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Bioaccumulation of Perfluoroalkyl Substances and Mercury in Fish Tissue: A Global Systematic Review

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ABSTRACT

PFASs and Hg are persistent, bio accumulative and toxic substances for living organisms. This study aimed to determine bioaccumulation of PFASs and Hg in fish tissue. Previously done peer reviewed papers were searched and collected in the study. Analysis of the results revealed that higher concentrations of PFASs were recorded in fish liver than in fish muscle which may be due to PFASs being proteinophilic and therefore, known to accumulate more in protein rich tissues. The bioaccumulation of PFASs increases with the increase in the carbon chain length. Findings of this study also illustrated that organic mercury is the most abundant form of mercury in fish tissue. Likewise, Hg may be highly accumulated in fish liver and sometimes in the fish muscle which could be due to the presence of high quantities of cysteine rich molecules and higher concentrations of natural metal-binding proteins or due to the active metabolic liver function which requires it to be a well-perfused organ. A higher level of PFASs and mercury was found in piscivorous fish which may due to bio magnification principle. Similarity between PFASs and Hg bioaccumulation may indicate that both might have similar transport, trophic level bioaccumulation pattern, route of exposure or factor and/or source of pollution. The presence of Hg actions may also enhance the adsorption of PFASs. Therefore, monitoring of PFASs and Hg is important, as, for example, an increase in PFASs and Hg contamination in developing countries is expected due to the increased modernization and importation of PFASs and Hg containing consumer products. Future studies can also include novel PFASs which are currently produced, and PFAS precursors to investigate their global distribution in aquatic ecosystems, and the pathways that cause PFASs and Hg pollution in the aquatic ecosystem.

Keywords: Aquatic ecosystem; Bioaccumulation; Fish; Mercury; Perfluoroalkyl substances

INTRODUCTION

PFASs and Hg are Persistent, Bio accumulative and Toxic (PBT) substances for living organisms. The development of organic chemical industries during the last century has led to increased production of a large number of anthropogenic chemicals like poly and Perfluoroalkyl Substances (PFASs). PFASs are amphiphilic chemicals, exhibiting both hydrophobic and hydrophilic properties. Their peculiar physical and chemical characteristics make them suitable for many applications such as in fire resistant foam, food packaging, and as polymer chain help for the manufacturing of fluorinated polymers. The presence of PFASs in the environment is exclusively a result of anthropogenic activities.

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Releases of PFASs are occurring during their whole life cycle. In addition, long distance transport of PFASs is favored by their volatile precursors. Due to their wide application and production, as well as the degradation of these volatile precursor compounds, PFASs have been globally detected in the environment and biota.

LITERATURE REVIEW

PFASs are considered as hazardous chemicals. The partitioning of PFASs depends on the carbon chain length, with the shorter chained compounds being more water soluble while long chained compounds prefer to sorb to sediment particles. Nutritional intake has been reported to be a key route of PFASs exposure for humans. Mercury (Hg) can originate from two main sources and is non-essential elements for living organisms at any concentration. Elemental mercury (Hgo), inorganic mercury (Hg^{2+}) and organic mercury (methyl mercury; MeHg or CH_3Hg^{+}) are the main chemical forms of Hg. All forms of Hg may have different ecological and toxicological effects. The biological conversion of inorganic mercury to MeHg, methylation (bioalkylation), is enhanced by sulphur reducing anaerobic bacteria; however, MeHg is the most toxic. Long range transport of Hg from localized sources can be enhanced by atmospheric transport followed by deposition. PFASs and Hg have been observed the bio-accumulation and magnification *via* food chain. In the aquatic ecosystem, contamination of fish by PFASs and Hg has been got global attention and may pose adverse effects on living organisms. Hg in fish has been studied globally, while PFASs are not well investigated in fish tissue. More is done in the Northern hemisphere including North America, Europe, and Asia, whereas less is done on the PFASs in African aquatic ecosystems. In addition, very little has been done on the atmospheric deposition of PFASs and Hg. Therefore, this is the first study on PFASs and Hg bio accumulation in fish tissue. Therefore, this study aimed to determine the distribution and bio accumulation of PFASs and Hg in the aquatic environment across the world [1-7].

METHODOLOGY

Searching Strategy and the Study Protocol

The study has been conducted between 19 May and 13 August 2022. Google Scholar, PubMed and SCOPUS were mainly used for web searching of peer reviewed articles focusing on the distribution and bio accumulation of PFASs and Hg in fish. Important key words mainly “PFAS (s)”, “Mercury”, “distribution of PFASs in the aquatic environment”, “distribution of Hg in the aquatic environment”, “PFASs in fish tissue”, “Mercury in fish tissue”, “bioaccumulation of PFASs in fish tissue” and “bioaccumulation of Hg in fish tissue” were used in the search engine databases. The study period of peer reviewed articles was left open ended to permit for an applicable amount of literatures to be included [8-12].

