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Investigating microplastic pollution in freshwater fish populations: An Indian perspective

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Abstract
The toxicity of microplastics (MPs) to fish has become a global problem. Now a days more or less amount of Microplastics are found in all aquatic environments and they may have an impact on the freshwater and aquatic biota's ability to feed, grow, reproduce, and survival and also cause tissue damage, oxidative stress, and changes in immune-related gene expression as well as antioxidant status in fish. About 71% of the earth surface is occupied by oceans, which holds 97% of the earth's water. The remaining 3% is present as water in ponds, streams, glaciers, ice caps, and as water vapor in the atmosphere. Microplastics can leach out chemicals and act as transport vectors by accumulating dangerous pollutants from the environment. Around 54.5% of microplastics floating in the ocean are polyethylene, and 16.5% are polypropylene and the remaining materials include polyester, polyvinyl chloride, polystyrene, and polyamides. Moreover, polyethylene and polypropylene are less dense than sea water, so they float and have an impact on aquatic surfaces. Therefore, it is important to understand the ecotoxicological impacts and mode of action of environmentally relevant MP concentrations on the health of aquatic organisms. Scientific knowledge is always expanding at a rapid rate, despite the fact that evidence of actual adverse effects is still extremely limited now a daysit is also necessary to have some research models that investigate the effects of realistic exposure scenarios at the individual and population levels. The large amount of data currently available for favourable treatment of ongoing management and legislative measures that focus on reducing the production, consumption, and discharge of microplastics into the world's aquatic freshwater. In the present study, we conducted a systematic review of behavioural, Locomotion, aggression, feeding and swimming, immunotoxicity, neurotoxicity and reproductive and developmental effects caused by fish consuming environmental microplastics at different life stages and also suggest some different mitigation strategies of microplastics for future.

Keywords: Toxicity. microplastics, ecotoxicological, immunotoxicity, neurotoxicity, oxidative stress

Introduction

Plastics have become an integral part of daily life over the past few decades due to its highly versatile nature and their ecotoxicological hazards have put them at the top of the study agenda for a few decades. We might assume that we live in a plastic world because plastic production has increased significantly during the past year. According to size, plastic trash is divided into four main categories worldwide:microplastics (>25 mm), mesoblastic (5–25 mm), microplastics (<5 mm), and nanoplastics (<100 nm) (Lee *et al.,* 2016). Thompson *et al.,* (2004) coined the term "microplastics" to describe plastic particles measuring 5 mm or less in size. Even though they are an essential component of everyday human requirements, they have turned into a burden on both individuals and their environment. Microplastics are microscopic particles produced during both the manufacturing process and the decomposition of bigger polymers. Due to their low density and toughness, plastics are used in a wide range of production processes. Primary microplastics are those that are made specifically as microbeads, pellets, fibres, etc. Secondary microplastics are those that are created when bigger plastic trash is broken down by the elements and decomposed. Depending on where they come from, microplastics are further separated into primary and secondary categories (Li *et al.,* 2018). Primary microplastics are made of tiny plastic particles that are designed to be as small as possible. Synthetic textiles and personal care items are where they are most commonly found. Secondary microplastics are big particles of plastic waste that fragment into smaller bits as a result of different environmental conditions.

Microplastics (MPs) contamination is currently causing environmental issues that are of global concern because of its significant impact on the ecosystem, food safety, and human health. Microplastics (MPs) are increasingly recognized as environmental contaminants that exert complex effects on fish and other aquatic organisms. One of the most widespread and long-lasting alterations to Earth's ecology is the build up of plastic debris in the ocean. Global Environment Outlook 6, UN Environment, 2019, predicted that every year 8 metric tonnes of plastic leak into the ocean from improper household garbage disposal. Due to poor waste management and mass production, plastics are discarded into the aquatic environment in significant amounts. About 6300 million metric tons of plastic garbage were produced worldwide in 2015, of which 9% was recycled, 12% was burned, and 79% was dumped in landfills or the environment. The environment may suffer if these plastic wastes are not disposed of in an environmentally responsible manner. Particularly, this concerns the oceans, where the vast majority of plastics wind up as a permanent contaminant. Plastics can break up into smaller bits due to a variety of environmental variables, even though they take a long time to break down naturally.

