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Assessing carcinogenic effects of polychlorinated biphenyl (PCB) in indoor public buildings: A study in Isfahan, Iran

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Abstract

Background: Polychlorinated biphenyls (PCBs) are persistent organic pollutants of significant concern due to their adverse health effects and widespread presence in indoor environments. Understanding the distribution and sources of PCB contamination in indoor settings is critical for effective risk management and mitigation strategies.

Methods: Dust samples were collected from 28 locations within public buildings in Isfahan. The concentration of PCBs was determined using an Agilent 7890A gas chromatograph-mass spectrometer. Additionally, the carcinogenic risk (CR) associated with PCB exposure via ingestion, inhalation, and dermal contact was assessed for both children and adults. PCBs with six chlorine atoms in their structure were the dominant group, with a mean concentration of 74.42 ± 22.10 ng/g.

Results: The CR values were categorized as low for both age groups via ingestion and dermal pathways, ranging between 4.04E-05 and 2.27E-05. Furthermore, all sampling locations were classified as low risk in terms of total CR effects.

Conclusion: Inhalation risks from PCB exposure were relatively low; however, concerns persist regarding PCBs acting as vectors for other contaminants, thus amplifying health risks through dermal contact and ingestion. Effective management strategies are essential to mitigate PCB exposures and protect public health in indoor environments.

Keywords: Polychlorinated Biphenyl, Carcinogenic Effects, Indoor, Public buildings

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Introduction

Polychlorinated biphenyls (PCBs) comprise a family of 209 structurally related chemical congeners that were extensively produced and introduced into commercial use in the late 1920s (1). These compounds were originally prized for their remarkable electrical insulating capabilities and resistance to flames, making them highly sought-after materials across a spectrum of industries, including electrical equipment manufacturing, construction, and consumer goods production (2). Their unique chemical structure, consisting of two connected benzene rings with varying degrees of chlorine substitution, contributed to their desirable properties but also underlies their persistence and environmental impact. As a result of their widespread use and disposal over decades (3), PCBs have become pervasive environmental contaminants, persisting in soils, sediments, and water bodies long after their original applications (4).

PCBs have emerged as a focal point for the environmental movement across the globe starting in the 1960s. Unfortunately, the durability and chemical stability that once made PCBs valuable in industrial settings now contribute to their negative ecological and health effects (5,6). Attention to this characteristic of PCBs arose in the mid-1960s when Swedish researchers identified trace amounts of these compounds in fish, wildlife, and the environment (7). They were later confirmed in environmental samples within the U.S. and then led to worries about worker safety and public health, prompting regulators to prohibit PCB production in the U.S. and other nations to enforce environmental cleanup initiatives (2).

PCBs are highly bioavailable, meaning they can readily enter organisms through various pathways, including dermal contact, ingestion, and inhalation. Dermal contact refers to absorption through the skin, which can

occur when someone touches contaminated surfaces or materials. Ingestion, however, involves the consumption of contaminated food, water, or dust particles, while inhalation indicates breathing in airborne particles or vapors containing PCBs. Once absorbed, PCBs possess the ability to bioaccumulate within organisms, particularly in fatty tissues where they can persist for extended periods (8). The biomagnification of PCBs presents significant environmental and health risks. Exposure to elevated levels, particularly of more toxic congeners, has been associated with various adverse health effects in both humans and wildlife, including reproductive and developmental issues, immune system impairment, and carcinogenic effects. Ranjbaran et al (9) assessed the ecological and human health risks posed by certain PCBs in surface soils of Tehran, Iran, and found that inhalation represents the primary pathway of exposure to PCBs, with children being at greater risk of cancer compared to adults. Pérez-Maldonado et al (10) similarly evaluated the potential toxic effects of soils contaminated with PCBs on children across four sites in Mexico. Their results highlighted that the carcinogenic risk (CR) is a significant concern in the studied regions. Furthermore, the recent findings of Mosallaei et al (11) regarding dust samples from Shiraz city, Iran, have indicated that CR from ingestion of PCBs is negligible, although other exposure routes warrant further investigation.

