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Review article

Risk assessment of persistent organic pollutants in fishes from Pakistan and its neighbouring countries

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Abstract

Persistent Organic Pollutants (POPs) include a wide range of compounds including dichlorodiphenyltrichloroethanes' (DDTs), hexachlorocyclohexanes (HCHs), polybrominated diphenyl ethers (PBDEs) and polychlorinated biphenyls (PCBs). These pollutants are present everywhere on earth *i.e.* soil, water and air. Their excessive use has adversely affected all ecosystems and their components including marine and freshwater, wildlife and human health. Although the use of POPs has been banned in many countries but they are still in use in many developing countries. This paper presents the sources and distribution of different POPs with special reference to their adverse effects and possible routes of contamination. Moreover, accumulation of these persistent pollutants in different body parts of fishes from major locations in Pakistan and its neighbouring countries (India, China and Iran) has been presented which exhibits their risk assessment for these important bioindicators of aquatic environments.

Key words: POPs; organic pollutant; pollutant effects; toxicity in fishes

1 | INTRODUCTION

Persistent Organic Pollutants (POPs) are a group of harmful chemicals with three major properties, bioaccumulation, persistence and extensive range transfer. Organochlorine Pesticides (OCPs), Polybrominated Diphenyl ethers (PBDEs), Polychlorinated Biphenyls (PCBs) and hexabromocyclododecane (HBCD) are the main groups of POPs occurring in the atmosphere of all over the world (IPCS 2002). More than 20 POPs have been listed so far by the Stockholm Convention, a global agreement for protection of humans and the environment against POPs contamination (Mwakalapa *et al.* 2018). POPs can be classified into three categories on the basis of their sources: pesticides, industrial chemicals and by-products (Yin *et al.* 2015).

OCPs are considered to be main pollutants with several studies reporting the worldwide consistent occurrence of OCPs (Hung *et al.* 2002). POPs are lipophilic, bioaccumulative and may be dangerous for human health (Darnerud *et al.* 2001). PCBs, the most persistent and challenging pollutant, are a collection of synthetic organic chemicals formed by chlorination of the biphenyl ring system (Ahmed *et al.* 2016). POPs have been detected in places where they had never been used due to their transportation potential (Barra *et al.* 2005). They are also known to be inadvertently released as by-products in combustion processes (UNIDO 2003; Mwakalapa *et al.* 2018). Organochlorine pesticides are very stable compounds for example the breakdown of dichlorodiphenyltrichloroethane (DDT) in soil ranges from 4 to 30 years (Afful *et al.* 2010). They are mostly used for insect and pest management for about 50 years (Patlak 1996). OCPs are a category of POPs that have raised extensive concern due to their high carcinogenicity, semi-volatility and their persistence, ability to bioaccumulate and effects wildlife (Wu *et al.* 1999).

OCPs have a possibility of bioaccumulation in the food chain, hence having hazard to human healthiness and environment as they are characterized by little water solubility, low polarity and elevated lipid solubility (Afful *et al.* 2010). Residues of chlorine containing pesticides have been present almost everywhere in the atmosphere of India owing to their pervasive utilisation in precedent time, that has revealed probability to accumulate in human blood, adipose cells and breast milk (Beg *et al.* 1989). Extensively consumed PBDEs and PCBs in China, are widely distributed in sediments (Chen *et al.* 2006). PBDEs are brominated flame retardant widely used to reduce the flammability of many combustible products, including, plastics, textiles, finishing material and electronic components (Chai *et al.* 2019).

Chemicals having long half-life and greater lipid solubility tend to accumulate in fatty tissues. Such lipid soluble chemicals travel through the cells easily and are stored in fat, where they turn out to be more persistent (Mahboob 2011a).PCBs and PBDEs can be stored in animals, because of their lipid solubility particularly in aquatic animals (Kuehl and Haebler 1995).

The environmental actions and ecotoxicity of POPs are of global apprehension as a result of their persistent, bioaccumulative, and lethal nature equally to animals and humans (Eqani *et al.* 2012a). Although fish and its foodstuffs confer only 10% in human being food, but still it accounts for 90% exposure to the persistent organic pollutants (Djien Liem *et al.* 2000). Due to direct exposure to water pollutants through the gills and skin fishes are a good indicator of toxic agents in aquatic environments (Chang 2018) Extensive manufacturing and utilization of persistent organic pollutants *i.e.*, polychlorinated biphenyls and organochlorine pesticides in industries and agriculture, has changed the worldwide biodiversity (Teng *et al.* 2012). Apart from environmental perspectives, report on circulation and occurrence of OCPs in commercially important fish species are accounted as an important feature in human health (Thomas *et al.* 2012). The particular apprehensions about the undesired effects of pollutants, including POPs, in the aquatic environment, is also revealed at the present European Directive regarding priority substances in the field of water policy (Directive 2013). Environmental Quality Standards (EQS) have been set in the framework of this Directive for few substances, for some compounds not only in water but also in biota (e.g. fish). The Water Framework Directive (WFD) established EQS values for biota below which no harmful effects are expected to wildlife or humans (Ábalos *et al.* 2019)