Microplastic pollution can now be deemed to be among the biggest threats to habitats and species worldwide and this indicates that India's freshwater systems are also affected. The problem of microplastic pollution in India as a country with copious numbers of rivers, lakes, and wetlands is surmounting as the country is experiencing intellectualization, urbanization, and poor agricultural management (Sruthy *et al.,* 2017) [42]. This problem is made worse by existing poor waste management systems whereby plastics end up…-floating in the waters of the rivers and so on. Plastic does not decay but disintegrates gradually, and when small enough, they sink into the water as microplastics (Priya *et al.,* 2022) [34]. Many publications during the recent years have shown that microplastic pollution is widespread in India and it is present not only in the water, but also in the sediment and the fauna – fish include. The purpose of the current study is to present an overview of the current state of understanding in terms of microplastic contamination in freshwater fish of India, especially in the north-eastern states. This review will also report on the spatial distribution of MP pollution across India freshwater habitats, microplastics types, and their origins in fish, as well as ecological and health risks. The study recovered intends to best understand the importance of fresh water fishes as bio indicators of micro plastics and their consequences towards the environment as well as public health. Thus, through a review of the current literature and analysis of gaps in knowledge, this paper will argue the observed trend for continuation of research on distribution, abundance and impact of microplastics on freshwater fish in India, especially in the underserved regions such as north-eastern region.

Microplastics in Aquatic Ecosystems

Freshwater ecosystems are under growing threat of microplastic pollution all over the world. Studies has evidenced that microplastic is nearly universal in aquatic ecosystems, including mountain lakes and heavily polluted rivers (Vivekanand *et al.,* 2021). A research done by the UN's environmental wing, UNEP in 2020 showed that freshwater systems which include the rivers, lakes or reservoirs are at a higher risk of suffering from microplastic pollution as a result of actions including dumping of wastes, industrial discharges or urban storm water runoff (Rossatto *et al.,* 2023) [38]. According to researchers, millions of tons of microplastic water get into the freshwater bodies every year whereby 267 thousand tons originate from cities or agricultural regions.

On the basis of its centrality of the food web and its relative vulnerability to contamination, the perhap s the most sensitive and wide- ranging group of indicator organisms is the freshwater fish. Their ability to ingest microplastics either by drinking polluted water or through consuming prey species offers research vital information about the levels of pollution and the possible impacts of the contaminants on water residents (Xu *et al.,* 2020). Research conducted and documented has established that microplastics are not only ingested by fish but are deposited in the tissues of those fish and may sometimes impact their eating habits and growth, ability to reproduce, and general health of such fish in a negative way (Zhou *et al.,* 2020) [50]. Moreover, fish transports microplastics from one trophic level to another and can eventually reach humans, which requires extensive assessment of their pollution of freshwater environments (Tursi *et al.,* 2022) [43].

India hosts a diverse fauna habitat consisting of numerous waterborne habitats that are significant for India's biosphere, food crop production and human lives (Priyasdarshani *et al.,* 2024) [35]. Some of these ecosystems are; the Ganges and Yamuna rivers, the Brahmaputra and Godavari rivers, scores of lakes, wetlands and reservoirs (Gupta *et al.,* 2024) [14]. The Ganges for example is one of the large Central River System in India and it supports of millions of people for water, food and agricultural requirements. Still, freshwater ecosystems of the India are under pressure from the pollution from industrial and domestic sources (Neelavannan *et al.,* 2023) [30]. Nowadays, microplastic was found at increasing rate in the Indian freshwater systems and many researchers are using different techniques to detect microplastics in water, sediment samples and fish (Singh *et al.,* 2024) [41].

