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Original Article

Effects of microplastics in freshwater fishes health and the implications for human health

Efeitos dos microplásticos na saúde dos peixes de água doce e as implicações para a saúde humana

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Abstract

The presence of microplastics in aquatic environments has raised concerns about their abundance and potential hazards to aquatic organisms. This review provides insight into the problem that may be of alarm for freshwater fish. Plastic pollution is not confined to marine ecosystems; freshwater also comprises plastic bits, as the most of plastic fragments enter oceans via rivers. Microplastics (MPs) can be consumed by fish and accumulated due to their size and poor biodegradability. Furthermore, it has the potential to enter the food chain and cause health problems. Evidence of MPs s ingestion has been reported in >150 fish species from both freshwater and marine systems. However, microplastic quantification and toxicity in freshwater ecosystems have been underestimated, ignored, and not reported as much as compared to the marine ecosystem. However, their abundance, influence, and toxicity in freshwater biota are not less than in marine ecosystems. The interaction of MPs with freshwater fish, as well as the risk of human consumption, remains a mystery. Nevertheless, our knowledge of the impacts of MPs on freshwater fish is still very limited. This study detailed the status of the toxicity of MPs in freshwater fish. This review will add to our understanding of the ecotoxicology of microplastics on freshwater fish and give subsequent research directions.

Keywords: ecotoxicology, freshwater ecosystem, microplastics, polyesters, polyethylene.

Resumo

A presença de microplásticos em ambientes aquáticos levantou preocupações sobre sua abundância e perigos potenciais para os organismos que vivem nesse meio. Esta revisão fornece informações sobre o problema que pode ser alarmante para os peixes de água doce. A poluição plástica não se limita aos ecossistemas marinhos; a água doce também contém pedaços de plástico, já que a maioria dos fragmentos de plástico entra nos oceanos por meio dos rios. Os microplásticos (MPs) podem ser consumidos pelos peixes e acumulados devido ao seu tamanho e baixa biodegradabilidade. Além disso, tem o potencial de entrar na cadeia alimentar e causar problemas de saúde. Evidências de ingestão de MPs foram relatadas em mais de 150 espécies de peixes de sistemas de água doce e marinhos. No entanto, a quantificação e a toxicidade de microplásticos em ecossistemas de água doce foram subestimadas, ignoradas e não relatadas tanto quanto em comparação com o ecossistema marinho. No entanto, sua abundância, influência e toxicidade na biota de água doce não são menores que nos ecossistemas marinhos. A interação de MPs com peixes de água doce, bem como o risco de consumo humano, permanece um mistério. Todavia, nosso conhecimento sobre os impactos das MPs em peixes de água doce ainda é muito limitado. Este estudo detalhou o status da toxicidade de MPs em peixes de água doce. Esta revisão aumentará nossa compreensão da ecotoxicologia de microplásticos em peixes de água doce e fornecerá direções de pesquisa subsequentes.

Palavras-chave: ecotoxicologia, ecossistema de água doce, microplásticos, poliésteres, polietileno.

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1. Introduction

Aquatic foods are increasingly recognized for their key role in food security and nutrition underscoring the urgent need to manage and protect this natural resource from pollution (Hassan et al., 2021a, b; Abidin et al., 2022). Microplastics are usually demarcated as debris lesser than 5 mm (Cheung and Fok, 2017; Bilal et al., 2023a) and have been observed to contaminate several aquatic ecosystems. Plastic global production has amplified dramatically over the last few decades, reaching 350 million tons in 2017. Plastics are utilized in modern life, such as wrapping, agriculture, electrical appliances, automotive, and so on (Brooks et al., 2018; Hassan et al., 2020b). Asia is the major producer of synthetic polymers (50%), Europe (19%), North America (18%), the Middle East and Africa (7%), and Latin America (4%) (Jambeck et al., 2015). Plastics are extensively used around the world due to easy processing, water resistance, and reliability. It is possible to say that we are existing in the plastic era (Lusher, 2015). The continued expansion of plastics production and use has occasioned a surge in the number of plastic litter discharged into the atmosphere. Continuous distortions of plastic items caused by weathering decay can result in an innumerable variety of microplastics. MPs are pervasive in nearly all kinds of aquatic environments, making them accessible to fish (Wang et al., 2020). Contamination of MPs in water is an alarm due to their widespread dispersal and possible threat to underwater life. MPs are identified in a wide array of aquatic systems. Plastic fibers are the most common kind of microplastics found in global water, and they are primarily caused by the breakdown of big debris (Wang et al., 2020). MPs seem to be common in the freshwater environments in Europe (Klein et al., 2015; Fischer et al., 2016), North America (Corcoran et al., 2015; Baldwin et al., 2016), and China (Su et al., 2016). Despite having a percentage removal of more than 98% of microplastics, a wastewater treatment plant on the Clyde River in Glasgow has been demonstrated to be able to discharge 65 million MPs into the water on a regular schedule (Murphy et al., 2016).

