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Polychlorinated biphenyls in residential soils and their health risk and hazard in an industrial city in India

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Significance for public health

The concentrations of polychlorinated biphenyls (PCBs) in soils from an industrial city in India were measured for the assessment of human health risk. PCBs composition profiles were dominated with tri-chlorinated and tetra-chlorinated biphenyls. The possible sources of PCBs contamination can be attributed to local industrial emissions and long range transport depositions. The daily intakes of PCBs, and corresponding incremental lifetime cancer risk and hazard quotient for humans were estimated and found to be lower than acceptable levels. This baseline study may provide database on persistent organic pollutants in tropical countries and may also be useful in risks assessment of the industrial pollutants on human population.

Abstract

Background. Polychlorinated biphenyls (PCBs) have never been produced in India, but were used in industrial applications. PCBs have been detected in environmental samples since 1966, and their sources in soils come from depositions of industrial applications, incinerators and biomass combustions. PCBs adsorb to soil particles and persist for long time due to their properties. Their close proximity may also lead to human exposure through ingestion, inhalation, dermal contact, and may exert neurotoxic, mutagenic and carcinogenic health effects.

Design and Methods. Residential soil from Korba, India, was extracted using pressurized liquid extraction procedure, cleaned on modified silica and quantified for PCBs. Soil ingestion was considered as the main exposure pathways of life-long intake of PCBs. Human health risk in terms of life time average daily dose, incremental lifetime cancer risk (ILCR) and non-cancer hazard quotient (HQ) were estimated using established guidelines.

Results. The estimated average ILCR from non dioxin like PCBs for human adults and children was 3.1×10^{-8} and 1.1×10^{-7}, respectively. ILCR from dioxin like PCBs for human adults and children was 3.1×10^{-6} and 1.1×10^{-5}, respectively. The HQ for PCBs was 6.3×10^{-4} and 2.2×10^{-3}, respectively for human adults and children. Study observed that ILCR from non dioxin like PCBs was lower than acceptable guideline range of 10^{-6}-10^{-4}, and ILCR from dioxin like PCBs was within the limit. HQ was lower than safe limit of 1.

Conclusions. Study concluded that human population residing in Korba had low health risk due to PCBs in residential soils.

Introduction

During the past decades, toxic persistent organic compounds have been synthesized and released into the environment for direct or indirect application. Among them, chlorinated pesticides, polycyclic aromatic hydrocarbons (PAHs), polychlorinated dibenzo-*p*-dioxins and dibenzo-*p*-furans (PCDDs/Fs) and polychlorinated biphenyls (PCBs) are more environmental and human health concern.[1] PCBs are odourless, tasteless, colourless or light colour synthetic chemical compounds. These are highly stable compounds and were primarily used in electrical and industrial applications such as in transformers and capacitors, lubricants, flame retardants, plasticizers, paint additives, etc.[2] There are no known natural sources of PCBs, they originate in the environment solely from anthropogenic sources including leakages from electrical transformers, waste disposals and spillage, and their contamination sources in soils are particularly from particulate and gaseous depositions from industrial applications.[3] PCBs may also be released into the environment by the burning of some wastes in municipal and industrial incinerators. Building materials, such as caulking may also constitute a source of PCB contamination in the buildings and in surrounding soil. PCBs contents in building with caulking materials in USA found up to 81 mg/kg in dust and 3.3 to 34 mg/kg in surrounding soils.[4,5]

Due to lipophilicity, toxicity, tendency to accumulate in food chains, and low chemical and biological degradation, PCBs have been banned globally under the Stockholm Convention on POPs.[1] Non-*ortho*-substituted PCBs that exhibit *dioxin-like* activities similar to 2,3,7,8-tetrachorinated dibenzo-*p*-dioxin (TCDD), based on their ability to interact with and activate the Ah receptor (AhR), are known as dioxin-like PCBs (DL-PCBs). The World Health Organization (WHO) and US Environmental Protection Agency (USEPA) has proposed toxic equivalency factors (TEFs) for dioxin-like PCBs based on comparison with TCDD, which is considered to be the most potent congener of PCDDs/Fs. PCBs, especially DL-PCBs exposure through ingestion, inhalation and skin contact have long been recognized for their potential to cause health effects in wide variety of plants and animal species including humans. Human exposure to these compounds has been associated with their adverse affect on endocrine system, in addition to being neurotoxic, mutagenic, and carcinogenic in the liver, biliary tract and skin.[6,7] Occurrence of PCBs in remote areas, far from their original sources is thought to be the result of long range atmospheric transport and precipitation.[8] PCB in the environment altered their compositions through various processes such as volatilization and partitioning, chemical or biological transformation, and bioaccumulation. PCBs adsorb strongly to soil, where they tend to persist due to their characteristic properties and,[7] soil acts as a good indicator of pollution and environmental risks.

