Congener specific distribution of polychlorinated dibenzo-*p*-dioxins and dibenzo-*p*-furans in ambient air particulates (<PM₁₀) in Delhi, India

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Abstract

Polychlorinated dibenzo-*p*-dioxins (PCDDs) and polychlorinated dibenzo-*p*-furans (PCDFs) are unintentionally formed during inefficient combustions and as a by-product. Due to their resistance to degradation and their toxic effect on health, PCDD/Fs are listed by the Stockholm Convention as persistent organic pollutants (POPs). Once released into the atmosphere, most of them are adsorbed to air particles and transported away from sources in atmosphere. India signed the Stockholm Convention India agreeing thereby to reduce and eliminate the use of POPs. The German agency for Technical Cooperation helped develop facilities for monitoring POPs at a national level in Delhi. This paper presents the data generated during a training assignment for Central Pollution Control Board officials at the German laboratory. Air borne particulate matter (<PM₁₀) was collected from 6 different locations in Delhi, India and analyzed in a German laboratory for 17 congeners of PCDD/Fs. The concentrations of Σ PCDD/Fs ranged between 1720-9010 fg m⁻³ (mean 5559 fg m⁻³) and their toxic equivalency values ranged from 67 to 460 fg I-toxic equivalent quantities (TEQ) m⁻³, with an average of 239 fg I-TEQ m⁻³ which was lower than the ambient air standards. The dominant congeners were octachlorinated dibenzo-*p*-dioxin (OCDD), octachlorinated dibenzo-*p*-furans (OCDF), 1,2,3,4,6,7,8-heptachlorinated dibenzo-*p*-furans, and 1,2,3,4,6,7,8-heptachlorinated dibenzo-*p*-dioxin. The contributions of individual homologs for Σ PCDD/Fs I-TEQ was in the order of OCDD (31%)>HCDF (21%)>hexachlorodibenzofurans (13%)=OCDF (13%)>HCDF (12%) and other individual congeners contribute less than 5%. High chlorinated congeners contributed with more than 80% for Σ PCDD/Fs I-TEQ. Rough estimates of tolerable daily intake (TDI) shows low health risk of exposure to Σ PCDD/Fs with inhalation of

0.098 pg I-TEQ kg⁻¹ day⁻¹ for adult and 0.152 pg TEQ kg⁻¹ day⁻¹ for children, which is much lower than World Health Organization recommended TDI for dioxins.

Introduction

Polychlorinated dibenzo-*p*-dioxins (PCDDs) and polychlorinated dibenzo-*p*-furans (PCDFs) are primarily formed from inefficient combustion processes, such as biomass combustion in incineration plants, sintering plants, cement kiln plants¹ and unintentional by-products from the synthesis of various chlorinated products.^{2,3} PCDD/Fs are ubiquitous chemicals, listed by the Stockholm Convention as one of 12 persistent organic pollutants (POPs). Due to their resistance to chemical, physical and biological degradation, they have been transported worldwide, affecting regions far from their original sources and found in all environmental media of the earth.⁴ PCDD/Fs adsorbed to dust particles in the atmosphere and most PCDD/Fs are found in the particulate phase.⁵ Gas-phase PCDD/Fs are believed to be depleted due to degradation reactions in the atmosphere, and the particle properties play an important role in the transport of particle-bound PCDD/Fs away from sources.⁶ Compared with the larger particles, the inhalable <PM₁₀ could remain longer in the air and, therefore, cause greater concern for human health.⁷ In this sense, the levels of PCDDs/Fs in <PM₁₀ have been recognized and have widened our knowledge about these pollutants resulting in stringent regulations aimed at protecting public health being established worldwide.⁸⁻¹⁴

Several studies have been carried out on the occurrence and distribution of PCDDs/Fs in India and have reported different matrices, such as water, soil, sludge,^{15,16} wildlife and biological samples,^{17,18} human milk^{19,20} and atmospheric air.²¹⁻²³