Despite the growing body of evidence underscoring the risks posed by PCBs, research focused on CR associated with PCB exposure remains limited in Iranian urban environments. Known for its rapid urbanization and industrial growth, Isfahan has become one of Iran's most heavily polluted cities, facing significant challenges related to dust and air pollution (12). Given this context, the present study investigated PCB concentrations in indoor dust from public buildings in Isfahan to provide potential implications for both human and environmental health in this city. Concerning previous studies, we calculated CR from dermal, ingestion, and inhalation exposure pathways, particularly focusing on children and adults. By doing so, this study aimed to provide a more comprehensive understanding of the health impacts of PCBs in Isfahan and contribute to the limited body of research on PCB risks in Iranian cities.

Materials and Methods

Sample collection

This descriptive cross-sectional study was conducted in various indoor public buildings in Isfahan city in 2023. A random systematic sampling procedure was employed to select 28 locations. All locations were public institutional buildings where air circulation during the weeks leading up to sampling was carried out by natural ventilation. Dust samples were collected from non-floor hard surfaces, such as tables, that had not been cleaned or disturbed for weeks, allowing dust to accumulate. Samples were collected using a clean brush from areas where dust had accumulated on rigid hard surfaces. The collected samples were homogenized using a porcelain mortar and then transferred to zip-lock polyethylene bags. Each sample was labeled with information regarding the geographical coordinates of the sampling station and the date of sampling. Subsequently, the samples were promptly stored on ice and transported to the laboratory, where they were stored at -15 °C until preparation and laboratory analysis. The geographical distribution of the sampling stations is depicted in Figure 1.

Sample preparation and PCB extraction

Ten gram of each dust sample was weighed using a digital laboratory balance with an accuracy of 0.0001 g. The samples were then extracted using 30 mL of acetonitrile with n-hexane in a 10:1 volume ratio at 100 °C. This extraction process was repeated three times, and the resulting extracts were combined. Before extraction, 100 mL of 209-CB (1 mg/L as a standard) was added to each sample, and the solution was allowed to equilibrate in a desiccator for two hours. Next, the sample volume was reduced to one mL using a rotary evaporator under a nitrogen stream. The concentrated samples were loaded onto a column containing two grams of silica gel impregnated with silver nitrate (10% silver nitrate by weight, comprised of one gram of activated silica gel, one gram of basic silica gel, four grams of activated silica gel, four grams of silicic acid (22% sulfuric acid), and one gram of anhydrous sodium sulfate, all from Merck, Germany. Subsequently, the eluent was concentrated via rotary evaporation, and the volume was reduced to one mL under pure nitrogen to prepare it for subsequent analysis. Finally, the concentration of PCB compounds (ng/g), including congeners 18, 28, 37, 44, 49, 52, 70, 74, 77, 81, 87, 101, 118, 123, 126, 128, 138, 153, 156, 167, 169, 170, 177, 180, 183, 189, 195, 199, 206, and 209, was identified and measured using an Agilent 7890A gas chromatograph-mass spectrometer equipped with a Split/Splitless inlet (Agilent model 5977B) and a quadrupole mass spectrometer.

In this study, gas chromatography-mass spectrometry (GC-MS) calibration was performed using perfluorinated aminopherine (PFTRA), and the separation process utilized a capillary column packed with a polydimethylsiloxane stationary phase (HP-5MS) comprising 95% of the column material, with dimensions of 30 m × 0.250 mL and a thickness of 0.250 micrometers. The selected ion monitoring (SIM) method was employed to analyze each sample. This method focuses on specific m/z ions with high frequency and sensitivity rather than covering a broad m/z range.