Accumulation of PCBs in soil may lead to contamination of vegetables and food chains.[2] The close proximity of soils to humans may also lead to human exposure through the consumption of contaminated food, and occupational exposure via ingestion, inhalation and dermal contact pathways. High content of these pollutants in soils may cause health risks to the living beings exposed to it. Therefore, several studies have been conducted around the world for assessing the status of human and environmental health risk due to PCBs in soils.[9-17]

PCBs have never been produced in India but used in industrial applications.[18] India is party to the Stockholm Convention with the objectives of intention of reducing and ultimately eliminating these pollutants.

Studies have been carried out in India, on the evaluation of PCBs in environmental matrices.[19-23] However, available reports on assessment of human health risk due to PCBs are less in numbers,[24+25] particularly, PCBs in soils and their risk were reported for North India, but no study was carried out in Central India. So, we determined 28 PCBs including 12 dioxin-like PCBs in residential soil and their health risk in the industrialized Korba city in Central India. This baseline data was compared with other studies, which may be useful in risks assessment of the industrial pollutants on human population.

Design and Methods

Study area and sampling

Korba, the study area, is located in the centre of the Korba District in Chhattisgarh, India (Figure 1) with the population of ~5×10^5. It is situated between geographical coordinates of 22°01' - 23°01' latitude and 82°08' - 83°09 longitude. Korba is enriched with coal and water resources (Hasdeo and Ahiran rivers) essential for power generation. Therefore, Korba is also known as *Power City* with several thermal and one hydro electric power plants generating more than 3650 MW of electricity. Besides these, one major aluminum plant is also operational in this area. Region experiences a typical climate, where April to June is summer, from June to October it is raining season with an average rainfall of 1500 mm, and winter season falls in November to February.

Sampling was carried out during June 2012 from twenty two locations.

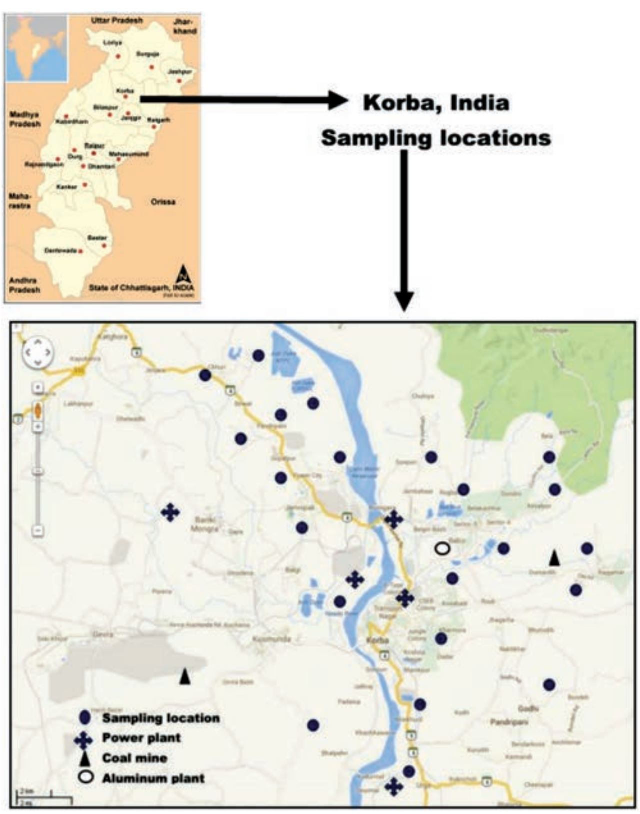

Figure 1. Map showing study area and sampling locations.

From each sampling location, approximately 500 grams of soil was collected in duplicates, and mixed thoroughly to ensure the representative sample from each location. An aliquot of homogenized soil was transferred to clean and labelled wide mouth amber glass containers. After labelling the sample containers, they were transported ice preserved to the laboratory and kept in refrigerator until further extraction.

