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Distribution and Ecotoxicological Risk Assessment of Persistent Organic Pollutants (POPs) In River Sediments from Delhi, India

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Abstract

Persistent organochlorine pesticides (OCPs) like hexachlorocyclohexane (HCH), and dichlorodiphenyltrichloroethane (DDT) and polychlorinated biphenyls (PCBs) and their ecotoxicological risks were investigated in river bank sediments from Yamuna in Delhi, India. The concentration of ∑HCH, ∑DDT and ∑PCBs ranges between 19.25-731.82 (208.17±20.66) ng g^{-1}, <0.01-21.21 (1.32±0.36) ng g^{-1} and 0.16 to 30.05 (7.69±0.90) ng g^{-1}, respectively. The composition analysis of HCH and ratio of α-HCH/γ-HCH reflects the usage of technical HCH and lindane. The ratios of DDT and their metabolites indicate historical inputs of DDT or the biotransformation of DDTs in this area. Tri and tetra chlorinated biphenyls (PCB-37 and PCB-44) contributed >80% of the ∑PCBs contamination. Concentration of HCHs, DDT and PCBs did not exceed sediment quality guidelines with the exception of lindane which was above sediment guidelines as lindane formulation are registered in India for use in public health practices to control vector borne diseases.

Keywords: Pesticides, POPs, HCH, DDT, PCBs, River Sediment, India

1. Introduction

For the past thirty years, a serious concern has arisen due to the presence of persistent organic pollutants (POPs) in the environment and their threat to the wild life and mankind. As is well known, DDT and PCBs were listed by the Stockholm Convention as 2 of 12 persistent organic pollutants (POPs) in 2004, and more recently, α-HCH, β-HCH, and γ-HCH (lindane) were added to the list in 2009 (Hu *et al*., 2010). HCH, DDT and polychlorinated biphenyls (PCBs) are ubiquitous chemicals and persistent, toxic and bio-accumulative in nature (Minh *et al*., 2006; Shegunova *et al*., 2007). These are long range transport pollutants and can be transported to regions far from their original sources, such as the Arctic (Halsall *et al*., 1998; Becker *et. al*., 2009). They have a wide range of acute and chronic health effects, including cancer, neurological damage, reproductive disorders, immune suppression, birth defects, and are also suspected endocrine disruptors (Van Den Berg *et al.* 2006; Wang *et al*., 2008; Mitra *et al*., 2011).

Their physico-chemical characteristics, which include hydrophobicity and resistance to degradation, make these chemicals ultimately to accumulate in soils, sediments and biota (Yang *et al*., 2005; Covaci *et al.* 2005; Kalantari and Ebadi, 2006; Hong *et al*., 2008; Wang *et al*., 2008; Musa *et al*., 2010) and in human body through dietary intake, inhalation and other indirect exposure (Ebadi and Shokrzadeh, 2006; Alle *et al*., 2009). OCPs have a great affinity for particulate matter so they can be deposited in the aquatic systems during sedimentation and can remain in sediments for very long due to their long half-life times. Sediment is a complex mixture of solids, liquids and gases which is the life support system for benthic biota (Hakanson, 1992). Potential effects on interest of these compounds are accumulation and persistence in sediments and can pose a hazard to sediment dwelling organisms at concentrations greater than sediment guidelines. Sediments are one of the best media for the monitoring of organic compounds as they provide valuable information of contamination in an aquatic ecosystem (Chang and Doong, 2006; El-Sherif *et al*., 2009; Gomez *et al*., 2011).