On 17th May 2004, the Stockholm Convention on POPs came into force with the intention of reducing and ultimately eliminating these pollutants. India is a signatory of the treaty the purpose of which is to encourage support for research on POPs. The Advisory Services in Environment Management (ASEM), the executive arm of the German agency for Technical Cooperation (GTZ) in India, helped develop facilities for monitoring POPs at the headquarters of the Central Pollution Control Board (CPCB). CPCB is a statutory body under the Ministry of Environment and Forest, and with this the Indian government is looking to identify the sources of persistent organic pollutants with a view to quantifying and estimating their potential release into the environment. A national implementation plan has already been developed.²⁴ This paper presents for the first

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time data on PCDDs/Fs levels in airborne particulate matter in Delhi which have been processed and analyzed at a German laboratory.

Materials and Methods

Study area

Delhi is the administrative capital city of India with a population of approximately 18 million. It is situated between the geographical coordinates of 28° 36' 36" N to 77° 13' 48" E. There are specified industrial zones with more than 8000 small to medium sized industries in the food, textile, chemical, paints, metallic and non-metallic dye sectors, etc.

The monitoring locations of the National Ambient Air Monitoring Programme in Delhi had been used for Ambient Air Sampling in

this study. Airborne particulate matter (PM₁₀) was monitored and sampled at 6 different locations in Delhi on US Environmental Protection Agency (USEPA) glass filter papers during March 2007 using respirable suspended particulate matter sampler (modified high volume sampler with cyclone for particle size cut off). Samples were taken every 24 h (6 a.m. to 6 a.m.) and collected operating the instrument at an average ambient airflow of 1.0 m³ min⁻¹. The exposed filter papers were wrapped in aluminum foil and shipped to Germany.

Chemicals and solvents

Solvents (acetone, dichloromethane, n-hexane, and cyclohexane) for organic trace analysis and chemicals (sodium sulfate, silver nitrate, potassium hydroxide, silica gel, aluminum oxide) were purchased from Merck (Darmstadt, Germany). Reference standard solutions of 17 PCDDs/Fs congeners in nonane (CS1 to CS5, extraction spike solutions and syringe spike solutions) used for instrument calibration, quantification, recovery and quality control were purchased from Wellington Laboratories Inc. (Guelph Ontario, Canada).

Sample extraction and cleanup

Sample extraction and cleanup was performed according to standard methods.²⁵ Sample extraction and cleanup was performed in the analytical laboratory for dioxin and furan of the Fraunhofer Institute for Process Engineering and Packaging (IVV) at Friesing, Germany. The exposed filter papers with particulate matter were spiked with the 2,3,7,8 substituted PCDD and PCDF as ¹³C₁₂ labeled quantification standards. The pollutants were extracted from the filter papers by Soxhlet with toluene for 24 h. Extracts were concentrated to near 5 mL using Buchi Rotary Vacuum Evaporator.

The extracts were cleaned after EN 1948 in two stages: first by modified multi-layer silica gel column and second alumina column chromatography. Primarily, cleanup of the extracts was performed on multilayered column (30x300 mm) packed with absorbent in the following order from bottom to top: 2.0 g activated silica, 5.0 g KOH silica, 1.0 g activated silica, 10.0 g sulfuric acid impregnated silica, 5.0 g silver nitrate coated silica and followed by 5.0 g sodium sulphate. After loading, the concentrated sample extracts were washed three times onto the column; the analytes were eluted with 250 mL n-hexane and concentrated to near 2.0 mL with rotavapor. The final cleanup of the concentrated elute was performed on aluminum oxide column (22x250 mm) using 25 g activated aluminum oxide (basic) and 10 g sodium sulphate. The elution of the analytes was carried out as fraction 1:60 mL n-hexane; fraction 2:120 mL of 2% dichloromethane in n-

hexane; and fraction 3:200 mL of dichloromethane/n-hexane (1:1 v/v). Fractions 1 and 2 were discarded as they contained unwanted analyte but dioxins containing fraction 3 were retained and concentrated to near 1.0 mL. The final concentrate was dried under gentle stream of high purity nitrogen. Before analysis, ¹³C₁₂ 1,2,3,4 tetrachlorinated dibenzo-*p*-dioxin (TCDD) was added as recovery standard.