Chemicals and materials

HPLC grade solvents used in sample processing were procured from Merck, India. Silica gel (100-200 mesh) procured from Sigma-Aldrich (USA) and activated at 130°C for 16 h. Anhydrous sodium sulphate (Merck, India) was cleaned with solvents and stored in the sealed desiccator. Reference standards of 28 PCB congeners were purchased from Dr. Ehrenstorfer (GmbH, Augsberg, Germany). Standard solutions with suitable concentrations were used for instrument calibration and other quality control analysis.

Sample extraction and clean-up

Soil samples were extracted using pressurized liquid extraction procedure as per USEPA's SW-846 Method 3545. 15-20 g sample was homogenized and dried by mixing with diatomaceous earth (ASE prep DE, Dionex, USA). The extraction was carried out with accelerated solvent extractor (ASE-350, Dionex, USA) using acetone: hexane (v/v, 1:1) in two cycles with 5 min. static time. The ASE was operated at 1500 psi and the oven was heated to 100°C. The extracts were concentrated to 2.0 mL using Rotatory Vacuum evaporator (Eyela, Japan).

The multilayered glass column chromatography with modified silica was performed for extract clean up. Multilayered silica column (300×30 mm) was packed from bottom to up with 2.5 g silica gel, 4.0 g silver nitrate silica gel, 2.5 silica gel, 4.0 basic silica gel, 2.5 g silica gel, 12.0 g acid silica and 5.0 g anhydrous sodium sulphate. The column was prerinsed with 100 mL n-hexane before sample was loaded. The elution of PCBs was subsequently carried out using 170 mL hexane and concentrated to 2.0 mL. The eluted extract was concentrated under gentle stream of pure nitrogen using Rotatory Vacuum evaporator and Turbo Vap (Caliper, USA) to 1.0 mL and transferred to auto sampler vial for PCBs analysis by gas chromatograph.

Quantification of polychlorinated biphenyls and quality control

Analysis of twenty eight PCB congeners (PCB-18, -37, -44, -49, -52, -70, -74, -77, -81, -105, -114, -118, -119, -123, -126, -128, -138, -151, -156, -157, -167, -168, -169, -170, -177, -187, -189 and -207) was carried out using gas chromatograph (Shimadzu SPD 2010) equipped with autosampler and electron capture detector (ECD, ^{63}Ni). One µL of clean sample extract was separated on HP-5MS column (60000×0.25 mm ×0.25 µm film). Initial column temperature of 170°C (1 min) was increased to 270°C at 3°C min^{-1} and held for 1 min, the temperature was again ramped to 290°C at 10°C min^{-1} and finally holds for 3 min. The injector and detector temperatures were kept at 225°C and 300°C, respectively. Purified laboratory grade nitrogen gas was used as carrier.

During analysis, required quality assurance quality control (QA/QC) was performed with procedural blanks, random duplicate samples, multi-level calibration curves (r^2, 0.999), calibration verification (<5%) and matrix spiked recovery (±20%). Each sample extract was analysed in duplicate and the average of two analyses was used in calculations. The detection limit (DL) was calculated with signal to noise ratio >3:1 by processing the eight aliquots of a spiked sample to produce a detectable response (s/n >3) and multiplying the standard deviation by 3 ($t_{students}$ value for eight replicates at 99% confidence level). Statistically calculated value (DL) for all PCB congeners (0.01 µg kg^{-1}) was used during data interpretation.

Health risk assessment

In this study, soil ingestion was considered as the main exposure pathways of life-long intake of contaminants in humans. Toxicity equivalency factors (TEFs) with reference to 2, 3, 7, 8,-TCDD have been assigned by World Health Organization for DL-PCBs for toxicity assessment. The toxic equivalent of DL-PCBs toxicity is expressed as toxic equivalent quotient (TEQ). Potential equivalent of carcinogenic dioxin-like PCBs was calculated using toxicity equivalency factors (TEFs).[7]

$$\text{Toxic equivalent (ng WHO}_{2005} - \text{TEQ kg}^{-1}) = \text{C} \times \text{TEF}$$

Where, C is the concentration of individual DL-PCB (µg kg^{-1}) and TEF is the corresponding toxicity equivalency factor.