In May 2004, Stockholm Convention on POPs entered into force with the intention of reducing, and ultimately eliminating these pollutants. As a party to the Convention, India is legally obligated to abide by the objectives of the treaty, and is encouraged to support research on POPs. In India, some studies have been conducted into distributions of POPs, such as intentionally released insecticide DDT and HCH, little known about the unintentionally released of other POPs, such as PCBs and dioxins. Investigations dealing with various environmental matrices in India revealed OCPs and PCBs contaminations in air, water, sediment (Guzzella *et al*., 2005; Zhang *et al.* 2008; Chakraborty *et al.* 2010; Kumar *et al*., 2011[a,b,c,d]; Devi *et al*., 2011; Mukherjee *et al*., 2011; Pozo *et al*., 2011), biota and humans (Senthil Kumar *et al*., 2001b; IPEN, 2006; Mishra *et al*., 2008; Devanathan *et al*., 2008; Someya *et al.*, 2009; Kumar and Mukherjee, 2011; Kumar *et al*., 2011). In continuation of support research on POPs, this study was aimed to evaluate persistent organochlorine pesticide (HCH and DDT) and polychlorinated biphenyls (PCBs) concentration in bank sediments from Yamuna River in Delhi, India. Further, their possible ecotoxicological effects were roughly evaluated by applying published sediment quality guidelines.

2. Materials and Method

2.1 Description of study area

The River Yamuna, a major tributary of River Ganges, originates from the Yamunotri glacier of the lower Himalayas. The river flows through Himachal Pradesh, Uttrakhand and Haryana states. It enters Delhi near Palla village after traversing a route of about 224 Km. and the River is tapped at Wazirabad through a barrage for drinking water supply to Delhi. Generally, no water is allowed to flow beyond Wazirabad barrage in dry season, as the available water is not adequate to fulfill the demand of water supply of Delhi. Whatever water flows in the downstream of Wazirabad barrage is the untreated or partially treated domestic and industrial wastewater contributed through several drains. Delhi alone generates 1,900 million liter per day (MLD) of sewage, against an installed wastewater treatment capacity of 1,270 MLD. Thus 630 MLD of untreated and partially treated sewage enters the river every day. After 22 Km downstream of Wazirabad barrage there is Okhla barrage and water is not allowed to flow through barrage during dry season. The total catchment area of Yamuna River in Delhi stretch is about 1485 Km^2.

Figure 1: Map showing Yamuna River in Delhi, India

2.2 Sampling

Sampling was carried out from the Yamuna river bank in Delhi extending between Palla, Wazirabad and Okhla (Figure 1). Sixty sediment samples in duplicates were collected during October, 2010. After sample collection pebbles and woods removed manually and mixed thoroughly to ensure that the sediment collected was truly representative of each location. Sub-samples of the sediment were subsequently taken and stored in labelled wide mouth amber glass bottles and transported ice-preserved to the laboratory and stored at -20^{0}C till further extraction.

2.3 Sample Extraction

The extraction of pollutants was carried out in Soxhlet apparatus using dichloromethane: acetone (1:1 v/v) as extraction solvent. 10-15 g wet sample was homogenized with sodium sulphate and the mixture was transferred into a clean cellulose extraction thimble and inserted into a Soxhlet assembly fitted with a 250 ml flask. A 150 ml of extraction solvent was added and the whole assembly was heated for 16 h. After extraction the extract was evaporated to near dryness under reduced pressure in a 40 ^{0}C water bath using Rotary Vacuum evaporator (Eyela, Japan). 20 ml hexane was added to the concentrated extract and evaporated to a small volume (about 1 ml).

2.4 Chromatographic column cleanup

The multilayered silica gel column chromatography was performed to separate target analytes from other interfering organic and polar species. Briefly multilayered silica gel column (300 mm x 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 pre-rinsed with 50 ml n-hexane before sample was loaded. The concentrated extracts and three 2 ml portions of hexane from rinsing the sample flask were transferred to top of the chromatography column. The elution of analytes was subsequently

carried out using 170 ml hexane and concentrated to 2.0 ml. The eluted extract was concentrated using Rotatory Vacuum evaporator and Turbo Vap (Caliper, USA) under gentle stream of pure nitrogen using to 1.0 ml. The extract was transferred to auto sampler vial and 1 µl was injected onto a gas chromatograph equipped with an electron capture detector (GC-ECD) for quantification.