Plastic enters into the water from inland sources, namely rivers, industrial and urban discharges, and runoff from residues and surrounding areas (Barboza et al., 2018a; Rahman et al., 2020; Hassan et al., 2024). It can be also caused by direct inputs such as aquaculture, oil and gas production, net loss in fisheries, and garbage discharged during maritime activities like tourism and salt production (Siddique et al., 2023). External factors such as biological degradation, photocatalytic degradation, and chemical weathering are largely responsible for MPs degradation. Chemical weathering induces crack propagation on the plastic's surface and can shatter particles into smaller pieces. Polypropylene, polyethylene, polystyrene, polyvinyl chloride, and polyethylene terephthalate are the major manufactured polymers. While Polyamide is the most widespread polymer used in the fisheries sector. Plastic polymers are classified into three groups based on their buoyancy in freshwater or saltwater, neutrally buoyant polymers, and negatively buoyant polymers (Karami, 2017; Khan et al., 2024). The majority of the evidence for MPs consumption by fish species came from the evaluation of fish gastrointestinal tract contents. Fish that have been revealed to be contaminated with microplastics include a diverse range of species and inhabit a wide range of water bodies. Plastic particles found in these wild-caught fish vary significantly in color, shape, and polymer type (Siddique et al., 2022; Bilal et al., 2024). The most frequently identified shapes of MPs in fish are fiber and fraction, which correspond to their dominance in global water bodies (Wang et al., 2020; Siddique et al., 2022).

MPs in water can be simply consumed by fish. Researchers have described the incidence of MPs in fish (Su et al., 2016; Bilal et al., 2021; Bilal et al., 2023a). MPs deposit in fish and have a wide range of negative impacts i.e decreased feeding activity, impeded growth, energy interruption, oxidative stress, and even genotoxicity (Lu et al., 2016; Hassan et al., 2023) According to Singh et al. (2022), (see Figure 1) MPs particles are easily ingested by fish in unintended ways due to their small size and similarity to natural food items (Crawford and Quinn, 2017). MPs hinder fish metabolism by lowering the amount of energy needed for growth and delaying ovulation (Wright et al., 2013). Upon consumption, MPs may adversely affect fish in three general, non-exclusive ways: (a) through the MP's effects (such as obstructing the GIT or producing distorted satiation); (b) through the siphoning of plasticizers, ingredients, and other toxic substances from within the MPs; and (c) through the inactivation of toxic emissions confined to the MPs (Strungaru et al., 2019). As ingested MPs associated with other pollutants affect brain and central nervous system cells, which may severely affect swimming and/or survival ability for freshwater fishes and their other behavioral changes. MPs have effects on freshwater fish at the cellular, tissue, population, community, and ecosystem levels. In fish, MPs cause cell death, oxidative stress, and DNA damage. MPs also have an impact on intestinal dysbiosis, aberrant neuromuscular function, and metabolic activity. MPs have an impact on locomotion, feeding, hatching time, population increase, community structure, and ecosystem structure (Parker et al., 2021). Swimming problems may be transient; nevertheless, other research shows that MP exposure has a greater negative influence on early development (Duan et al., 2020; Pannetier et al., 2020). Physically bound MPs and/or smaller NPs in fish eggs can disrupt gaseous exchange and delay hatching periods (Batel et al., 2018; Duan et al., 2020). A few studies have shown that MP exposure has dose-dependent impacts on freshwater fish, though these effects may only happen at a specific MP intensity, implying MP thresholds for impact, making the correlation between exposure and impact more complicated than a simple linear dose-effect relationship (Mazurais et al., 2015; Lei et al., 2018; Qu et al., 2019). In terms of physical consequences, the bio perseverance of microplastics may result in a variety of biological effects such as inflammatory response, mutagenicity, oxidative stress, cell death, and necrotizing. If these situations hold, a variety of consequences may occur, including tissue injury, fibrosis, and carcinogenesis. The transformation approach may occur as a result of the polymers (Khan et al., 2015).

Researchers have revealed that plastics critically pertain to the spoiling of the aquatic environment. Plastic particle

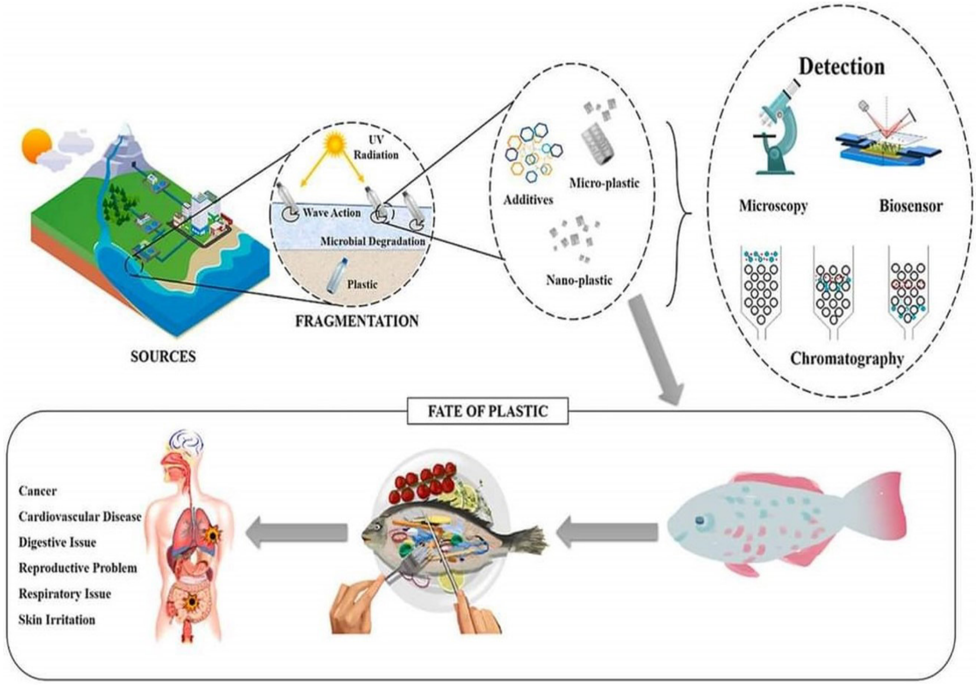

Figure 1. Detection of microplastics in fishes and human health risks associated with ingestion exposure.