Recent studies on the microplastic pollution has revealed that India's water bodies are also affected and traces of microplastics have been detected in the Ganges-Yamuna belt and a host of other rivers, lakes and ponds. The identification of microplastics in these water bodies shows how grave the problem is, and has implications on water inhabitants such as fish. Works also state that microplastic pollution exists not only in the water but in the sediment and the biota – fish, which may indicate a trophic transport of microplastics in the water. For instance, the north-eastern area of India, which possesses diverse bio-diversity potential and consists of some categories of threatened fish species, has sparse documented data on microplastic pollution. Due to many factors, this region's ecosystems are under pressure from pollution resulting from urbanization, industrialization, and extensive agricultural activities.

Geographic Distribution of Microplastics in Indian Freshwater Bodies

Reports on microplastic pollution of freshwater ecosystems in India established high microplastic loads in some of the most important rivers, lakes, and wetlands in the country. Of these the rivers most impacted are the Ganges along with its branches such as the Yamuna River (Singh *et al.,* 2024) [41]. These are not only the cardiovascular systems of millions of people culturally and economically but are now widely polluted by industrial, agricultural, and domestic waste. A cross-sectional study in the Ganges River basin identified the microplastics density of up to 2.5 microplastics per litre in some stretches with the maximal denseness detected near the cities' and industries' regions (Kumar *et al.,* 2021). Likewise, water samples from the Yamuna River that discharges through the National Capital Region of Delhi also contained detectable microplastics. The prospects of microplastic pollution of the Yamuna are worrying: concentrations as high as 4 microplastic particles per litre were found in water samples taken from industrialized areas (Vaid *et al.,* 2022) [45]. Research also reveals that microplastic is detected in the sediment analysis of the river, which indicate that it may take a relatively long time for such particles to be deposited in the riverbed.

Godavari and Mahanadi which are two other major rivers in India are also experiencing increasing Microplastic presence at 1.2 – 3.8 microplastics per liter in water (Gupta *et al.,* 2024) [14]. Similar to the large rivers of India, microplastic pollution has also been detected in some of the largest lakes and wetlands in the country, including Chilika in Odisha and Vembanad in Kerala. Microplastic concentrations were up to 1.6 microplastics per litre in Chilika Lake, validated Ramsar Wetland of International Importance, with a tall branch in the shallow regions that witness maximum anthropogenic interference (Laju *et al.,* 2022) [20].

There is still a dearth of research regarding microplastic pollution especially in the north-eastern part of India and mainly the Brahmaputra River. Nevertheless, since the river has recently experienced deforestation, urbanization and agriculture practices, it is expected that microplastics are also found in this zone. Given these circumstances, there is considerable and alarming latitude for microplastic pollution to grow, as urbanization expands and waste management improves poorly in this a region. The sources of microplastic pollution in the regions are mainly located around urban centers, industrialized and Agricultural zones. Delhi, Kolkata, Chennai and Mumbai posing major threats are located alongside some of the major river systems that are reasons high plastic consumption and bad waste disposal systems. This problem has been worsened by the prevailing high rates of urbanization, rudimentary waste management systems across the minor towns and rural areas of India.

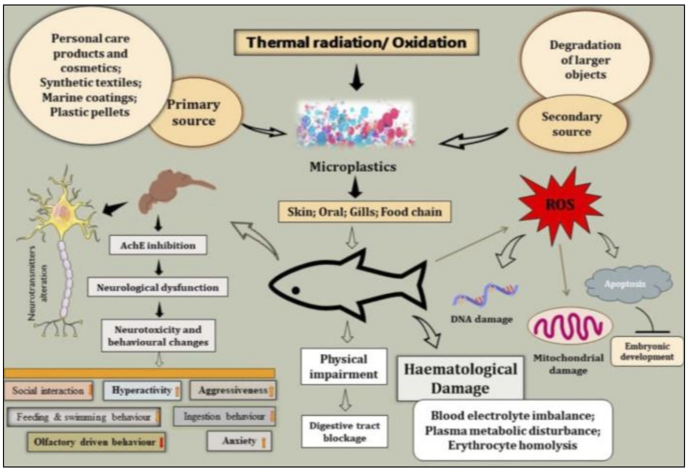
Microplastics in Freshwater Fish Populations