Aquatic toxicity has become an important part for the assessment of environmentally harmful pollutants. Generally, the probable impact of pollutants is greater for aquatic organisms (Yousafzai and Shakoori 2011; Mishra and Devi 2013). Increasing awareness about the impacts of persistent organic pollutants resulted in happening of the Stockholm Convention (2001). According to this Convention, POPs include three industrial chemicals and nine OCPs (Akhtar *et al.* 2014). The agricultural employment of OCPs, particularly, HCH and DDT are banned universally from the 1970 to 1990s, because these pollutants are non-degradable and therefore are persistent in environment up to decades (Guo *et al.* 2008). Even though their application has been limited in many countries since 1970, particularly in developed countries but some emerging countries are still consuming them because of low price and industrial and agricultural adaptability (Zhou *et al.* 2006). These forbidden chemicals are still continuously being used in Pakistan owing to their low price and easy accessibility (Eqani *et al.* 2012a).

2 | METHODS

Data for this review article have been collected from various online sources and sites. Articles were downloaded from different databases including Web of Science, Science Direct, NCBI, ResearchGate and Google Scholar. The keywords used to search data were POPs, sources of POPs, toxicity in fishes, effect of POPs on fishes and the results that appeared were then filtered according to the relevance to the topic being reviewed. More focus was given to the literature related to China, India, Iran and Pakistan. While searching for the literature the main aim was to collect data from recent as well as past papers to give perspective to the readers about all the information related to POP’s.

3 | RESULTS AND DISCUSSION

A total of 60 studies were recorded from China (Table 1). As indicated in Table 1 DDTs were the most common contaminant in China. While in Table 2 total 51 studies were recorded from India and, similar to China, DDTs were found to be extensively present in fishes.

Table 3 shows studies from Iran. Six studies were recorded because very literature was found regarding POPs contamination in fishes from Iran. Table 3 also indicated presence of DDTs as the most common contaminant. Table 4 shows 13 studies from Pakistan with DDTs as the most common contaminant. All the four tables show that DDTs are the most common form of POPs occurring in fishes.

3.1 | Harmful effects of Persistent organic pollutants

Pesticide contamination poses important risk to the environment and the non-target organisms including beneficial soil microorganisms, plants, fish, birds and humans (Aktar *et al.* 2009). Pesticides affect the fish through a variety of ways mostly by damaging their different fundamental organs such as gills as these are primary organs to be exposed to water-borne contaminants (Gallagher and Diguilo 1992). POPs have been known to have carcinogenic, reproductive, teratogenic, immunologic and neurological effects in living organisms (Kodavanti *et al.* 1998). Several of OCPs and their metabolic products have been known to cause a variety of ecological effects and reproduction and birth disorders in human (Edwards 1987), cancer, endocrine disruptions and loss of immune function (Adeyemi *et al.* 2008). Acute concentration of pesticides in water causes death of fish, whereas sub acute condition leaves residues in them, rendering them unsuitable for human utilisation. Elevated pesticide application immobilizes and causes death in fishes, kills eggs and larva of bivalve mollusks (Davis 1961). The utilisation of biota from polluted water reservoir is well thought-out to be a central course of introduction to OCPs (Johansen *et al.* 1996) subsequently causing health problems in humans, principally loss of endocrine function, breast cancer, births imperfections, testicular melanoma and lesser sperm count (Garry 2004). Fishes stressed by pesticides exhibit disorders in behaviour, reproduction, survival, growth, and respiration (Mani and Konar 1975). Most of these pollutants act as possible carcinogens or mutagens affecting reproductive sequences of wildlife and are conferred to work as ecological hormones (Colbom *et al.* 1993). Polybrominated diphenyl ethers can harm behaviour, memory and learning process in laboratory animals (Fowles *et al.* 1994). Hexachlorobromine has a wide variety of noxious effects on trial animals, including disorders of thyroid function, hepatotoxicity, carcinogenicity, immune repression; neurotoxicity and reproductive toxicity (ATSDR 2002). PCB-exposed employees have revealed poor health outcomes including liver modifications, hypertension and dermal transformation (Kimbrough *et al.* 1999).

