International Journal of Entomology Research
www.entomologyjournals.com
ISSN: 2455-4758
Received: 17-11-2022, Accepted: 04-12-2022, Published: 20-12-2022
Volume 7, Issue 12, 2022, Page No. 115-123

Distribution of polycyclic aromatic hydrocarbons (PAHs) in environment and its toxicological analysis on the fish tissues in last two decades

Poonam, Sandhya
Department of Zoology, School of life Sciences Babasaheb Bhimrao Ambedkar University, Lucknow, Uttar Pradesh, India

Abstract
Polycyclic aromatic hydrocarbons (PAHs) are priority pollutants, containing more than two fused benzene rings. They can be divided into low (2-3 rings) and high (4-6 rings) molecular weight compounds. They are raised by natural as well as anthropogenic activity. Anthropogenic activities are namely pyrogenic (incomplete combustion of fossil fuel, auto mobile, power plant, wastes incinerators) and petrogenic (crude oil and petroleum products like diesel, kerosene, petrol, lubricating oil asphalt). They enter in atmosphere and aquatic ecosystem by industrial, domestic wastes water discharges, agricultural and surface run off. They caused many adverse effects in aquatic ecosystem. They trend to bioaccumulate in fish tissues, led to deteriorate impacts. Fish play a vital role in environment, entertainment, economic and major dietary sources (protein, PUFA, energy, vitamins and minerals). In present investigation, the effects of PAHs on fish were estimated in last twenty one year. Both types of PAHs, (LMW) and (HMW) were accumulated in fish. The most studied organs were muscle, liver/bile, gonads, gills, gall bladder, gut, head, eggs, skeleton and brain. PAHs caused behavioural, developmental and reproductive abnormalities in fish. However many studies have been done of PAHs contamination in fish but it is noticed that skin, eye and gills which are directly exposed organs to the surroundings, need to investigate the impacts of PAHs in these organs. Thus, we should emphasize the prevention and remediation of PAHs in aquatic ecosystem.

Keywords: eyes, gills, muscle, PAHs, skin

Introduction

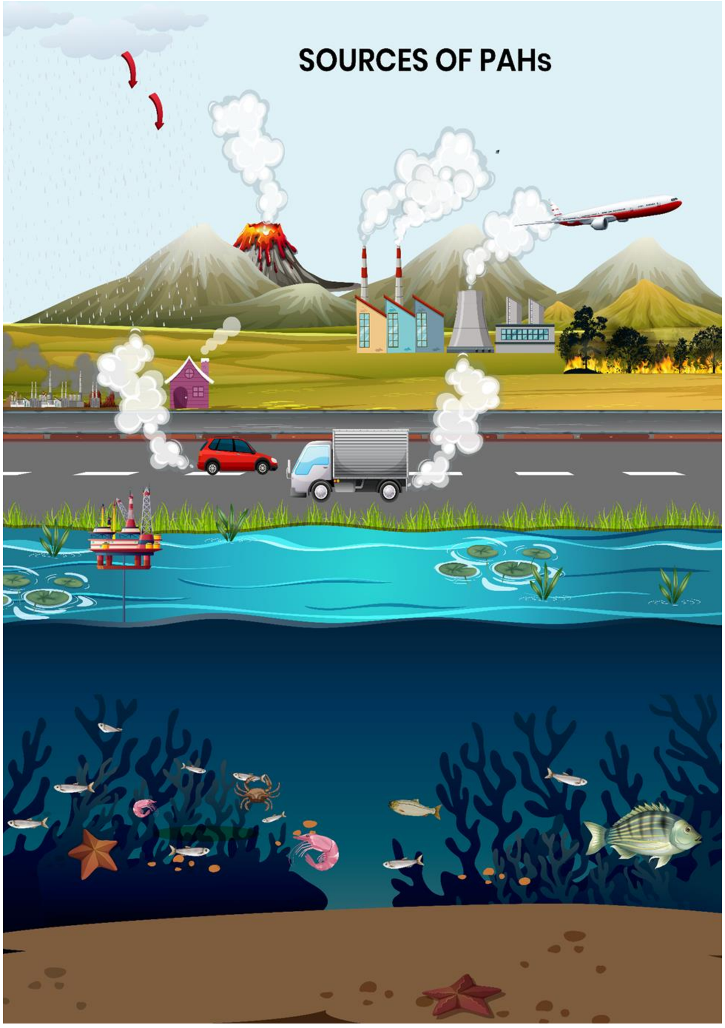
Polycyclic aromatic hydrocarbons (PAHs) are nonbiodegradable and persistent organic pollutants, pose a major risk to global population due to their carcinogenic and mutagenic nature (Agarwal *et al.,* 2006) [1]. They are classified as low molecular weight LMW (2-3 rings) and high molecular weight HMW (4-6 rings) compounds (Evans *et al.* 2019) [16]. Approximately more than 100 PAHs are found (Malik *et al.,* 2011). They are originated from naturals and anthropogenic activities which are categorized in two groups namely pyrogenic (incomplete combustion of fossil fuel, auto mobile, power plants that generate wastes incinerators) and petrogenic (crude oil and petroleum products like diesel, kerosene, petrol, lubricating oil and asphalt) sources. Two to three rings PAHs are dominated in petrogenic while Three to four rings PAHs are dominated in pyrogenic sources (Rabia aslam *et al.,* 2022). They enter in atmosphere and aquatic environment by industrial as well as domestic wastes water discharge, oil slippage, agricultural, urban and surface run off. These sources are the main contributors of PAHs in aquatic ecosystem. Aquatic organisms including fish are directly affected by environmental contaminants. These contaminants having PAHs containing chemicals (personal care products like cosmetics, shampoo, soap, sunscreen and toothpaste and pharmaceutical) which shows acute effects and physiological disorder in fish (Matzenbacher *et al.,* 2019) [33]. Fish play a vital role in various fields such as economic, pharmaceutical, cosmetics, nutritional and entertainment purpose and consumed by human widely as main content of protein, energy, vitamins, polyunsaturated fatty acid and minerals (Varol and Sunbul 2018) [45]. The pollution in inland and coastal waters can be measured by fish disease, therefore they can be used as suitable bio indicator for monitoring the anthropogenic stress in water bodies (Logan 2007) [29]. PAHs trend to bio accumulate in fish tissues by partitioning of cell membrane, causing many adverse effects to these individuals (Behera *et al.,* 2018) [8]. However, many studies regarding to the toxicity of PAHs on fish have been done but in last decade, the rapid urbanization and industrialization leading to thrilling pollution in inland surface water therefore it is extremely need to find out the PAHs distribution in aquatic ecosystem and how these compounds affect fish while in their surroundings. Therefore, in this review we summarized the toxicity analysis of PAHs on fish and its impact in their vital organs in last twenty one years.

