Environ Monit Assess (2020) 192: 122
https://doi.org/10.1007/s10661-020-8082-z

Status of pesticide residues in water, sediment, and fishes of Chilika Lake, India

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Received: 29 July 2019 / Accepted: 8 January 2020 / Published online: 17 January 2020

Abstract Chilika Lake is the largest coastal lagoon in Asia and the second largest in the world covering an area of 1100 km^2 and spread over three districts of Odisha state of India. It is the first Indian wetland designated as a wetland of international importance under the Ramsar Convention in 1981. The lake ecosystem sustains large and diversified resources of plants and animals including fisheries. Pollution of the ecosystem caused by residues of pesticides originating from different sources was assessed through multiple sampling from 2012 to 2016 from three potential sites of contamination, viz., Palur Bridge, Daya River Estuary, and Makara River. Incidence of organochlorinated (OC) pesticide residues was noticed in about 25% water samples. HCH (α, γ&δ), DDD (op′), DDE (op′&pp.′) and heptachlor were the OCs detected in concentration varying from 0.025 to 23.4 μg/l. None of the eight targeted synthetic pyrethroid (SP) pesticides was found in water, but among the organophosphates (OP), chlorpyrifos (0.019–2.73 μg/l), and dichlorvos (0.647 μg/l) were recorded. In sediment samples, residues of OC or OP pesticides were not present, but one SP pesticide was recorded. Fish samples were contaminated to the extent of 55%, mostly with residues of OCs and OPs and less with SPs. However, their concentrations were below the permissible limit, so there was no direct threat of health hazards to humans.

Keywords Pesticide residues · Water · Sediment · Fish · Chilika Lake

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Introduction

The presence of toxic substances in aquatic systems has deleterious effects on its ecology and biodiversity. They can reduce water and sediment quality and productivity and also adversely affect fish health and other biological attributes. From water and sediments, these substances can accumulate in the food chain and persist there to exert toxicity. Most fishes accumulate these contaminants from their direct environments such as diet items, sediments, and water through gills. Ubiquitous occurrence of pesticide residues in different environments including aquatic ecosystem is widely reported (Eichelberger and Lichtenberg 1971; Mohapatra et al. 1995; Rovedatti et al. 2001; Doong et al. 2002; Singh et al. 2005; Samoh and Ibrahim 2009; Chen et al. 2011; Liu et al. 2012; Ibigbami et al. 2015; Chatterjee et al. 2016). They enter into the water bodies mainly from catchments and adjacent agricultural fields, apart from domestic usage through drainage (Scott et al. 1999; Honnen et al. 2001). Pesticides are transported from an application area to other locations in the environment

primarily through water (Barbash and Resek 1996). Being intrinsically toxic substances, pesticides may retard growth and metabolism in flora and fauna in the aquatic ecosystem. Many of the pesticides have endocrine disruption properties so adversely affect the reproduction of fish and other aquatic animals. Along the food chain, pesticide residues are transferred from lower to higher trophic levels, and residues are also biomagnified in the process (Kim 2020).

Chilika Lake is a highly productive coastal lagoon ecosystem located in the Odisha state of India bordering Bay of Bengal. Because of its rich biodiversity and socioeconomic importance, the lake was designated as a Ramsar site in 1981. However, the Chilika has been subjected to constant pressure because of various natural and anthropogenic factors. Due to changes in the ecological characters caused by the degradation of its ecosystem, the lake was included in the Montreux Record (threatened list of Ramsar site) in 1993 (CDA Annual Report 2013–14). Pollution of the lake at various sites takes place due to effluents carried by 52 rivers and rivulets draining into it and also from the vast catchment area. Thorough scanning of the literature revealed that not much study on the occurrence of pesticide residue has been conducted on Chilika Lake ecosystem excepting Dhananjayan (2012) who investigated mass mortality of waterfowl in Nalbana Bird Sanctuary and Chilika Lake and thus determined OC pesticides and polychlorinated biphenyls in tissues of different water birds. Therefore, keeping in view the paramount importance of food safety and the confidence of consumers on the brand value of the product, it was imperative to investigate the load of pesticide residues accumulated in fishes and also their status in water and sediment of the lake.

