Eco-Toxicological Risk Assessment of HCH, DDT and their Possible Sources by Isomeric Ratio Distribution in Sediments from Sundarban Mangrove Ecosystem in Bay of Bengal, India

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Abstract

Persistent organochlorine pesticides (OCPs) like hexachlorocyclohexane (HCH), and dichlorodiphenyltrichloroethane (DDT), their isomeric ratios and ecotoxicological risks assessment was studied in sediments from Sundarbans in India. The average concentration of α-HCH, γ-HCH, p,p'-DDT, p,p'-DDD and p,p'-DDE was 6.93 ± 1.03, 4.82 ± 0.77, 2.36 ± 0.37, 1.11 ± 0.22 and 1.68 ± 0.44 ng g^{-1}, respectively. These levels significantly moved up to 10 km offshore and decline offshore (22.5 km). Isomeric ratios of DDT and HCH reflects the recent input of HCH and DDT. α/γ-HCH ratio indicates usage of technical HCH and lindane. Relatively, higher amounts DDT, than DDD and DDE, indicates either minimal degradation or recent input of technical DDT. Moreover, ratios of p,p'-DDT/(p,p'-DDD+p,p'-DDE), p,p'-DDT/∑DDT, and p,p'-DDT/p,p'-DDE shows a possible fresh DDT input and DDD/DDE ratio indicates anaerobic degradation of DDT. Although the overall mean concentration of HCH and DDT were lower than available guidelines however, γ-HCH and p,p'-DDT in some locations were above sediment guidelines, this may be due to as lindane and DDT are registered for public health practices in India.

Keywords: Pesticides**,** HCH, DDT, Sediments, Mangrove ecosystem, Bay of Bengal, India

1. Introduction

Organochlorine pesticides (OCPs), such as HCH and DDT are persistent, toxic and bio-accumulative in nature (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). OCPs 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 (Wang *et al.,* 2008). As is well known, DDT was listed by the Stockholm Convention as 1 of 12 persistent organic pollutants (POPs) in 2004, and more recently, α-HCH, and γ-HCH (lindane) were added to the list in 2009 (Hu *et al*., 2010).

Their physico-chemical characteristics, which include hydrophobicity and resistance to degradation, make these chemicals ultimately to accumulate in soils and sediments (Covaci *et al*., 2005; Hu *et al.,* 2009). OCPs enter the coastal areas from the agricultural cultivation, drainage, runoff, and by volatilization of deposition (Spencer *et al.,* 1973; Gomez *et al*., 2011) so estuarine sediments can act as long-term sinks for these anthropogenic contaminants. 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. So, 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).

In India, there are 165 pesticides registered for use and there is a sequential rise in the production and consumption of pesticides during last three decades. India is the fourth largest pesticide producer in the world after the US, Japan and China. During 2003-2004, the domestic production of pesticides was approximately 85 TMT (thousand metric tons), and about 60 TMT used annually (Anonymous, 2005) out of this, 4100 MT of technical grade pesticides were used in West Bengal (Bhattacharyya *et al*., 2009; Gupta, 2010).
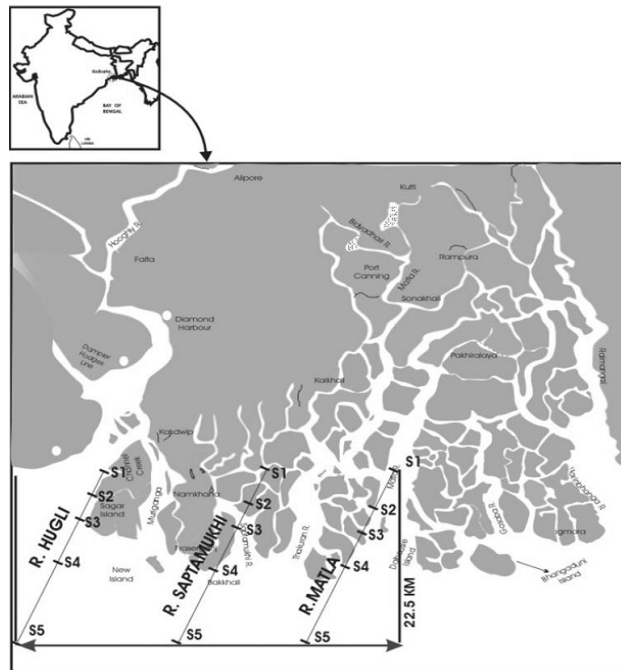