Material and method

Our literature searched is based on two approaches-

First**,** the searched carried out by searching articles that represent the effects of PAHs in water as well as in fish from e-resources platform JSTOR, Sringer link, Taylor and Francis, Nature, American Chemical Society, Pubmed, Oxford University for this literature.

Second, we selected twenty one year of publications that relate to the impacts of PAHs on fish. The relevant study materials are selected after excluding some articles based on title, abstract, full text evaluation which were not match with the study purpose. Therefore from 2001 to 2022, total 202 numbers of potentially relevant records are taken that matched with present study.



Sources: wetransfer_final-v1-ai_2022-11-29_1307

Graph 1

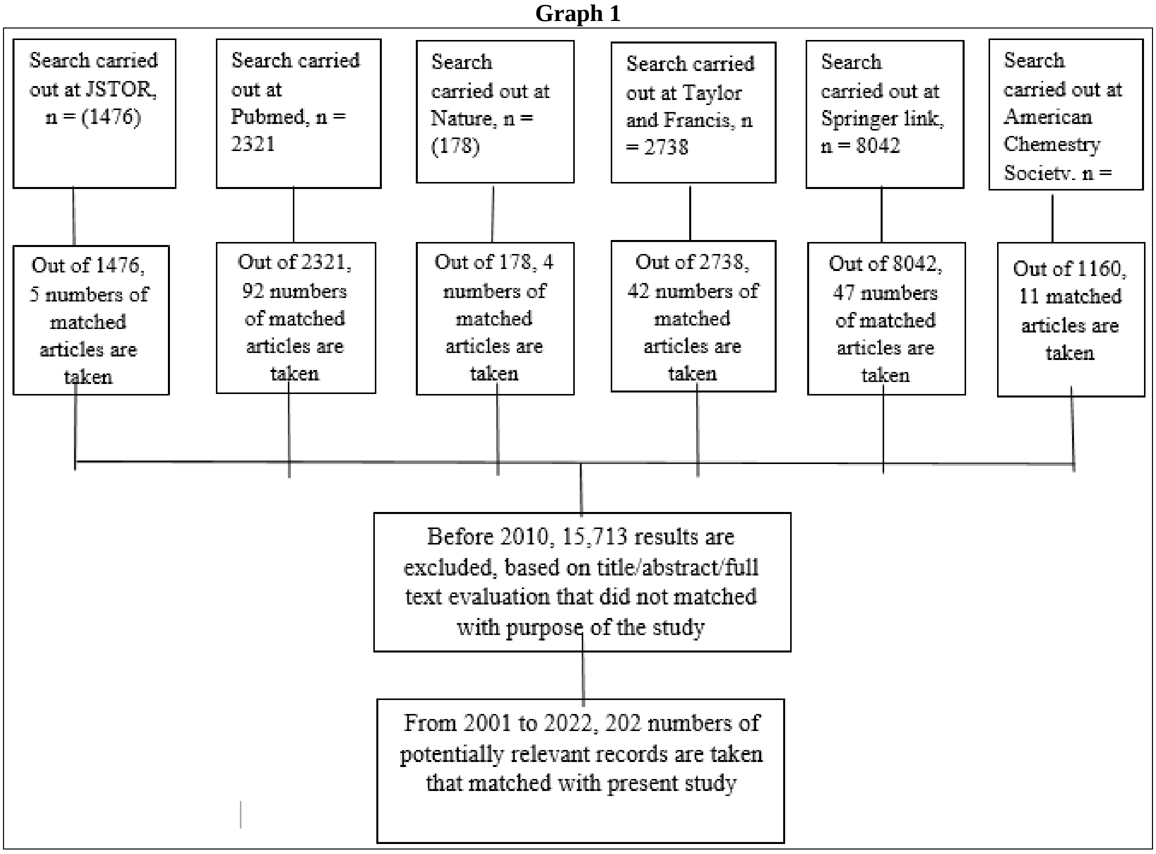


Fig 1: Flow chart representing the literature search methodology and article selection for the this review