Materials and methods

Study area and sampling location

Chilika, a large coastal brackish water body, is situated between 19°28′–19°54′north latitude and 85°05′–85°38′east longitude on the east coast of India, bordering the state of Odisha. The water spread area of the lagoon spans between 906 and 1165km^2 during summer and monsoon months. Based on the salinity and depth, the lake has been demarcated into different ecological sectors, viz., marine water, brackish water, and freshwater. The catchment area of Chilika is spread over 4085 km^2. The lake is a hot spot of biodiversity and habitat for diverse types of flora and fauna including some rare, vulnerable, and endangered species (Chilika Newsletter, February 2015). The lake is known for its lucrative marine water, brackish water, and freshwater fisheries. Its rich fishery resource supports more than 0.2 million fisher folks living in and around the lake (CDA Annual Report 2013–14). Fish, prawn, and crab constitute the main fisheries output of the lake.

Three sampling sites, viz., Palur Bridge (CS-1), Daya-Makara River Estuary (CS-2), and Daya River (CS-3) of the Chilika Lake (Fig. 1), were selected where the chances of pollution were higher. Sampling was done from the three sites in different seasons from 2012 to 2016. Water samples ($n = 90$) were collected from subsurface using a standard water sampler and immediately transferred to dark 1-l capacity glass bottles. From each sampling site, three samples were taken across the width and pooled to make a composite sample. Sediment samples ($n = 90$) were collected with a sampling dredge from three different spots of a sampling site, mixed together to make into a composite samples, and immediately transferred to glass jars. Fish samples ($n = 125$) collected while they were being fished from the sampling stations were cleaned, labeled, and packed in icebox filled with ice. Samples were subsequently brought to the laboratory and stored at refrigerated condition (4 °C for water, 20 °C for sediment and fish).

Chemicals and reagents

Based on the persistence behavior and usage, the following 36 compounds of pesticides including some of their isomers and their metabolites belonging to three groups, viz., organochlorinated (OC), organophosphates (OP), and synthetic pyrethroids (SP), were selected for residue analysis.

Targeted pesticides

Organochlorinated (OC): HCH isomers (α, β, γ, δ), DDE (op′ and pp′), DDD (op′ and pp′), DDT (op′ and pp′), endosulfan (α, β, sulfate), dicofol, aldrin, and heptachlor

Organophosphates (OP): dichlorvos, phorate, dimethoate, monocrotophos, phosphamidon, Mmthyl parathion, malathion, chlorpyrifos, quinalphos, and triazophos