2.5 Instrumental analysis

In the present study DDTs (*p,p'*-DDE, *p,p'*-DDD, *o,p'*-DDT and *p,p'*-DDT) and HCHs (α-HCH, β-HCH, γ-HCH, and δ–HCH) and 15 congeners of polychlorinated biphenyls (PCBs) were analyzed. Separation and Quantification of pesticides in the sample extracts was carried out using Gas Chromatograph (Perkin Elmer, Clarus 500) attached with autosampler and equipped with an Electron Capture Detector (ECD, ^{63}Ni), on fused silica capillary column 25 m x 0.20 mm id 0.33 µm film (Elite-1). The column oven temperature was initially maintained at 170^{o} C and programmed to 220^{o}C (7^{0}C min^{-1}) and again ramped to 250^{o}C at 5^{o}C min^{-1} and held for 6.86 min. The injector and detector temperature were maintained at 250^{o}C and 350^{o}C respectively. Purified nitrogen gas was used as carrier at the flow rate of 1.0 ml. min^{-1}.

A total of 15 PCB congeners (PCB -18, -37, -44, -49, -52, -70, -74, -119, -128, -138, -151, -170, -177, -187, and 207) were detected and quantified. The separation and quantification of polychlorinated biphenyls (PCBs) was performed by gas chromatography (Shimadzu 2010, Japan) attached with autosampler and equipped with an Electron Capture Detector (ECD, ^{63}Ni), on capillary column (HP-5MS, Agilent) 60 m x 0.25 mm x 0.25 µm film. The temperature program of the column oven was set to 170^{o} C for 1 min then increased with 3^{0}C min^{-1} to 270^{o}C, kept for 1 min, then further ramped with 10^{o}C min^{-1} to 290^{o}C at and kept for 3 min. The injector and detector temperature were maintained at 225^{o}C and 300^{o}C respectively. Purified nitrogen gas was used as carrier at the flow rate of 1.0 ml. min^{-1}.

2.6 Analytical quality control

Certified reference standards from Sigma (USA) and Dr. Ehrenstorfer (GmbH, Germany) were used for the quantification of OCPs and PCBs, respectively. The target analytes were identified in the sample extract by comparing the retention time from the standard mixture and quantified using the response factors from five level calibration curves of the standards. Appropriate quality assurance quality control (QA/QC) analysis was performed, including analysis of procedural blanks (analyte concentrations were <MDL 'method detection limit'), random duplicate samples (Standard deviation <5), calibration curves with the r^2 value of 0.999, and matrix spike recovery 100±20%. Each sample was analysed in duplicate and the average was used in calculations. Moisture content was determined to report data on dry weight basis. Levels <0.01 ng g^{-1} and <0.10 ng g^{-1} were taken as zero (0) in the calculations for OCPs and PCBs, respectively. The results of the analysis are reported in ng g^{-1} dry weight (dry wt.) basis.

3. Results and Discussions

3.1 Organochlorine pesticides

The concentration of isomers of HCH and DDT in sediments from Yamuna River bank in Delhi, India is shown in Table 1. Concentrations of HCHs in sediments were higher than those of DDTs. The ∑HCH ranges from 19.25 to 731.82 with a mean value of 208.17±20.66 ng g^{-1} whereas the ∑DDT ranges from <0.01 to 21.21 with a mean value of 1.32±0.36 ng g^{-1}. HCH isomers have been detected as a worldwide contaminant. The properties of higher water solubility vapor pressure, biodegradability, lower lipophilicity and particle affinity, of HCH relative to DDT (Hu *et al.,* 2010) could account for the higher concentrations of HCH in sediments. Differences in composition of HCH or DDT isomers in the environment could indicate different contamination sources (Doong *et al*., 2002).