Inclusion and Exclusion Criteria

For the inclusion of peer reviewed papers in the study, basically, the following considerations were taken such as all factors related to metals in surface water of Ethiopia. The focus of the study was on published and peer reviewed papers. However, books, reviewed papers, conference articles and master and PhD thesis were excluded from the study. In addition, bioaccumulations (concentration) of PFASs and Hg in aquatic organisms, other than fish, were excluded. However, throughout the review, all searches may have a limitation according to the following considerations: (1) Published literatures may be omitted due to a lack of a linkage with the important keywords, (2) All used literatures were only in the English versions, (3) Some may not available due to closed access, (4) Others were not catalogued in the electronic databases, and (5) All included studies are cross-sectional studies (**Figure 1**).

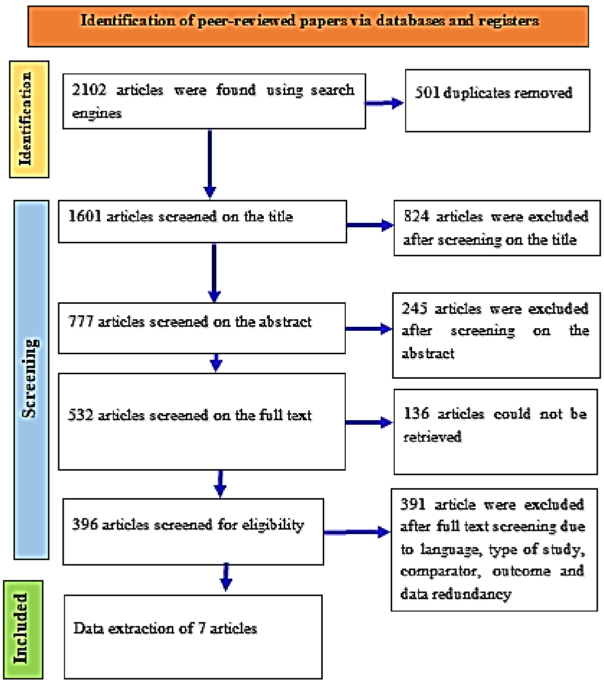

Figure 1: A flowchart representing the methodology of the review.

RESULTS AND DISCUSSION

Data Accessibility

After searching, 1046 peer reviewed articles focusing on the distribution and bio accumulation pattern of PFASs and Hg in fish tissue globally, only 7 articles were used for analysis of result. The concentrations of PFASs and Hg from globally done studies are summarized in **Table 1**. Results of the study illustrated that the most common detected PFASs in fish tissue were PFDA, PFUnDA, PFDoDA, PFOS and PFOA.

Table 1: Distribution, concentration and bioaccumulation pattern of PFASs and Hg in fish tissue.

Reference and study country	Detected PFASs concentration in fish tissue (liver and/or muscle)	Concentration in fish tissue (mg/g ww)	Hg concentration in fish tissue (µg/Kg ww	Pearson correlation between detected PFAS and Hg (R^2 or p-value)
Ahrens, et al.	PFDA	7.43	0. 416	$p<0.05$
	PFNA	1.54		$p<0.05$
	PFUnDA	14.31		$p<0.05$
	PFDoDA	5.28		$p<0.05$
	PFTeDA	2.78		$p<0.05$
	PFOS	3.6		$p>0.05$
Sjoholm	PFNA	0.13	0. 167	$p>0.05$
	PFDA	0.554		$p>0.05$
	PFUnDA	0.189		$p>0.05$
	PFDoDA	0.174		$p > 0.05$
	PFTeDA	0.01		$p > 0.05$
	PFBS	0.223		$p>0.05$
	PFOS	0.02		R=0.94
Arinaitwe, et al.	PFOS	2.19	2.8	$p=0.016$
	PFUnDA	2.19		R=0.701
Negm	PFNA	0.04	0.41	$p>0.05$
	PFDA	0.067		$p=0.0001$
	PFUnDA	0.24		$p=0.024$
	PFDoDA	0.12		$p=0.037$
	PFTeDA	0.023		$p>0.05$
	PFBS	0.01		$p>0.05$
	PFOS	0.19		$p>0.05$
Mazzoni, et al.	PFOS	3.9	0. 111	$p<0.05$
Melake, et al.	PFDA	0.263	0.471	$p>0.05$
	PFUnDA	0.93		$p>0.05$
	PFDoDA	0.07		$p>0.05$
	PFOS	0.38		$p>0.05$
	PFOA	0.345		$p=0.018$