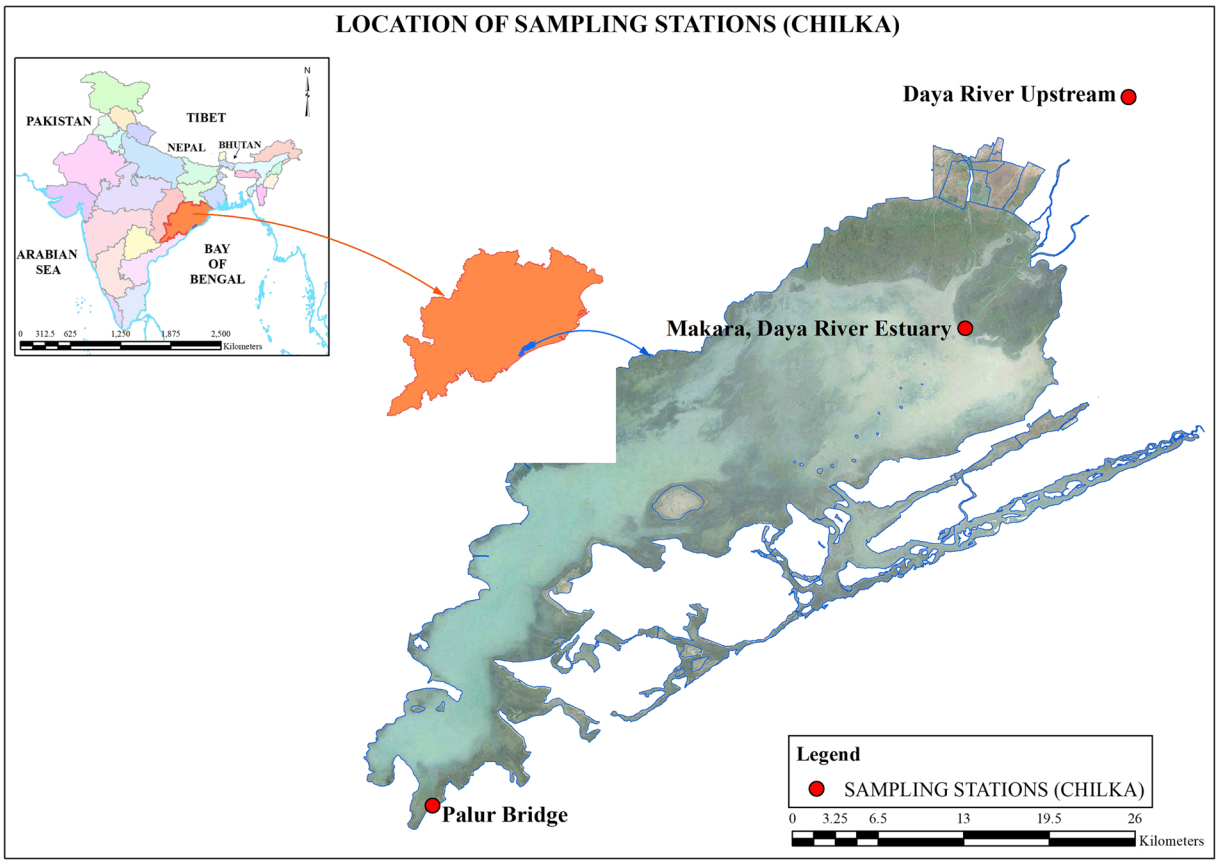

Fig. 1 Map of the study area and sampling stations

Synthetic pyrethroids (SP): bifenthrin, fenpropathrin, cyhalothrin, cyfluthrin, cypermethrin, fenvalerate, fluvalinate, and deltamethrin

Certified reference standards of pesticides were procured from M/s. Sigma Chemicals. Solvents used in the analysis were purified and redistilled. Other reagents, viz., florisil, silica gel, and sodium sulfate, were properly activated at high temperature (300–600 °C) before use.

Analysis

Water samples were extracted and cleaned up according to AOAC (1993). Fish samples were processed as per Tanabe et al. (1994) with minor modifications for extraction and clean up. In short, macerated and homogenized tissue (flesh, gill, liver) samples were extracted with hexane and acetone (1:1 *v*/v, 250 ml) in the Soxhlet apparatus for 6 h continuously. The extracts were concentrated using a rotary vacuum evaporator (RVE) before column clean up.

Sediment samples were dried under shade, pulverized, and sieved. The extraction of sediments was done in a horizontal rotary shaker with hexane and acetone (1:1 *v*/v, 50 ml) continuously for 2 h. Extracts were subsequently filtrated in a Buchner filtering assembly using Whatman No.1 filter paper and concentrated in RVE. The concentrated extracts were subjected to clean up.

The chromatographic column was packed with preactivated florisil, sodium sulfate, and silica gel in hexane. Columns were eluted with hexane and acetone (1:1 *v*/v, 50 ml). The eluates were concentrated and reconstituted in isooctane for chromatographic analysis.

The qualitative and quantitative analysis was done in Agilent 6890 N gas chromatograph fitted with Ni^{63} micro-electron capture detector (ECD) and nitrogen-phosphorous detector (NPD). HP 5MS (30 mm × 0.25 mm id × 0.25 μ film) capillary column was used for OC and SP. The operation conditions of GC for OCs and OPs were as follows: For OCs: Column temperature 180oC hold for 1 min, increase in temperature @3oC/min to 230oC, hold for 5 min then increase in

temperature @ 10oC/min to 265oC, hold for 10 min; Injector temperature at 260oC, split ratio (1:10), Detector temperature at 300oC; For SPs: Column temperature 250oC, hold for 1 min, then increase in temperature @5oC/min to 280oC, hold for 10 min, Injector temperature at 280oC, split ratio (1:10), Detector temperature at 300oC. Carrier gas for both OCs and SPs: He @ 1ml/min and makeup: N_2 @30ml/min. For OPs capillary column HP 5 (30mm×0.32mm id×0.25μ film) was used and the operating conditions were: column temperature 120 °C hold for 1 min, increase in temperature @10 °C/min to 200 °C hold for 5 min, then increase in temperature @ 20 °C/min to 240 °C hold for 10 min, Injector temperature at 250 °C, Detector temperature at 300 °C, Carrier gas He @ 2 ml/min, Detector gas H_2 @ 3 ml/min and air @ 60 ml/min. The injection volume was 1 μl in all cases.