Figure 1: Map showing sampling stations in Sundarban mangrove ecosystem, India

For the past thirty years, a serious concern has arisen due to the presence of pesticides in the environment and their threat to the wild life and mankind. 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. During last few years studies, OCPs contamination in different matrices from north-eastern region of India have been reported (Zhang *et al*., 2008; Someya *et al.,* 2009; Devanathan *et al*., 2009; Chakraborty *et al.,* 2010; Devi *et al.,* 2011). There is no comprehensive study of sediment contamination by organochlorine pesticides in the north east coast of India, where important estuaries are subjected to the discharge of Rivers like Matla, Saptamukhi, and Hugli with a total catchment area draining into the sea that covers the major north eastern agricultural areas in India. Limited reports on organochlorines in sediments from the coast of Bay of Bengal with limited study area are available (Bhattacharya *et al*., 2003; Guzzella *et al*., 2005). This study was aimed to evaluate persistent organochlorine pesticide (HCH and DDT) concentrations in sediments from the north east coast of India in the Bay of Bengal, which includes intertidal zone of Sundarbans mangrove ecosystem in Bay of Bengal.

2. Materials and Method
2.1 Study area
The Sundarbans (426,300 ha), situated at the apex of the Bay of Bengal (between 21^0 13' to 22^0 40'N latitude and 88^0 03' to 89^0 07'E longitude) is the largest mangrove ecosystem of world being controlled by the depositional activities of the Ganges and Brahmaputra. A group of islands and a dense network of rivers,

canals, and creeks comprise the area (Figure 1). The geomorphology, hydrodynamics and ecology of this area is largely influenced by the sediments transported by the Hugli and Matla River. The Hugli estuary is one of the important estuaries in the east coast of India with a 8×10^5 km^2 catchment area, which supports the world's largest mangrove ecosystem,. The Hugli River collects and transports natural weathering products as well as potentially harmful elements derived from anthropogenic sources and presently contributes 300×10^9 m^3 of water and 520×10^6 tons of sediments to its basin (Sarkar *et al*., 2007).

In the present study 15 sampling stations on an array of three transects covered about 90 km long and extending up to 22.5 km off-shore. The selected transects were as: Matla (T-I), Saptamukhi (T-II), and Hugli (T-III) River, located within the Sundarban Nature Reserve. The sampling stations at each transect were fixed geographical co-ordinates predetermined by GPS and designated as: S1 (Inshore - 500 m before coast line), S2 (2 km offshore or at 5 fathom depth whichever is closer), S3 (5 km offshore), S4 (10 km offshore) and S5 (22.5 km offshore).

2.2 Sampling and sample extraction
Sediment samples were collected from on-board CRV (Coastal Research Vessel) *Sagar Poorvi*, using Van-Veen Grab sampler. The inter-tidal zone of each transect (Stn No 01–03) were sampled at low tides. Samples from each station were thoroughly mixed to ensure that the sediment collected was truly representative of each station. Sub-samples of the sediment were subsequently taken and stored in labelled wide mouth amber glass bottles and transported ice-preserved to the laboratory. Samples were air dried in a dust free environment, grinded with a granite pestle and mortar and passed through a 200 mesh sieve then stored at -20^{0}C until further chemical processing.