The emergence of microplastics in freshwater fish populations is the problem in environmental science which has many open questions not only about the influence on aquatic life but also about potential dangers for peoples' health at the consumption of mainly affected fish species. Plastic microscopic components, which are particles that are smaller than 5mm are known as microplastics and the have been identified in different water dwelling animals and Fishes inclusive which can affect the creature and their social surrounding. The prevalence of MPs in fresh water fish stocks and more so in Indian water bodies is under rising research consideration especially given the growing rate of industries, urban centers and agriculture inputs affecting India's freshwater systems (Parvin *et al.,* 2014; Li *et al.*, 2020) [22, 33].

Types and Concentration of Microplastics Found in Fish

In composition, size, shape, and polymer, the gaps are identified among the types of microplastics in freshwater fish. Fibers are the most recognized type of microplastic particles present in fish followed by fragmentation and beads (Gola *et al.,* 2021) [13]. Of the microplastics which were identified among the fish from Ganges and Yamuna, more than 60 percent were identified as fibers and of these, identifiable sources included synthetic fabrics such as polyester and nylon (Gupta *et al.,* 2024) [14]. Second in abundance were fragments or particles that may have come from the degradation of larger plastic debris such as bottles, bags, and containers, comprising of around 30 per cent of the identified microplastics. This study found that microbeads, some of which are used in vigorous washing creams, accounted for just 5% of the microplastics identified in fish (Verma *et al.*, 2022) [46].

In a view of polymer type, some authors have reported different synthetic materials, among which polyester, polyethylene, polypropylene, nylon is found frequently in freshwater fish from India. Especially blamed fibers are polyester and nylon since it is proven that fibers of these types remain floating on water for very long periods of time and can be traced to clothes and textiles. Plasticizers including polyethylene and polypropylene identified in packaging materials and plastic containers were also other frequently identified in the fish from the urban river system. The degree of polymer was detected suggesting that plastics are present in both the urban and rural water systems (Rodrigues *et al.,* 2019) [37]. Microplastics accumulation in fish tissues is influenced by species, water quality, and local pollution level. It was reported in fish muscles from the Ganges River, it varied from 1.5 to 3.5 microplastic particles per gram of the tissue (Mishra *et al.*, 2023) [27]. The highest levels were recorded in those fish species that subsist on detritus and rugs of bass boats and live on the sea bed like *Heteropneustes fossilis* and *Catla catla*. On the other hand, the concentration in surface-feeding species was comparatively less, 1-2 parts per gram for *Channa punctata*. Fish gills and digestive systems also had higher microplastic content than muscles, with both fragments and fibers dominating the samples. This indicates that gills may have a huge implication in the absorption of microplastics, perhaps because they filter particles from water (Nithin *et al.,* 2022) [32]. Another study on fish in the Bhakra Nangal Reservoir showed microplastics in fish ranging from 0.33 to 5 P/G of fish tissue and was dependent on fish habitat and species. This study also identified the fact that larger fish and fish species at higher trophic level had higher density of microplastics deposits due to bioaccumulation as these fish feed on other organisms and micro plastics are deposited in the organisms and passed along the food chain (Cao *et al.*, 2023) [5].



(**Source:** Hassan *et al.*, 2023)

Fig 1: Different toxic effects of MPs in fishes

Behavioural Effects in Fishes Due to Microplastics

The effect of MPs on fish behaviour is of significant concern as it impedes their normal function in natural habitats (Table 1).