Validation of method and quality control

The detector linear range was established from the five points external standard calibration using individual and standard mixture at levels of 0.001 mg/l to 0.01 mg/l. Recovery experiment was conducted by fortifying water (at 0.01–1 μg/l), sediment, and fish tissue (at 0.01 μg/g to 1 μg/g) with pesticide standards and employing the same extraction and clean-up methods as performed in the case of actual samples to estimate the trueness of the method. The blank analysis was performed to check interference.

For confirmation of the identity of compounds detected, few samples were also analyzed in Agilent 7890A GC/MS/TQ system through outsourcing. The condition of the analysis was as follows:

Column: Capillary HP 5 MS capillary column (30 mm × 0.25 mm id × 0.25 μ), Column temperature 70 °C (2.5 min), increase in temperature @ 20 °C/min to 180 °C, hold for 0 min, then increase in temperature @5 °C/min to 200 °C, hold for 3 min, then increase in temperature @5 °C/min to 220 °C, hold for 2 min then increase in temperature @ 7 °C/min to 240 °C, hold for 0 min then increase in temperature @ 10 °C/min to 290 °C, hold for 6 min; Injector temperature 70 °C for 0.25 min then increase in temperature @ 300 °C/min to 290 °C, hold for 15 min; Carrier gas: He @ 1 ml/min column flow; MSD transfer line temp. 280 °C for 0 min; Source temperature 230 °C, Ion source: EI ionization (−70 EV); MS-1 and MS-2 Quad temperature at 150 °C.

Risk assessment

USEPA (the United States Environmental Protection Agency) guidelines (USEPA 1998) were followed to assess the potential risks to human health associated with the consumption of fish contaminated with pesticide residues. The estimated daily intake (EDI) of pesticides was measured based on the average concentration of residue in fish, the average per capita fish consumption, and the average body weight of the consumer. The average per capita fish consumption is 27 g/person/day according to the Ministry of Statistics and Program Implementation, Government of India (CSO-MSS-2011). The average hypothetical body weight of 15 kg for children (up to 10 years) and 50 kg for an adult was assumed. A 100% absorption rate and 100% bioavailability of consumed pesticides were also assumed. The EDI was compared with the acceptable daily intake (ADI) of the pesticide to evaluate the risk. Hazard index (HI) which is the ratio of EDI and ADI (Fianko et al. 2011) was also calculated for adults and children.

Results and discussion

The average method recovery was on the range of 82.5–105%, and the method limit of detection was 0.01 μg/l for water and 0.001 μg/g for sediment and fish. The overall extent of contamination of water, sediment, and fish of Chilika is depicted in Fig. 2. While 31% of samples of water contained pesticide residues but concerning sediments only 5% of the samples were positive, however, the accumulation of residues of different pesticides was recorded in about 55% of fish samples.

Pesticide residues in water

Residues of OCs were detected in 31% samples. Among the 16 targeted OCs, HCH (α, γ&δ), DDD (op′), DDE (op′and pp.′), and heptachlor were detected. While γ-HCH was found twice (July 2012 and September 2015), α and δ-HCH were recorded only in September 2015 and September 2013, respectively. The concentration of γ-HCH varied from 0.03–6.08 μg/l, while that of α and δ were between 0.025–0.265 and 0.05–0.256 μg/l, respectively. DDT per se was not found, but its isomers/metabolites as DDD and DDE were detected. DDD (op′) was detected only in July 2012 in samples of all the