Result and Discussion

Geographical distribution of PAHs and its accumulation in fish: Table 1 indicates both PAHs exposure in laboratory and field surveys demonstrated that PAHs adversely affected fish. The investigation of PAHs distribution have been done in water bodies, soil, sediment and air by many authors (Duttagupta *et al.,* 2020; Kumar *et al.,* 2013; Sharma *et al.,* 2008; Ellickson *et al.,* 2017) [13, 25, 15]. The majority of PAHs distribution depend on its sources. On this view, the spreading of PAHs might be varied by geographical and seasonal parameters. The distribution of PAHs could be present from Greenland to high mountain lake (Europe) (Vives *et al.,* 2004). PAHs distribution widely occur near the urban areas due to elevation of pollution that include both pyrogenic as well as petrogenic sources (Ravindra khaiwal 2008). Kmbrough *et al.,* 2021 noted that near to urban areas, automobiles exhaust contributes to major sources of PAHs distribution while in remote areas the major sources of PAHs distribution are atmospheric deposition. Furthermore Tatiana Recabarren-Villaden *et al.,* 2021 described that petrogenic sources are dominated in colder season while pyrogenic in warmer season. The types of these sources and its resistivity influence fish in their surroundings. Table 1 summarized the distribution and bioaccumulation of PAHs in vital organs of many fish species. The present study represent that the most investigation of PAHs accumulation have been done on muscle tissues (Table 1) that contributes major organ as its nutritional source. Muscle is edible part of fish, pose a major concern. Aquatic organisms including fish could uptake PAHs from water, sediments and the organisms of lower trophic level (Wang *et al.,* 2021). Sources and distribution of PAHs in water as well as the degree at which the compounds are adsorbed to a particulate matter represent its bioavailability. The bioavailability of PAHs in water bodies directly influence fish by ecological factors such as feeding habitat (surface, channel and bottom), the rate of movement and reproduction status and biological factors (Rahmanpour *et al.,* 2014). The bioavailability of PAHs resulted increasing its metabolites in bile which contributes in detoxification mechanism of PAHs compounds. PAHs are low water soluble compounds, trend to settled down at bottom (sediment), affect bottom dwelling fish with PAHs accumulation (0.157ml/mg), altered trophic animals via food web (Lopez *et al.,* 2020). Mohammad A. Khairy *et al.,* 2014 evaluated PAHs concentration in benthic species and benthopelagic species and noticed that the concentration of PAHs were higher in benthopelagic sps ($2.5 \times 10^3 - 2.1 \times 10^7$) than benthic sps. ($1.5 \times 10^3 - 1.5 \times 10^7$). Similarly, Ei Deeb *et al.,* 2007 also noticed that the accumulation of BaP was prominent in muscle tissues of bottom dwelling fish. Cheung *et al.,* 2007 concluded that concentration of PAHs in catfish (*Clarius fuscus*) on ventral, axial muscle were 24.8ng/g and 9.1ng/g respectively, suggested that catfish is bottom dwelling fish and absorption could be greater in ventral region than axial due to direct contact to the sediment. PAHs enter in fish tissue by dietary intake, diffusion through the skin and gills. However, in aquatic environment, fish have sufficient degree of avoidance and tolerable ability against PAHs (Table1). Avoidance is the first line of defence displayed by fish against PAHs contaminants. Claireaux *et al.,* 2018 observed that 20% diluted water soluble fraction (WSF) showing avoidance behaviour in European sea bass *(Dicentrarchus labrax).* Many researchers observed change in swimming performance in fish after exposing to PAHs (Table 1). Bautista *et al.,* 2019, performed experiment in laboratory and found, an elevation aggressive behaviour in fighting fish (*Betta splendens*) after exposing of crude oil. The present reviewed suggested that bioaccumulation of LMW PAHs might be higher than HMW PAHs and its accumulation might be depends on their habitat, size of PAHs (LMW or HMW), seasonal durability and sex also. However, many researchers observed that 2 – 4 rings or LMW PAHs were dominated in fish tissues (Liang *et al.,* 2007; Bua *et al.,* 2021; Li *et al.,* 2021) on contrast Lopez *et al.,* 2020 described that the muscle of *Megalops Atlanticus* dominated with (5 – 6) HMW PAHs. Vives *et al.,* 2004 [46] determined that accumulation of Phe (3 ring) was predominated over Fln and Pyr (4 rings) in fish tissues. Malik *et al.,* 2008 [32] also noted that accumulation of LMW PAHs were higher in fish (*Channa punctatus*) than HMW PAHs. Devarajan *et al.,* 2021 found, HMW PAHs were greater in native species while LMW PAHs (nap, flu, phe, Ant, pyr) were higher in introduced species this indicates HMW PAHs are persistent and are taken up by fish in native habitat. They are able to excrete out LMW PAHs while HMW PAHs could not be easily excreted. On contrary, LMW PAHs could be easily accumulate in fish tissues, therefore introduced fish have higher LMW PAHs. LMW PAHs are slightly water soluble, can be easily taken up through the gills and skin (Farag Malhat *et al.,* 2021) [31]. According to Zhang *et al.,* 2015 LMW PAHs were predominated in gills suggesting that water transport system could be reason for major exposure and also concluded that Fish mainly absorbed PAHs from plants rather than water. As Ziling yu *et al.,* 2019, planktivores fish having significantly greater concentration of PAHs than omnivores. Same as, Rahmanpour *et al.,* 2014 [36] observed, Nap and Acy were high in *Liza abu* a phytoplantivores than omnivores (*Aurigequula fasciata*) and carnivores *(Alepes djedaba).* Omnivores and Carnivores fish have a very simple digestive tract because meat is easy to digest on the other hand herbivore fish are not able excrete PAHs. These findings indicates that PAHs could be greatly accumulated by dietary intake rather than gills water transport system. Frapiccini *et al.,* 2018 [17] figured out the concentration (ng/g) of PAHs i.e 6.7, 13.1, 32.0 in muscle, liver and gills respectively, suggested that gills are continually exposed to the direct contact to the surrounding medium, causing highest accumulation, on the other hand liver work as detoxification mechanism, showing lower level of PAHs. Rimayi and Chimuka 2019 [39] observed that Flu and Nap were most abundant in Sharptooth catfish (*Clarias gariepinus*) and bioaccumulation followed the order: muscle > kidney > liver > spleen while this series in common carp (*Cyprinus carpio*) were as liver > muscle > kidney > spleen, showing least accumulation were presented in spleen. It may be due to the sensitivity of Carps that needs to immediate biotransformation of PAHs compounds and lipid metabolism which take place in the liver. Similerly, Jafarabadi *et al.,* 2018 studied on three species namely *Lutjanus argentimacululatus*, *Lethrinus microdon* and *Scomberomorus guttatus*, found $\sum_{39}$PAHs were higher in liver than the muscle. Tatiana Recabarren-Villaden *et al.,* 2021 found that the bioaccumulation were not observed in spring and summer season because of high biotransformation process. On the other hand, the highest value of accumulation were observed in winter season.