Table 1: HCH and DDT concentrations (ng g^{-1} dry wt.) in sediments from Yamuna River

Compound	Range		Mean	SE*	%
	Min.	Max.			
p,p'-DDE	<0.01	4.66	0.51	0.11	0.2
p,p'-DDD	<0.01	0.06	<0.01	<0.01	<0.01
o,p'-DDT	<0.01	14.43	0.49	0.24	0.2
p,p'-DDT	<0.01	3.21	0.32	0.09	0.2
∑DDT	<0.01	*21.21*	*1.32*	*0.36*	*0.6*
α-HCH	3.00	272.60	112.38	11.62	53.6
β-HCH	4.56	59.13	16.12	1.08	7.7
γ-HCH	5.19	332.21	63.84	7.82	30.5
δ-HCH	<0.01	67.88	15.83	1.55	7.6
∑HCH	*19.25*	*731.82*	*208.17*	*20.66*	*99.4*
∑OCPs	*20.54*	*735.73*	*209.49*	*20.77*	*100*

*SE (standard error) = SD/√n

Technical HCH has been used as a broad spectrum pesticide for agricultural purposes, which has been banned since 1997 in India. Technical HCH consists principally of four isomers, α-HCH (60-70%), β-HCH (5-12%), γ-HCH (10-15%), δ-HCH (6-10%), while lindane contains >99% of γ-HCH (Qui *et al*., 2004; Zhou *et al.*, 2006). . The average concentration of α-HCH, β-HCH, γ-HCH and δ-HCH in this study was 112.38±11.62 ng g^{-1} (54%), 16.12±1.08 ng g^{-1} (7.7%), 63.84±7.82 ng g^{-1} (30.7%) and 15.83±1.55 ng g^{-1} (7.6%), respectively (Table 1, Figure 2).

The ratio of α-HCH to γ-HCH has been used to identify the possible HCH source. The ratio of α-HCH to γ-HCH between 3 and 7 is indicative of fresh input of technical HCH (Yang *et al*., 2008). However, a lindane source will show the reduced ratio close or <1 (Iwata *et al*., 1993; Willet *et al.*, 1998). The ratio of α-HCH/γ-HCH varied in the range of 0.58-3.61with the mean of 1.62 (Table 2), which reflects the usage of technical HCH and lindane. Other studies also anticipated the use of technical HCH as well as lindane in India (Iwata *et al.*, 1993; Zhang *et al*., 2008; Chakraborty *et al.*, 2010; Kumar and Mukherjee, 2011; Kumar *et al*., 2011; Devi *et al*., 2011). The technical mixture of HCH was produced and used in India until it was banned in 1997, and lindane formulation are registered for use in public health practices to control vector borne diseases and for pest control in selected crops (Gupta, 2004; CAPE, 2005).

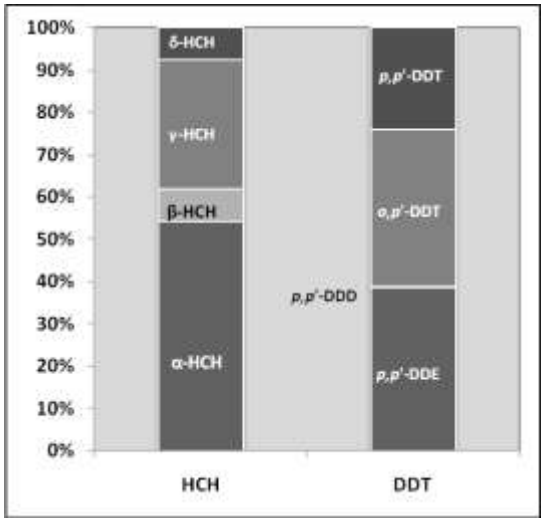

Figure 2: Percent distribution of HCH and DDT isomers in sediments

Table 2: HCH and DDT isomers ratios in sediments from Yamuna River

Compound ratio	Range		Mean	SE*
	Min.	Max.		
α/γ-HCH	0.58	3.61	1.62	0.10
o,p'/*p,p'*-DDT	<0.01	6.81	0.82	0.22
p,p'-DDT/*p,p'*-DDE	<0.01	1.04	0.23	0.05
p,p'-DDT/∑DDT	<0.01	1.00	0.25	0.05
p,p'-DDT/(*p,p*/-DDE+*p,p'*-DDD)	<0.01	2.13	0.38	0.67