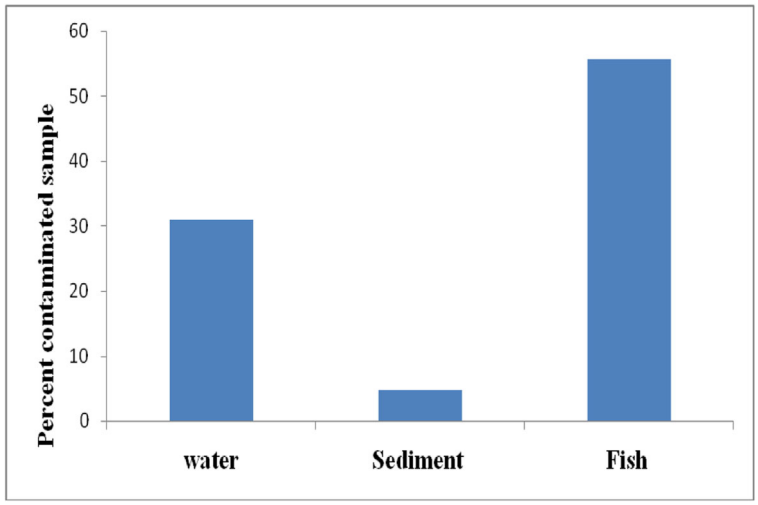

Fig. 2 Extent of contamination of Chilika samples with pesticide residues

three sites at a concentration of 8.99–23.4 μg/l. DDE (pp′) was present at third location, i.e., Station 3 (Daya River) in November 2013 and February 2015 at concentration 0.017–0.062 μg/l, while op′ DDE (0.116 μg/l) was detected only in February 2015. Heptachlor residue (0.04–1 μg/l) was found in samples of all the three sites in October 2012 and in September 2013. However, it was not noticed in any sample afterward. The source of these pesticides is believed to be mainly through rivers discharging into the lake.

In India, there is no reference value or limit of pollutant concentration permitted for aquatic life. However, USEPA has recommended water quality criteria for aquatic life. As per USEPA recommendation, CMC (critical maximum concentration) of lindane is 0.95 μg/l. Samples of the three sites collected in July 2012 contained lindane at higher concentrations, while samples of September 2013 had a lower concentration than the reference limit. For DDT (pp′), the recommended CMC is 1.1 μg/l which applies to its metabolites too. The concentration of DDD (op′) detected in July 2012 exceeded the recommended level. However, DDE present in November 2013 and February 2015 samples were below the limit. The CMC of heptachlor is 0.52 μg/l. Out of six samples (three each in October 2012 and September 2013) containing heptachlor residues, three samples of October 2012 had higher concentrations than the CMC.

None of the eight targeted SPs was found in any of the water samples. Among the OPs, residue of chlorpyrifos was detected in the Daya River site (CS-3) in February 2015 and June 2016 and in Palur Bridge site in June 2016 at concentrations varying from 0.019–2.73 μg/l. The CMC of chlorpyrifos in water is 0.083 μg/l which was exceeded in one sample (Station 2, February 2015), and in others, concentrations were below the limit. Other than chlorpyrifos, residue of dichlorvos (0.647 μg/l) was found in a sample of Daya-Makara River Estuary (CS-2) collected in March 2016. No other sample was found to contain residues of any other OP. The overall range of concentration of residues detected in water is shown in Fig. 3.

Pesticide residues in sediment

No residues of OC or OP pesticide were detected in any of the sediment samples except in one sample of Station 3 containing residue of fenpropathrin, one of the eight targeted SP, at a concentration of 0.081 μg/g. In addition to samples from Palur Bridge (CS-1), Daya-Makara River Estuary (CS-2), and Daya River (CS-3), sediment samples from other stations in the central sector were also analyzed. But the accumulation of residues of any targeted pesticide could not be recorded.

Pesticide residues in fishes and shellfishes

Samples of fish species (*Labeo calbasu*, *Scatopha gusargus*, *Dendrophysa russelli*, *Plotosus canius*, *Etroplus suratensis*, *Arius tenuispinis*, *Mystus seenghala*, *Wallago attu*, *Cirrhinus reba*, *Liza macrolepis*, *Mugil cephalus*, *Eleutheronema tetradactylum*, *Mystus gulio*, *Daysciaena albida*, *Lates calcarifer*) and shellfish (*Fenneropenaeus indicus* and *Penaeus monodon*) were