exposure can cause all sorts of sub-lethal effects in fish and other aquatic organisms, including impaired feeding, oxidative damage, growth retardants, and behavioral changes. The zebrafish (*Danio rerio*) is a small freshwater teleost with many similarities to other vertebrate species in terms of the genome, brain patterning, and neural and physiological system (Chen et al., 2017). Fish is a crucial source of proteins for humans, and the possible effects of MPs on fish require special consideration. Although freshwater can accumulate a large number of microplastic particles and fibers, fewer attempts have been done to track microplastics in freshwater than in seawater. Microplastic quantification and toxicity in the freshwater ecosystem have been underestimated, ignored, and not reported much as compared to marine ecosystems. However, the abundance, influence, and toxicity of MPs in freshwater biota are not less than in marine ecosystems. This review aims to highlight the existing literature on microplastic quantification and its influence on freshwater fauna and recommendations for new research to fully understand the issue.

2. Identification of Microplastics

Natural material in the sample that follows the MPs during water sample density dispersion usually hampers the confirmation of MPs particles. As a result, it is unavoidable to destroy natural debris to reduce the chance of undervaluation of trivial plastic bits. Natural material can be destroyed using chemical or enzymatically catalyzed reactions. Before or after separation, natural debris is chemically removed by processing the sample with hydrogen peroxide, combinations of hydrogen peroxide and sulfuric acid, and Fenton-like processes (Liebezeit and Dubaish, 2012; Imhof et al., 2013; Yonkos et al., 2014).

Visual Identification is frequently used to remove MPs from the sample and to identify them (Hidalgo-Ruz et al., 2012). Tiny particles should be separated using a dissecting microscope (Doyle et al., 2011), large size MPs contamination in freshwater systems microplastics can be (>1 mm) recognized by the naked eye (Morét-Ferguson et al., 2010). When arranging water samples, Bogorov counting chambers might be useful. To prevent misidentification, it was advised that particles be visually identified using defined criteria in conjunction with a careful and cautious inspection (Norén, 2007). Yet, it is strongly encouraged, particularly for smaller MPs, to evaluate potential microplastics using reliable practices (e.g., spectroscopic methods) to adequately determine synthetic polymers (Dekiff et al., 2014). By studying the thermal breakdown of products of possible microplastic particles in samples, pyrolysis-GC/MS may be utilized to gather information on their chemical composition (Fries et al., 2013). Plastic polymer pyrolysis products produce distinct programs, which aid in the appropriate identification of diverse polymer kinds by contrast with reference programs of known virgin polymer samples. Following the extraction of microplastic from deposits, this method was previously applied (Nuelle et al., 2014). Infrared (IR) or Fourier transform infrared (FTIR) spectroscopy is a method that, when combined with Raman spectroscopy, enables the accurate determination of plastic particles based on their unique IR spectra. Absorption may be monitored, yielding a unique infrared spectrum. IR spectroscopy is an effective tool for detecting MPs since plastic polymers have extremely unique IR spectra (Hidalgo-Ruz et al., 2012).

3. Evidence of Microplastics in Freshwater

Freshwaters are incredibly rich and diversified and supply a wide range of critical ecosystem services while occupying a very little amount of the earth's surface (0.01%). Many anthropogenic stresses, such as excess nutrients, habitat degradation, biological invaders, and climate change, are already putting them in danger (Parker et al., 2021). Preliminary research of freshwater systems reveals that the presence and interrelationship of MPs are as substantial as those reported in marine systems. MPs have been found in freshwater in Europe, North America, and Asia, and the study show that MPs are consumed by freshwater fish (Eerkes-Medrano et al., 2015). Initial freshwater studies have identified primary and secondary microplastics (Table.1). In samples from the North American Great Lakes, microplastics of consumer origin with the same size, color, form, and elemental analysis as microbeads were discovered from commercial facial cleansers (Eriksen et al., 2013). In lakes and rivers, primary microplastics have been discovered. The second most common residue in Los Angeles basin waterways were pre-production plastic polymers pods (Moore et al., 2011), and the most abundant fragments in Lake Huron (Zbyszewski and Corcoran, 2011). Several studies have been reported on microplastics in freshwater in the Lake River Rhine, Europe (Mani et al., 2015), Grade Lakes tributaries, USA (Baldwin et al., 2016), Lakes Winnipeg, Canada (Anderson et al., 2017), Taihu Lake, China (Paul-Pont et al., 2016), River Thames Basin, UK (Horton et al., 2017a), Laurentian Great Lakes, North America (Driedger et al., 2015), Lake Poyang, China (Yuan et al., 2019) and Taihu Lake (Su et al., 2016) (Table 1). MP concentration levels in Rhine River surface water samples average 892,777 particles km^2 with the highest concentration of 3.9 million particles km2 (Mani et al., 2015). Along the Rhine and Main rivers in Germany, the particles in river shore silt varied widely from 228 to 3,763 and 786 to 1,368 particles kg^{-1} (Klein et al., 2015). At the Three Gorges Dam in China, high surface water concentrations (192–13,617 particles km^2) have been documented, which have been attributed to the privation of wastewater treatment services in lesser communities, as well as infrastructural challenges with recycling and waste disposal (Zhang et al., 2015). Since these studies rely on visual observation techniques for isolation and analysis, the actual MP levels may be miscalculated (Reddy et al., 2006). The emergence and causes of MPs in freshwater matrices in Africa, Asia, and Europe are addressed (Cepoi et al., 2016; Rist and Hartmann, 2018; Wu et al., 2018).

