use of cleansing products per day								
Do not use	54	43	0.073	0.041	0.004	0.167		81%
Once	13	10	0.074	0.063	0.004	0.181	0.3095	69%
Two times or more	59	47	0.060	0.049	0.004	0.181		69%
Total	126	100	0.067	0.047	0.004	0.181		74%

Benzene concentration was significantly influenced by air relative humidity ($p<0.002$), whereas it did not significantly influence by household type ($p<0.503$), room type ($p<0.255$), household volume ($p<0.169$), construction year ($p<0.78$), air temperature ($p<0.825$), respectively (Table 6).

Table 6. Risk factors for benzene concentration using multiple regression

Risk factors	Benzene concentration, mg/m³						R-square	F-value
	Coef.	Std. Err.	t	p- value	95% Conf. Interval			
Household type	0.0075593	0.011229	0.67	0.503	-0.01483	0.029944		
Room type	0.0053828	0.004686	1.15	0.255	-0.00396	0.014725		
Household volume	-0.0176223	0.012693	-1.39	0.169	-0.04293	0.00768		
Construction year	-0.0020248	0.007213	-0.28	0.78	-0.0164	0.012354	0.0481	0.91
Air temperature	-0.0002584	0.0011668	-0.22	0.825	-0.0025719	0.0020552		
Air relative humidity	-0.0013147	0.00041	-3.21	0.002	-0.0021276	-0.000501		
Constant	0.0772904	0.045843	1.69	0.096	-0.0141	0.168677		

During most diurnal time, benzene level exceeded both the Indoor Air Quality Act of South Korea standard and the recommended level by the Health Minister and the Construction and Urban Development Minister of Mongolia (Figure 3).

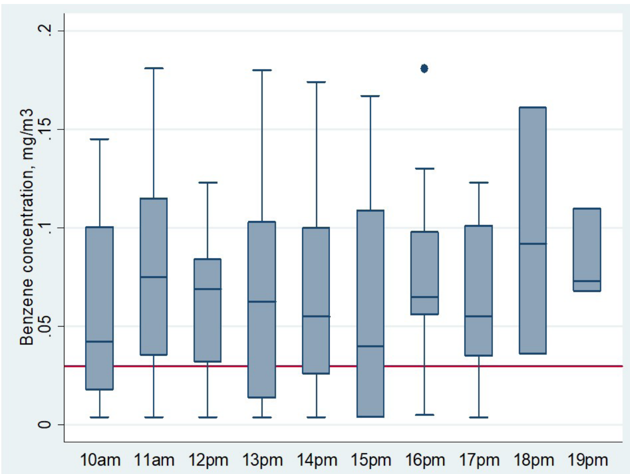

Figure 3. Diurnal characterization of benzene in households

Discussion

Results of the study showed that indoor levels of benzene at 133 households located in Chingeltei and Bayangol districts of Ulaanbaatar city were significantly higher than the indoor air quality standards and guidelines. Benzene has been detected at relatively high levels in indoor environments. Some exposure can occur from building materials such as paints and adhesives. Several factors affect the indoor levels of benzene, including heavy traffic areas, outdoor air pollution, benzene-containing consumer products, and dwelling characteristics. Children and older peoplewho spend more time indoors are more vulnerable to benzene exposure. There were no significant differences in benzene concentration if the owner bought new furniture or had painted and repaired their dwelling for the last two months and the vicinity of the major roads. Numerous studies have been conducted on environmental and personal exposures to VOCs at various types of residential buildings worldwide. According to the US EPA, indoor VOC levels are about 2.5 times higher than outdoor ones. Katsoyiannis et al. have suggested that carpets could increase indoor VOCs and HCHO pollution levels depending on the types, ranging from 10 to 1,000 µg/m3[13]. In Korea, exposure to VOCs at high concentrations occurs in newly-constructed residential buildings as well [14]. VOCs can be emitted from various sources, including wall and floor materials, wooden furniture, and carpets, which could adversely affect health. Among the VOCs, benzene is emitted explicitly from human activities such as cleaning [15], painting [16], the use of consumer products [17], the storage and use of solvents, and smoking tobacco, respectively. Despite the insignificant difference between smoking and benzene concentration in our study, each piece of cigarette could emit 430 to 590 µg of benzene [18]. Indoor benzene concentrations were broadly measured in various studies conducted in the USA, Australia, and Europe, which ranged from 2.6-5.8 µg/m3 [19]. On the other hand, indoor benzene concentrations were higher in Asian countries. For example, in India, benzene concentrations were measured about 103 µg/m3 where kerosene stoves were used in households [20]. Our results of benzene concentrations were comparable with other study reports from some cities in China, such as Guanzhou, with an average level of 57.4 µg/m3[21]. In apartments, benzene concentrations were measured as 18.4–35.4 µg/m3 and 23–35 µg/m3 in Singapore and the Republic of Korea, respectively [22]. We have not found a significant difference in benzene concentration by household type, room type of households, room volume, building construction year, wall and floor material, buying new furniture or have had repaired and painting their dwellings for last 2 months, major road vicinity, and indoor smoking. Previously, studies have reported that VOCs could significantly differ by construction year, especially if built before or after 2000 [23]. Generally, indoor air pollutants tend to be found at higher levels in newly-constructed buildings, as it is usually established with new wooden furniture [14].Nevertheless, it is substantial to assess the health effects of benzene in a more comprehensive way since each household type had shown more than 60 µg/m3 of benzene concentration on average.At an individual level, there could be cost-effective approaches to prevent indoor air pollution exposure, including wearing masks when outdoors, maintaining closed doors and windows, and utilizing HEPA filters indoors[24]. This study has the following strengths. Firstly, there has yet to be a study that characterized indoor VOCs, specifically benzene, in Ulaanbaatar city with an adequate sample size. We included a total of 133 households in the analysis, which was enough to compare these households by major influencing factors, including household type, room type of households, room volume, building construction year, wall and floor material, buying new furniture or having had repaired and painted their dwellings for last 2 months, major road vicinity and indoor smoking status. Secondly, we characterized the daily concentration of benzene in households. It can be practical for residents to reduce their exposure to benzene, knowing the peak engagement periods related to the time activity patterns. Nevertheless, this study has the following limitations. Since we did not measure outdoor VOC levels, achieving indoor and outdoor level ratios was impractical, as shown in previous studies. In addition, our data collection period did not cover monthly or seasonal variation in VOCs in indoor environments. We have not estimated the risk for children and adults based on our exposure concentration. We have not yet calculated the chances of leukemia's long-term health outcomes, including asthma and other respiratory and cardiovascular diseases. Future studies are required to explore the impacts of prolonged exposure to indoor VOCs on long-term health, mainly focused on the cancer risks among the Ulaanbaatar city population.

Conclusion

Indoor VOCs, specifically benzene concentration is higher than the recommended level of Order No. A105/08 by Health Minister and Construction and Urban Development Minister, 2017, in 133 households of Ulaanbaatar city. Indoor benzene concentration did not statistically vary by household type, room type, household volume, building construction year, construction wall material, construction floor material, either bought new furniture or have had repaired and painted their dwellings for last 2 months, vicinity to significant road, indoor smoking status. Further epidemiological studies should be conducted to identify the association between benzene and long-term effects among the citizens of Ulaanbaatar city.

Conflict of Interest

As the designated corresponding author, I attest that all other authors have seen and agreed to the submission.

This paper has not been published anywhere and is not currently being considered for publication anywhere else. To our knowledge, there are no conflicts of interest. As the designated corresponding author, I attest that all other authors have seen and agreed to the submission.

Acknowledgements

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