Helium, with a purity of 99.99% and a flow rate of one mL per minute, was used as the carrier gas. To optimize

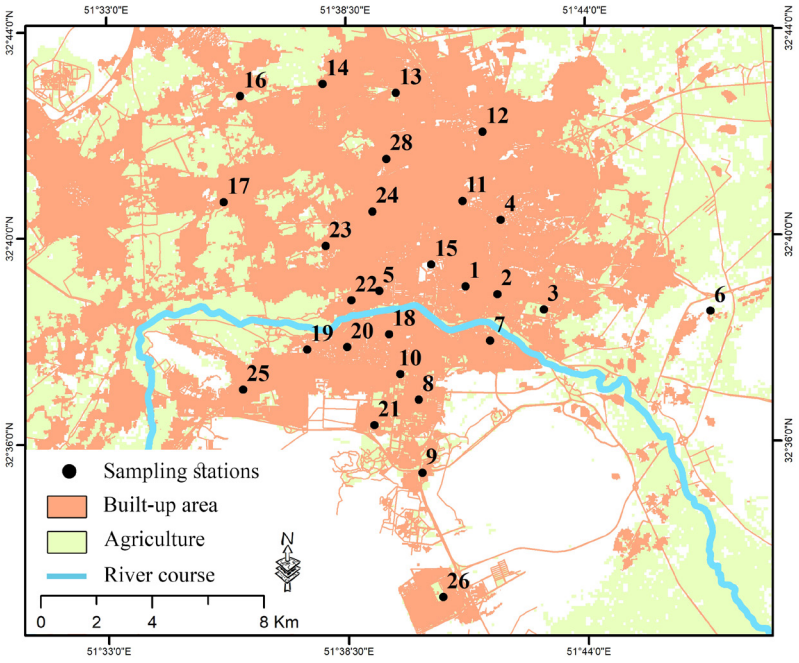

Figure 1. Location of surface dust sampling points in Isfahan city

the separation and peak resolution in the chromatogram, various temperature programs were applied to the column and injector. The splitless inlet mode was utilized, and the instrument was controlled using ChemStation E.02.01.1177 software. The inlet temperature was set to 290 °C. The initial oven temperature was held at 70 °C for 1 minute and then ramped up to 300 °C over 7 minutes. Additionally, the temperatures of the quadrupole mass analyzer and injector were maintained at 230 and 150 °C, respectively, with the injector set at 300 °C. These parameters were carefully chosen to optimize the separation and detection of target compounds during the GC-MS analysis. The PCB concentrations (in ng/g) obtained were evaluated for normality and statistical differences among the stations using the Kolmogorov-Smirnov test, as well as associated parametric or non-parametric mean comparison tests. To measure the limit of detection (LOD), three samples with various concentrations were chosen, and each sample was measured seven times.

Health risk assessment of PCB compounds

To evaluate the health risks and carcinogenic hazards associated with PCB exposure via ingestion, inhalation, and dermal contact with dust contaminated by PCBs, equations 1 through 4 were utilized. In equation 1, CRing represents the mean carcinogenic risk resulting from direct ingestion of PCB concentration in dust samples. The ingestion rate of PCB-contaminated dust particles (IR_{soil} *days*) was considered 100 mg.day^{-1} for adults and 200 mg.day^{-1} for children. Exposure frequency (EF) was set at 365 day.year^{-1} and exposure duration (ED) was set at 6 years for children and 24 years for adults for all equations. Additionally, the cancer slope factor (CFS_{ing}) of 7.3 mg.kg^{-1} day^{-1} was applied for both. An average human body weight (BW) of 70 kg and an exposure duration of 70 years (AT = 25,550 days) were considered for calculating the carcinogenic risk (Table 1).