Dried sediment (20 gm) was taken in a 250 ml flask and mixed with 20 ml of water then extracted three times with 100 ml extracting solvent mixture of acetone: hexane (1:1 v/v) in a mechanical shaker for one hour. The extract was collected separately and the process was repeated twice. The pools of extracts were transferred to a 1 l separatory funnel containing 200 ml of hexane. After manual shaking, the aqueous layer was discarded and the hexane layer was washed with hexane washed water then filtered through anhydrous sodium sulphate to remove traces of water contents. The extract was concentrated to near 5 ml using rotatry vacuum evaporator (Buchi, Switzerland).

2.3 Chromatographic column cleanup
The column chromatography was performed to remove interfering organic and polar species. Briefly, a florisil column (250 mm x 25 mm) was packed from the bottom up with 20 g of activated florisil and 5.0 g anhydrous sodium sulphate. The column was pre-rinsed with 50 ml of hexane before the sample was loaded. The first fraction was eluted with 100 ml of pentane for removal of aliphatic hydrocarbon. The second fraction was eluted with 200 ml of 10 % diethyl ether in hexane for pesticides. The eluted extract was concentrated using a Rotatory Vacuum evaporator to 1.0 ml. The concentrated extract was finally cleaned up with 5% fuming sulphuric acid in concentrated sulphuric acid and then with hexane washed water. 1 µl of cleaned extract was injected onto a gas chromatograph equipped with an electron capture detector (GC-ECD) for quantification.

2.4 Instrumental quantification
Separation and Quantification of organochlorine pesticides (OCPs) was carried out using a Gas Chromatograph (Varian Star Series 3400, Australia) equipped with a ^{63}Ni Electron Capture Detector (ECD). A fused capillary column (Rtx 5) of 30 m x 0.25 mm id with 0.5 μm of stationary phase (5% diphenyl-95% dimethyl polysiloxane) was used for all the determinations. The column oven temperature was initially maintained at 180°C for 1 min and programmed to increase at 10°C min^{-1} to 225°C for 10 min, and ramped to 250°C at 10^{0}C min^{-1} and held for 10 min. The injector and detector temperature were maintained at 250°C and 325°C respectively. Purified nitrogen gas (99.99% purity) used as carrier gas with flow rate of 1.0 ml/min.

2.5 Analytical Quality Control
Certified standards (AccuStandards Inc, USA) were used for calibration of the instruments. Resolved peaks were integrated using Varian Star workstations software. The concentrations of analyte were determined by

comparing the peak area of the samples and five level calibration curves of the standards. The correlation coefficient of the calibration curves were ranged from 0.9980 to 0.9990. The peak identification was conducted by the accurate retention time of each standard. An appropriate quality assurance/ quality control (QA/QC) analysis was performed including a method blank processing along with the samples to check any loss or cross contamination during the sample processing (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 (86-96±12%). A reporting limit of > 0.01 µg kg^{-1} dry wt. was taken for calculation. The results were reported as ng g^{-1} dry weight (dry wt.) basis.

3. Results and Discussions
3.1 Distribution of HCH and DDT in sediments
The concentration of isomers of HCH, DDT and their isomers in sediments from north east coast of India is shown in Table 1. Concentrations of HCHs (69%) in sediments were higher than those of DDTs (31%) (Figure 2). The average concentration of α-HCH and γ-HCH in the study area ranges from 0.10 to 26.53 ng g^{-1} and from 0.12 to 25.25 ng g^{-1}, respectively. 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 could account for the higher concentrations of HCH in sediments (Hu *et al*., 2010). The higher concentrations of pesticides in sediments from Matla (T-I) and Saptamukhi Rivers (T-II) could be attributed by the influences from the eastern part of Kolkata and adjoining areas of Sundarbans, where pesticides are used in agriculture and public health practices. The dredging of the surface sediment from Hugli River; a navigational channel to the Haldia and Kolkata ports has carried out regularly, tends to be the reason for lower pesticides levels.