*SE (standard error) = SD/√n

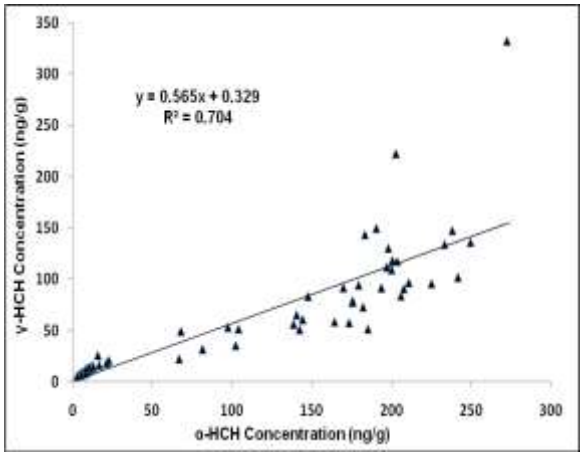

Figure 3: Relationship of α–HCH and γ–HCH in sediment samples.

It is to note that, in the mixture of past technical HCH and current lindane application, a significant correlation between α–HCH and γ–HCH was still observed in the studied sediments (Figure 3). Moreover, the α–HCH in higher concentration indicated a fresh source of α–HCH, contrary to the past application of technical HCH. The explanation of transformation of γ–HCH to α–HCH is the best in terms of maintaining the correlation between each other. Walker *et al*. (1999) has well explained the transformation of γ–HCH into other HCH isomers. In particular, γ–HCH may be transformed under ultraviolet radiation and through biological degradation in sediments into α–HCH (Benezet and Matsumura, 1973; Malaiyandi and Shah, 1980). The studied area is located under the Tropic of Cancer line with strong ultraviolet radiation and an anaerobic environment in most times. Our results suggested that the transformation from γ–HCH into α–HCH under such conditions may be significant.

The composition difference of DDT and its metabolites have been used to identify the possible sources of DDT as well as their fate in the aquatic environment (Guo *et al*., 2009). In the present study, occurrence of DDT isomers was on order as: *o,p'*-DDT>*p,p'*-DDT>*p,p'*-DDE>*p,p'*-DDD with DDT (61%), DDD (1%), and DDE (38%) (Figure 2). The relatively high concentration of DDT than DDD and DDE in this study area indicated either that there was minimal degradation of DDT or there has been more recently input of technical DDT. *o,p'*-DDT was the dominant isomer among DDTs with mean concentration of 0.49±0.24 ng g^{-1}, followed by *p,p'*-DDT and other metabolites (DDD and DDE). DDTs can be volatilized to an ambient environment in a few days (Atlas and Giam, 1988). After the DDT applications, much of the DDT slowly converted to DDE and DDD under aerobic and anaerobic conditions, respectively (Baxter, 1990; Aislabie *et al.*, 1997), hence the ratios between the DDT and DDE and DDD is often used as an indication of age (recent or historic) of the source of DDT (Qian *et al*., 2006). A ratio (*p,p'*-DDT/*p,p'*-DDD+*p,p'*-DDE) much greater than 1 indicates fresh use of DDT; however a small ratio indicates historical DDT applications (Ma *et al*., 2008). In the present study, the average ratios of *p,p'*-DDT/(*p,p'*-DDD+*p,p'*-DDE) 0.38 (Table 2), indicates historical inputs of DDT

to the sediments. The ratio of *p,p'*-DDT and *p,p'*-DDE can be used to estimate the existence of technical DDT in recent inputs. A ratio of 0.33 or less is considered as aged mixture, while a relatively high *p,p'*-DDT/*p,p'*-DDE ratio implies a recent input. In our study the ratio of *p,p'*-DDT/*p,p'*-DDE was 0.23 indicates aged DDT input in the this river system. In this study the dominance of *o,p'*-DDT indicates a possible fresh *o,p'*-DDT input. This may be caused by higher long-range atmospheric transport (LRAT) tendency of *o,p'*-DDT under tropical climate conditions. The vapour pressure of *o,p'*-DDT is 7.5 times higher than *p,p'*-DDT leading to greater volatilization of *o,p'*-DDT to the atmosphere (Spencer and Cliath, 1972), and *p,p'*-DDT metabolizes much faster in a subtropical environment (Telekar *et al*., 1977. After DDT application, much of the DDT may be converted to *p,p'*-DDE. Elevated concentrations of *p,p'*-DDE have been interpreted as a result of its conversion to *p,p'*-DDE by UV radiation during atmospheric transport (Atlas and Giam, 1988). The *o,p'*-DDT/*p,p'*-DDT ratio was reported to be 0.2~0.26 in technical DDT and ~7.5 in dicofol products. In our study the ratio of *o,p'*-DDT/*p,p'*-DDT is 0.82, indicates no dicofol usage.