MPs were found to be higher in the southern parts of Lake Huron in North America and Lake Hovsgol in Mongolia, where there is heavy industry (Zbyszewski and Corcoran, 2011; Free et al., 2014). In terms of the correlation between microplastic existence and sewage management, the authors reported that the population using certain ingredients, such as microbeads in beauty products that are incapable to acquire MPs, adds value to the availability of MPs in freshwater (Eriksen et al., 2013). These workers also believe that the occurrence of microbeads in samples was caused by the use of cumulative sewage overflow in the Great Lakes. Microplastic concentrations may also vary depending on how close you are to a wastewater treatment facility (Hoellein et al., 2014). Microplastic contamination in freshwater is widespread and global. According to the findings, MPs have primarily been recorded in Western Europe and North America (Horton et al., 2017b), parts of China (Zhang et al., 2018), the UK (Blair et al., 2019), Europe (Bordós et al., 2019). MPs identified in these studies comprise data from water and sediments, as well as a variety of compositions (Table 1).

4. Microplastics in Freshwater Fishes

Fish is an essential biological component of freshwater ecosystems with great nutritional and economic importance around the world. Developing countries account for around 94% of all freshwater fisheries, providing food and a livelihood for millions of the world's poorest people while also adding to the general economy through exporting, tourism, and recreation (FAO, 2007). In scientific research, fish are capable of ingesting MPs (Oliveira et al., 2013; Mazurais et al., 2015; Bilal et al., 2021), though considerably higher meditations of MPs than those found in nature (Costa et al., 2016; Phuong et al., 2016). There is growing evidence that MPs are encountered by wild freshwater fish through their gills and/or skin. MP contact by fish is expected to occur mostly during active feeding (Abbasi et al., 2018; Hurt et al., 2020). Additionally, experimental investigations have shown that MP builds up in the gills (Mak et al., 2019; Roch et al., 2020). As a result, in addition to ambient contact via breathing and swimming, passive absorption of MPs is another reservoir of MPs. Considering that MP dispersion and penetrations vary, with generally larger loadings in sediments comparable to overlying surface waters, freshwater fish foraging habitats should also influence MP encounter rates (Boucher et al., 2019; Bondelind et al., 2020). Notably, because the amount of MPs ingested is small, the assimilation of MPs by fish in situ has been frequently observed. Following MPs ingestion, there is a risk of linked chemical contaminants leaching and accumulating in edible tissue. MPs disclosure through fish may be feasible if MPs can cross the GIT or gill via transcellular utilization or extracellular dissemination (Handy et al., 2008).

According to several studies on adult and larval Zebra fish, MPs were originally consumed before persisting and causing abnormalities, intestinal damage, and metabolic changes (Chen et al., 2017; Sleight et al., 2017; Lei et al., 2018). The identification of MPs in 13 species with including 35 individuals the study was study conducted in the Xiangxi River in China, as well as the abundance and characteristics of MPs found in fishes digestion pathways, were all reported. Polyethylene and nylon were found in the digestive tracts of 25.7% of the fish samples evaluated for MPs (Table 2), according to Zhang et al. (2017). In research undertaken by Dantas et al. (2012) nylon fragments are used to assess plastic intake in two drum species, *Stellifer brasiliensis*, and *Stellifer stellife*, as it varies with season and size class. Plastic was consumed across all species. Fish in the middle estuary had the most consumed fragments in their guts during the late monsoon season.

Table 1. Studies reporting the occurrence of microplastics in freshwater ecosystem.