Instrumental analysis

Identification and quantification of PCDDs/Fs were performed in the laboratory of the Bavarian Environmental Agency, Augsburg, Germany by HRGC-HRMS (Thermo, Finnigan MAT 95) coupled to auto sampler using a positive electron ionization (EI+) source operating selective ion mode at a 10,000 resolution (10% valley definition). Chromatographic separation was performed on a weakly polar 60 m×0.25 ID×0.25 μm (DB-XLB) capillary column. Quantification of each congener was performed by direct comparison of peak areas of mass fragmentograms for the (M+2)⁺-ion of the native compound and the (M+2)⁺-ion of the corresponding ¹³C₁₂-labeled standard (isotopic dilution method). For congeners with a concentration below the limit of quantification, signal to noise value of 10:1 of the mass was used for quantification.

Analytical quality assurance and quality control procedures were conducted using method blank and recovery of target analytes by spiking ¹³C₁₂-labeled standards. Recovery rates of ¹³C₁₂-labeled internal standards were within the acceptable 50-130% ranges set by the EN 1948 methods. Toxic equivalent quantities (TEQ) were calculated by multiplying the concentration of individual PCDD/PCDF congener with the corresponding toxicity equivalent factors (TEFs) proposed by the international system.²⁶ The results were presented as fg m⁻³ and their toxic equivalent in fg I-TEQ m⁻³.

Results

Concentrations of polychlorinated dibenzo-*p*-dioxins/ dibenzo-*p*-furans

The concentrations of 17 individual PCDD/PCDFs congeners and their I-TEQs in particulate matter (<PM₁₀) of Delhi are presented in Table 1 and Table 2, respectively. The concentrations of ΣPCDD/PCDFs in ambient air in Delhi ranged from 1720-9010 fg m⁻³ (mean 5559 fg m⁻³) and their TEQ values ranged between 67 to 460 fg I-TEQ m⁻³ (average 239 fg I-TEQ m⁻³).

Congener profiles and group homolog pro-

files of native PCDD/Fs in atmospheric particulate matter (<PM₁₀) in Delhi are illustrated in Figure 1 and Figure 2, respectively. The dominant congeners were octachlorinated dibenzo-*p*-dioxin (OCDD) (31%), 1,2,3,4,6,7,8-heptachlorinated dibenzo-*p*-furans (HpCDF) (19%), octachlorinated dibenzo-*p*-furans (OCDF) (13%) and 1,2,3,4,6,7,8-heptachlorinated dibenzo-*p*-dioxin (HpCDD) (12%) and all these together accounted for more than 75% of total native PCDD/PCDFs concentration (Table 1 and Figure 1) and these are all highly chlorinated PCDD/Fs. OCDD had the lowest toxic potency (toxic equivalency factor proposed internationally, I-TEF=0.0001), thus significantly lowering the total PCDD/F I-TEQ concentration. Similar profiles were obtained for all sampling locations and were found to be characterized by the predominance of OCDD, OCDF, 1,2,3,4,6,7,8-HpCDF and 1,2,3,4,6,7,8-HpCDD in the ambient air. The contributions of these four congeners to the total concentrations of PCDD/Fs were generally high. Considering homologous groups, an increase in the PCDDs concentrations was observed as chlorination level increased (low chlorinated<high chlorinated) (Figure 2). However, PCDF concentration increased with the increase in the degree of chlorination up to hepta-chlorinated. 2,3,4,7,8-pentachlorinated dibenzo-*p*-furans (34%) and 1,2,3,7,8-pentachlorinated dibenzo-*p*-dioxin (16%) congeners represent the higher TEQ values which both had high toxic potency (toxic equivalency factor proposed internationally I-TEF=0.5 and 1, respectively) thus significantly increasing the total PCDD/F I-TEQ and accounted for 50% (Table 2). The percent contributions of individual homolog for ΣPCDDs/Fs I-TEQ were in the order of OCDD (31%)>HCDF (21%)>hexachlorodibenzofurans (HxCDF) (13%)=OCDF (13%)>HCDF (12%) and other individual congeners have less than 5% contribution. High chlorinated congeners of PCDD (OCDD and HCDD) and PCDF (HxCDF, HCDF and OCDF) contributed with 43% and 47% for the ΣPCDD/Fs, I-TEQ (Figure 2).