3.2 | Sources

The arbitrary and injudicious uses of OCPs have led to the contamination of water bodies (Singh *et al.* 2005). In current days, extensive open dumping of municipal wastes in developing countries of Asia is thought to be one of the main reasons of POPs saturation in environment (Watanabe *et al.* 2005). Sediment is one of the main sinks of OCPs in the environment, since OCPs are readily adsorbed onto suspended particulate matter and then precipitate into river, lake and marine sediments because of their high hydrophobicity and low water solubility (Sun *et al.* 2010) POPs can be removed from the water cycle for long periods when confiscated in sediments. However, if sediments are remobilised, they can be reintroduced into the ecosystem and the food chain, probably becoming a source of local or even global contamination (Guigue *et al*. 2017; Liber *et al.* 2019). Ingestion of contaminated food, respiration and dermal assimilation are considered to be the main sources of uptake of POPs in humans, although respiration and dermal absorption is not the most important pathway. Several scientists have established that more than 90% of noxious wastes are acquired from contaminated food (Fürst *et al.* 1990). Numerous pesticides can critically contaminate surrounding areas because they can volatilize and easily accumulate in the atmosphere (USGS 1995). Improper storage and handling, damaged Containers, corroded metal drums, rotten sacks leads to the seepage of pesticides to the neighbouring locations (Jan *et al.* 2009). Large amount of OCPs containing residues reach marine environment through atmospheric accumulation, agricultural overflow and sewerage discharge (GESAMP 1989). Surface runoff, demolished factories of OCPs, where higher amounts of DDTs and other OCPs are discarded, are also one of the important sources of the OCPs pollution in the different environmental regions (Eqani *et al.* 2011). Residual chemicals of pesticides also find their way to aquatic reservoirs with agricultural runoff (Scott *et al.* 1999), sewage treatment units (Honnen *et al.* 2001), industrial waste chemicals and accidental spills (Lambert 1997). Pesticides drained to the aquatic environment comes both from surface run-off from paddy fields or through direct application into ponds for the control of parasites (Das and Mukherjee 2000). Mostly pesticides come across marine reservoirs through leakage and cause pollution of surface and ground water (Mahboob *et al.* 2011a).

3.3 | Risk Assessments of POPs in fishes

Species holding a higher position on the food chain such as dolphins and humans are exposed to POPs mostly through contaminated fish consumption (Fair *et al.* 2018) Fishes are proficient to build up elevated concentrations of pesticide residue deposits inside them than the surroundings (Siddiqui *et al.* 2005). As compared to terrestrial animals, aquatic organisms like fish have been revealed to have better capacity of bioaccumulation of pollutant residues because of their lesser mono-oxygenase activity so fish are an important bioindicator of contaminated aquatic environment (Davodi *et al.* 2011). Aquatic farms are usually nearby agricultural sites and human residential areas. Several OCPs were previously used as insecticides for controlling crop ectoparasites, introducing pesticides into the water and soil and therefore contaminating aquaculture products. Such a breeding approach is susceptible to OCP residues, necessitating the observation of persistent agents for their prevention and treatment

(Chang 2017). HOCs are capable to penetrate into a fish, largely by two means, *i.e.* bioaccumulation through the course of the aqueous environment or biomagnification all the way through food network preys (Kiriluk *et al.* 1995).

Fishes are an excellent bio-indicator of aquatic environment examination and can perform an important function in evaluating possible risks connected with pollutants in the marine ecosystem since they can be effected directly from agriculture based organic pollutants or indirectly by consuming contaminated food web preys of ecosystem (Lakra and Nagpure 2009). Generally, it is thought that aquatic organisms generally intake pollutants directly from surrounding water bodies, not from their food, and accessibility of pollutants may also vary with season (Mahboob *et al.* 2011b). Aquatic environments may be contaminated by direct release of waste products containing PCBs into waterway, lakes and sea side localities (Eqani *et al.* 2012a and 2012b). Another potential supplier of PCBs is making oceanic liners for ship breaking. These ship breaking processes discharge numerous detrimental pollutants mainly PCBs and asbestos (National Implementation Plan, Government of India 2011). Rigorous waste recycling activities can also speed up the release of PCBs and PBDEs into the environment (Robinson 2009). The use of PCBs and OCPs in the agricultural land mainly led to the accretion of these compounds in the environment (Shakeri *et al.* 2015). Humans can intake OCPs through consuming contaminated food, breathing polluted air or by absorbing pollutants through skin (Safe 1998; Alle *et al.* 2009), by using fish and fish products (Alcock *et al.* 1998; Zhao *et al.* 2009). Among all sources contaminated food is thought to be the major source of exposure towards POPs in humans therefore in order to assess extent of its human exposure, it is of prime significance to analyse concentration of POPs in different foodstuff (IPCS 2002). Fish constitute a major source of protein and it has been suggested that a large segment of the world's population is exposed to POPs through seafood (Fair *et al.* 2018).