Location	Microplastics type	Maximum Abundance/ sources	Reference
Lake Hovsgol, Mongolia	PP, PY, PE	20264 items/km^2 W	Free et al. (2014)
River Rhine, Europe	PLE, APC, PP, PY, PFE	892777 items/km^2 W	Mani et al. (2015)
Grade Lakes tributaries, USA	PLE, APC, PP, PY, PFE	0.05 to 32 items/m^2 W	Baldwin et al. (2016)
Lakes Winnipeg, Canada	PLE, APC, PP, PY, PFE	52508-748027 items/km^2 W	Anderson et al. (2017)
Taihu Lake, China	PM, Methacrylate PC	4.4-25.8 items/L W	Paul-Pont et al. (2016)
River Thames Basin, UK	Cellophane, PLE, PP	185-660 items/kg S	Horton et al. (2017a)
Laurentian Great Lakes, North America	PP, PY, Polycarbonate	0.85–0.92 g/cm^3 SW	Driedger et al. (2015)
Lake Poyang, China	PP, PE	5–34 items/L W	Yuan et al. (2019)
Taihu Lake	cellophane, PP, PLE	3.4-25.8 Items/L W	Su et al. (2016)
Dongting, Hong Lakes in China	PP, PE, PC	1250–4650 n/m^3 SW	Wang et al. (2018)
Remote Lakes in Tibet	PP, PE	20,264 particles/km W	Free et al. (2014)
Vembanad Lake, India	PE, PY, PLE	96–496 particles m^{-2} S	Sruthy and Ramasamy (2017)
Italian subalpine Lakes	PE, PY, PP	25000 items/m^2 SW	Sighicelli et al. (2018)
Dongting Lake, China	PE, PY	320-480 items/m^2 And 200-1150 items/m^2 SW	Jiang et al. (2018a)
Wuhan, China	PE, PY	1660.0-8925 particles/m SW	Wang et al. (2017)
River Ravi, Lahore Pakistan	PE, PP	2074 ± 3651 MPs/m^3 W	Irfan et al. (2020)
Dutch river delta and Amsterdam canals	Not detected	NA	Leslie et al. (2017)
Kelvin River, UK	Fibers	0.26685 g/L S	Blair et al. (2019)
Carpathian Basin, Europe	PE, PP and PY	0.4716 g/L SW	Bordós et al. (2019)
The lagoon of Bizerte, Tunisia	PP and PE	2.106 g/L S	Toumi et al. (2019)
Wei River, China	Fibers	0.918 g/L SW	Ding et al. (2019)
Flemish rivers, Belgium	Not identified	0.0153 g/L W	Slootmaekers et al. (2019)
Bloukrans River, Australia	Not identified	0.216 g/L S	Nel et al. (2018)
Dutch wastewater treatment plant effluent, Netherlands	Effluents	0.00297 g/ E	Van Wezel et al. (2016)
WWTP effluent Scotland	Flakes, fibers, film, beads, foam	250e15700/m^3 E	Murphy et al. (2016)
Los Angeles, USA	Irregularly shaped fragments	0.002/m^3 E	Carr et al. (2016)
Oldenburg, Germany	Particles, fibers	10e9000/m^3 E	Mintenig et al. (2017)
Helsinki, Finland	films, spheres	5e2000/m^3 E	Talvitie et al. (2017)
Rivers Germany	foam, fibers, pellets, films	2.9e214/m^3 SW	Heb et al. (2018)
Tamar Estuary, UK	Floating plastic debris	0.028/m^3 SW	Sadri and Thompson (2014)
Urban Lakes, Hanjiang and Wuhan Rivers, China	Colored granules, films, pellets, fiber	1660 e8925/m^3 SW	Wang et al. (2017)
North Sea coast, Netherlands	Colored granules, films, pellets, fiber	27000/m^3 SW	Karlsson et al. (2017)

Notes: PP (Polypropylene), PY (Polystyrene), PE (Polyethylene), PLE (Polyester), APC (Acetyl Polyvinyl Chloride), PC (Polyvinyl Chloride), PM (Polymethylene), WWTP (Waste Water Treatment Plants) and NA (Not applicable).

Polyethylene reduces the toxicity of pollutants (pyrene) on the *Pomatoschistus microps* (found in estuaries) in Portugal (Oliveira et al., 2013). When microplastics were prevalent, fish subjected to pyrene died later (Oliveira et al., 2013). Three significant catfish species from the South Western Atlantic estuaries (*Cathorops agassizii,*

Table 2. Studies on microplastics in freshwater fishes.

Taxa	Location	Type of polymers	Concentration of MPs	Reference
European flounder (*Platichtyhys flesu)* and European smelt (*Osmerus eperlerus*)	River Thames, Uk	PY, PA, PE	75%, 20%	McGoran et al. (2017)
Bluegill (*Lepomis macrochirus*) and longear (*Lepomis megalotis)*	Brazos river Basin, USA	PY, PA, PE	45%	Peters and Bratton (2016)
Gudgeon (*Gobio gobio*)	Eleven French River	PY, PA, PE	12%	Sanchez et al. (2014)
Thirteen different fish species	Xiangxi Bay of three gorges reservoir, China	PA, PE	25%	Zhang et al. (2017)
Forty-six different fish spp.	Amazon river estuary	PA, PE	1.2 to 5.0 items/ individual	Schmidt et al. (2018)
Eleven fish species	Rio de la Plata estuary, Argentina	PA, PE	19.2 items/individual	Pazos et al. (2017)
Thirteen Fish Spp.	Xiangxi River, China	PE	25.7% fish spp.	Zhang et al. (2017)
Drum species (*Stellifer brasiliensis* and *Stellifer stellife)*	Tropical estuaries, Brazil	Poly filament nylon	6.9 and 9.2% of individuals spp.	Dantas et al. (2012)
Common goby, (*Pomatoschistus microps)*	Estuaries, Portugal	PE and Pyrene	Not identified	Oliveira et al. (2013)
Catfish species	South Western Atlantic estuaries, a tropical estuary of the Brazilian Northeast	Nylon fragments and hard plastic	17% and 33% of individuals spp.	Possatto et al. (2011)
Gerreidae Fish	Tropical estuary in Northeast Brazil	Blue nylon fragments	4.9 and 33.4% of individuals	Ramos et al. (2012)
(*Oryzias latipes*)	Brackish, USA	PE	Not Identified	Rochman et al. (2013)
gudgeons (Gobio gobio)	French rivers, France	Fiber and pellets	12% of individuals	Sanchez et al. (2014)
African catfish (*Clarias gariepinus*).	Malaysia	PN (Phe)- loaded low-density PE (LDPE) fragments		Karami et al. (2016)
Goldfish (*Carassius auratus*)	Canada, USA	Microbeads microfibers	-3 particles/50 retained	Grigorakis et al. (2017)
Zebra fish (*Danio rerio)*	China	PS	20–2,000 µg L1	Lu et al. (2016)
Carassius carassius		PE,	NA	Mattsson et al. (2017)
Carassius auratus		PP	NA	Grigorakis et al. (2017)
Acipenser transmontanus		PE	NA	Rochman et al. (2017)
Clarias gariepinus	Malaysia	PN (Phe)- loaded low-density PE	(50 or 500 mg/L)	Karami et al. (2016)
Fathead minnow *(Pimephalespromelas*)	Germany	PY and PC	PS: 41.0 nm, PC: 158.7 nm	Greven et al. (2016)
Rastrilleger kanagurta and *Epinephalus*	India	PE and PP	ND	Kumar et al. (2018)