Inhalation risk assessment

Diet ingestion, inhalation and dermal contact are the main pathways of direct exposure to toxic pollutants. Ambient and indoor air are potential sources of inhalation exposure to toxic substances. Adults and children may be exposed to contaminants in ambient air and may also inhale chemicals from various sources. Dioxins are associated strongly with carcinogenesis. To ensure public safety as far as possible, the tolerable daily intake of dioxins has been set by international agencies. The tolerable daily intake (TDI) is the amount of intake per kg of body weight per day of a chemical substance suspected of having adverse health effects when absorbed into the

Table 1. Concentration of polychlorinated dibenzo-*p*-dioxins/dibenzo-*p*-furans (fg m⁻³) in ambient air (PM₁₀) in Delhi.

Congener name	Sampling locations						All locations		
	DA1	DA2	DA3	DA4	DA5	DA6	Range	Mean	%
2,3,7,8-TCDD	5	<1	<1	<1	10	<1	<1-10	3	<1
1,2,3,7,8-PeCDD	70	10	50	10	70	20	10-70	38	1
1,2,3,4,7,8-HxCDD	53	10	40	<1	50	20	<1-53	29	1
1,2,3,6,7,8-HxCDD	117	20	90	10	110	60	10-117	68	1
1,2,3,7,8,9-HxCDD	80	10	70	10	70	30	10-80	45	1
1,2,3,4,6,7,8-HpCDD	1017	90	960	270	1040	620	90-1040	666	12
OCDD	2670	950	2290	800	2220	1530	800-2670	1743	31
2,3,7,8-TCDF	177	100	110	80	170	100	80-117	123	2
1,2,3,7,8-PeCDF	160	60	80	50	200	60	50-200	102	2
2,3,4,7,8-PeCDF	277	70	150	50	320	100	50-320	161	3
1,2,3,4,7,8-HxCDF	387	70	300	70	480	140	70-480	241	4
1,2,3,6,7,8-HxCDF	317	60	230	50	460	120	50-460	206	4
2,3,4,6,7,8-HxCDF	40	<1	<1	<1	30	<1	<1-40	35	<1
1,2,3,7,8,9-HxCDF	350	50	290	30	410	170	30-410	217	4
1,2,3,4,6,7,8-HpCDF	1477	220	1770	170	1930	690	170-1930	1043	19
1,2,3,4,7,8,9-HpCDF	183	20	200	30	240	90	20-240	127	2
OCDF	923	150	1540	90	1200	510	90-1540	736	13
ΣPCDDs	4012	1090	3500	1100	3570	2280	1090-4012	2592	47
ΣPCDFs	4290	800	4670	620	5440	1980	620-5440	2967	53
ΣPCDD/ΣPCDF	0.94	1.36	0.75	1.77	0.66	1.15	0.66-1.77	1.10	-
ΣPCDDs/Fs	8302	1890	8170	1720	9010	4260	1720-9010	5559	100

PCDDs, polychlorinated dibenzo-*p*-dioxins; PCDFs, polychlorinated dibenzo-*p*-furans; TCDD, tetrachlorinated dibenzo-*p*-dioxin; HpCDF, heptachlorinated dibenzo-*p*-furans; HpCDD, heptachlorinated dibenzo-*p*-dioxin; PeCDF, pentachlorinated dibenzo-*p*-furans; PeCDD, pentachlorinated dibenzo-*p*-dioxin; HxCDF, hexachlorodibenzofurans.

Table 2. Toxic equivalent quantities (TEQ) of polychlorinated dibenzo-*p*-dioxins/dibenzo-*p*-furans (fg I-TEQ m⁻³) in ambient air (PM₁₀) in Delhi.