Table 1: HCH and DDT Concentrations (ng g^{-1}) in sediments from Sundarban mangrove ecosystem, India

Transect	α-HCH	γ-HCH	DDT	DDD	DDE
T-I	1.05-26.53	0.75-25.25	0.05-7.02	0.02-9.62	0.07-6.60
(Matla)	(10.38±2.05)**	(7.38±1.64)	(2.91±0.51)	(1.53±0.54)	(1.34±0.45)
T-II	0.10-26.14	0.12-17.07	0.02-5.40	0.05-3.35	0.07-6.32
(Saptamukhi)	(6.51±1.84)	(5.44±1.32)	(1.99±0.40)	(0.77±0.20)	(1.86±0.53)
T-III	0.52-17.15	0.27-6.15	0.12-15.72	0.15-3.27	0.10-16.27
(Hugli)	(4.63±1.10)	(2.01±0.38)	(2.40±1.04)	(1.13±0.23)	(2.24±1.21)
All	0.10-26.53	0.12-25.25	0.02-15.72	0.02-9.62	0.07-16.27
	(6.93±1.03)	(4.82±0.77)	(2.36±0.37)	(1.11±0.22)	(1.68±0.44)

*Std. Err. (SD/√n), **mean±SE are in parenthesis

The occurrence of pesticide residues significantly moved up to 10 km offshore (station 04) and decline offshore 22.5 km (station 05) (Figure 3). Such distribution of pesticides may be due to sand bars interfering the movement of surficial sediment with the tidal waters. These results reveal that specific contamination sources were available in this sector. Further, it can be explained that sand bars interfering sediment movement, greater usage of pesticides in eastern part of Kolkata and human settlement areas of Sundarbans played a major role for specific contamination in these River systems.

3.2 Compositional and isomeric ratio analysis for possible sources
Differences in composition of HCH or DDT isomers in the environment could indicate different contamination sources (Doong *et al*., 2002). The isomeric ratios of HCH and DDT isomers obtained from this study were presented in Table 2 and from station-wise were depicted in Figure 4.
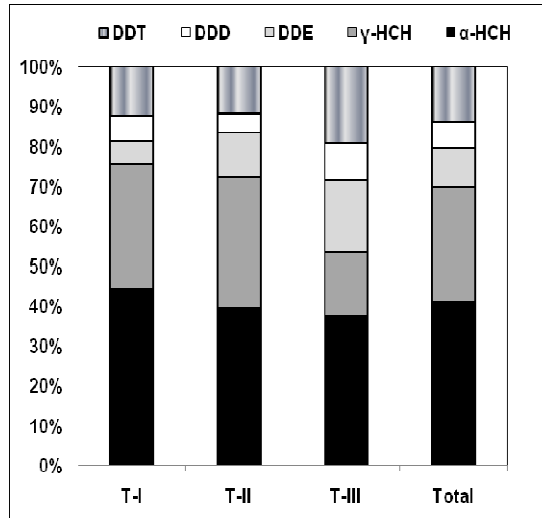
Figure 2: Transect-wise percent distribution of HCH and DDT isomers in sediments
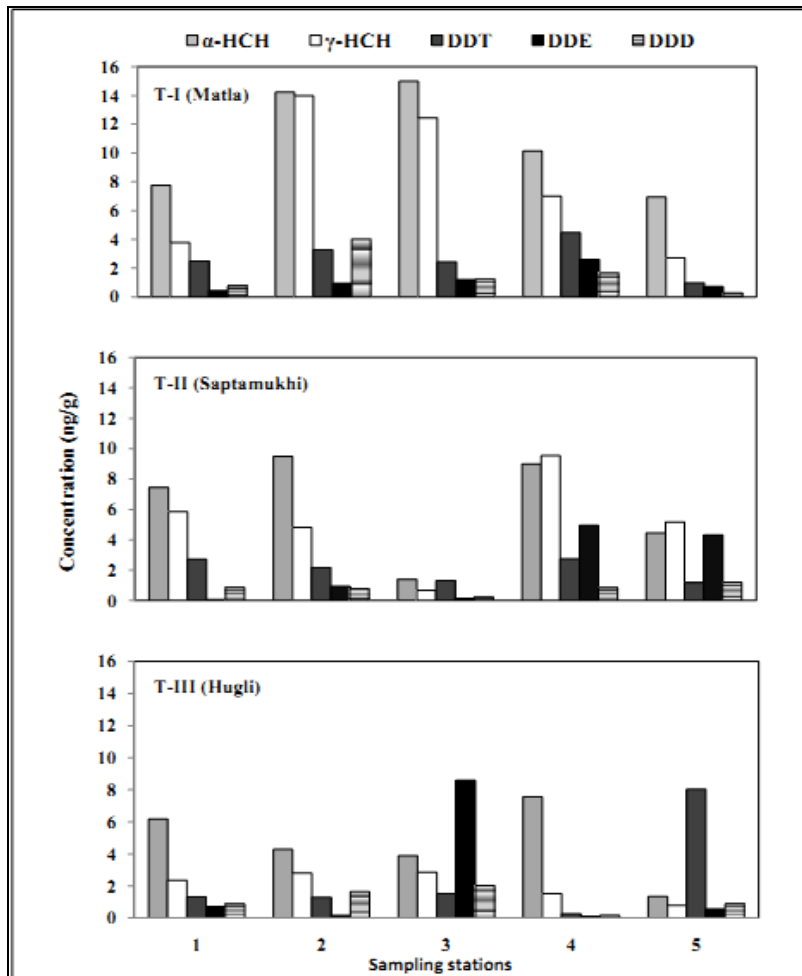