Further investigation carried out and deduced that the accumulation can be sex dependent. Levengood *et al.*, 2001 also found that the accumulation of PAHs were higher in females than males as well as small fish are more prone to PAHs accumulation than larger fish. Apart from the natural habitat, fish culture might be pose a risk for human due to PAHs accumulation. The increasing demand of food for growing population, many chemicals are used for aquaculture to the socioeconomic purpose that also led to PAHs accumulation in fish. Kong *et al.*, 2005 [24] found that pond fish having high level of PAHs than market fish (*Tilapia massambicus).* Table 2 represent the concentration of PAHs in different kinds of water bodies (river, lake, sea, ocean etc.), sediments and in fish. Bioaccumulation factor (BAF) and bioaccumulation sediment factor (BASF) is defined as the transfer factor in fish tissues from aquatic ecosystem e.g. water and sediment and was calculated by given equation:

$$BAF = \frac{PAH\ concentration\ in\ aquatic\ (animal)}{PAH\ concentration\ in\ sediment\ and\ water}$$

BAF = (Akinsanya *et al.*, 2018)

Table 1: Bioaccumulation of PAHs in fish from water (BAF) and sediment (BSAF)

S. No.	Concentration of (PAHs)	Water (µg/L)	Sediment (µg/kg)	Fish	BASF	BAF	Reference
1.	Nap, Acy, Fln	3.08	45.4	90.7	1.99	29.44	Tongo *et al.*, (2017)
2.	∑PAHs	195-1006	302-1290	8.80-26.1	0.157	35.893	Sogbanmu *et al.*, (2019)
3.	∑PAHs	51.20–162.37 µg/ L	15.33-133.61(µg/g)	26.52 to 2055.00 µg/g	5.292	13.290	Froehner *et al.*, (2018)
4.	∑PAHs	0.80-18.34 µg/l	113.50-3384.34 ng/g	3.11-17.76 ng/g	0.006	1.22	Sinaei *et al.* (2014)
5.	∑PAHs	27.54– 55.04 ng/l	80.31–639.23ng/g	67.3–533.9ng/g	1.0482	9.0915	Zhang *et al.*, (2015)

It is necessary to evaluate the potential human health risks associated with consumption of PAHs contaminated fisheries and its products. Table 2 shows bioaccumulation of PAHs in fish from water (BAF) as well as sediment (BSAF). It was analysed that the bioaccumulation in fish from water were comparatively higher than the sediment. The accumulation of PAHs from water (BAF) are as; 35.893 > 29.44 > 13.290 > 9.0915 >1.22 while from sediment (BSAF) are as; 53.07 > 5.292 > 1.99 > 1.0482 > 0.838 > 0.157 > 0.006 in fish. Polluted fish may create significant hazard for human health (Akhbarizadeh *et al.*, 2019) [3]. European Commison regulation 1881/2006 of December 2006 fixed the maximum level of BaP in fish tissue is 2µg/kg. Similarly, fish are categorized as not contaminated, contaminated, minimally, moderately and highly contaminated for PAHs and their value were fixed as:

Fish tissues	PAHs concentration (µg/kg)
Not contaminated	< 10
Minimally contaminated	10-99
Moderately	100-1000
Highly	> 1000

(Gomes *et al.*, 2010)

Table 2

S. No.	Fish	River	Tissues	PAHs	Concentration	Reference
1.	*E. Coioides*	Persian Gulf (western Asia)	Muscle	∑PAHs	4.65µg/kg	Akhbarizadeh *et al.*, (2019)
2.	1. Silver croaker 2. Snakfish 3. Hairtail 4. Blood porgy 5. Sulphur goatfish 6. Big head croaker 7. Blue scad 8. Japanese rudderfish 9. Japanese scad 10. Big head pinnah croaker 11. Red barracuda 12. Indian mackerel 13. Blood porgy 14. Indian driftfish 15. Golden thresd 16. Japanese scad 17. Red bigeye 18. Tilefish	Northern South China Sea	Muscle	∑PAHs	199-606ng/g	Ziling yu *et al.*, (2019)
3.	Tilefish (*Lopholatilus chamaeleonticeps*) king snake eel (*Ophichthus rex*) red snapper (*Lutjanus campechanus*)	Gulf of Maxico	Bile	Naphthalene	240 µg/g 38 µg/g	Snyder *et al.*, (2015)

					61 µg/g	
4.	Fighting fish (*Betta splendens*)	In Lab	Behavoiur	Crude oil	340, 3960, 8820ng/g	Bautista *et al.*, (2019)
5.	European sea bass (*Dicentrarchus labrax*)	In Lab	Avoidance	∑PAHs	8.54 µg/l	Claireaux *et al.*, (2018)
6.	European sea Bass	In Lab	Blood Plasma	∑PAHs	10^{-3} and 10^{-5}mg/l	Nilles *et al.*, (2009)
7.	1. Catfish(*Clarius fuscus*) 2. Yellow seafin (*Acanthopeyrus latus)* 3. Golden threadfin bream (*Nemipterus virgotus*)	Market fish	Ventral and axial Muscles	PAHs	24.8ng/g (ventral) 9.1ng/g (axial) 15.5ng/g(axial) 18.1 ng/g (ventral) 57.0ng/g (axial) 118ng/g	Cheung *et al.*, (2007)
8.	Common sole (*Solea Solea*)	north Adriatic Sea	Muscle, Liver, Gills	PAHs	6.7 ng/g 13.1ng/g 32.0ng/g	Frapiccini *et al.*, (2018)
9.	*Diapterus rhombeus, Bardiela ranchus, Isopisthus parvipinnis, Cathorops spixii, Menthicirrhus americanus, Genidens genidens, Cynoscion leiarchus, Eucinostomus argenteus*	Paranagua Bay	Liver and Muscle	PAHs	26.52 to 2055.00µg/g	Froehner *et al.*, (2018)
10.	Gilthead seabream (*Sparus aurata*)	In lab	Behaviour, Muscle	Fluorene, phenanthrene, Pyrene	39-77µg/L	Gonc-alves *et al.*, (2008)
11.	*Lutjanus argentimaculatus, Lethrinus microdon, Scomberomorus guttatus,*	Persian Gulf Iran	Liver Muscle	$\sum PAHs_{39}$	535ng/g (Liver) 398ng/g (Muscle)	Jafarabadi *et al.*, (2019)
12.	Red drum (*Sciaenops ocellatus*)	Gulf of Maxico	Cardiorespiratory Swim performance	$\sum PAH_{50}$	4.1 – 12.1µg/L	Johansen *et al.*, (2017)
13.	Tilapia, Bighead carp, Grass carp Crucian carp	Pearl river Delta (China)	Muscle	PAHs	0.67ng/g	Kong *et al.*, (2005)
14.	Tilapia	Mai Po Marshes, Hong Kong	Viscera Muscle	∑PAHs	505-854ng/g 184-194ng/g	Y. Liang *et al.*, (2007)
15.	Zebra fish (*Danio rario*)	In Lab	Swimming and metabolic performance	∑PAHs	100mg/L	Lucas *et al.*, (2016)
16.	*Channa punctatus*(Bloch)	Gomti river, India	Muscle	∑PAHs	12.85 and 34.89 ng/g	Malik *et al.*, (2008)
17.	*L. abu* *S. albella* *A. fasciata* *A. djedaba*	Persian Gulf	Liver	$\sum PAH_{10}$	3,802.02ng/g 3,990.62ng/g 2,007.12ng/g 1,501.37ng/g	Rahmanpour *et al.*, (2014)
18.	*Ramnogaster arcuata* *Micropogonias furnieri* *Cynoscion guatucupa* *Mustelus schmitti*	South Atlantic coastal areas	Muscle	$\sum PAHs_{17}$	64 ng/g 45 ng/g 28 ng/g 16 ng/g	Recabarren-Villalon´*et al.*, (2021)
19.	Mudskipper (*Boleophthalmus dussumieri*)	coastal areas of the Persian Gulf	Liver Blood	∑PAHs	3.99–46.64 ng/g	Sinaei *et al.*, (2012)
20.	Barnacles (*F. citerosum*)	Guanabara Bay, Southeast Brazil	Muscle	∑PAHs	30–150 lg/L	Soares-Gomes *et al.*, (2010)
21.	*Sarotherodon melanotheron* (Black-Jawed Tilapia) *Gerres melanopterus* (Gerres) *Liza falcipinnis* (Sicklefin Mullet) *Pseudotolithus elongatus* (Bobo Croaker)	Lagos lagoon, Nigeria	Whole fish tissues	∑PAHs	8.80- 26.1µg/kg	Sogbanmu *et al.*, (2018)
22.	Goldfish (*Carassius*	In Lab	Scale(osteoblast,	OHPAHs	10^{-7}M, 10^{-6}M, 10^{-}	Nobuo Suzuki