Congener name	Sampling locations						All locations		
	DA1	DA2	DA3	DA4	DA5	DA6	Range	Mean	%
2,3,7,8-TCDD	5.0	<1	<1	<1	10.0	<1	<1-10	3	1
1,2,3,7,8-PeCDD	70.0	10.0	50.0	10.0	70.0	20.0	10-70	38	16
1,2,3,4,7,8-HxCDD	5.3	1.0	4.0	<1	5.0	2.0	<1-5	3	1
1,2,3,6,7,8-HxCDD	11.7	2.0	9.0	1.0	11.0	6.0	1-12	7	3
1,2,3,7,8,9-HxCDD	8.0	1.0	7.0	1.0	7.0	3.0	1-8	5	2
1,2,3,4,6,7,8-HpCDD	10.2	1.0	9.6	2.7	10.4	6.2	1-10	7	3
OCDD	<1	<1	<1	<1	<1	<1	<1	<1	<1
2,3,7,8-TCDF	17.7	10.0	11.0	8.0	17.0	10.0	8-18	12	5
1,2,3,7,8-PeCDF	8.0	3.0	4.0	2.5	10.0	3.0	3-10	5	2
2,3,4,7,8-PeCDF	138.3	35.0	75.0	25.0	160.0	50.0	25-160	81	34
1,2,3,4,7,8-HxCDF	38.7	7.0	30.0	7.0	48.0	14.0	7-48	24	10
1,2,3,6,7,8-HxCDF	31.7	6.0	23.0	5.0	46.0	12.0	5-46	21	9
2,3,4,6,7,8-HxCDF	4.0	<1	<1	<1	3.0	<1	<1-4	1	<1
1,2,3,7,8,9-HxCDF	35.0	5.0	29.0	3.0	41.0	17.0	3-41	22	9
1,2,3,4,6,7,8-HpCDF	14.8	2.2	17.7	1.7	19.3	6.9	2-19	10	4
1,2,3,4,7,8,9-HpCDF	1.8	<1	2.0	<1	2.4	1.0	<1-2	1	1
OCDF	<1	<1	<1	<1	<1	<1	<1	<1	<1
ΣPCDDs/Fs	400	83	272	67	460	151	67-460	239	100

PCDDs, polychlorinated dibenzo-*p*-dioxins; PCDFs, polychlorinated dibenzo-*p*-furans; TCDD, tetrachlorinated dibenzo-*p*-dioxin; HpCDF, heptachlorinated dibenzo-*p*-furans; HpCDD, heptachlorinated dibenzo-*p*-dioxin; PeCDF, pentachlorinated dibenzo-*p*-furans; PeCDD, pentachlorinated dibenzo-*p*-dioxin; HxCDF, hexachlorodibenzofurans.

body over a long period of time. Daily dioxin inhalation exposure doses in Delhi for adults and children are computed by the equation after Health Canada²⁷ (1995) and Agency for Toxic Substances and Disease Registry (ATSDR).²⁸

$$ED_{inh} = (IR \times Conc_{air} \times EF) / BW$$

Where ED_{inh} is the inhalation exposure dose in pg I-TEQ $kg^{-1} day^{-1}$, IR is inhalation rate (20 $m^3 day^{-1}$ for adults and 12 $m^3 day^{-1}$ for children); $Conc_{air}$ is the average air concentration of dioxin in pg I-TEQ m^{-3} ; EF is exposure factor and conservatively used as 1 for this study, representing a daily exposure to the PCDD/Fs; BW is the body weight (70 kg for adults and 27 kg for children).

In our study, the gaseous PCDD/Fs were not determined. Previous studies carried out in Asian countries indicate that the range of relative particle-bound PCDD/Fs concentration is wider²⁹ i.e. from 36.4% to 71.5%. For the calculation of total TEQ concentration we conservatively used the values of 70% PCDD/Fs in particle and 30% PCDD/Fs in gaseous phase.³⁰ The total TEQ values thus calculated was 341 fg I-TEQ m^{-3} . The rough estimates of inhalation risk of PCDD/Fs are presented in Table 3 which shows that residents in Delhi have inhalation exposure to PCDD/Fs with 0.098 pg I-TEQ $kg^{-1} day^{-1}$ for adults and 0.152 pg TEQ $kg^{-1} day^{-1}$ for children.