Incremental lifetime cancer risk (ILCR) and hazard quotient (HQ) was assessed by calculating the lifetime average daily dose (LADD) of PCBs.[26,27] Equations used for estimating LADD, ILCR and HQ were as:

$$\text{LADD (mg kg}^{-1}\text{ d}^{-1}) = (\text{Cs} \times \text{IR} \times \text{F} \times \text{EF} \times \text{ED}) / (\text{BW} \times \text{AT})$$

$$\text{Cancer Risk (ILCR)} = \text{LADD} \times \text{Cancer Oral Slope Factor (CSF)}$$

$$\text{Hazard Quotient (HQ)} = \text{LADD/RfD}$$

Where, Cs is the pollutant concentration in soil (µg kg^{-1}), IR is the soil ingestion rate (mg/kg/d), F is the unit conversion factor, EF is exposure frequency (days/year), ED is the life time exposure duration (years), BW is the body weight (kg), and AT is the averaging time for carcinogens (ED×EF days). CSF is oral cancer slope factor (per mg/kg/day). RfD is the reference dose of individual dioxin like PCBs (per mg/kg/day).[28] Input parameters for risk estimates are mentioned in Table 1.[24,26,29,30]

Environmental health risk was carried out by comparing the PCBs levels in soils from Korba with stipulated guidelines for PCBs in soils for the protection of human and environment health. In India, guidelines for PCBs in soils have not yet established, therefore recommended guidelines from USA, New Zealand and Canada were adopted for the ecotoxicological risk assessment in this study.[27,28,31]

Results

Distribution of polychlorinated biphenyls in soils

In this study, we analysed twenty eight PCB congeners, including WHO's dioxin like PCBs in soils collected from different locations of Korba and their observed concentrations are presented in Table 2. The concentration of ∑28PCBs and ∑12DL-PCBs ranged between 3.25-25.22 µg kg^{-1} and 0.12-2.25 µg kg^{-1} with the mean and median value of 9.21 µg kg^{-1} and 0.65 µg kg^{-1}, and 8.22 (±1.17) µg kg^{-1} and 0.36 (±0.14) µg kg^{-1}, respectively (Table 2). PCB patterns were characterized in terms of individual homolog, but not by lower or higher chlorinated biphenyl. The PCB homolog pattern in soils at different locations is depicted in Figure 2. Tri- to tetra-chlorinated congeners were the major contributors and accounted for 88% to total PCBs and the contribution of remaining homolog is about 12%. Average concentration of total 3CBs, 4CBs, 5CBs, 6CBs and 7CBs was 7.7 µg kg^{-1}, 2.8 µg kg^{-1}, 0.6

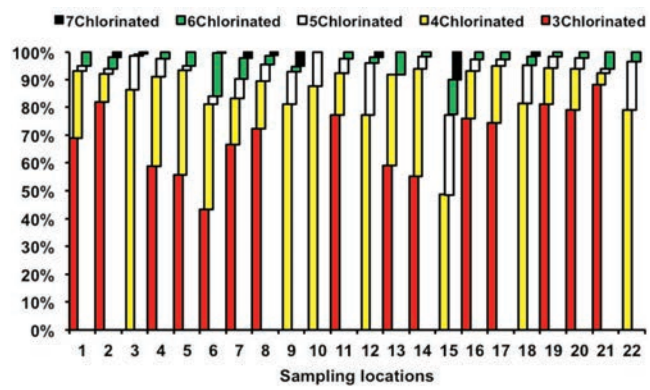

Figure 2. Polychlorinated biphenyls homolog pattern in soils at different locations.

Table 1. Summary of input parameters used in calculation for health risk assessment.

Symbol	Parameter	Unit	Point estimate	Ref.
Cs	Concentration	µg kg^{-1}	-	Present data
IR	Soil ingestion rate	mg day^{-1}	adult 100 children 200	24
EF	Exposure frequency	days/year	365 days/year	24
LT (EF×ED)	Life time	days	adult 25,550 children 4382	24
CSF	Cancer slope factor	mg kg^{-1} d^{-1}	PCBs 2 DL-PCBs=1.5×10^5	24
RfD	Reference dose	mg kg^{-1} d^{-1}	CB-77=1.0×10–5, CB-81=3.3×10^{-6}, CB-126=1.0×10^{-8}, CB-169 =3.3×10^{-8} CB-105,114,123,156,157,167,189=3.3×10^{-5}	26
ED	Exposure duration	years	adult 70 children 12	24,29
BW	Body weight	kg	adult 60 children 35	30

μg kg^{-1}, 0.5 μg kg^{-1} and 0.2 μg kg^{-1}, respectively. 3CBs (57%) was the most dominant homolog followed by tetra-chlorinated (31%).