	auratus)		osteoclast		⁵M	*et al.,* (2009)
23.	*Clarias gariepinus*	Ovia river, Southern Nigeria	Whole body tissues	naphthalene, acenaphthylene, fluoranthene	90.7μg/L	Tongo *et al.,* (2017)
24.	*Ptychocheilus oregonensis* (northern pikeminnow) *Richardsonius balteatus* (redside shiner) *Catostomus macrocheilus* (largescale sucker) *Mylocheilus caurinus* (peamouth) *Acrocheilus alutaceus* (chiselmouth)	Willamette River,	Skeletal deformities	∑PAHs	<5ng/L	VILLENEUVE *et al.,* (2005)
25.	Trout	Mountain lake (Europe) Remote Lake (Greenland)	Liver	∑PAHs	9 and 44 ng/g	Vives *et al.,* (2004)
26.	*Cyprinus carpio* *Macrobrachium nipponense* *Carassius auratus* *Channa argus.*	Nansi Lake (China)	Muscle	∑PAHs	67.3–533.9 ng/g	Zhang *et al.,* (2015)
27.	*Mullus surmuletus*	Catania Gulf (Sicily)	Muscle	∑PAHs	0.25 to 6.10 ng/g	Bua *et al.,* (2021)
28.	(*Solea solea*) (*Diplodus vulgaris*)	Abu Qir Bay Egyptian Mediterranean Sea	Muscle	∑PAHs	1,770 ng/g 1,203 ng/g	Deeb *et al.,* (2007)

Metabolism and excretion of PAHs

However, the half-lives of PAHs are relatively short compared to other pollutants. Therefore, they are considered to metabolized/excreted quickly. As Liver and kidney contribute as a main organs to the detoxification mechanism. The detoxification mechanism of PAHs and its enzymes are well known. The most studies organs in detoxification mechanism of PAHs searched are carried out in liver and bile globally (Table 1. LMW PAHs are eliminated through the skin and across the gills (passive diffusion) on the other hand the biotransformation of HMW PAHs are occurred into liver followed by bile (Zhang *et al.,* 2015) [50]. In liver, PAHs induce genes expression of cytochrome P450 enzymes group that led to PAHs metabolism. In this metabolism pathway, many intermediates are formed that can bind to DNA cause carcinogenicity/mutagenicity. Nap, Fln, Pyr and Bap causing adduct formation in similar mechanism and inhibit the replication mechanisms that initiate the carcinogenic process, DNA strained break, oxidative stress, cytotoxicity in rainbow trout (Mazyar Yazdani 2020) [49]. Lipid rich tissues having high ability to accumulate PAHs which altered fatty acid composition by biotransformation process and causes DNA adduct formation (genotoxicity) in Atlantic cod (*Gadus morhua*) and Haddock (*Melanogrammus aeglefinus*) (Balk *et al.,* 2011) [6]. Palanikumar *et al.,* 2012 [34] determined genotoxic effects including binucleated micronuclei, nuclear bud, fragmented apoptotic cell and DNA damage in fish tissues. Moreover, Suzuki *et al.,* 2009 found that monohyroxylated PAHs inhibit both osteoblast and osteoclast activity in scales of gold fish and sea water, polluted with high concentration PAHs inhibits osteoblastic activity in scales of goldfish (*Carassius auratus*). Kidney also play a major role in detoxification mechanism. Furthermore, Nilles *et al.,* 2009 [5] investigated, Ant, Chy, DahA altered the concentration of lysozyme in European Seabass **(***Dicentrarchus labrax).*