TABLE 1 Concentration of persistent organic pollutants (POPs) in fishes from major locations in China.

Fish	Location	PCBs (ng/g)	HCHs (ng/g)	DDTs (ng/g)	Aldrin (ng/g)	Endosulfan (ng/g)	PBDEs (ng/g)	CHLs (ng/g)	HBCDs (ng/g)	HCB (ng/g)	Reference
Channa argus	Nanjing	15	-	-	-	-	190	-	-	-	Su *et al.* (2012)
Navodon septentrionalis	Haimen Bay	14.22	1.62	2.68	-	-	-	0.08	-	-	Shi *et al.* (2013)
Synchiropus splendidus	Guagdong	130	22	160	-	-	21	-	-	-	Qui *et al.* (2012)
Hypophthalmichthys molitrix	Yangtze River	-	-	-	-	-	1100	-	25	-	Xian *et al.* (2008)
Carassius cuvieri	Yangtze River	-	-	-	-	-	32	-	24	-	Xian *et al.* (2008)
Ilisha elongata	Daya Bay	-	0.26	40	-	-	0.1	0.84	-	-	Guo *et al.* (2008)
Nibea acuta	Pearl River Estuary	-	0.20	80	-	-	1.9	4.78	-	-	Guo *et al.* (2008)
Hypophthalmichthys molitrix	Poyang Lake	-	1.66–31.25	0.063–1.80	45.8–240.15	1.24– 26.71	-	-	-	-	Zhao *et al.* (2014)
Mugil cephalus	Guagdong province	0.02–7.65	0.13–24.06	0.14–698.9	-	-	0.0012 – 3.85	-	-	-	Meng *et al.* (2007)
Acipenser sinensis	Yangtze River	-	-	-	-	-	25.0	-	-	-	Zhang *et al.* (2010)
Mytilus viridis	Xiamen island	65.2	33.8	0.37	-	-	-	-	-	-	Chen *et al.* (2002)
Trichiurus lepturus	Shanghai	0.83	0.10	1.98	-	-	-	0.06	-	-	Yang *et al.* (2006)
Lateolabrax japonicus	Qiantang River	-	3.07	9.33	0.83	-	-	-	-	-	Zhou *et al.* (2007)
Saurida tumbil	Haimen Bay	24.87	2.30	3.03	-	-	-	0.27	-	-	Shi *et al.* (2013)
Decapterus maruadis	Shantou Harbour	7.73	2.74	8.99	-	-	-	9.53	-	-	Shi *et al.* (2013)

TABLE 1 Continued.