Figure 3: Station-wise profile of HCH and DDT isomers in sediments

HCHs: 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 and γ-HCH in this study was 6.93±1.03 and 4.82±0.77 ng g^{-1}, respectively. The α/γ-HCH ratio has been used to identify the possible HCH source. The ratio of α-HCH to γ-HCH higher than 3 indicates input of technical HCH and long range transport (Lane *et al.,* 1992). However, a ratio close or <1 is characteristics of lindane sources (Iwata *et al.,* 1993; Willet *et al.*, 1998). The ratio of α-HCH/γ-HCH varied in the range of 0.36-4.70 at T-I, 0.09-4.27 at T-II and 0.55-6.41 at T-III. However, the overall ratio ranged from 0.09 to 6.41 with mean value of 1.96 (Table 2), which reflects the regular usage of technical HCH and lindane (γ-HCH) in this area. Iwata *et al.*, (1993) reported α/γ-HCH ratios of 4.8-9.6 in the Bay of Bengal and Arabian Sea, and 0.65-2.4 for the Eastern Indian Ocean. However, other studies anticipated the use of technical HCH as well as lindane in India (Bhattacharya *et al.*, 2003; Zhang *et al.*, 2008; Chakraborty *et al.*, 2010; Devi *et al.*, 2011; Kumar *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).

Table 2: HCH and DDT isomers ratios in sediments from Sundarban mangrove ecosystem, India

Isomers ratios	Sampling Transects			
	T-I (Matla)	T-II (Saptamukhi)	T-III (Hugli)	All Transects
α/γ-HCH	0.36-4.70 (1.77)*	0.09-4.27 (1.53)	0.55-6.41 (2.81)	0.09-6.41 (1.96)
p,p' DDT/∑DDT	0.08-1.00 (0.58)	0.07-0.86 (0.54)	0.11-0.86 (0.44)	0.07-1.00 (0.51)
p,p' DDT/ *p,p'* DDE	0.12-7.45 (2.51)	0.12-12.67 (2.78)	0.15-14.97 (4.26)	0.12-14.97 (2.96)
p,p' DDD/ *p,p'* DDE	0.16-2.43 (1.20)	0.02-2.91 (1.51)	0.20-1.70 (0.88)	0.02-2.91 (1.35)
p,p' DDT/(*p,p'* DDE+*p,p'* DDD)	0.34-9.41 (3.51)	0.27-13.02 (3.09)	1.15-16.52 (4.88)	0.27-16.52 (3.64)