Discussion

Concentrations of polychlorinated dibenzo-*p*-dioxins dibenzo-*p*-furans

The observed concentrations of PCDDs/Fs in ambient air at were considerably lower than the ambient air standard of 0.6 pg I-TEQ m^{-3} proposed by Japan¹⁴ and 1.0 pg I-TEQ m^{-3} expressed as 2,3,7,8-TCDD equivalents in the ambient air in the State of Connecticut in USA.⁸ According to Lohmann and Jones,⁶ PCDD/F concentrations for the total sum of TEQ are typically as follows: remote <10 fg I-TEQ m^{-3} ; rural ~20-50 fg I-TEQ m^{-3} ; and urban/industrial ~100-400 fg I-TEQ m^{-3} . Concentrations of PCDDs/Fs observed in Delhi are comparable to those found in other urban areas worldwide. Similar to our results, the concentrations of Σ PCDD/Fs have been reported by other workers.³¹⁻³⁴ The observed concentrations of Σ PCDD/Fs in this study were higher than those in ambient air of Taiwan,³⁵ Durban, South Africa,³⁶ Manizales, Colombia,³⁷ Porto, Portugal,³⁸ and selected cities of Hong Kong.³⁹ However, higher concentrations of Σ PCDD/F in ambient air have been reported in literature.^{30,40-43}

Group homolog distribution of PCDDs/Fs in

Table 3. Rough assessment of inhalation risk (pg I-toxic equivalent quantities $kg^{-1} day^{-1}$) of polychlorinated dibenzo-*p*-dioxins/Fs in Delhi.

Locations	Concentration		PCDD/Fs inhalation	
	Air phase	(pg I-TEQ m^{-3})	Adult	Children
DA1	Particle phase	0.400	0.114	0.178
	Particle+gas phase*	0.571	0.163	0.254
DA2	Particle phase	0.083	0.024	0.037
	Particle+gas phase*	0.119	0.034	0.053
DA3	Particle phase	0.272	0.078	0.121
	Particle+gas phase*	0.389	0.111	0.172
DA4	Particle phase	0.067	0.019	0.029
	Particle+gas phase*	0.096	0.027	0.043
DA5	Particle phase	0.460	0.131	0.204
	Particle+gas phase*	0.657	0.188	0.292
DA6	Particle phase	0.151	0.043	0.067
	Particle+gas phase*	0.216	0.062	0.096
All locations	Particle phase	0.239	0.068	0.106
	Particle+gas phase*	0.341	0.098	0.152

PCDDs/Fs, polychlorinated dibenzo-*p*-dioxins/dibenzo-*p*-furans; TEQ, toxic equivalent quantities. *Gaseous PCDD/Fs are conservatively estimated as 30% of the total PCDD/Fs.

Figure 1. Concentration profiles of polychlorinated dibenzo-*p*-dioxin/dibenzo-*p*-furans congener in ambient air (PM_{10}) in Delhi.

Figure 2. Percent of native polychlorinated dibenzo-*p*-dioxin/dibenzo-*p*-furans homologues in ambient air (PM_{10}) in Delhi.