Bioaccumula ion of PFASs and Hg in Fish Tissue

Bioaccumulation leads to a higher concentration of pollutants in an organism due to the uptake *via* all possible routes. Analysis of the results revealed that a higher concentrations of PFASs were recorded in fish liver than in fish muscle which is similar to previous findings which may due to that PFASs are proteinophilic and therefore, known to accumulate more in protein rich tissues. In herbivorous fish species, relatively, a larger proportion of short chain PFASs was observed, while long chains were found in piscivorous fish species and short chain PFASs are commonly found in flora. Analysis of the results of collected data show the bioaccumulation pattern of PFASs increases with the increase in carbon chain length. This was as expected and was similar to earlier studies. Literatures documented that the most detected form of Hg (50%-99% of the total mercury, THg, in fish tissue is MeHg. It is more toxic, lipophilic and can accumulate in the food chain. Fish may acquire MeHg from water which may originate from precipitation (atmospheric source), runoff from wetlands (terrestrial sources) and internal production of MeHg (in lake methylation. Long range atmospheric transport and deposition is also the main pathway for Hg in aquatic ecosystem including fish. Similar to previously done reports, Hg was highly accumulated in fish liver and sometimes in fish muscle, because the liver acts as a store for metals, detoxification and redistribution. This could be also due to the presence of high quantities of cysteine rich molecules and higher concentrations of metallothioneins in the liver or due to the active metabolic liver function which requires it to be a well perfused organ. The uptake and transport of metals *via* the blood to the liver could therefore also contribute to the observed higher concentrations. Likewise, previously done documents, anlysis of the result reveals a higher level of MeHg is found in piscivorous fish. This may due to the bio-magnification potential of Hg *via* food chain and this can be supported by that the neurotoxic form of mercury, (MeHg), has been shown to bio accumulate and magnify in fish tissue. In fish tissue, the concentration of MeHg is also proportional to trophic level position (*i.e*., higher in higher trophic level fish or piscivorous fish), diet, size and age.

Analysis of the collected data from literatures shows that there was a significant correlation between PFASs and Hg concentration. This was a similar pattern as, for instance, there was a significant positive correlation between PFASs; (PFCAs) and Hg; PFOS and Hg. Other has also observed that the increase in bioaccumulation of PFOS was linear with Hg. This indicates that PFASs and Hg might have similar transport, trophic level bioaccumulation pattern, source of pollution, similar exposure routes and/or factors. Sometimes, the presence of Hg cations may also enhance the adsorption of PFASs, *i.e*. PFASs may tend to lose its protons (become anionic) and charged negatively. However, this needs a further study to identify the impact of cations on PFASs adsorption [13-18].

Possible Human Exposure to PFASs and Hg

Ingestion of contaminated water and food, inhalation of indoor air and contact with PFASs contaminated media are the possible routes of human exposure. In most countries, people mainly consume only the fish muscle. Therefore, the main route for human exposure to PFASs and Hg worldwide is *via* dietary intake (fish consumption). Detected concentrations of PFASs and Hg in fish muscle may or not pose human health risk [19,20]. Adverse health effects through consumption of PFASs and Hg contaminated fish are expected when the weekly fish consumption is higher than the tolerable maximum weekly (MEA) fish consumption. However, further and detail studies are need to determine possible human risks posed by consumption of fish contaminated with PFASs and Hg.

CONCLUSION

PFASs and Hg had similar bioaccumulation patterns. Finding of this study revealed that a higher concentration of PFAS and Hg was found in fish liver than in muscle. Piscivorous fish accumulate more PFASs and Hg. However, estimation of possible human and ecological risk requires further studies. The finding of the present study emphasized the crucial importance of controlling and monitoring of aquatic ecosystems and may an input for management approaches for reducing these pollutants. Therefore, monitoring PFASs and Hg is important, as, for example, an increase of PFASs contamination in developing countries is expected due to the increased modernization and importation of PFASs containing consumer products. Although PFASs monitoring is challenging and often not feasible due to the high costs of the analyses and the lack of analytical capacity especially in developing countries, there is a need to investigate the environmental distribution and potential risks posed by PFASs and Hg in these countries. Moreover, future studies should also include some novel PFASs. Finally, this study may serve as a baseline for governments, risk managers and policymakers to alleviate the pollution of the aquatic ecosystems and environmental risks.

AUTHOR CONTRIBUTION STATEMENT

Conceptualization: BAM.

Developing methods: BAM, SME,TSA.

Data analysis: BAM, SME, TSA.

Writing and editing: BAM, SME, TSA

CONFLICT OF INTEREST STATEMENT

The authors declare that, no conflict of interest.

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