Effects of PAHs on various vital organs of fish

Fish are vulnerable to PAHs contamination, therefore researchers have paid attention to the effects of PAHs on vital organs of fish. There were thirty one experiments performed in laboratory which include behavioural, developmental, liver, gonads, gills, gall bladder, gut, head, eggs, skeleton and brain deformities (Table1). Typically, PAHs affect liver and increase its antioxidants enzymes (EROD, SOD, CAT, GST and LPO). However, Fish does not show direct physiological changes but they display avoidance and resistance behavioural against PAHs. Oil spilling cause enormous death of fish in ocean at the time of transportation. In this regard, many studied have been done in deep water horizon (DWH). According to Heintz *et al.,* 2007 [20] PAHs exposure led to 15% suppression of marine survival compared to nonexposed fish Pink salmon. Baustista *et al.,* 2019 concluded that the exposure of crude oil displayed aggressive behaviour, morphological changes and reduced reproductive activity in male Siamese fighting fish (*Betta splendens*). Similarly, Claireaux *et al.,* 2018 [11] observed that water soluble fraction (WSF), having total PAH 8.54ug/L showed significance avoidance response within 7.5 minute in European Seabass. Many researches have been done on the toxicity of three rings PAHs on fish (Table 1). PAHs could modulate cardiorespiratory function and swimming ability of Red drum larvae, apoptosis in Minnows (*Gobiocypris rarus*) (Johansen *et al.,* 2017) [21]. Gonc-alves *et al.,* 2008 noticed Pyr was the most potent congeners for swimming and lethargy activity while Flu was the least for swimming and lethargy. Pyr at 0.031μM and 0.039μM concentration impaired swimming and lethargy respectively while Flu at 0.29μM and 0.26μM affect swimming and lethargy respectively. Surprisingly, Lucas *et al.,* 2016 noted that pyrogenic could not affect fish whatever the duration while petrogenic affect swimming performance and metabolic activity. Frapiciini *et al.,* 2018 suggested that

HMW PAHs affect the spawning and post spawning stage of Red mullet (*Mullus barbatus*). Most of the studies have been done individually as for BaP, Phe (Table 1). Globally, the major researches have been done on cardiac development followed by muscle and liver/bile (Table 1). PAHs can affect fish in any developmental stage such as deformities in embryo, skeleton, cardiac dysfunction etc. According to Villeneuve *et al.*, 2005 [47] exposure of PAHs might be result of cataract formation, embryo deformities, developmental cardiac defects, mortality and modulation in haematological parameter.

Conclusion

Although, there are many researches have been done on toxicological perspective of PAHs in fish. In present study it is investigated that how fish were threatening by PAHs contamination in last twenty one year. It is concluded that most of the researches have been done in muscle, liver/bile, behaviour, developmental, gonads, gills, gall bladder, gut, head, eggs, skeleton and brain deformities in fish in last two decades. However skin, eyes, gills are directly exposed to surroundings, therefore it is need to investigate the effects of PAHs on these organs in fish. PAHs affect fish population which contribute as environmental, entertainment, economic and major dietary sources for human beings. Fish also affect inland ecological system by food web. It may be possible to manage and understand environmental risks caused by PAHs in fish. Thus we should emphasize the prevention and remediation of PAHs in aquatic ecosystem.

Abbreviation

Naphthalene	(Nap)
Acenaphthylene	(Acy)
Acenaphthene	(Ace)
Fluorene	(Flu)
Phenanthrene	(Phe)
Anthracene	(Ant)
Fluoranthene	(Flu)
Pyrene	(Pyr)
Benzo(a)anthracene	(BaA)
Chrycene	(Chy)
Benzo(b)fluoranthene	(BbF)
Benzo(k)fluoranthene	(BkF)
Benzo(a)pyrene	(BaP)
Dibenzo(a.h)anthracene	(DbA)
Benzo(ghi)perylene	(Bper)
Indeno(1,2,3-cd)pyrene	(IP

Reference

1. Agarwal T, Khillare PS, Shridhar V. PAHs contamination in Bank sediment of the Yamuna River, Delhi, India. *Environ Monit Assess*,2006:123(1-3):151-166. doi:10.1007/s10661-006-9189-6
2. Akinsanya B, Adebusoye SA, Alinson T, Ukwa UD. Bioaccumulation of polycyclic aromatic hydrocarbons, histopathological alterations and parasito-fauna in bentho-pelagic host from Snake Island, Lagos, Nigeria. *J Basic Appl Zool*,2018:79(1). doi:10.1186/s41936-018-0046-2
3. Akhbarizadeh R, Moore F, Keshavarzi B. Polycyclic aromatic hydrocarbons and potentially toxic elements in seafood from the Persian Gulf: presence, trophic transfer, and chronic intake risk assessment. Environ Geochem Health,2019:41(6):2803-2820. doi:10.1007/s10653-019-00343-1
4. Aslam R, Sharif F, Baqar M, Shahzad L. Source identification and risk assessment of polycyclic aromatic hydrocarbons (PAHs) in air and dust samples of Lahore City. *Sci Rep*,2022:12(1):1-15. doi:10.1038/s41598-022-06437-8
5. Bado-Nilles A, Quentel C, Thomas-Guyon H, Le Floch S. Effects of two oils and 16 pure polycyclic aromatic hydrocarbons on plasmatic immune parameters in the European sea bass, Dicentrarchus labrax (Linné). *Toxicol Vitr*,2009:23(2):235-241. doi:10.1016/j.tiv.2008.12.001
6. Balk L, Hylland K, Hansson T, *et al*. Biomarkers in natural fish populations indicate adverse biological effects of offshore oil production. *PLoS One*,2011:6(5). doi:10.1371/journal.pone.0019735
7. Bautista NM, Pothini T, Meng K, Burggren WW. Behavioral consequences of dietary exposure to crude oil extracts in the Siamese fighting fish (Betta splendens). *Aquat Toxicol*,2019:207(August 2018):34-42. doi:10.1016/j.aquatox.2018.11.025
8. Behera BK, Das A, Sarkar DJ, *et al*. Polycyclic Aromatic Hydrocarbons (PAHs) in inland aquatic ecosystems: Perils and remedies through biosensors and bioremediation. *Environ Pollut*,2018:241:212-233. doi:10.1016/j.envpol.2018.05.016
9. Bua RO, Contino A, Giuffrida A. Polycyclic aromatic hydrocarbons in Mullus surmuletus from the Catania Gulf (Sicily, Italy): distribution and potential health risks. *Environ Sci Pollut Res*,2021:28(7):7756-7765. doi:10.1007/s11356-020-11052-z
10. Cheung KC, Leung HM, Kong KY, Wong MH. Residual levels of DDTs and PAHs in freshwater and marine fish from Hong Kong markets and their health risk assessment. *Chemosphere*,2007:66(3):460-468. doi:10.1016/j.chemosphere.2006.06.008
11. Claireaux G, Quéau P, Marras S, *et al*. Avoidance threshold to oil water-soluble fraction by a juvenile marine teleost fish. *Environ Toxicol Chem*,2018:37(3):854-859. doi:10.1002/etc.4019
12. Devarajan M, Muralidharan S, Prakasham K, Nambirajan K. Variation in Polycyclic Aromatic Hydrocarbon Contamination Between Native and Introduced Species of Fishes of Pallikaranai Wetland, Chennai, Tamil Nadu, India. *Bull Environ Contam Toxicol*,2021:107(3):459-465. doi:10.1007/s00128-021-03207-6
13. Duttagupta S, Mukherjee A, Routh J, Devi LG, Bhattacharya A, Bhattacharya J. Role of aquifer media in determining the fate of polycyclic aromatic hydrocarbons in the natural water and sediments along the lower Ganges river basin. *J Environ Sci Heal - Part A Toxic/Hazardous Subst Environ Eng*,2020:55(4):354-373. doi:10.1080/10934529.2019.1696617
14. El Deeb KZ, Said TO, El Naggar MH, Shreadah MA. Distribution and sources of aliphatic and polycyclic aromatic hydrocarbons in surface sediments, fish and bivalves of Abu Qir Bay (Egyptian Mediterranean Sea). *Bull Environ Contam Toxicol*,2007:78(5):373-379. doi:10.1007/s00128-007-9173-z
15. Ellickson KM, Mcmahon CM, Herbrandson C, *et al*. Analysis of polycyclic aromatic hydrocarbons (PAHs) in air using passive sampling calibrated with active