Fish	Location	PCBs (ng/g)	HCHs (ng/g)	DDTs (ng/g)	Aldrin (ng/g)	Endosulfan (ng/g)	PBDEs (ng/g)	CHLs (ng/g)	HBCDs (ng/g)	HCB (ng/g)	Reference
Platicephalus indicus	Bohai Bay	-	-	-	-	-	2.5	-	-	-	Tian *et al.* (2010)
Plectorhinchus diagram-mus	Yongxing Island	11	-	40	-	-	11	-	-	-	Sun *et al.* (2014)
Epinephelus fasciatus	Yongxing Island	18	-	93	-	-	6.9	-	-	-	Sun *et al.* (2014)
Pompus echinogaster	Hangzhou Bay	109	24	430	-	-	-	11	-	-	Nakata *et al.* (2005)
Clarias lazera	Gaobeidian Lake	3.04	3.25	31.8	-	-	-	-	-	4.10	Li *et al.* (2008a)
Pelodiscus sinensis	Gaobeidian Lake	0.63	2.32	2.38	-	-	-	-	-	0.61	Li *et al.* (2008a)
Ptychobarbus dipagon	Lhasa River	-	0.32	2.5	-	-	-	-	-	-	Yang *et al.* (2007)
Argyrosomus argentatus	East China Sea	-	0.01	6.4	-	-	-	0.70	-	0.42	Jiang *et al.* (2005)
Cinnamon flounder	East China Sea	-	-	4.2	-	-	-	0.88	-	0.29	Jiang *et al.* (2005)
Cyprinus carpio	Taihu Lake	-	6.29	0.84	-	-	-	0.47	-	-	Zhao *et al.* (2013)
Ctenopharyngodon idellus	Taihu lake	-	38.12	11.48	38.55	11.23	-	2.87	-	-	Zhao *et al.* (2013)
Siniperca kneri	Hong Kong	-	-	82.2	-	-	-	-	-	-	Cheung *et al.* (2007)
Platycephalus indicus	Hong Kong	-	-	43.2	-	-	-	-	-	-	Cheung *et al.* (2007)
Trachinotus blochii	Hong Kong	-	-	1018	-	-	-	-	-	-	Cheung *et al.* (2007)
Micropterus salmoides	Shunde	-	-	1401	-	-	-	-	-	-	Leung *et al.* (2010)
Channa asiatica	Zhongshan	-	-	1665	-	-	-	-	-	-	Leung *et al.* (2010)
Clarias fuscus	Zhongshan	-	-	386	-	-	-	-	-	-	Leung *et al.* (2010)
Parasilurus asotus	Baiyangdang lake	-	84	32	-	-	-	-	-	-	Hu *et al.* (2010)
Saurida undosquamis	Natuna Is-land	26.4	-	16.7	-	-	5.55	-	-	-	Hao *et al.* (2014)
Upeneus bensasi	Natuna Is-land	14.3	-	10.8	-	-	2.85	-	-	-	Hao *et al.* (2014)
Decapterus russelli	Natuna Is-land	31.9	-	24.4	-	-	7.64	-	-	-	Hao *et al.* (2014)
Misgumus anguillicaudatas	Huairou Res-ervoir	-	6.41	44.2	-	-	-	-	-	-	Li *et al.* (2008b)
Hemicultureleuciscultures	Gaobeidian Lake	22.7	8.48	88.3	-	-	-	-	-	-	Li *et al.* (2008b)
Auxis rochei	Zhoushan fishery	3.82	--	-	-	-	1.68	-	-	-	Shang *et al.* (2016)
Tenualosa reevesii	Zhoushan fishery	1.37	--	-	-	-	0.21	-	-	-	Shang *et al.* (2016)
Pseudosciaena crocea	Wenzhou	-	-	-	-	-	2.84	-	-	-	Xia *et al.* (2011)

TABLE 1 Continued.

Fish	Location	PCBs (ng/g)	HCHs (ng/g)	DDTs (ng/g)	Aldrin (ng/g)	Endosulfan (ng/g)	PBDEs (ng/g)	CHLs (ng/g)	HBCDs (ng/g)	HCB (ng/g)	Reference
Pampus argenteus	Quanzhou	-	-	-	-	-	1.11	-	-	-	Xia *et al.* (2011)
Cambarus catagius	China	-	-	-	-	-	-	-	85.3	-	Hu *et al.* (2011)
Sausa chinensis	Pearl River Estuary	1790	960	62700	14.8	-	-	85.9	-	63.7	Gui *et al.* (2014)
Magalobrama ambly-cephala	Lake Chaohu	-	1.16	13.51	-	0.12	-	0.03	-	1.67	Liu *et al.* (2016)
Aristichtyhs nobilis	Hong kong	0.87	-	0.040	-	-	-	-	-	-	Zhou *et al.* (1999)
Monopterus albus	Yangtze River delta	37	30	970	-	0.74	34	0.34	16	0.05	Zhou *et al.* (2016)
Collichthys lucidus	Pearl River Estuary	92	8.0	200	-	-	3.8	-	-	-	Sun *et al.* (2015a)
Osteomugil ophuyseni	Pearl River Estuary	64	9.7	820	-	-	3.9	-	-	-	Sun *et al.* (2015a)
Pseudosciaena crocea	Qingdao	-	-	-	-	-	-	-	5.4	-	Xia *et al.* (2011)
Culter alburnus	Lake Chaohu	-	-	-	-	-	120.65-129.77	-	-	-	Yang *et al.* (2015)
Cirrhinus molitorella	Beijiang River	830	18	590	-	-	77	-	-	-	Sun *et al.* (2016)
Hypostomus plecostomus	Dongjiang River	290	12	600	-	-	200	-	-	-	Sun *et al.* (2016)
Sardinella jussieu	Pearl River Estuary	570	-	710	-	-	38	-	-	-	Sun *et al.* (2015b)
Coilia mystus	Pearl river estuary	130	-	300	-	-	8.1	-	-	-	Sun *et al.* (2015b)
Mylopharyngodon piceus	Wanzhou	-	0.32	9.47	-	0.02	-	0.06	-	-	Wang *et al.* (2016)
Carassius carassius	Wushan	-	0.10	2.66	-	0.01	-	0.01	-	-	Wang *et al.* (2016)
Tilapia nilotica	Dongjiang River	-	-	-	-	-	100	-	-	-	He *et al.* (2012)
Cirrhina molitorella	Dongjiang River	-	-	-	-	-	92	-	-	-	He *et al.* (2012)
Pseudosciaena crocea	Dalian	0.01–23	-	-	-	-	-	-	-	-	Xia *et al.* (2012)

PCBs, polychlorinated biphenyls; HCHs, hexachlorocyclohexane; DDTs, dichlorodiphenyltrichloroethanes; PBDEs, polybrominated diphenyl ethers; CHLs, chlordane; HBCDs, hexabromocyclododecane; HCB, hexachlorobanzene.