The WHO toxicity equivalent quotient (TEQ) for 12 DL-PCBs varying greatly among locations, ranged between 1.52-64.32 ng-TEQ kg^{-1} with the mean and median values of 12.47 ng-TEQ kg^{-1} and 7.41ng-TEQ kg^{-1} (±3.38 ng-TEQ kg^{-1}), respectively (Table 3). Non ortho-PCB congener CB-169 was the main contributor and accounted for >99% to total TEQ. Congener CB-169 represent the higher TEQ values which had the second high toxic potency after PCB-126 (toxic equivalency factor for 126 and 169 is 0.1 and 0.03, respectively). PCB-126 concentration was below detection limit at all the locations, thus PCB-169 was sole contributor and significantly increased the ∑TEQ with the contribution of >99%.

Human intake of polychlorinated biphenyls and health risk assessment

Human adults and children may be exposed to PCB contaminated soils through different intake pathways. Due to carcinogenicity of PCBs and intake of contaminated soil through ingestion, human adults and children may get exposure to PCBs. Therefore, PCBs and DL-PCBs exposure assessment was carried out by estimating the incremental life time daily dose (LADD) followed by potential cancer risk (incremental life time cancer risk) (ILCR) and non-cancer risk (hazard quotient, HQ). For this study, the calculated LADD, ILCR for human adults and children from non-DL-PCBs, DL-PCBs-TEQ and HQ were presented in Table 3. The LADD of non-DL-PCBs for adults and children was between 4.6×10^{-9}-3.6×10^{-8} mg kg^{-1} d^{-1} and 2.4×10^{-8}-1.9×10^{-7} mg kg^{-1} d^{-1}, with an average value of 1.3×10^{-8} mg kg^{-1} d^{-1} and 6.8×10^{-8} mg kg^{-1} d^{-1}, respectively. However, the LADD of DL-PCB-TEQ for adults and children ranged between 2.2×10^{-12}-9.2×10^{-11} mg TEQ kg^{-1} d^{-1} and 1.1×10^{-11}-4.8×10^{-10} mg TEQ kg^{-1} d^{-1}, respectively with the mean value of 1.8×10^{-11} mg TEQ kg^{-1} d^{-1} and 9.2×10^{-11} mg TEQ kg^{-1} d^{-1}, respectively for adults and children.

Risks for human adults and children from non-DL-PCBs and DL-PCBs were estimated in terms of incremental life time cancer risk (ILCR) and hazardous quotient (HQ). The estimated ILCR from non-DL-PCBs to adults and children was between 9.3×10^{-9}-7.2×10^{-8} and 4.8×10^{-8}-3.7×10^{-7}, respectively, with an average value of 2.6×10^{-8} and 1.4×10^{-7}, respectively. However, the ILCR from DL-PCB-TEQ to adults and children was in the range of 3.3×10^{-7}-1.4×10^{-5} and 1.7×10^{-6}-7.1×10^{-5}, respectively with an average value of 2.7×10^{-6} and 1.4×10^{-5}, respectively.

The non-carcinogenic hazard quotients (HQs) for human adults and children from PCBs exposure through soil ingestion pathway were quantified. The average HQs was 5.4×10^{-4} and 2.8×10^{-3} for adults and children respectively (Table 3), and ranged between 6.6×10^{-5} to 2.8×10^{-3} and 3.4×10^{-4} to 1.4×10^{-2} for adults and children respectively (Figure 3).

Table 2. Concentrations (μg kg^{-1}) of polychlorinated biphenyls in residential soils from Korba, India.