Table 1: Effect of microplastic on behaviour of fish

Species	Developmental stage	Exposure duration	MPs types	MPs sizes	Concentration	Behavioral effects	Possible causes	References
Common goby (*Pomatoschistus microps*)	Juvenile	96 hours	PE	420–500 µm	-	Confusion with prey. Predatory efficiency performance decreased.	Developmental factors may affect fish prey	(Cunningham *et al.*, 2021) [8]
Gilt-head bream (*Sparus aurata*)	Juvenile	21 days	PE	100–500 µm	4.52 ± 2.30, 4.06 ± 1.52, and 4.05 ± 1.58 % diet	More assertive in social interactions. Low feeding	Activation of antioxidant enzymes. Elevated SOD and CAT activity. Lipid peroxidation	(Rios-Fuster *et al*., 2021) [36]
Zebrafish (*Danio rerio*)	Adult		PE	247.5 µm	0.5–9.4 %	Showed spitting behaviour. Ingestion behaviour changes by various fopod volumes.	-	(Mitchell *et al.*, 2020) [28]
Zebrafish (*Danio rerio*)	Adult	20 days	PE and PS	90 and 25 µm	90 % and 10 %	Altered locomotion activity	Up-regulation of the circadian clock gene nr1d4b in liver transcripts.	(Limonta *et al.* 2019)
Spiny chromis (*Acanthochromis polyacanthus*)	Juvenile	6 weeks	PET	2 mm	0.055–0.16 mg/L	No significant egffect in behaviour	Lower number of plastics found in the gastrointestinal tract.	(Critchell and Hoogenboom, 2018)
Crucian carp (*Carassius carassius*)			PS	24–27 nm	9.3 × 1012 particles/mL	Impacts feeding and shoaling. Reduced activity, longer periods of feeding, closer together, and less explorative.	Effect on metabolism.	(Mattsson *et al.*, 2015)
Goldfish (*Carassius auratus*)	Juvenile	28 days	PS	500 nm and 30 µm	25 mg/mL	Olfactory responses to L-cysteine and taurocholic acid significantly impaired.	Hampered odour detection, action potential production, transmission of olfactory brain signals, and information processing. Suppression of GFA2, GFA28, GFB1, and GFB8 genes.	(Shi *et al.*, 2021) [40]
Jacopever (*Sebastes schlegelii*)	Juvenile	14 days	PS	15 µm	1 × 106 microspheres/L	Reduced feeding and increased shoaling. Decreased swimming and exploration ability.	Stimulates digestion and the gut and reduces food intake due to changes in appetite and behaviour. Respiratory stress and lesions. Change in ion regulation and oxygen consumption	(Yin *et al.*, 2018) [47]

Hyperactivity and Hypoactivity Locomotion in Fishes Due to Microplastics

Fish movement patterns are an important measure of their capacity to deploy energy for specific processes and functions such as feeding, migration and predator avoidance (Domenici *et al.,* 2007; Langova *et al.,* 2023) [10, 21]. It was also noted that MPs can affect fish motility under some circumstances. For example, 7-day adult zebra fish exposed to PS-MPs (5 µm) at concentrations from 0.001 to 20 mg/L (or 14.5–2.9 × 10 particles/ml) were hyperactive, swam more distances, and were active more often (Chen *et al.,* 2020). In their study the increased activity was correlated with decrease glucose and acetaldehyde concentration and increased amino acid concentration in the liver indicating energy failure. But, the change in the level of MPs seems to cause variable effects on locomotor activity, disparities of which are reported by some studies could be due to several exposures duration, particle sizes, uptake and type of MPs. For example, when 5-day-old zebra fish larvae were exposed to 50 nm polystyrene nanoparticles reduced activity level was observed (Browne *et al.,* 2008). A little less is known about the behavioural changes which occur due to MP exposure in fish according to other studies, there have been changes in fish behaviour based on MP exposure. Im *et al.* (2022) [18], they found that early postnatal PS-MPs for only 10 days caused hyperactivity in adulthood together with changes of related genes including oxidative stress genes (nrf2a and sod2), nervous system genes (nrbf2, slc6a4b, and npy) in zebra fish. In a similar vein, Yu *et al.* (2022) [48] reported that adult zebra fish shown hyperactivity and related to altered cholinergic system and dopamine and serotonin (5-HT) levels in the brain after exposure to waterborne (40–47 µm, 0.1–10 mg/L) and foodborne (0.01±0.01 µg/mg; 0.1±0.1 particles/m.