Since 1996, DDT was banned as an agricultural pesticide (Battu *et al*., 2004); however, nearly 85% of the DDT produced in India is used for public health practices for residual spray (Sharma *et al*., 2003). The possible sources of DDTs are the combined effect of past and ongoing use in vector control or from sprays on open dumping sites.

3.2 Polychlorinated biphenyls (PCBs)

The concentration of PCB congeners in sediments from Yamuna River bank in Delhi are presented in Table 3. The average concentration of ∑PCBs was 7.69±0.90 ng g^{-1} and range between 0.16-30.05 ng g^{-1} (dry wt.). Among the studied PCB congeners the PCB-37 was the highest in concentration (4.99±0.57 ng g^{-1}), followed by PCB-44 (2.82±0.34 ng g^{-1}), PCB-52 (1.37±0.01 ng g^{-1}), PCB-207 (0.53±0.22 ng g^{-1}), and PCB-18 (0.52±0.06 ng g^{-1}), other congener concentration were comparatively low and ranged between <0.10-0.33 ng g^{-1} dry. Tri and tetra chlorinated biphenyl congener (PCB-37 and -44) alone contributed more than 80% of the total PCBs in sediments from Yamuna River. Very limited data is available on the environmental concentration of PCBs in India although high levels were reported in 1994 (Iwata *et al.*, 1994) and recently elevated levels have been observed at New Delhi and other major metropolition cities in India (Pozo *et al*., 2009; Chakraborty *et al*., 2010). India is growing at an exponential rate in terms of electronic waste (e-waste), generating approximately 150,000 t/year, much of which is stockpiled or poorly managed. Polychlorinated biphenyls (PCBs), which have been widely used in industrial production, may also be present in the electronic waste stream. Maximum amount of e-waste generated in the country ends up at New Delhi for recycling purpose though in an informal manner which can be one possible source for PCBs. A statistically significant ($p<0.05$) positive linear correlation has been observed between the amount of e-waste generated in 2005 and the PCB concentration in the atmosphere of Indian cities (Pozo *et al.*, 2006). Other possible sources are from open biomass burning which is common in agricultural field after crop harvesting, and depositions of emissions from wood processing, paint and dying, chemicals and transformer manufacturing units. These PCBs sources also include off gassing from closed system such as older equipments (e.g. transformers that contain large quantities of PCB fluids), and PVC (polyvinylchloride) manufacture.

Table 3: Concentrations of PCB congeners (ng g^{-1} dry wt.) in sediments from Yamuna River

Congener No.	Range		Mean	SE*	%
	Min	Max			
PCB – 18	0.15	1.27	0.52	0.06	0.57
PCB - 37	0.10	18.34	4.99	0.57	57.28
PCB - 44	0.15	14.17	2.82	0.34	35.41
PCB - 49	<0.10	0.71	<0.10	<0.10	<0.10
PCB - 52	0.16	2.57	1.37	<0.10	0.04
PCB - 70	0.16	0.55	0.33	<0.10	0.36

PCB - 74	0.12	0.14	0.13	<0.10	0.06
PCB - 119	<0.10	0.26	0.10	<0.10	0.93
PCB - 128	0.14	0.18	0.16	<0.10	0.04
PCB - 138	<0.10	<0.10	<0.10	<0.10	0.04
PCB - 151	<0.10	<0.10	<0.10	<0.10	<0.10
PCB - 170	<0.10	<0.10	<0.10	<0.10	<0.10
PCB - 177	<0.10	0.23	0.10	<0.10	0.40
PCB - 187	<0.10	<0.10	<0.10	<0.10	<0.10
PCB - 207	<0.10	3.22	0.53	0.22	4.05
∑PCBs	0.16	30.05	7.69	0.90	100