measurements *. *Environ Pollut*,2017:231:487-496. doi:10.1016/j.envpol.2017.08.049
16. Evans MS, McMaster M, Muir DCG, Parrott J, Tetreault GR, Keating J. Forage fish and polycyclic aromatic compounds in the Fort McMurray oil sands area: Body burden comparisons with environmental distributions and consumption guidelines. *Environ Pollut*,2019:255:113135. doi:10.1016/j.envpol.2019.113135
17. Frapiccini E, Annibaldi A, Betti M, Polidori P, Truzzi C, Marini M. Polycyclic aromatic hydrocarbon (PAH) accumulation in different common sole (Solea solea) tissues from the North Adriatic Sea peculiar impacted area. *Mar Pollut Bull*,2018:137(October):61-68. doi:10.1016/j.marpolbul.2018.10.002
18. Froehner S, Rizzi J, Vieira LM, Sanez J. PAHs in Water, Sediment and Biota in an Area with Port Activities. Arch Environ Contam Toxicol,2018:75(2):236-246. doi:10.1007/s00244-018-0538-6
19. Gonçalves R, Scholze M, Ferreira AM, Martins M, Correia AD. The joint effect of polycyclic aromatic hydrocarbons on fish behavior. *Environ Res*,2008:108(2):205-213. doi:10.1016/j.envres.2008.07.008
20. Heintz RA. Chronic exposure to polynuclear aromatic hydrocarbons in natal habitats leads to decreased equilibrium size, growth, and stability of pink salmon populations. *Integr Environ Assess Manag*,2007:3(3):351-363. doi:10.1897/1551-3793(2007)3[351:CETPAH]2.0.CO;2
21. Johansen JL, Esbaugh AJ. Sustained impairment of respiratory function and swim performance following acute oil exposure in a coastal marine fish. *Aquat Toxicol*,2017:187(December 2016):82-89. doi:10.1016/j.aquatox.2017.04.002
22. Khairy MA, Weinstein MP, Lohmann R. the Aquatic Food Web of a Tidal River. Published online, 2014.
23. Kimbrough K, Jacob A, Regan S, *et al*. Characterization of polycyclic aromatic hydrocarbons in the Great Lakes Basin using dreissenid mussels. *Environ Monit Assess*,2021:193(12). doi:10.1007/s10661-021-09401-7
24. Kong KY, Cheung KC, Wong CKC, Wong MH. Residues of DDTs, PAHs and some heavy metals in fish (tilapia) collected from Hong Kong and mainland China. *J Environ Sci Heal - Part A Toxic/Hazardous Subst Environ Eng*,2005:40(11):2105-2115. doi:10.1080/10934520500232738
25. Kumar B, Gaur R, Kumar S, Sharma CS. Environmental and Human Health Risk Assessment of Benzo(a)pyrene Levels in Agricultural Soils from the National Capital Region, Delhi, India. *Hum Ecol Risk Assess*,2013:19(1):118-125. doi:10.1080/10807039.2012.726818
26. Levengood JM, Schaeffer DJ. Polycyclic aromatic hydrocarbons in fish and crayfish from the Calumet region of southwestern Lake Michigan. *Ecotoxicology*,2011:20(6):1411-1421. doi:10.1007/s10646-011-0698-x
27. Liang Y, Tse MF, Young L, Wong MH. Distribution patterns of polycyclic aromatic hydrocarbons (PAHs) in the sediments and fish at Mai Po Marshes Nature Reserve, Hong Kong. *Water Res*,2007:41(6):1303-1311. doi:10.1016/j.watres.2006.11.048
28. Li Y, Guo N, Zou X, *et al*. Pollution level and health risk assessment of polycyclic aromatic hydrocarbons in marine fish from two coastal regions, the South China Sea. *Mar Pollut Bull*,2021:168(May). doi:10.1016/j.marpolbul.2021.112376
29. Logan DT. Perspective on ecotoxicology of PAHs to fish. *Hum Ecol Risk Assess*,2007:13(2):302-316. doi:10.1080/10807030701226749
30. Lucas J, Percelay I, Larcher T, Lefrançois C. Effects of pyrolytic and petrogenic polycyclic aromatic hydrocarbons on swimming and metabolic performance of zebrafish contaminated by ingestion. *Ecotoxicol Environ Saf*,2016:132:145-152. doi:10.1016/j.ecoenv.2016.05.035
31. Malhat F, Loutfy N, El Menyawi MAI, Ahmed MT. Review of Contamination by Polycyclic Aromatic Hydrocarbons (PAHs) in Egyptian Aquatic Environment. *Polycycl Aromat Compd*,2021:41(7):1447-1458. doi:10.1080/10406638.2019.1684325
32. Malik A, Ojha P, Singh KP. Distribution of polycyclic aromatic hydrocarbons in edible fish from Gomti River, India. *Bull Environ Contam Toxicol*,2008:80(2):134-138. doi:10.1007/s00128-007-9331-3
33. Matzenbacher CA, Da Silva J, Garcia ALH, Cappetta M, de Freitas TRO. Anthropogenic Effects on Natural Mammalian Populations: Correlation Between Telomere Length and Coal Exposure. *Sci Rep*,2019:9(1):1-9. doi:10.1038/s41598-019-42804-8
34. Palanikumar L, Kumaraguru AK, Ramakritinan CM, Anand M. Genotoxic assessment of anthracene and benzo [a] pyrene to milkfish Chanos chanos. *Toxicol Environ Chem*,2012:94(2):350-363. doi:10.1080/02772248.2011.642657
35. Ravindra K, Sokhi R, Van Grieken R. Atmospheric polycyclic aromatic hydrocarbons: Source attribution, emission factors and regulation. *Atmos Environ*,2008:42(13):2895-2921. doi:10.1016/j.atmosenv.2007.12.010
36. Rahmanpour S, Farzaneh Ghorghani N, Lotfi Ashtiyani SM. Polycyclic aromatic hydrocarbon (PAH) in four fish species from different trophic levels in the Persian Gulf. *Environ Monit Assess*,2014:186(11):7047-7053. doi:10.1007/s10661-014-3909-0
37. Ranjbar Jafarabadi A, Riyahi Bakhtiari A, Yaghoobi Z, Kong Yap C, Maisano M, Cappello T. Distributions and compositional patterns of polycyclic aromatic hydrocarbons (PAHs) and their derivatives in three edible fishes from Kharg coral Island, Persian Gulf, Iran. *Chemosphere*,2019:215:835-845. doi:10.1016/j.chemosphere.2018.10.092
38. Recabarren-Villalón T, Ronda AC, Oliva AL, Cazorla AL, Marcovecchio JE, Arias AH. Seasonal distribution pattern and bioaccumulation of Polycyclic aromatic hydrocarbons (PAHs) in four bioindicator coastal fishes of Argentina. *Environ Pollut*,2021:291(April). doi:10.1016/j.envpol.2021.118125
39. Rimayi C, Chimuka L. Organ-specific bioaccumulation of PCBs and PAHs in African sharptooth catfish (Clarias gariepinus) and common carp (Cyprinus carpio) from the Hartbeespoort Dam, South Africa.