Equation 2 estimates the carcinogenic risk from PCB inhalation (CRinh) due to exposure to PCBs in the air. The inhalation rate (IR_{air}) was set at 5.65 ($m^3.day^{-1}$) for children and 13.04 ($m^3.day^{-1}$) for adults. The particle emission factor (PEF) was considered as 1.36×10^9 ($m^3.kg^{-1}$). The cancer slope factor for inhalation (CFS_{inh}) was set at 3.85 $(mg.kg^{-1}\ day^{-1})^{-1}$ for both age groups. Equation 3 was applied to assess the carcinogenic risk associated with dermal contact (CRder) with PCB-contaminated dust. Skin area (SA- $cm^2.day^{-1}$) and absorption factor (AF- $mg.cm^{-2}$) were considered to be 2800 and 0.02 for children and 5700 and 0.07 for adults, respectively. The dermal absorption factor (ABS) was set at 0.13, and the gastrointestinal absorption factor (GIABS) was considered as 1 (Table 1). Equation 4 was used to calculate the total carcinogenic risk (TCR) by summing the results obtained from equations 1 to 3. The resulting CR values were classified into four distinct classes to categorize the carcinogenic effects, ranging from very low to very high, as detailed in Table 2.

$$CR_{ing} = \frac{CS \times \left(CFS_{ing} \times \sqrt[3]{BW/70}\right) \times IR_{soil} \times EF \times ED}{BW \times AT \times 10^6} \quad (1)$$

$$CR_{inh} = \frac{CS \times \left(CFS_{inh} \times \sqrt[3]{BW/70}\right) \times IR_{air} \times EF \times ED}{BW \times AT \times PEF} \quad (2)$$

$$CR_{\ddot{u}} = \frac{CS \times \left(CFS_{\ddot{u}} \times \sqrt[3]{BW/70}\right) \times SA \times AF \times ABS \times EF \times ED}{BW \times AT \times 10^{6}} \quad (3)$$

$$TCR \square CR_{der} \quad CR_{ing} \quad CR_{inh} \quad (4)$$

Results

The mean concentrations of PCBs (Figure 2) varied significantly between the sampling stations. The highest mean concentration of PCBs was found at station S24 (10.72 ± 11.00 ng/g), followed by S6 (9.52 ± 10.88 ng/g) and S22 (9.12 ± 9.70 ng/g), respectively. Conversely, the lowest mean concentrations of PCBs were observed at stations S10-11 and S12, all registering values of less than 3.00 ng/g. Representative chromatograms from PCB detection are provided in Figure 3. The Kolmogorov-Smirnov test indicated the absence of normal distribution among the stations. Furthermore, the Kruskal-Wallis test revealed that most stations exhibited statistically similar PCB concentrations, with a notable difference observed between S24 and S1-12 (Figure 2). Across all stations, there was considerable variability in the concentrations of different PCBs, exceeding the mean values. As illustrated in Figure 4A, PCBs with six chlorine atoms in their structure were the dominant group, with a mean concentration of 74.42 ± 22.10 ng/g, while PCBs with 2 and 9 chlorine atoms, showed the lowest concentrations, at 1.58 ± 0.66 and 2.19 ± 0.92 ng/g, respectively. Despite significant differences in the concentrations of PCBs with varying numbers of chlorine atoms, their concentrations were found to be significantly correlated. All correlation coefficients were positive ($r > 0.564$) and statistically significant at the 0.01 confidence level (Figure 4B).

The mean CR values were computed for both the adult and child groups across three pathways: inhalation, dermal contact, and ingestion. The CR values via inhalation were observed to be lower than those via dermal contact and ingestion, with mean values of 1.15E-09 ± 3.29E-10 for adults and 3.48E-10 ± 9.95E-11 for children. According to the CR classes provided in Table 3, the risk level is assessed as very low for both groups. Conversely, the CR values were categorized as low for both groups via ingestion and dermal pathways. The CRing (cancer risk via ingestion) ranged between 1.31E-05 and 3.83E-05 for adults and 1.83E-05 and 5.35E-05 for children. The mean CRing was higher in children (3.17E-05 ± 9.08E-06) than in adults (2.27E-05 ± 6.50E-06). Similarly, the mean CRder (cancer risk via dermal contact) was also higher in children compared to adults, although the difference was not significant. Moreover, the highest CRder observed in children (6.81E-05) did not differ significantly from that observed in adults (6.67E-05) (Table 3). Figure 5 shows station-based TCR values among both children and adults.