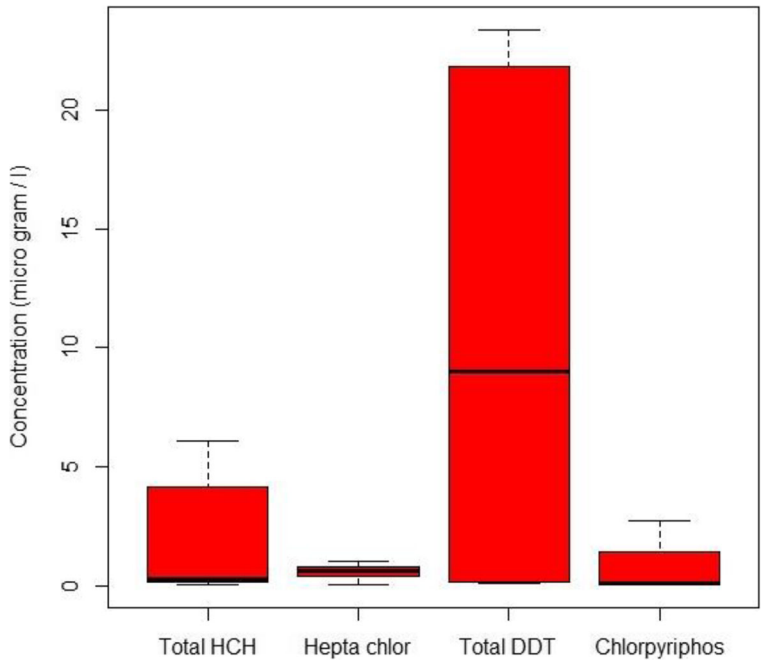

Fig. 3 Level of pesticide residues in water of Chilika Lake

collected from the study area during the period of investigation. The whole body of the fish or flesh and different organs like the gill and liver depending on the size of the fish were taken for analysis.

Organochlorinated (OC) pesticides

Residues of OCs were detected in 55% fish samples. Among the different OCs targeted for analysis, HCH isomers, DDTs, dicofol, heptachlor, and endosulfan were found present in different fishes. HCH isomers, viz., α, β, γ, and δ, were detected in fish. The α-HCH was found in three species, viz., the liver of *D. russelli* (2.8 μg/g), the flesh of *E. suratensis* (0.032 μg/g), and shellfish *F. indicus* (0.02 μg/g). The β-HCH could be recorded only in shrimp sample (*P. monodon*), while γ-HCH (0.002 μg/g) was recorded in *D. albida*. The δ isomer of HCH was observed only in the flesh of *E. suratensis* (0.036 μg/g). Among the DDT isomers and metabolites, DDD and DDE were recorded in a number of fish samples at a concentration varying from 0.005 to 0.54 μg/g. The pp.' DDE, the most stable metabolite of DDE, was found to be more frequent in occurrence than others. However, residue of pp.' DDT was also recorded in the flesh of *E. suratensis*. Dicofol, a DDT analog as well as an acaricide, was present in *E. tetradactylum* and *L. macrolepis* at a concentration of 0.03 μg/g. The presence of endosulfan residues in fish was very rare. Only β-endosulfan (0.001–0.02 μg/g) in *D. albida* and *E. tetradactylum* and endosulfan sulfate in the former were recorded. Residues of heptachlor were found present at concentration 0.016–0.837 μg/g in the flesh, gill, and also liver of many fishes, viz., *L. calbasu*, *S. argus*, *D. russelli*, *E. suratensis*, and *F. indicus* collected in 2012, but only in *L. macrolepis* collected in 2013. However, in fish samples collected in subsequent years, heptachlor could not be detected. The overall level of OC residues detected in fish is shown in Fig. 4.

The occurrence of OC residues in fish and prawn from wetland and associated water bodies is also reported earlier. The presence of α and γ HCH, endosulfan, and pp.'DDT at concentrations higher than their respective tolerance limits (TL) in prawn (*F. monodon*) collected from ponds near Kolleru Lake wetland, India, was reported by Sreenavasa Rao (2006). Dhananjayan and Muralidharan (2010) recorded the presence of HCH (2.1–51.7 μg/kg), DDT (BDL-12.3 μg/kg), and endosulfan (BDL-4.3 μg/kg) residues in fishes from different wetlands of Karnataka, India. In many fishes, viz., *Clarias gariepinus*, *Oreochromis niloticus*, *Tilapia zilli*, *Heterotis niloticus*, and *Chrysichthys nigrodigitatus* collected from Ogbese river of Nigeria, residues of different OCs like HCH, DDT, endosulfan, heptachlor, endrin, dieldrin, etc. were detected, and concentration of total OC pesticides varied from 0.139 to 0.49 μg/kg