Environ Monit Assess,2019:191(11). doi:10.1007/s10661-019-7912-3

40. Sinaei M, Araghi PE, Mashinchian A, Fatemi M, Riazi G. Application of biomarkers in mudskipper (Boleophthalmus dussumieri) to assess polycyclic aromatic hydrocarbons (PAHs) pollution in coastal areas of the Persian Gulf. *Ecotoxicol Environ Saf*,2012:84:311-318. doi:10.1016/j.ecoenv.2012.07.028
41. Soares-Gomes A, Neves RL, Aucélio R, *et al*. Changes and variations of polycyclic aromatic hydrocarbon concentrations in fish, barnacles and crabs following an oil spill in a mangrove of Guanabara Bay, Southeast Brazil. *Mar Pollut Bull*,2010:60(8):1359-1363. doi:10.1016/j.marpolbul.2010.05.013
42. Sogbanmu TO, Osibona AO, Oguntunde OA, Otitoloju AA. Biomarkers of toxicity in Clarias gariepinus exposed to sublethal concentrations of polycyclic aromatic hydrocarbons. *African J Aquat Sci*,2018:43(3):281-292. doi:10.2989/16085914.2018.1491825
43. Suzuki N, Hayakawa K, Kameda T, *et al*. Monohydroxylated polycyclic aromatic hydrocarbons inhibit both osteoclastic and osteoblastic activities in teleost scales. *Life Sci*,2009:84(13-14):482-488. doi:10.1016/j.lfs.2009.01.008
44. Tongo I, Ezemonye L, Akpeh K. Distribution, characterization, and human health risk assessment of polycyclic aromatic hydrocarbons (PAHs) in Ovia River, Southern Nigeria. *Environ Monit Assess*,2017:189(6). doi:10.1007/s10661-017-5931-5
45. Varol M, Sünbül MR. Multiple approaches to assess human health risks from carcinogenic and non-carcinogenic metals via consumption of five fish species from a large reservoir in Turkey. *Sci Total Environ*,2018:633:684-694. doi:10.1016/j.scitotenv.2018.03.218
46. Vives I, Grimalt JO, Fernández P, Rosseland B. Polycyclic aromatic hydrocarbons in fish from remote and high mountain lakes in Europe and Greenland. *Sci Total Environ*,2004:324(1-3):67-77. doi:10.1016/j.scitotenv.2003.10.026
47. Villeneuve DL, Curtis LR, Jenkins JJ, *et al*. Environmental stresses and skeletal deformities in fish from the Willamette River, Oregon. *Environ Sci Technol*,2005:39(10):3495-3506. doi:10.1021/es048570c
48. Wang H, Xia X, Wang Z, Liu R, Muir DCG, Wang WX. Contribution of Dietary Uptake to PAH Bioaccumulation in a Simplified Pelagic Food Chain: Modeling the Influences of Continuous vs Intermittent Feeding in Zooplankton and Fish. *Environ Sci Technol*,2021:55(3):1930-1940. doi:10.1021/acs.est.0c06970
49. Yazdani M. Comparative toxicity of selected PAHs in rainbow trout hepatocytes: genotoxicity, oxidative stress and cytotoxicity. *Drug Chem Toxicol*,2020:43(1):71-78. doi:10.1080/01480545.2018.1497054
50. Zhang G, Pan Z, Wang X, Mo X, Li X. Distribution and accumulation of polycyclic aromatic hydrocarbons (PAHs) in the food web of Nansi Lake, China. *Environ Monit Assess*,2015:187(4):1-12. doi:10.1007/s10661-015-4362-4