TABLE 2 Concentration of persistent organic pollutants (POPs) from major locations in India.

Fish	Location	PCBs (ng/g)	HCHs (ng/g)	DDTs (ng/g)	Aldrin (ng/g)	Endosulfan (ng/g)	PBDEs (ng/g)	CHLs (ng/g)	HBCDs (ng/g)	HCB (ng/g)	Reference
Stenalla longirostiss	South western Indian Ocean	955	20	0.14	-	-	60	-	-		Dirtu *et al.* (2016)
Tursiops aduncus	South western Indian Ocean	5200	10	0.07	-	-	95	-	-		Dirtu *et al.* (2016)
Rita rita	Gomti River, Janpur	-	2.31	5.79	0.08	0.12	-	-	-		Singh *et al.* (2008)
Clarias gariepinus	Gujartal	-	80.54	47.71	-	-	-	-	-		Singh *et al.* (2008)

TABLE 2 Continued.

Fish	Location	PCBs (ng/g)	HCHs (ng/g)	DDTs (ng/g)	Aldrin (ng/g)	Endosulfan (ng/g)	PBDEs (ng/g)	CHLs (ng/g)	HBCDs (ng/g)	HCB (ng/g)	Reference
Cyprinus carpio communis	Gujartal	-	40.38	32.26	-	-	-	-	-		Singh *et al.* (2008)
Scomberomorus commersonn	Cochin	-	9.1	7.8	-	1.75	-	-	-		Jyanthi and Muralidharan (2014)
Liza parsia	River Cauvery	-	1.82	3.23	1.7	-	-	-	-		Bhuvaneshwari and Rajendran (2012)
Xenentodon cancila	Haridwar	200	110	3700	-	-	-	0.8	-	0.3	Senthilkumar *et al.* (1999)
Mystus cavasius	Allahabad	110	57	120	-	-	-	3.2	-	0.4	Senthilkumar *et al.* (1999)
Platanista gangetica	Ganges	16	28	110	1.9	-	-	5.8	-	2.4	Kannan *et al.* (1994)
Stenella longirostris	Bay of Bengal	0.77–2.0	0.07–0.17	16–33	-	-	-	0.07–0.32	-	0.01–0.02	Prudente *et al.* (1997)
Sousa chinensis	Bay of Bengal	4.0–5.0	0.14–1.5	41–63	-	-	-	0.09-0.14	-	0.01-0.01	Prudente *et al.* (1997)
Tursoips truncatus	Porto Novo	390	130	5900	-	-	-	-	-	4.8	Tanabe *et al.* (1993)
Sphyraena acutipinnis	Northern Arabian Sea	-	-	40.4	2.81	-	-	-	-	-	Shailaja and Nair (1997)
Chorinemus tol	Northern Arabian Sea	-	-	1.38	0.35	-	-	-	-	-	Shailaja and Nair (1997)
Scomberomorus guttatus	Northern Arabian Sea	-	-	13.1	<0.02	-	-	-	-	-	Shailaja and Nair (1997)
Nemipterus japonicus	Northern Arabian Sea	-	-	9.92	0.56	-	-	-	-	-	Shailaja and Nair (1997)
Lethrinus spp.	Northern Arabian Sea	-	-	38.8	3.78	-	-	-	-	-	Shailaja and Nair (1997)
Chirocentrus dorab	Northern Arabian Sea	-	-	4.68	<0.02	-	-	-	-	-	Shailaja and Nair (1997)
Sillago maculata	Pondicherry	-	0.10	0.05	-	-	-	-	-	-	Rajendran *et al.* (1992)
Pampus argenteus	Madras	-	0.36	0.34	-	-	-	-	-	-	Rajendran *et al.* (1992)
Hirundichthys coromandelensis	Cuaddalor	-	0.63	0.32	-	-	-	-	-	-	Rajendran *et al.* (1992)
Synagris striatus	Bay of Bengal	-	-	7.66	0.25	-	-	-	-	-	Shailaja and Singbal (1994)
Sillago sihama	Bay of Bengal	-	-	13.87	0.54	-	-	-	-	-	Shailaja and Singbal (1994)
Sardinella fimbriata	Eastern Arabian Sea		-	54.3	-	-	-	-	-	-	Hamilton (1989)
Chiloscillum indicus	Eastern Arabian Sea	-	-	204.5	-	-	-	-	-	-	Hamilton (1989)
Lethrinus conchyliatus	Rameshwaram coast	-	13	10	-	22	-	-	-	-	Muralidharan *et al.* (2009)
Trichiurus savala	Calicut region	-	-	-	2.20	-	-	-	-	-	Sankar *et al.* (2006)
Lutjanus rivulatus	Calicut region	-	-	-	0.96	-	-	-	-	-	Sankar *et al.* (2006)

TABLE 2 Continued.