Congener	Range	Mean	Median	SE	ΣPCBs, %
PCB-18	1.65-20.41	6.84	5.87	1.01	51
PCB-37	0.26-5.17	1.62	1.06	0.35	6.4
PCB-44	0.33-2.52	1.09	0.72	0.15	7.6
PCB-49	0.85-2.13	1.34	1.14	0.11	5.3
PCB-52	0.17-2.16	0.69	0.60	0.10	6.8
PCB-70	0.11-1.29	0.47	0.44	0.06	3.9
PCB-74	0.08-1.35	0.64	0.53	0.07	7.0
PCB-119	0.11-1.08	0.49	0.39	0.06	4.3
PCB-128	BDL				
PCB-138	BDL				
PCB-151	0.05-0.29	0.17	0.19	0.02	0.8
PCB-168	BDL				
PCB-170	BDL				
PCB-177	0.05-0.33	0.15	0.12	0.02	0.6
PCB-187	BDL				
PCB-207	0.06-0.34	0.16	0.07	0.03	0.2
ΣPCBs	2.99-23.47	8.62	7.95	1.09	93.5
PCB-77	BDL				
PCB-81	0.06-0.23	0.13	0.12	0.02	0.3
PCB-105	BDL				
PCB-114	0.06-0.40	0.17	0.14	0.02	0.8
PCB-118	0.06-0.14	0.08	0.07	0.01	0.2
PCB-123	0.05-0.58	0.23	0.19	0.04	0.8
PCB-126	BDL				
PCB-156	BDL				
PCB-157	BDL				
PCB-167	BDL				
PCB-169	0.05-2.14	0.42	0.25	0.11	3.9
PCB-189	0.09-0.25	0.16	0.14	0.01	0.5
ΣDL-PCBs	0.12-2.25	0.65	0.36	0.14	6.5
Σ28PCBs	3.25-25.22	9.21	8.22	1.17	100

SE, standard error; PCB, polychlorinated biphenyl; BDL, below detection limit.

Table 3. Estimated polychlorinated biphenyls (PCBs) toxic equivalent quotient, and life time average daily dose, incremental life time cancer risk and hazardous quotient for adults and children due to PCBs exposure.

Parameters	Range		Mean	Median
	Min.	Max.		
Toxic equivalent (ng WHO$_{2005}$-TEQ kg^{-1})	1.52	64.32	12.47	7.41
LADD$_{Non\ DL\text{-}PCBs}$ (mg kg^{-1} d^{-1})				
Adults	5.4×10^{-9}	4.2×10^{-8}	1.5×10^{-8}	1.4×10^{-8}
Children	1.9×10^{-8}	1.4×10^{-7}	5.3×10^{-8}	4.7×10^{-8}
LADD$_{DL\text{-}PCBs\text{-}TEQ}$ (mg kg^{-1} d^{-1})				
Adults	2.5×10^{-12}	1.1×10^{-10}	2.1×10^{-11}	1.2×10^{-11}
Children	8.7×10^{-12}	3.7×10^{-10}	7.1×10^{-11}	4.2×10^{-11}
ILCR$_{Non\ DL\text{-}PCBs}$				
Adults	1.1×10^{-8}	8.4×10^{-8}	3.1×10^{-8}	2.7×10^{-8}
Children	3.7×10^{-8}	2.9×10^{-7}	1.1×10^{-7}	9.4×10^{-8}
ILCR$_{DL\text{-}PCBs\text{-}TEQ}$				
Adults	3.8×10^{-7}	1.6×10^{-5}	3.1×10^{-6}	1.9×10^{-6}
Children	1.3×10^{-6}	5.5×10^{-5}	1.1×10^{-5}	6.4×10^{-6}
HQ				
Adults	7.7×10^{-5}	3.2×10^{-3}	6.3×10^{-4}	3.7×10^{-4}
Children	2.6×10^{-4}	1.1×10^{-2}	2.2×10^{-3}	1.3×10^{-3}

LADD, life time average daily dose; ILCR, incremental life time cancer risk; HQ, hazardous quotient; TEC, toxic equivalent quotient.

Discussion

Polychlorinated biphenyls in soils

PCB-18 was the major congener and accounted for 51% of ∑PCBs, the contribution of any other congener being less than 8%. WHO's DL-PCBs accounted for 6.5% to ∑28PCBs. *Non-Ortho* PCBs were contributing comparatively more than mono-ortho PCBs to total DL-PCBs. PCB congener 169 was the dominant contributor and accounted for 60% to ∑DL-PCBs.