Table 1. Health risk assessment parameters used to measure carcinogenic risk through ingestion, dermal contact, and inhalation

Symbol	Unit	Age Group	
		Child	Adult
Cs	mg/kg	Figure 1	Figure 1
BW	kg	15	70
EF	$day.year^{-1}$	365	365
ED	Year	6	24
IR_{air}	$m^3.day^{-1}$	5.65	13.04
IR_{soil}	$mg.day^{-1}$	200	100
SA	$cm^2.day^{-1}$	2800	5700
AF	$mg.cm^{-2}$	0.02	0.07
ABS	Unitless	0.13	0.13
AT	Day	25550	25550
Pef	$m^3.kg^{-1}$	1.36×10^9	1.36×10^9
CFS_{der}	$(mg.kg^{-1}\ day^{-1})^{-1}$	25	25
CFS_{ing}	$(mg.kg^{-1}\ day^{-1})^{-1}$	7.3	7.3
CFS_{inh}	$(mg.kg^{-1}\ day^{-1})^{-1}$	3.85	3.85

Source: Pérez-Maldonado et al (10) and Ranjbaran et al (9).

Table 2. Carcinogenic risk classes and their quantitative effects from very low to very high

Effect	Class	CR Value Range
Very high	1	$CR \geq 10^{-1}$
High	2	$10^{-3} \leq CR < 10^{-1}$
Moderate	3	$10^{-4} < CR \leq 10^{-3}$
Low	4	$10^{-6} < CR \leq 10^{-4}$
Very low	5	$CR \leq 10^{-6}$

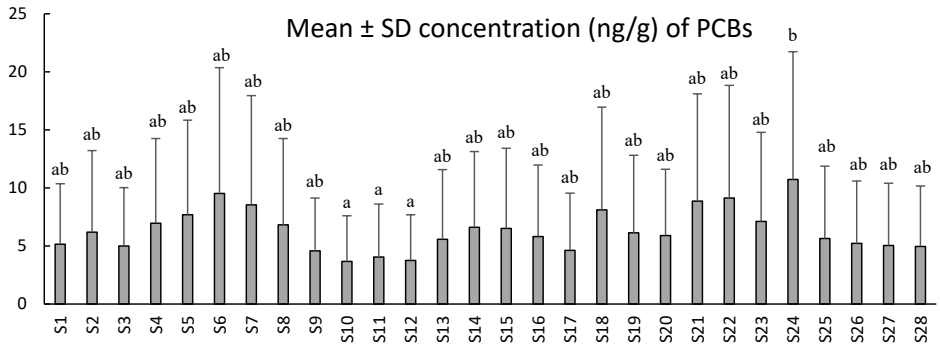

Figure 2. The error bars show the standard deviation of the PCB concentration at each station. Different letters indicate statistically significant differences ($P \leq 0.05$)