Aggressive Behaviour in Fishes Due to Microplastics

As for animals, aggression can be defined as a complex of behaviors directed towards other animals or objects: conspecifics. MPs can modulate aggression in various ways. For instance, Hollerova *et al.* (2023) [17] feed PS-MPs to the rainbow trout (*Oncorhynchus mykiss*) for six weeks and obtain varying amounts of MPs – 0.5 %, 2%, 5%. If only exposure lead to increased aggression and activity in a similar manner as it defined in learning theory. Although direct contacts between an MP and an organism may trigger actual physiological or neurological alterations that influence behaviour, other influences such as a decreased appetite or altered blood content may also be important. Moreover, aggression can be triggered by stressors other than MPs, such as infections or pathogens, which can cause skin damage and alter behaviour and hunger responses, as observed in rainbow trout (Martins *et al*., 2012) [25].

Feeding and Swimming Behaviour

Consuming foods determine the nutrient intake in organisms which is required in growth and development and for exercise of other biological processes. There is speculation that fish take in plastics in a way that they feed on prey in tests carried out in laboratories. Several works have reported the ingestion of plastics by fish (da Costa Araújo; Markic *et al.*, 2020) [1, 24]. Feeding behavior is significant since chemical additives in MPs could interfere since feeding behaviors are a critical component in an organism's lifetime. For instance, zebra fish feed on particles (from 0.5% of 247.5 µm particles to 9.4 %) when mixed with food (Kim *et al.,* 2019). On the other hand, when zebra fish feed on MPs, they tend to eject them, and this suggest that they can distinguish MPs from food. This raises an interesting question of whether such fish may decide to take MPs rather than food leading to starvation. While there are a lot of concerns regarding the actual increase of MPs being uncontrolled and unintentional, it has to be said that the notion of intentional uptake cannot be ruled out absolutely.

It is established that during the hunt, zebra fish possess excellent vision, and demonstrate very flexible body movements. When presented with food or MPs, they had enhanced spinning behaviours to reveal possible attempts to ingest the MPs. If the amount of food provided is altered in relation to MPs, it was possible to demonstrate that zebra fish differentiate between them (Kim *et al.,* 2019). They were able to reject MPs when exposed to 20 mg of it; this was shown by an increase in spitting behavior, a reflex action normally associated within non-food items. Another work by McCormick *et al.* (2020) [26] documented polystyrene Consumption by larval Ambon damselfish (*Pomacentrus amboinensis*). Of the fish, 85% have had absorbed the plastic spheres within their stomachs and the quantity varied between one to thirty three particles within a fish averaging 4.5 spheres in the stomach. They can also affect other feeding behaviours Choices of feeding sites and the timing of feeding also undergo changes due to MPs. Yin *et al.* (2018) [47] tested the effects of polystyrene MPs on the jacopever (*Sebastes schlegelii*) and revealed that the fish altered their activity under the condition when they were exposed to 1million MPs per litre of water; their energy and fat content also decreased. In particular, perpetual and MPs exposure prolonged periods of foraging time, implying a suppressive impact on feeding. Besides, fish experienced decline in their swimming and movement ability, and this make them easily caught by predators. Results of the studies also pointed to negative impacts on foraging and curiosity as seen where fish exposed to MPs lacked the desire to move round. These kinds of behavioural changes could be attributed to either an increase in water content of the brain, or breakdown of the larger MPs to particles which can affect organs, the Oxidative stress or gastrointestinal stimulation which in turn may affect digestion and food intake (Yin *et al.,* 2018) [47].