In recently conducted studies, similar observations have been reported for PCBs in environmental matrices in India.[19,21,23] Major activities such as combustion process, automobile exhaust and the industrial activities have been reported as potential sources of PCBs in industrial areas.[32]

After release, PCB congeners in the ambient environment partition into the gaseous and particle phases. The partitioning of lower chlorinated congeners (Cl≤6) in the gas phase is higher compared with higher chlorinated congeners (Cl≥7).[33] Thus, low chlorinated congeners undergo greater long-range atmospheric transport to areas outside their source site than the higher chlorinated congeners. The observed homolog pattern in this study may have originated from the short range atmospheric transport from industrial sites,[17] and medium-range regional atmospheric deposition.[9] Soils from the areas those having more activities such as open fires, cooking and heating in residential areas, may have higher concentrations of PCBs, especially during the winter season. During such activities, especially burning of mixtures of waste, containing garden wastes, paper, plastics, PVC (polyvinyl chloride) and painted wood may produce relatively large amount of dioxin like-PCBs.

Global comparison of polychlorinated biphenyls in soils

Concentrations of PCBs observed in soils from Korba were compared with the recent measurements in other soils around the world including India. The comparative information is presented in Table 4.[10-17,22,23,33-38] The concentration ranges of PCBs observed in Korba (3.25-25.22 μg kg^{-1}) were comparable to sampling locations in Kurukshetra, India,[23] Beijing, China,[10] Central Ghana,[12] Estarreja, Portugal.[14] However, PCB levels were lower when compare to Mazandaran and Guilan, Iran,[15] Punjab, Pakistan,[16] Delhi, India,[22] Zhejiang, China,[17] Guangdong, China,[33] Moscow,[35] North India,[34] North America[35] and USA.[36-38] On the other hand PCBs concentrations in our study were higher than those reported from Addis Ababa, Ethiopia,[11] southeast China,[13] Binzhou, China,[34] Bursa, Turkey (Table 4).[37]

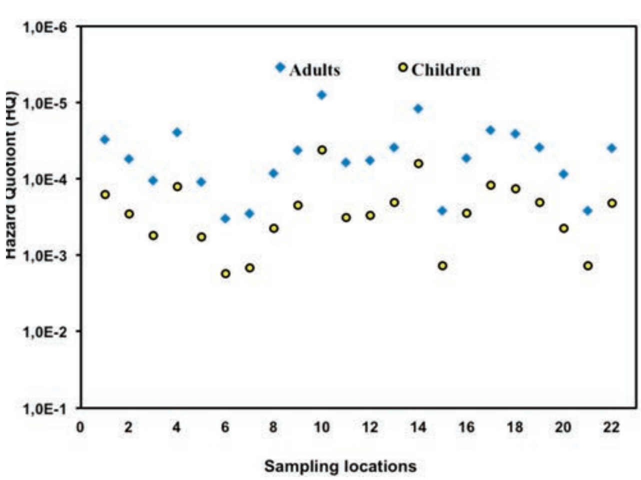

Figure 3. Hazard quotiont to adults and children due to total polychlorinated biphenyls exposure.

Health risk estimates

The estimated LADD of DL-PCBs-TEQ for adults and children corresponds to 0.018 pg TEQ kg^{-1} d^{-1} or 0.126 pg TEQ kg^{-1} week^{-1} and 0.092 pg TEQ kg^{-1} d^{-1} or 0.644 pg TEQ kg^{-1} week^{-1}, respectively. These estimated TEQ intakes for adults and children residing in Korba were lower when compared to recommended tolerable daily intake (TDI) or tolerable weekly intake (TWI) of TEQ set by the international agencies for safety of the public health. FAO/WHO and Agency for Toxic Substances and Disease Registry (ATSDR) and New Zealand Ministry of Health recommended the TDI for acute sub-chronic and chronic exposures to dioxins-TEQ as 1.0 pg TEQ kg^{-1} d^{-1}.[2,39,40] Environment Agency of United Kingdom recommended estimated adult intakes for PCDDs, PCDFs and dioxin-like PCBs as 2 pg WHO-TEQ kg^{-1} d^{-1}.[41] European Commission's Scientific Committee for Food (SCF) recommended and fixed a TDI and TWI of 2 pg WHO-TEQ kg^{-1} 14 pg WHO-TEQ kg^{-1} for dioxins and DL-PCBs.[40] In Asia, Japan established the comparatively higher TDI of dioxins as 4 pg-TEQ kg^{-1} d^{-1}.[42]