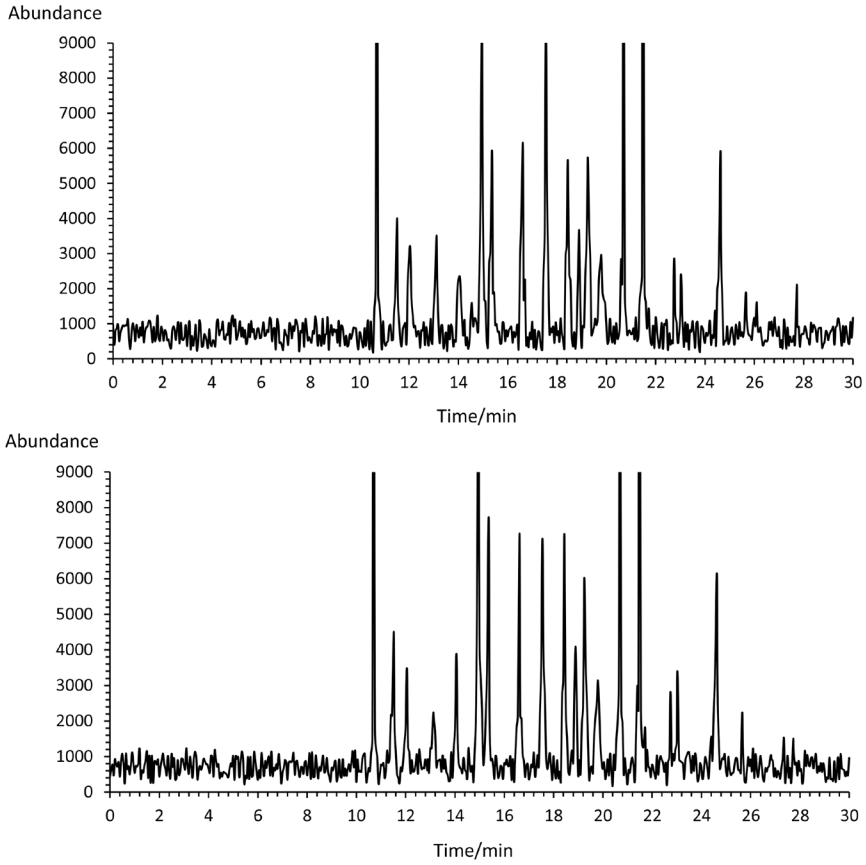

Figure 3. Representative chromatograms from PCB detection. The y-axis represents the signal strength (abundance) corresponding to the quantity of the compound detected by the analytical instrument, while the x-axis shows the time it takes for a specific PCB congener to pass through the chromatographic column and reach the detector

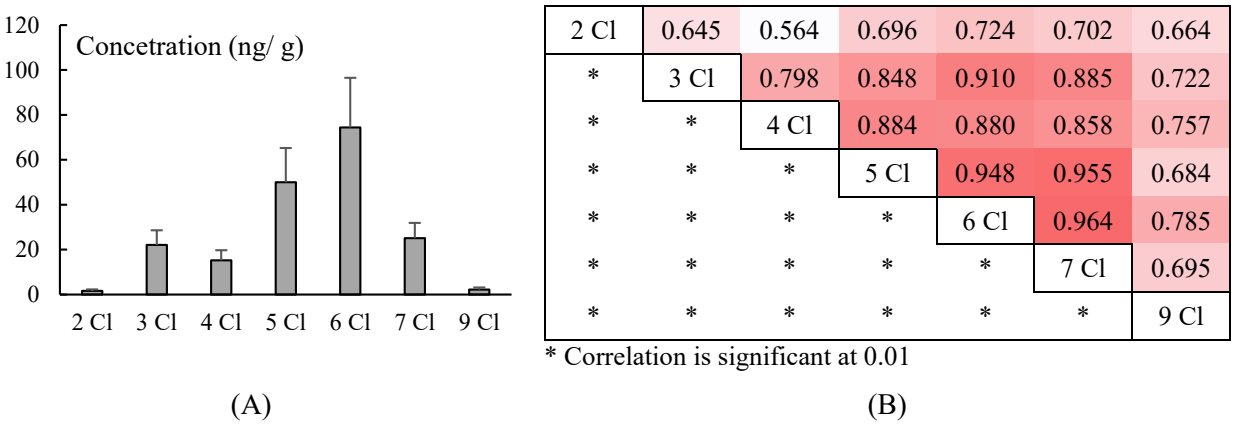

Figure 4. (A) Mean concentration of PCBs based on chlorine atoms (B) correlation coefficients among the PCBs with different chlorine atoms