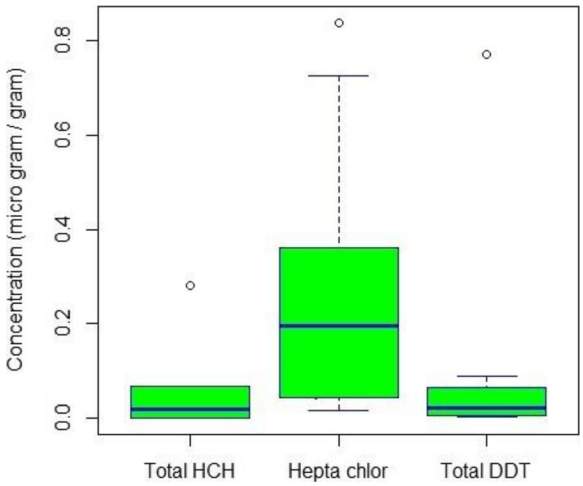

Fig. 4 Level of organochlorine pesticide residues in fishes of Chilika Lake

(Ibigbami et al. 2015). Incidence of residue of OC pesticides, viz., pp.' DDE and pp.' DDT in Pangasius catfish (*Pangasianodon hypophthalmus*) at concentration 1676–17.34 and 21.3–22.05 μg/kg, is also reported from India (Chatterjee et al. 2016). Nag et al. (2016) could detect HCH isomers (α, β, γ, δ), pp.'DDE, op'DDD, pp.'DDT, endosulfan (α, β, sulfate), and dicofol residues in *Cirrhinus mrigala*, *Cyprinus carpio*, and *Oreochromis mossambicus* obtained from East Kolkata Wetlands, India, but their concentrations were below the respective TL. Although previous studies on occurrence of OC residues in fish of Chilika Lake were not available for comparison of the present data, Dhananjayan (2012) reported the presence of HCH (BDL-811 μg/kg) and DDT (BDL-1987 μg/kg) along with PCBs (polychlorinated biphenyls) residues in tissues of dead water birds in Nalbana Bird Sanctuary in Chilika Lake.

Organophosphate (OP) pesticides

Methyl parathion (0.033–0.039 μg/g) and chlorpyrifos (0.046–0.053 μg/g) were detected in flesh of *Mugil cephalus* and *Daysciaena albida* samples collected in February 2015. Chlorpyrifos residue (0.003–0.017 μg/g) was also recorded in *M. cephalus*, *E. suratensis*, *L. calcarifer*, *E. tetradactylum*, and *P. monodon* in June 2016 samples. However, the incidence of OP residues was not recorded in any other sample. Although no other report on the occurrence of OP residues in Chilika fish is available, Chatterjee et al. (2016) could also detect residues of few OPs like methyl parathion (0.066–0.071 μg /g), quinalphos (0.014–0.305 μg/g), malathion (0.007–0.055 μg/g), and chlorpyrifos (0.006–0.01 μg/g) in *Pangasianodon hypophthalmus* collected from different locations of Andhra Pradesh and Kerala states in India.

Synthetic pyrethroid (SP) pesticides

In fish samples collected in October 2012, bifenthrin was found in liver samples of *P. indicus*, *P. canius*, and *A. tenuispinis* at concentrations ranged between 0.305 and 0.933 μg/g having a mean value of 0.659 μg/g. Cyfluthrin and fenvalerate were detected in the liver of *S. argus* at concentrations 0.036 and 0.059 μg/g respectively. Nag et al. (2015) reported presence of cyfluthrin residues in fish (*Cirrhinus mrigala*) from East Kolkata Wetlands. Fenpropathrin (0.17 μg/g) was found in the whole body of *P. indicus*. No SP residue was detected in samples collected subsequently. The overall level of OP and SP residues detected in fish is shown in Table 1.

Comparison of pesticide residue levels with their respective tolerance limits

The tolerance limit (TL) of HCH isomers in fish is 0.25 μg/g as per FSSR [Food Safety and Standards (Contaminants, Toxins and Residues) Regulations] 2011, recommended by Food Safety and Standards Authority of India (FSSAI). In one sample, i.e., the liver of *D. russelli*, the level of α-HCH exceeded the limit, and while in all other positive samples, HCH concentrations were below the limit (Table 2). As per FSSR, no TL has been set for heptachlor. Similarly, aldrin too has no set FSSR MRL for fish. But, MRL of 0.1 μg/g for aldrin fixed by Japan for fish and crustaceans (http://www.db.ffcr.or.jp/front/pesticides_comp, accessed on 15th November (2019) has been exceeded in one out of two positive samples with the pesticide. The TL of total DDT comprising all isomers and metabolites of DDT is 7 μg/g in fish as per the FSSR. Concentrations of DDT and its metabolites detected in all the fish samples were below the TL. Endosulfan residues detected in two samples were also much below the TL of 0.2 μg/g as per the FSSR. As tolerance limits were not available, residues of SPs like bifenthrin, fenpropathrin, fenvalerate, and cyfluthrin and OPs like chlorpyrifos and methyl parathion detected in fish samples could not be compared.