Notes: PY (Polystyrene), PA (Polyamide), PE (Polyethylene), LDPE (Low-density polyethylene), PS (Polystyrene), PP (Polypropylene), PN (Phenonthrene) (Polyvinyl Chloride), NA (Not applicable) and ND (Not identified).

Cathorops spixii, and *Sciades herzbergii*) were evaluated in a tropical estuary. Plastics have been consumed by individuals from all three species. Plastic was consumed by all size-classes (Possatto et al., 2011; Ramos et al., 2012).

Microplastic item intake by three Gerreidae fish species (*Eucinostomus melanopterus, Eugerres brasilianus,* and *Diapterus rhombeus*) in a tropical estuary in Northeast Brazil was evaluated for three distinct size classes. The number of ingested fragments varied across size classes. In the United States, laboratory research was done to examine the danger of compounds sorbed on MPs in Japanese medaka. Toxins sorbed on microplastics bioaccumulate in fish, causing liver toxicity. Microplastic accumulation in fish can result in liver glycogen reduction (Rochman et al., 2013).

Sanchez et al. (2014) investigated the presence of MPs in the GIT of gudgeons (*Gobio gobio*) in French rivers. He reported the presence of MPs in the digestive tracts of 13% of gudgeons (Sanchez et al., 2014). The frequency of MP consumption in fish samples was correlated with their food intake strategies. Polystyrene was found in freshwater zebrafish (*D. rerio*) in China. Polystyrene leads to inflammation and lipid acquisition and metabolic changes in zebrafish (Lu et al., 2016). Oliveira et al. (2013) determined whether polyethylene microspheres affect the hazard of pyrene to common goby juveniles (*Pomatoschistus microps*). Microplastics raised biliary pyrene metabolite levels and prolonged pyrene-induced fish mortality.

Chen et al. (2017) analyze the toxicity of MPs and nano plastics on zebrafish (*D. rerio*) larvae. MPs had no profound impacts; whereas nano-plastics hindered larval motility by 22% in the last nightfall period, substantially reduced larvae body length by 6%, and impeded acetylcholinesterase activity by 40%. Moreover, oxidative impairment and body length decrease were recognized as the major causes of hypoactivity. Karami et al. (2016) investigated the impact of virgin or Phe-loaded low-density polyethylene bits on several biomarker responses in juvenile African catfish (*Clarias gariepinus*). In the *C. gariepinus* brain, one or both Phe treatments enhanced the degree of tissue change (DTC) while lowering the transcription levels of forkhead box L2 (foxl2) and tryptophan hydroxylase 2 (tph2). This study highlighted the ability of virgin LDPE fragments to cause toxicity and change the detrimental effects of Phe in *C. gariepinus*.

A study examined the effects of polystyrene-MPs (40 mm), and cadmium (Cd) on early juvenile discus fish *Symphysodon aequifasciatus*. MPs and Cd had no negative consequences on growth or survival, according to the findings (Wen et al., 2018). However, when exposed to Cd, the aggregation of Cd in the body of the fish is reduced with higher MP dosages, as evidenced by a lower metallothionein content (Wen et al., 2018). Haghi and Banaee (2017) studied the impact of paraquat and microplastics on blood biochemical markers in common carp (*Cyprinus carpio*). Blood biochemical analysis found that 0.4 mg L^{-1} paraquat and a combination of paraquat and microplastic ingestion increased aspartate aminotransferase (AST), alkaline phosphatase (ALP), and glucose levels. Albumin levels have risen dramatically when fish were treated with a combination of paraquat and 2 mg L^{-1} microplastics.

Polystyrene and polycarbonate nano-plastic were described in plasma, and the effects of polystyrene and polycarbonate nano-plastic on the fathead minnow's immune system were investigated. When neutrophils were subjected to PSNP or PCNP, there was a significant elevation in primary granule degranulation and the production of neutrophil extracellular traps (NETs) compared to non-control, but the oxidative explosion was less affected (Greven et al., 2016). The researchers (Zhang et al., 2019) investigated the effect of polystyrene microplastics (PS-MPs) on the dispersion and bioaccumulation of roxithromycin (ROX) in the freshwater fish red tilapia (*Oreochromis niloticus*), as well as their interacting biochemical consequences in red tilapia. PS-MPs were observed to increase ROX bioaccumulation in fish tissues when contrasted to ROX exposure alone. MPs may influence the fate and toxicity of other organic contaminants in fish.