*Mean values are given in parenthesis

It is to note that, in the mixture of past technical HCH and current lindane application, a significant correlation (r^2=0.574) between α–HCH and γ–HCH was still observed in the studied sediments (Figure 5). 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 which is more stable (Benezet and Matsumura, 1973; Malaiyandi and Shah, 1980). The studied area is located under the Tropic of Cancer line with strong ultraviolet radiation and a biological active environment in most times. Our results suggested that the transformation from γ–HCH into α–HCH under such conditions may be significant.

DDTs: The ratios between the parent compound of DDT and its metabolites (DDD and DDE) can be used to

identify the possible sources in the aquatic environment (Guo *et al.,* 2009). In the present study, occurrence of DDT isomers was on order as: *p,p'*-DDT> *p,p'*-DDE>*p,p'*-DDD and ranged from 0.02-15.72, 0.07-16.27 and 0.02-9.62 ng g^{-1}, respectively. DDT alone accounted 46% to the ∑DDT, followed by DDE (33%), and DDD (21%) (Figure 2). The relatively high concentration of DDT than DDD and DDE in this study area indicated either that there was slow degradation of DDT or there has been more recently input of technical DDT. It is reported that DDTs can 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) and biotransformation of the DDT (Qian *et al.,* 2006). A ratio (DDT/DDD+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 ratio of DDT/(DDD+DDE) for Matla (T-I), Saptamukhi (T-II) and Hugli (T-III) River were in the range of 0.34-9.41 (3.51), 0.27-13.02 (3.09) and 1.15-16.52 (4.88), respectively with the overall mean of 3.64 and ranged 0.27-16.52 (Table 2), indicates that there is a recent inputs of DDT to the sediments of the Sundarbans mangrove ecosystem of India. 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 <1 is considered as aged mixture, while a relatively high (>1) *p,p'*-DDT/*p,p'*-DDE ratio indicates DDT use in the last 5 years (Tavares *et al.,* 1999; Li *et al.*, 2009). In our study the pooled mean ratio of *p,p'*-DDT/*p,p'*-DDE was 2.96 indicates recent DDT input in this ecosystem. The residence time of *p,p'*-DDT could be estimated using the ratio of *p,p'*-DDT to ∑DDT. The *p,p'*-DDT/∑DDT ratio for technical DDTs was reported to be <1 (WHO 1989). The mean ratio of *p,p'*-DDT to ∑DDT in present study was 0.51, which indicates the presence of technical DDT.
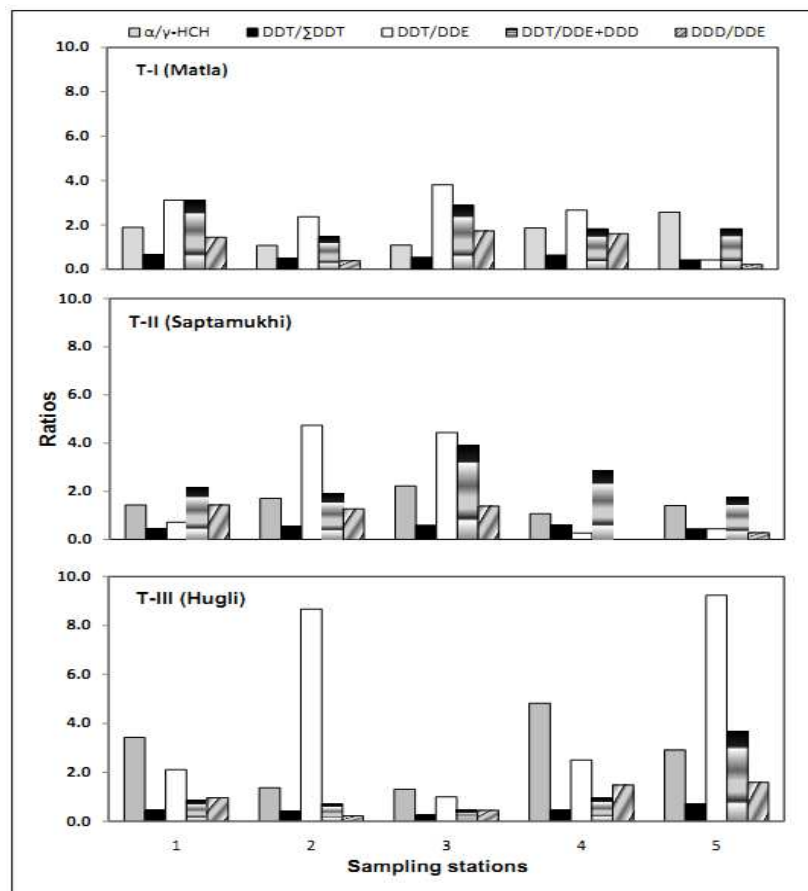