The observed cancer risks and HQ from this study were compared with other available studies. The cancer risks in Korba were found to be comparable with Delhi (adults 6.04×10^{-8}, children 3.13×10^{-7}),[22] Kurukshetra (adults 3.31×10^{-8}, children 1.71×10^{-7}) in India and Lisbon and Viseu in Portugal (adult 1.4×10^{-8}).[14,23] But, cancer risk was lower than Midway Atoll, USA (adult 0.11×10^{-6}), Catalan, Spain (adult 3.1×10^{-5}),[43] Zhejiang, China (adult 6.50×10^{-6} - 1.24×10^{-4})[44] and Finland (adult 2.3×10^{-6}).[45] The non-cancer risk in Korba were lower when compare with Delhi (adults 0.105, children 0.330),[22] Kurukshetra (adults 1.69×10^{-4} - 1.09×10^{-3}, children 9.09×10^{-3} - 1.26×10^{-2}) in India,[23] and Finland (adult, 0.8),[46] but higher than those from Catalan, Spain (adults, 8.3×10^{-5}, children, 8.9×10^{-5}).[43]

The estimated ILCR and HQs for residents of Korba were within acceptable risk limit of ILCR (10^{-4}), and of HQs (HQ=1) indicating a low risk.

Eco-toxicological health risk of polychlorinated biphenyls

Environmental guidelines for PCBs in soil have not been established in India. Therefore, non-carcinogenic effects of PCBs on environmental health in this area were assessed by applying guideline levels from USA, Canada and New Zealand. The concentration levels of PCBs observed from this study for Korba were much lower than USA (500 μg kg^{-1} and 5000 μg kg^{-1}, respectively for agriculture and, urban park and residential land use),[27] Canada (500 μg kg^{-1} to 33,000 μg kg^{-1} for different land use)[28] and New Zealand (soil screening criteria for PCBs, 220 μg kg^{-1} and 20,000 μg kg^{-1}, respectively for residential and parkland areas).[31] Therefore, study concluded with no environmental health risk and adverse effects on the soil micro-organisms, due to PCBs in studied soils.

Conclusions

The study concluded that concentrations of PCBs including dioxin like-PCBs were lower than recommended guidelines for soils for the protection of human and environmental health. Observed levels of PCBs were dominated with tri-chlorinated (3-Chlorine) and tetra-chlorinated (4-Chlorine) biphenyls. The possible sources of PCBs contamination in Korba can be attributed to local industrial emissions and long range

Table 4. Σ polychlorinated biphenyls in soils from India and other countries: comparison with present study.

Location	Land use	ΣPCBs concentration ($\mu g\ kg^{-1}$) Range	Mean	Ref.
Korba, India	Mixed	3.25-25.22	9.21	This study
Beijing, China	Urban	BDL-37.11	11.70	10
Addis Ababa, Ethiopia	Urban	0.4-19	3.80	11
Central, Ghana	Industrialized	1.32-12.94	8.17	12
Southeast, China	Industrialized	BDL-55.4	3.16	13
Estarreja, Portugal	Urban	2.3-17	8.8	14
Mazandaran and Guilan, Iran	Agriculture	7.5-34.6	25.7	15
Punjab, Pakistan	Mixed	7-45	-	16
Zhejiang, China	Industrialized	0.61-127.33	-	17
Delhi, India	Urban	1.08-100.67	21.16	22
Kurukshetra, India	Urban	3.33-34.81	11.57	23
Guangdong, China	Industrialized	7.4-4000	17-470	33
Binzhou, China	Urban-rural	BDL-87	2.6	34
Moscow, Russia	Urban	2.1-50.8	-	35
North India	Agriculture	<0.01-99.40	18.83	36
Bursa, Turkey	Industrialized	0.21-5.46	2.12	37
North America	Grassland	7.9-93	-	35
Sauget, IL, USA	Industrialized	-	487.2	36
Cedar Rapids, IA, USA	Garden	3-1200	56	37
Midway Atoll, USA	Military base	2.6-148.8	50.7	38

transport depositions. Estimated daily intakes of PCBs including dioxin like PCBs, and corresponding health risks, in terms of ILCR and HQ were lower than safe acceptable levels for human adults and children.

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