Microplastics (MPs) were found in the gastrointestinal contents of coastal freshwater fish in the Rio de la Plata Estuary. The existence of MPs was confirmed in 100% of the fish. The concentration of MPs in stomach contents was substantially greater near sewage discharge. There was no correlation discovered between the number of MPs and the length, weight, or eating habits of the fish. The variations in the mean number of MPs in fish reported in this study suggest that environmental MP accessibility may play a substantial role in determining the inequalities seen among sample locations surveyed (Pazos et al., 2017). Jabeen et al. (2018) fed three different types of virgin MPs types, including fibers and pieces to Goldfish (*Carassius auratus*. When contrasted to the control, fish exposed to plastic lost substantial weight. Fibers were discovered in the gills and the GIT, and feces were unlikely to collect in the GIT. The livers of fish open to fibers showed obvious and severe changes. The distal gut revealed more significant and severe alterations than the proximal intestine, most likely owing to fiber consumption. Fish subjected to fragments had the incidence of reverting and circulatory abnormalities, notably in the upper and lower jaws, and in the lower jaw and liver, correspondingly. Polyamide, rayon, and polyethylene were the primary polymers detected through ATR-FTIR (Pegado et al., 2018).

The presence of MPs in two species of fish, *Epinephalus merra* and *Rastrilleger kanagurta* was studied in India. Particles were found in the intestines of 12 of the 40 fish tested. FTIR analysis revealed the microplastics as polyethylene and polypropylene (Kumar et al., 2018). Silva-Cavalcanti et al. (2017) tested for microplastic consumption of *Hoplosternum littorale*, a prevalent freshwater fish ingested in semi-arid South America. We discovered that fish swallowed more plastics in urbanized areas of the river and that MP consumption was inversely linked with the richness of other food items in individual fish guts. The goal of the study was to see how these pollutants affected the swimming capability of juvenile *Dicentrarchus labrax*. Microplastics, mercury, and all of the mixtures lowered fish swimming velocity and resistance time considerably. Furthermore, behavioral abnormalities such as sluggish and irregular swimming behavior were found (Barboza et al., 2018b). A study in China looked at plastic pollution in six kinds of freshwater fish. Micro- or microplastics were identified in all of the species. The fiber in form, translucent in color, and cellophane in substance dominated the plastics (Jabeen et al., 2017). The study's goal was to count the number and kinds of microplastics consumed by fish in different freshwater of the Gulf of Mexico. Microplastics were detected in the digestive systems of 8% of the freshwater fish and 10% of the marine fish examined in this research. The percentage of microplastics ingested by fish in non-urbanized streams was lower (5%) than in one of the urbanized streams (Neches River, 29 percent) (Phillips and Bonner, 2015).

Research undertaken by Peters and Bratton (2016) investigated MPs and synthetic fiber intake by longear (*Lepomis megalotis*), bluegill (*Lepomis macrochirus*), and sunfish (*Centrarchidae* sp.) in the Brazos River Basin, USA. A total of 436 sunfish were caught, and microplastics were found in 196 (45 percent) of their guts. Because microplastic consumption is so common, further research is needed to determine the residence time of microplastics inside the stomach and intestines, the probability of food web transmission, and the harmful effects on animal health.

Bivalve mollusks are now the major source of food exposure to microplastics (shellfish). Shellfish are a significant food source, accounting for roughly 22 million tons of fish output via capture and aquaculture in 2012 (almost 15 million USD) (Barange, 2018). Bivalves eat by pushing huge amounts of water through their shells' pallial chamber, keeping particles in suspension on their gills for later digestion (Ward and Shumway, 2004). MPs have also been found in wild and cultured shellfish intended for human ingestion. Microplastic infestation of shellfish is not restricted to China. Microplastic fibers have polluted mussels in Canada and Belgium (Witte et al., 2014). Microplastics were discovered from farmed mussels and store-bought Pacific oysters in Belgium after a 3-day depuration period. According to the average retrieved amount, the European shellfish user may invest up to 11,000 microplastics each year (Van Cauwenberghe and Janssen, 2014).

Potential MPs have been found in meals other than seafood. Microfibers and fragments have been found in sugar and honey (Liebezeit and Liebezeit, 2013). Microplastics have recently been discovered in fifteen different kinds of store-bought sea salt. There have been reports of up to 681 MPs/kg of oceanic salt down to 45 m. The utmost frequent form of plastic identified was PET, followed by PE. The pollution was most likely caused by the coastal waters used to create sea salt (Yang et al., 2015), Though MPs may be available as a result of air accumulation at certain locations. Microplastics are presently contaminating food meant for human ingestion, with unknown consequences.

5. Microplastics as a Vector for Pathogen Transfer and Biotoxins

Microplastics pollution is a new ecological concern that poses a risk to fish and human health. Fish is being contaminated with MP worldwide and it finds its way to human body through food (Bilal et al., 2023a). A major threat to human health is created by MPs in seafood. The human diet must include seafood. There is a significant threat that intestinal MPs infection will spread to other body systems. Two of the most typical ways that MPs enter the human body are endocytosis and persorption. Toxicological effects may have a negative impact on fish performance, which is important to take seriously as humans frequently consume fish as part of their diets (Hassan et al., 2021a; Bilal et al., 2023b). Toxins have the potential to cause serious health problems in humans. A few trials on fish have revealed that MPs and their related toxins bio-accumulate and cause issues such as intestinal injury and alterations in metabolic profiles (Li et al., 2018). MP might serve as a transporter of environmental toxins from water to fish. Even though different modeling studies reach contrasting conclusions (Antunes et al., 2013; Koelmans et al., 2013). According to an investigation, fish bare to pollutants sorbed to MP bioaccumulate these chemicals and have harmful effects (Zettler et al., 2013). MP can serve as a carrier for waterborne infections in humans. The point that the microbes on MP are different from those in nearby water (Harrison, 2012; Zettler et al., 2013), implies that MP can act as a new habitat. To date, the dynamic interactions between microorganisms and microbial assemblages as major players in aquatic ecosystems/food webs and MP, mainly in freshwater, have remained unclear and warrant additional investigation.