Figure 4: Station-wise isomeric ratios of HCH and DDT in sediments

Moreover, the ratio of DDD/DDE can reveal the degradation pathways of DDT, since DDE and DDD are the aerobic and anaerobic degradation products of DDT, respectively. A ratio of DDD/DDE lower than one (<1) shows aerobic degradation and higher than one (>1) indicates anaerobic degradation (Doong *et al*., 2002; Hiller *et al*., 2011). As shown in Table 2 and Figure 5, ratios of DDD/DDE in sediments were ranged between 0.02-2.91 with an average of 1.35. This indicates that degradation of parent DDT was prevalent under anaerobic conditions. However, Hugli (T-III) River shows aerobic degradation where sediment dredging continuously takes place.

Although local inputs cannot be ruled out, this may be caused by relatively high DDT concentrations in the eastern region of India (Zhang *et al*., 2008; Chakraborty *et al*., 2010; Devi *et al*., 2011) coupled with the higher long-range atmospheric transport (LART) tendency of DDT under tropical climate conditions. The *p,p'*-DDT metabolizes much faster in a subtropical environment (Spencer and Cliath, 1972; 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 dominance of the DDT compounds is common in developing Asian countries (Iwata *et al*., 1993). Higher concentration of DDT have been observed in air, vegetables and mother's milk samples collected from Kolkata (Zhang *et al.,* 2008; Devanathan, *et al*.,2008; Chakraborty *et al*., 2010; Kumar and Mukherjee, 2011).
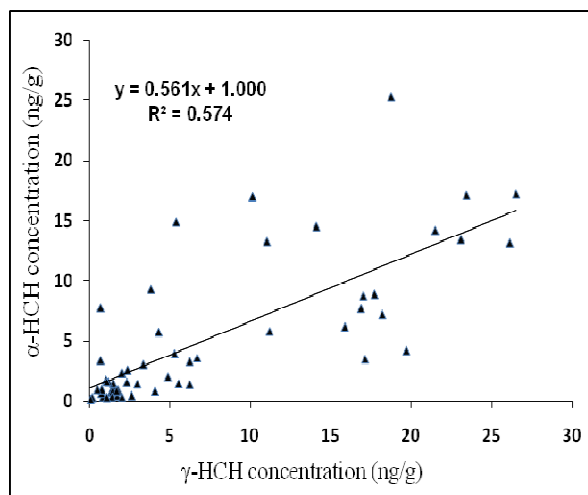

Figure 5: Relationship of α-HCH and γ-HCH in sediment samples.

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.