Neurotoxicity in Fishes Due to Microplastics

MPs can affect the enzymes important for development of nerves and bring about lipid peroxidation in fish. MPs have been proved to decrease the levels of several neurotransmitters such as dopamine, gabba-M, melatonin, vasopressin, serotonin, oxytocin, naamk and kisspeptin. AChE is one of the most influential enzymes with the respect of the presented issue as being responsible for the neuromuscular activity and widely used in toxicity testing. AChE plays the role of an enzyme that degrades acetylcholine, which is critical for synaptic transmission of neurotransmitters and normal neuromuscular communication (Barboza *et al.,* 2018b; Hamed *et al.,* 2024c) [3, 15]. MPs have neurotoxic impacts as evidenced by lowered levels of AChE activity and increased levels of lipid peroxidation in the brain. For instance, in European seabass it has been proven that MPs causes decrease in AChE activity and this is toxic to neurons (Barboza *et al.,* 2018b) [3]. In Nile tilapia (*Oreochromis niloticus*), MPs reduced the AChE activity at the level of 1, 10, and 100 μg/L in 14 days, and it has been reported that a reduction in AChE activity is related to the disturbance of other biochemical activities and neurotoxicity. The build up of ACh in the synapse because of AChE inhibition sharply decreases the activity of AChE in the brain which creates neurotoxicity (Hamed *et al.,* 2022b) [16]. Reduced AChE activity is one of the ways that MPs may cause neurotoxicity and subsequently motor deficits. This disruption of an action potential signals may lead to weakness in muscles as well as shaking and poor coordination (Chen *et al.,* 2017) [6]. Several researchers have demonstrated that AChE is depleted different species of fish treated with MPs include *Cyprinus carpio* (L.) or common carp (Banaee *et al.,* 2019) [2] and zebra fish (Chen *et al.,* 2017; Umamaheswari *et al.,* 2021) [6, 44]. Such results indicate that MPs exposure results in AChE inhibition, thereby affecting neurotransmission and behavior and motor coordination.

Immunotoxicity in Fishes Due to Microplastics

Fish possess an innate immune response that supports the adaptive immune system, helping defend against foreign toxins (Kim *et al*., 2023) [19]. However, MPs exposure can disrupt this defense mechanism. For example, Choi *et al.* (2023) found that exposure to polyamide (PA) MPs at concentrations of 0, 4, 8, 16, 32, and 64 mg/L over a 2-week period in crucian carp led to decreased levels of immunoglobulin M (IgM). In addition to immunoglobulins, lysozymes are crucial components of the innate immune system in fish, responsible for breaking down bacterial cell walls by cleaving the peptidoglycan layers. MPs exposure has been shown to affect lysozyme activity in fish. Zhang *et al.* (2022) [49] reported alterations in lysozyme levels in fish exposed to MPs, while Hamed *et al.* (2022b) [16] noted a decrease in lysozyme activity in common carp exposed to 100 mg/L of polyethylene (PE) MPs for 15 days. Interestingly, during the same period, the activity of myeloperoxidase (MPO), another immune enzyme, increased significantly in these fish. Fish possess an innate immune response that supports the adaptive immune system, helping defend against foreign toxins (Kim and Kang, 2016). However, MPs exposure can disrupt this defense mechanism. For example, Choi *et al.* (2023) found that exposure to polyamide (PA) MPs at concentrations of 0, 4, 8, 16, 32, and 64 mg/L over a 2-week period in crucian carp led to decreased levels of immunoglobulin M (IgM). In addition to immunoglobulins, lysozymes are crucial components of the innate immune system in fish, responsible for breaking down bacterial cell walls by cleaving the peptidoglycan layers. MPs exposure has been shown to affect lysozyme activity in fish. Zhang *et al.* (2022) [49] reported alterations in lysozyme levels in fish exposed to MPs, while Hamed *et al.* (2022b) [16] noted a decrease in lysozyme activity in common carp exposed to 100 mg/L of polyethylene (PE) MPs for 15 days. Interestingly, during the same period, the activity of myeloperoxidase (MPO), another immune enzyme, increased significantly in these fish.