PCBs (ng/g)	PCBs (ng/g)	PCBs (ng/g)	PCBs (ng/g)	PCBs (ng/g)	PCBs (ng/g)	PCBs (ng/g)	PCBs (ng/g)	PCBs (ng/g)	PCBs (ng/g)	PCBs (ng/g)	PCBs (ng/g)
Girella tricuspidata	Alibagh west coast	-	1.3	2	-	-	-	-	-	-	Pandit *et al.* (2001)
Labeo rohita	Punjab	-	0.05	0.013	-	-	-	-	-	-	Kaur *et al.* (2008)
Hypophthalmicthys molitrix	Punjab	-	0.006	0.011	-	-	-	-	-	-	Kaur *et al.* (2008)
Aoriichthys aor	Raj Mahal	-	1078.6	118.9	16.03	15.6	-	-	-	-	Kumari *et al.* (2001)
Labeo rohita	Mokama	-	628.9	56.7	30.8		-	-	-	-	Kumari *et al.* (2001)
Clupisoma garua	Patna	-	249	-	225.1	15.8	-	-	-	-	Kumari *et al.* (2001)
Rita rita	Buxar	-	338.5	26.6	86.1	7.9	-	-	-	-	Kumari *et al.* (2001)
Chirocentrus dorab	Mumbai west coast	-	4.96–19.12	14.88–58.30	-	-	-	-	-	-	Sethuraman *et al.* (2013)
Tursiops truncatus	South east coast	25.37	79.81	0.681	-	-	-	-	-	-	Karuppiah *et al.* (2005)
Therapon jarbou	Tropical coastal environment	-	-	0.4–89.27	-	0.02–2.47	-	-	-	-	Sarkar *et al.* (2008)
Parastromateus niger	India	-	-	0.04	0.09	-	-	-	-	-	Radhakrishnan and Antony (1989)
Puntius spp.	Kodinar	-	-	8.67	-	3.40	-	-	-	-	Zynudheen and Radhakrishnan (2004)
Labeo rhita	Rajkot	-	-	4.73	-	0.005	-	-	-	-	Zynudheen and Radhakrishnan (2004)
Labeo bata	Mahala Reservoir, Jaipur	-	6.83	2.66	1.62	-	-	-	-	-	Bakre *et al.* (1990)
Puntius sarana	Mahala Reservoir, Jaipur	-	0.71	0.31	0.45	-	-	-	-	-	Bakre *et al.* (1990)
Tachysurus maculatus	Cochin coast	-	17	4	-	14	-	-	-	-	Muralidharan *et al.* (2009)
Rastrelliger kanagurta	Rameshwaram coast	-	34	5	-	23	-	-	-	-	Muralidharan *et al.* (2009)
Orcaella brevirostris	Chilika Lake	28	180	1100	-	-	-	1.7	-	3.6	Kannan *et al.* (2005)
Scoliodon laticaudus	Coastal environment, Mumbai	-	33.73	32.56	-	-	-	-	-	-	Pandit *et al.* (2002)
Scomberomorous commersoni	Parangipettai	3.8	1.7	31	-	-	-	-	-	0.04	Ramesh *et al.* (1992)
Cynoglossus paraplagusia	Parangipettai	8.9	4.8	12	-	-	-	-	-	0.07	Ramesh *et al.* (1992)
Channa punctatus	Gomti River	-	0.21	0.12	0.30	0.35	-	0.55	-	-	Malik *et al.* (2007)

PCBs, polychlorinated biphenyls; HCHs, hexachlorocyclohexane; DDTs, dichlorodiphenyltrichloroethanes; PBDEs, polybrominated diphenyl ethers; CHLs, chlordane; HBCDs, hexabromocyclododecane; HCB, hexachlorobanzene.

TABLE 3: Concentration of persistent organic pollutants (POPs) in fishes of Iran.