Delhi was similar to that found by various researchers in the ambient air for other cities in the world.^{6,34,35} It is interesting to note that the homologous groups profile found in this study is very similar to that of air borne particulate from Standard Reference Material (SRM-1649) of National Institute Standards and Technology.⁴⁴

During many chemical reactions it has been found that PCDDs and PCDFs are formed as unwanted by-products. Another important primary source of PCDDs and PCDFs are combustion processes that involve burning of chlorinated organic or inorganic compounds resulting in the formation of PCDDs and PCDFs. Of special importance are the incinerations of various types of wastes, such as municipal, hospital and hazardous wastes, and the production of iron and steel and other metals (copper, magnesium, nickel).⁴⁵ In general, the ratio of $\Sigma\text{PCDD}/\Sigma\text{PCDF}$ was previously reported to be a good indicator for possible formation processes or emission sources of the PCDD/Fs.⁴⁶ The ratio of $\Sigma\text{PCDD}/\Sigma\text{PCDF}$ from chemical reaction formation is greater than 1, while *de novo* synthesis during combustion processes normally shows a ratio of $\Sigma\text{PCDD}/\Sigma\text{PCDF}$ less than 1.^{30,31} In this study, the ratio of $\Sigma\text{PCDD}/\Sigma\text{PCDF}$ varies from 0.66 to 1.77 (average 1.10) (Table 1). In addition to the observation from the SPCDDs/S PCDFs ratio, the TEQs for PCDFs were 2-3 times higher than those for PCDDs. In our study, PCDFs were the major contributors to the TEQs in the atmospheric particles at different locations in Delhi. This is in agreement with data reported for particle-bound PCDD/Fs.⁵ The characteristics of the profiles and $\Sigma\text{PCDD}/\Sigma\text{PCDF}$ ratios suggest the reaction processes are driven from precursors as well as by *de novo* synthesis during combustions. The homolog profiles at sampling locations DA1, DA3 and DA5 were enriched in PCDFs, and can, therefore, be classified as *source* profiles,⁴⁷ meaning that the source for the homologs at these locations were not far away. Therefore, it indicates that *de novo* synthesis could be the main formation mechanism for the sources of the PCDD/PCDFs in the ambient air of Delhi, India, which could be highly influenced by anthropogenic activities like combustion sources such as small diffuse combustion sources, *e.g.* domestic burning of fossil fuels, traffic, non-industrial combustion and uncontrolled open mass burning.

Inhalation risk assessment

The Joint FAO/WHO Expert Committee on Food Additives¹⁰ recommended a TDI for dioxin as 1.0 pg I-TEQ kg⁻¹ d⁻¹ and a warning value of 4.0 pg I-TEQ kg⁻¹ d⁻¹ or 70 pg to 280 pg day⁻¹ for 70 kg adult. The USEPA⁸ recommends that the daily inhalation exposure to dioxins should not exceed 1.0 pg WHO₉₈-TEQ kg⁻¹ d⁻¹. The

ATSDR⁴⁸ assessed the non-cancer risks from dioxin exposure by setting minimal risk levels (MRLs) for acute sub-chronic and chronic exposures to dioxins, and the chronic MRL was set at 1 pg kg⁻¹ d⁻¹. The Scientific Committee for Food of the European Commission¹¹ set a tolerable weekly intake of 14 pg WHO-TEQ/kg body weight for dioxins and 12 dioxin-like PCBs. In 1999, Japan¹³ established the TDI of dioxins at 4 pg-TEQ kg⁻¹ d⁻¹.

Table 3 shows that residents of Delhi seem to have a low health risk from exposure to PCDD/Fs. However, the most significant uptake route of dioxins and furans is via the diet. Almost 95% of TDI is taken up by food contamination. Inhalation intake doses have been reported to contribute approximately 1-2% to the total daily intake.^{13,32} Due to lack of data about PCDD/F diet exposure we cannot give precise total daily dioxin intake. However, according to our inhalation results, we can conclude that the TDIs of dioxins for the residents of Delhi, India were extremely low.

Conclusions

The concentrations of PCDD/PCDFs in ambient air in Delhi were lower than the ambient air standard stipulated by various environmental agencies. Rough estimated TDIs of inhalable PCDD/Fs for residents in Delhi are very low. Suggested sources could be anthropogenic activities of small diffuse combustions, *e.g.* domestic burning of fossil fuels, traffic, non-industrial combustion and uncontrolled open mass burning. The current data are still not sufficient to allow us to draw any concrete conclusions concerning the situation in Delhi and other Indian cities. More monitoring programs and studies on PCDD/Fs are required.

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