3.3 Eco-toxicological risk assessment
The eco-toxicological risk assessment of HCH and DDT in sediments was evaluated using sediment quality guidelines (SQGs). SQGs are based on pollutant concentrations to harmful effects on sediment dwelling organisms or intended to be predictive of effects on sediment dwelling organisms (MacDonald *et al.,* 1996). In India, no environmental guidelines have been established for HCH and DDT in marine sediments. Therefore, ecotoxicological effects of OCPs in this study area were roughly evaluated by applying published sediment quality guidelines from Canada, National Oceanography and Atmospheric Administration (NOAA) and Wisconsin's consensus based sediment quality guidelines (CBSQGs) (MacDonald *et al*., 1996; NOAA, 1999; CCME, 2002; WDES, 2003). Table 4 shows the comparison of the obtained data in this study for pesticides with available guidelines such as threshold effect level/concentration, probable effect level/concentration,

effect range-low/medium and interim sediment quality guidelines from environmental agencies. Concentrations of DDT and their metabolites (DDD & DDE) were lower than guideline values; although, DDT exceeded the effect range-low and ISQGs, but ∑DDT were lower than all the guideline values except ERL were it exceeded at all the stations. The level of α-HCH was lower than probable effect concentration (PEC), but at sampling transect –I and T-II exceeded the threshold effect concentration (TEC). γ-HCH concentration at T-III was lower than CBSQGs but, at most of the sampling stations it was higher than available guideline values. The assessment indicates that ecotoxicological risk may not be ruled out since the level of γ-HCH exceeded the ISQGs and PEL values and level of DDT exceeded the TEL, ERL and ISQGs. This might cause ecological concern to benthic organisms. As mentioned earlier, lindane and DDT are registered in India for use in public health practices to control vector borne diseases.

4. Conclusions

Potential eco-toxicological risk of HCH and DDT and their isomeric ratios distribution were studied in surface sediments from Sundarbans mangrove ecosystem in the Bay of Bengal. The study suggests usage of HCH and DDT and their contamination in Sundarbans mangrove ecosystem. Compositional analysis of DDT and HCH indicates recent input of DDT and lindane in this area. DDD and DDE ratio shows the anaerobic degradation of DDT. Based on the sediment quality guidelines, levels of overall HCH and DDT in sediments were lower than guideline values. However, ecotoxicological risk may exist since the level of γ-HCH (lindane) and *p,p'*-DDT exceeded the guideline values at some sampling locations, as DDT and lindane are used for public health programme in India. Therefore, negative implications to the benthic organisms may be expected due to elevated concentration of these compounds.

Table 3: Available marine sediment quality guidelines for OCPs: comparison with present study (ng g^{-1})

Country	DDD	DDE	DDT	∑DDT	α-HCH	γ-HCH	Reference
NOAA, Washington							
TEL	1.22	2.07	1.19	3.89	-	-	NOAA, 1999
ERL	2.0	2.2	1.0	1.58	-	-	
PEL	7.81	374	7.0	46.1	-	-	
ERM	20	27	4.77	51.7	-	-	
CCME, Canada							CCME, 2002
ISQG	1.22	2.07	1.19	-	-	0.32	
PEL	7.81	374	4.77	-	-	0.99	
CBSQG, Wisconsin							WDES, 2003
TEC	4.9	3.2	4.2	5.3	6.0	3.0	
PEC	28	31	63	572	100	5.0	
Sundarbans, India							
T-I	1.53	1.34	2.91	5.01	10.38	7.38	**Present study**
T-II	0.77	1.86	1.99	3.82	6.51	5.44	
T-III	1.13	2.24	2.40	4.21	4.63	2.01	
Total area	1.11	1.68	2.36	4.31	6.93	4.82	

T-I (Matla River), T-II (Saptamukhi River), T-III (Hugli River), TEL= threshold effect level, ERL=effect range low, ERM=effect range medium, TEC=threshold effect concentration, PEC=probable effect concentration, ISQG=Interim Sediment Quality Guidelines, PEL=probable effects level, CBSQG=Consensus based sediment quality guidelines.

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