Table 1 Organophosphate and synthetic pyrethroid pesticide residues detected in fish from Chilika Lake

Fish samples	Tissue/organ	Pesticides detected and their concentration (in μg/g)					
		Methyl parathion	Chlorpyrifos	Bifenthrin	Fenpropathrin	Cyfluthrin	Fenvalerate
F. indicus	Liver			0.74			
	Whole body				0.17		
S. argus	Liver					0.036	0.059
P. canius	Liver			0.93			
E. suratensis	Flesh		0.003				
A. tenuispinis	Liver			0.3			
E. tetradactylum	Flesh		0.008				
M. cephalus	Flesh	0.033	0.017–0.046				
D. albida	Flesh	0.039	0.053				
L. calcarifer	Flesh		0.005				
Penaeus monodon	Flesh		0.008				

Assessment of health hazard

The EDI of pesticides through the consumption of contaminated fish by children and adult and health hazards associated with it is presented in Table 2. The data revealed that EDI of all the detected pesticides was much below their respective ADIs. Therefore, the average daily exposure of pesticide residues is lower than the reference dose or ADI, which is considered as acceptable and safe levels of exposure during lifetime (USEPA 1996). The hazard indices observed were too low to cause any direct hazard to human health as a result of the consumption of fish from the lake.

Summary and conclusion

This is perhaps the first comprehensive report on the status of pesticide residue contamination in Chilika Lake water, sediment, and fishes. It was observed that the overall extent and level of contamination were very

Table 2 Dietary risk and hazard assessment of the contaminants detected in fish

Pesticide	Average concentration detected in fish (μg/kg)	ADI (μg/kg body wt/day)	Estimated daily intake (μg/kg body wt/day)		Hazard Index	
			Adult = 50 kg	Child = 15 kg	Adult = 50 kg	Child = 15 kg
α-HCH	951	5	0.51354	1.71180	0.103	0.342
β-HCH	1	5	0.00054	0.00180	0.0001	0.0004
γ-HCH	2	5	0.00108	0.00360	0.0002	0.0007
δ-HCH	35	5	0.01890	0.06300	0.0038	0.0126
ΣDDT	121	10	0.06534	0.21780	0.0065	0.0218
ΣEndosulfan	22	6	0.01188	0.03960	0.0020	0.0066
Dicofol	31	2	0.01674	0.05580	0.0084	0.0279
Chlorpyrifos	0.02	10	0.00001	0.00004	0.000001	0.000004
Me-Parathion	0.036	3	0.00002	0.00006	0.000006	0.000022
Bifenthrin	0.66	20	0.00036	0.00119	0.000018	0.000059
Fenpropathrin	0.17	30	0.00009	0.00031	0.000003	0.000010
Cyfluthrin	0.036	20	0.00002	0.00006	0.000001	0.000003
Fenvalerate	0.06	20	0.00003	0.00011	0.000002	0.000005

low. About 31% of water samples were contaminated with OC residues, while the occurrence of OPs was still lower, and no SP residue contamination was found in water. In few water sample concentrations of lindane, op'DDD and heptachlor were above the CMC, while for other positive samples, the levels were below the USEPA limit. No accumulation of residues of targeted pesticides was observed in sediments. In fish, few targeted pesticides like HCH, DDTs, heptachlor, endosulfan, dicofol among the OCs; chlorpyrifos and methyl parathion among the OPs; and cyfluthrin, fenvalerate, and fenpropathrin among the SPs were detected in flesh and organs like the gill and liver. But the concentrations were below the FSSR tolerance limits. So the fishes of Chilika Lake can be considered safe for consumption from the point of view pesticide residues.

However, some of the pesticides are highly persistent, lipophilic, and bioaccumulative. These chemicals, albeit at very low concentrations, can bio-magnify at each trophic level of the food chain. Being toxic substance, certain pesticides even in a minute amount in water or sediment may pose a problem to aquatic organisms including fish in the long run.

Hence, regular surveillance and monitoring are recommended to assess the pollution status of the lake.

Acknowledgments The authors are grateful to the former and present Director, ICAR-Central Inland Fisheries Research Institute, Barrackpore, India, for providing necessary facilities and the Chilika Development Authority, Government of Odisha, India, for financial support for carrying out the research work through the CIFRI-CDA/ICZM consultancy project "Post restoration assessment of the ecology and fisheries diversity of Chilika lake."

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