Table 3. The results of carcinogenic risk among children and adults from three pathways—dermal, inhalation, and ingestion—and their corresponding risk classes

Human type	Carcinogenic risk	Descriptive statistic				Effect
		Min	Max	Mean	SD	
Adult	CRinhale	6.64E-10	1.94E-09	1.15E-09	3.29E-10	Very low
	CRingest	1.31E-05	3.83E-05	2.27E-05	6.50E-06	Low
	CRdermal	2.33E-05	6.67E-05	3.95E-05	1.16E-05	Low
Child	CRinhale	2.01E-10	5.87E-10	3.48E-10	9.95E-11	Very low
	CRingest	1.83E-05	5.35E-05	3.17E-05	9.08E-06	Low
	CRdermal	2.29E-05	6.81E-05	4.04E-05	1.13E-05	Low

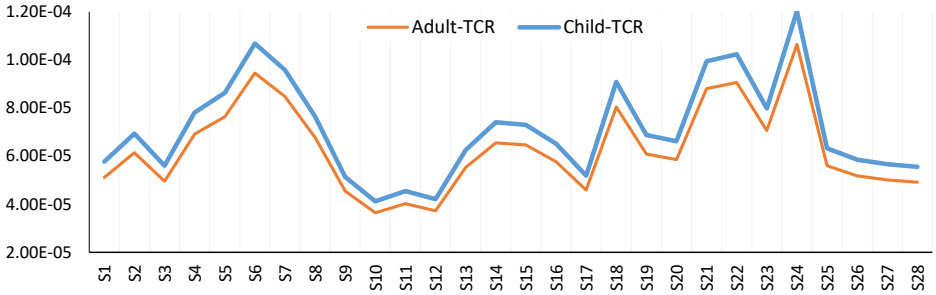

Figure 5. The results of the total carcinogenic risk (TCR) at the study stations for children and adults

In stations exhibiting higher concentrations of PCBs, TCR values were notably elevated, particularly at stations S6 and S24, while stations S10-12 showed the lowest CR values. The disparity between adults and children was not substantial, although the values observed in children were higher at all stations. These findings indicate that all stations within the region fall into the Low-risk category in terms of total CR effect.

Discussion

PCB concentration and distribution

The analysis of PCBs in indoor environments is a critical public health concern, as these enclosed spaces can act as reservoirs for PCBs, posing a significant threat to human health. The mean concentration of various PCBs (30 congeners) identified in this study was 6.35 ng/g, which is comparable to the value reported by Abafe and Martincigh (13) in Thessaloniki, Greece, but more than twice the concentration measured by Mosallaei et al (11) in indoor dust of Shiraz city, Iran. Limited sources of PCBs in public buildings and natural ventilation and the decreasing use of PCB-containing materials over time have also contributed to the lower levels. Existing studies indicate that these concentrations can even reach up to 650 ng/g in indoor environments, depending on the location and internal materials of the buildings (14), but are generally decreasing over time due to technological progress and limited application of PCB-containing materials (15).

Our results showed that the PCB concentrations measured in different indoor environments of the city are not statistically different, suggesting that their sources are uniformly distributed across the city, which resulted in consistent PCB concentrations. Moreover, this uniformity could indicate the presence of similar sources (products) of PCBs and comparable pathways leading to the deposition of PCBs on indoor surfaces, which might primarily include building materials and ventilation under the influence of some environmental conditions such as temperature, humidity, and air circulation. The highly significant correlation among various PCBs with different chlorine atoms also supports the existence of similar sources across the city. Among them, the high concentration of 6-Cl PCBs found in all samples might be attributed to their structure, which allows them to bind more firmly to various dust particles and exhibit lower solubility in water, thereby making them more prevalent in dust samples (16). Although the specific congeners may vary between studies, there are analogous instances where 6-Cl PCBs exhibited the highest concentration among other types in indoor dust samples, as demonstrated by the findings of Wang, (17) in Hong Kong and Guangzhou, China.