Note: <0.10=below detection limit,*standard error=SD/√n

3.3 Eco-toxicological risk assessment

Effects on the organisms are usually considered to be an early warning indicator of potential human health impacts (Qian *et al.,* 2006). In India, no environmental standards have been established for HCH, DDT and PCBs in marine or riverine sediments. Therefore, ecotoxicological effects of these pollutants in this study area were roughly evaluated by applying published sediment quality guidelines such as threshold and probable effect level and consensus based sediment quality guidelines (CBSQGs) from National Oceanography and Atmospheric Administration (NOAA) and Wisconsin (MacDonald *et al.,* 2000; WDNS, 2003). Table 4 shows the comparison of the obtained data in this study for the residue of these pollutants in sediments from Yamuna River with available guidelines from environmental agencies. Concentrations of DDTs and PCBs were lower than the guideline values and assumed no adverse effects to the biota. On the other hand, comparing to the recommended TEC (threshold effect concentration), PEC (probable effect concentration) and Wisconsin's CBSQGs for HCH in sediments, the concentrations of α-HCH and β-HCH were higher than the threshold effect concentration (TEC), but lower than medium effect concentration (MEC) and probable effect concentration (PEC) of CBSQG. Concentration of lindane (γ-HCH) is exceptional which exceeds the guideline concentrations. As mentioned earlier, lindane formulation is registered for use in public health practices to control vector borne diseases which are prevalent in post monsoon season (August-October). So, ecotoxicological risk may not be ruled out since the level of γ-HCH exceeded the guideline values and might cause ecological concern to river ecosystem.

4. Conclusions

As a party to the Stockholm Convention, India is legally obligated to abide by the objectives of the treaty, and is encouraged to support research on POPs. Distribution of persistent organic pollutant (HCH, DDT and PCBs) and their potential ecotoxicological risk were studied in bank sediments from Yamuna River in Delhi. This study indicates the contamination from technical HCH and lindane (γ-HCH) usage. DDT and PCBs were in low concentrations. Based on the sediment quality guidelines, levels of studied POPs in sediments were lower than guideline values. However, ecotoxicological risk of lindane (γ-HCH) may exist since the level of this compound exceeded the guidelines. Therefore, negative implications to the benthic biota may be expected due to elevated lindane (γ-HCH).

Table 4: Available fresh water sediments quality guidelines for OCPs: comparison with present study (ng g^{-1} dw).

Guidelines	DDD	DDE	DDT	∑DDT	α-HCH	β-HCH	γ -HCH	PCBs
Threshold Effect Concentration (TEC)*								
TEL	3.54	1.42	-	7.0	-	-	0.94	34.1

LEL	8.0	5.0	8.0	7.0	-	-	3.0	70
MET	10.0	7.0	9.0	-	-	-	3.0	200
ERL	2.0	2.0	1.0	3.0	-	-	-	50
Probable Effect Concentration (PEC)*								
PEL	8.51	6.75	-	4450	-	-	1.38	277
SEL	60	190	710	120	-	-	10	5300
TET	60	50	50	-	-	-	9	1000
ERM	20	15	7	350	-	-	-	400
Wisconsin's CBSQGs**								
TEC	4.9	3.2	4.2	5.3	6	5	3.0	60
MEC	16.5	17.0	33.6	289.0	53	108	4.0	368
PEC	28.0	31.0	63.0	572.0	100	210	5.0	676
present study	**-**	**0.51**	**0.40**	**1.32**	**112.38**	**16.12**	**63.84**	**7.69**

TEL=Threshold effect level, LEL=Lowest effect level, MET=Minimum effect threshold, ERL=Effect level low, PEL=Probable effects level, SEL=Severe effects level, TET=Toxic effect threshold, ERM=Effect range median, CBSQGs=consensus based sediment quality guidelines.
*MacDonald et al., 2000,
**WDNR, 2003

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