One of the commonly stated possible environmental activities for artificial nanoparticles and MPs is their capability to act as carriers for other contaminants. Synthetic nanoparticles and primary MPs will interact with other chemical compounds such as preservatives. As a result, the particles are intentionally and unintentionally mixed with other chemical compounds. An ordinarily passive and non-toxic bit may become a transporter of harmful substances as a result of this mechanism (Teuten et al., 2007). Engineered nanomaterials have been shown to absorb and transport organic pollutants in the aquatic environment (Hofmann and Von der Kammer, 2009; Hartmann and Baun, 2010; Vickers, 2017).

The biological consequences include the potential for microorganisms to be transferred geographically. Since plastics are usually extra durable, microbes can rapidly colonize the exterior of MPs and be carried with the MPs (Li et al., 2018). While this association is well understood and its consequences, such as disease development in a sterile environment, are explored, there is little literature published to show the broad biofilm (Mc-Cormick et al., 2014). Microplastics obtained from the river in Chicago were subjected to high-throughput sequencing analysis. They discovered that some of the committed taxa were plastic-decaying entities, implying that MPs can transfer microbial accumulations in freshwater. Their research also highlighted the possibility of pathogenic wastewater-allied bacteria being disposed into waterways via MPs with the organisms attached. A survey on MPs-linked microbes in the Yangtze Estuary reported the existence of pathogenic organisms on microplastics as well (Jiang et al., 2018a,b). Briefly, gene sequencing studies suggested that MPs can act as a carrier for the transmission of impending pathogens such as Arcobacter and Vibrio spp. (Hadi et al., 2008; Zettler et al., 2013; Harrison et al., 2014; McCormick et al., 2014; Amaral-Zettler et al., 2015). Schmidt et al. (2014) found precise outcomes for Vibrio taxa identifying the presence of pathogenic organisms influencing animals such as fish samples. The existence of

Vibrio spp. on marine plastics was only recently validated by (MALDI-ToF MS) (Kirstein et al., 2016). In research carried out by (Kirstein et al., 2016), *V. fluviales*, and *V. parahaemolyticus* were found on MPs. These species, in addition to alginolyticus, were discovered on plastics accumulated in the brackish Baltic Sea.

6. Possible Solutions and Control Strategies

Microplastic contamination is a worldwide ecological issue. The harm instigated by MPs contamination is not confined to a fixed place, and its impression and harm are worldwide. As a result, the administration and mitigation of MPs contamination necessitate global assistance and a coordinated response from all governments. On the one hand, active involvement in international conferences is suggested to improve international interaction and coordination, treatment approaches, and policy recommendations for the prevention of MPs contamination (Gong and Xie, 2020; Hassan et al., 2020a). Source reduction is a crucial step in reducing MPs contamination. Microplastics should be controlled at the source by strong rules, and the manufacture and trade of products that might pollute the environment with MPs should be forbidden. Microplastics, such as microbeads, have been banned for industrial usage in various countries due to their negative consequences. The United States, for example, outlawed the use of microbeads in 2015 with the adoption of the Microbead-Free Water Act (Auta et al., 2017).

The advancement of the biological elimination of microplastics has piqued the interest of many people. Some bacteria in the environment are capable of breaking down microplastics (Ball, 2017). Biodegradable plastics can be tainted by ambient microbes after they have been ditched. It is currently an efficient method of avoiding and regulating microplastic pollution, as well as an excellent solution for non-biodegradable plastics. At the same time, due to processing costs, breakdown efficacy, and other limitations, biodegradable polymers cannot completely replace conventional plastics shortly (Gong and Xie, 2020). Filter feeders like bivalves can deliver nutrients from the water column to the benthic zone of rivers and lakes via wastes and pseudo feces. The filter feeder bivalve *Anodontites trapesialis* was evaluated as a latent sentinel organism for freshwater effluence in the South American Pantanal region. *Anodontites trapesialis* can be regarded as a promising sentinel organism for detecting microplastic contamination in freshwater (Moreschi et al., 2020). In many developing and least developing countries, there are no precise rules governing MPs contamination. It does, still, have legislation in place in its capital that governs the usage of plastic such as polyethylene bags. These plastics-ban regulations will aid as a first phase in the development of additional regulations to combat plastic contamination.

7. Conclusion

MPs have been detected in numerous sites in the world, triggering extensive public concerns. Freshwater systems have equivalent or perhaps worse MPs contamination than marine environments. However, Microplastics quantification and toxicity in freshwater ecosystems have been underestimated, ignored, and not reported much as compared to the marine ecosystems, their abundance, influence, and toxicity in freshwater biota are not less than a marine ecosystem. The current status of microplastic contamination in freshwater was summarized in this review article. The potential environmental impacts, such as ingestion and toxicity to freshwater fish, were discussed. As a consequence, future investigations of the incidence and ecotoxicology of microplastics on freshwater fish are needed to fully understand the issue. Progress on this concern entails a strong systematic foundation as well as relevant legislation at global and national levels (EEA, 2012).

Acknowledgements figure

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