Carcinogenic effects of PCBs

There is substantial evidence indicating that exposure to PCB-contaminated dust poses a heightened health risk for young children. For example, Wang et al (17) demonstrated that this risk differential can exceed threefold in both indoor and outdoor environments of urban areas. Furthermore, numerous studies highlight that this risk is more pronounced among both young children and adults through dermal contact and ingestion (18). The present study supports these assertions. Our results indicate that the CR values associated with inhalation are significantly lower compared to those anticipated for ingestion and dermal contact, classifying inhalation CR as very low. This finding aligns with the conclusion drawn by Chandra Yadav et al (19), suggesting that human exposure to organochlorine compounds in indoor spaces via inhalation can be considered very low and negligible. Due to the chemical structure of PCBs, which includes hydrophobic properties and strong binding to dust particles (4), the primary exposure routes were found to be through skin contact with contaminated surfaces and the ingestion of dust particles. Therefore, the persistence of PCBs on surfaces makes them more accessible through these pathways than inhalation. In other words, this phenomenon is likely due to the low volatility of these compounds, which often bind to dust particles or surfaces rather than remaining freely airborne (11).

The CR values associated with ingestion and dermal contact were classified as low and were marginally higher among children than adults. This indicates that exposure to dust-bound PCBs is currently not a significant concern in the indoor public buildings of our city. This observation is consistent with the findings from other Iranian cities of similar size and climatic characteristics, such as Shiraz (11). Nevertheless, PCB concentrations and associated

CR effects have the potential to increase to higher levels and may even serve as vectors for other contaminants. For example, the presence of PCBs can enhance the exposure and bioavailability of co-adsorbed pollutants, thereby heightening health risks associated with indoor air quality, surface contamination, and dietary exposure. Effective management and remediation strategies are essential for mitigating exposures to PCBs and associated pollutants in indoor environments, ultimately reducing risks to human health. To address potential PCB exposure and associated risks, regular monitoring programs should be implemented in public buildings to detect any increases in PCB concentrations. Additionally, mechanical ventilation systems should be improved to minimize the buildup of airborne pollutants, and frequent cleaning of non-floor hard surfaces, particularly in high-traffic areas, should be ensured.

Conclusion

This study highlights the significant public health concern posed by PCB contamination in indoor environments. The uniform distribution of PCB sources across Isfahan suggests consistent exposure levels, underscoring the necessity of comprehending and addressing the pathways through which PCBs accumulate and affect indoor settings. While the identified risks were relatively low, particularly concerning inhalation, there are lingering concerns regarding the potential for PCBs to serve as vectors for other contaminants, thereby amplifying health risks through diverse exposure routes. Consequently, effective management and remediation strategies are imperative to decrease PCB exposures and mitigate associated health risks within indoor settings. Continued research efforts are warranted to further elucidate the sources, distribution, and impacts of PCB contamination, providing insights for targeted interventions aimed at safeguarding public health and promoting safer indoor environments.

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Authors' contributions

Conceptualization: Atefeh Chamani.
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Investigation: Mohammad Javad Saeedi.
Methodology: Mohammad Javad Saeedi.
Project administration: Atefeh Chamani.
Resources: Atefeh Chamani, Mohammad Javad Saeedi.
Software: Mohammad Javad Saeedi.
Supervision: Atefeh Chamani.
Validation: Atefeh Chamani.
Visualization: Mohammad Javad Saeedi.
Writing–original draft: Mohammad Javad Saeedi.
Writing–review & editing: Atefeh Chamani, Mohammad Javad Saeedi.

Competing interests

The authors declare no conflicts of interest or competing financial or personal relationships that could have influenced the results or interpretation of this study.

Ethical issues

The proposal for the present study was reviewed and approved by the Research Committee of Isfahan (Khorasgan) Branch, Islamic Azad University.

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