Fish	Body parts	Location	PCBs (ng/g)	HCHs (ng/g)	DDTs (ng/g)	Endosulfan (ng/g)	CHLs (ng/g)	References
Ctenophardndo idella	Muscle	Shadegan marshes	200	280	310	-	-	Davodi *et al.* (2011)
Thunnus tonggol	Edible parts	Hormozgan province	733.15	-	297.35	-	-	Nozar *et al.* (2013)
Leucicus cephalis	Tissues	Shahid Rajaei dam	0.065	0.028	0.240	-	-	Shakeri *et al.* (2015)
Barbus barbus	Tissues	Shaid Rajaei dam	0.036	0.108	0.070	-	-	Shakeri *et al.* (2015)
Cyprinus carpio	Muscle	Tashk Lake	-	-	4.218	0.781	0.032	Kafilzadeh (2015)

PCBs, polychlorinated biphenyls; HCHs, hexachlorocyclohexane; DDTs, dichlorodiphenyltrichloroethanes; CHLs, chlordane

TABLE 4: Concentration of persistent organic pollutants (POPs) in fishes from Pakistan.

Fish	Location	PCBs (ng/g)	HCHs (ng/g)	DDTs (ng/g)	Endosulfan (ug/g)	Reference
Catla catla	Ravi river	-	-	2.46	0.136	Akhtar *et al.* (2014)
Tor putitora	Kabul River, KPK	-	94.6	73.6	-	Aamir *et al.* (2016)
Cirrhinus mrigla	Taunsa barrage	0.33	0.52	0.41	-	Robinson *et al.* (2016)
Wallago attu	Guddu barrage	0.62	0.54	0.89	-	Robinson *et al.* (2016)
Labeo calbasu	Sukkhur	0.43	0.51	0.21	-	Robinson *et al.* (2016)
Scomberomorus guttatus	Hyderabad	247.8	-	-	-	Ahmed *et al.* (2016)
Cirrhinus mrigala	River Chenab, Jhang	-	-	0.008	0.005	Mahboob *et al.* (2011a)
Mastacembalis aramtus	River Chenab	108	-	190	-	Eqani *et al.* (2013)
Catla catla	River Ravi	-	-	-	19.155	Mahboob *et al.* (2015)
Labeo rohita	Faisalabad	-	-	0.135	0.048	Rana *et al.* (2011)
Perna viridis	Manora channel	-	-	55.58	-	Munshi *et al.* (2005)
Acanthopagurus spp.	Hawksbay channel	-	-	69.23	-	Munshi *et al.* (2005)
Cyprinus carpio	Head Bulloki, Ravi River	-	-	-	13.62	Mahboob *et al.* (2013)

PCBs, polychlorinated biphenyls; HCHs, hexachlorocyclohexane; DDTs, dichlorodiphenyltrichloroethanes; CHLs, chlordane

Level of POPs in fishes from China and India were the highest. There are different factors, recorded from these two countries, which can contribute to high POPs level in fishes including high density population, industrialisation, pollution, high consumption of pesticides and insecticides POPs were found to be present in gills, tissues, liver, brain, blubber and muscles of fishes but many studies revealed that muscles are commonly affected by POPs. DDTs were the most abundant form of POPs present in fishes from China followed by the PCBs, HCHs and PBDEs. The pattern of POPs contamination in fishes from China is DDTs > HCHs > PCBs > PBDEs > HBCDs > Aldrin. Whereas, in India, the most common contaminants was DDTs followed by HCHs and Aldrin. The pattern of POPs contamination in fishes of India was DDTs > HCHs > Aldrin > PCBs > PBDEs > HBCDs. The pattern of contamination in fishes from Iran was DDTs > PCBs > HCHs > Aldrin while in Pakistan it was DDTs > PCBs > Endosulfan > HCHs > Aldrin.

DDTs were found to be the most abundant form of POPs contamination in fishes from all the four countries while Aldrin was the least common contaminant in fishes from China, Iran and Pakistan except India where its concentration was considerably higher, compared three remaining countries.

4 | CONCLUSION

POPs are designated as the most persistent and stable compounds in environment. From this study it is concluded that POPs have been present in higher concentrations in fishes from all major aquatic sites in Pakistan, China, India and Iran. Review of available experimental studies on bioaccumulation of POPs in few of these countries revealed significant presence of PCBs, HCHs, DDTs, Aldrin, endosulfan, PBDEs, CHLs and HBCDs in different body parts of native fish species, which, being a part of the food web, are a source of transmission of these contaminant and can also serve as an important bio-indicator of these pollutants. Consumption of such contaminated aquatic organisms is a major route of POPs contamination in humans. Furthermore high residual contamination of POPs is due to their extensive use in past. There is a need to manage POPs concentration in environment that will help to reduce the contamination and health risk of these persistent compounds.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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