Reproductive and Developmental Effects of MPs in Fishes

Reproductive systems act through hormones in all vertebrates including fish using hypothalamic-pituitary-gonadal (HPG) and hypothalamic-pituitary-renal (HPR) systems (Faheem & Bhandari, 2021) [12]. These systems, especially the hypothalamus – pituitary – gonads – liver (HPG-L) play control a number of important functions including gonadal development, gametogenesis, formation of yolk in eggs, synthesis of steroid hormones, and in sex transformation in fish (Borella *et al.,* 2020) [4]. GnRH is produced by the hypothalamus, which stimulates the anterior lobe of the pituitary gland to release FSH and LH hormones that stimulate gonads to synthesise the dominant sex steroids: 17β-estradiol and 11-ketotestosterone in the process of receptor binding (Hachfi *et al.,* 2012). Nevertheless, MPs have a tendency to leak out contaminants from water and thus, when ingested by fish affect its endocrine system changing hormone levels, and influencing reproduction (Hamed *et al.,* 2020; Sayed *et al.,* 2021) [39]. MPs are widely accepted as carriers of EDCs that can impact reproductive function by engaging the sex hormone receptors (Celino-Brady *et al.,* 2021). MPs poses effects on sexual maturation and gonadal development and spawning season in fish besides affecting fecundity, Gonadosomatic index, fertilization ability, and gamete quality (Zhang *et al.,* 2021). Likely, the detrimental effects of many of the identified MPs and other environmental pollutants on male and female reproductive health are accumulated over long periods of exposure. For instance, indications of the histological alteration in gonads of zebra fish after 21 days of exposure to 100 μg/L of polystyrene (PS) MPs include a thin testis basement membrane which they attributed to elevated ROS generation (Qiang & Cheng, 2021). In a like manner, early adjusted exposure to polyethylene (PE) MPs at 50 mg/L affected the hatching rates of zebrafish by bringing teratogenic abnormalities in the advancement of embryos.

Reducing Microplastic Pollution in Freshwater Systems

One of the best strategies to control microplastics pollution is to control their entry into freshwater bodies. This is matters a great deal through implementing laws and regulations through the policymakers in a bid to reduce usage and emissions of plastics. One measure still under advocacy in India is the complete ban on single-use plastics. The Indian government has already initiated very important measures which include the Plastic Waste Management Rules (2016) that control the use, disposal and consumption of plastics. However, further actions are required to protect against microplastics – material that is derived from the decomposition of larger plastics.

Tight measures of regulating should employ the necessary laws and factors towards the control of plastic waste especially through recycle information and control of plastic packaged goods in urban and rural areas. The findings show that rivers including the Ganges and the Yamuna annually transfer large volumes of plastic waste many of which in form microplastics on degrading. A report of CPCB published in December 2021 has revealed that the rate of plastic waste in India's river has increased up to 30% in the last 10 years mainly because the current unorganized system of waste management and collection. Improvement of sorting and recycling at source and the overall increase of recycling levels would reduce considerably the introduction of plastics and microplastics into rivers and thus diminish the concentrations of microplastics in the freshwaters. Thus, the further development of the policy is needed, and enhancing of the waste management systems at the local level plays a significant role. Graded with the fastest rate of urbanization in the country, plastic waste problem in India has compounded. Development or improvement of structures to allow proper collection and elimination of wastes especially in the developing world countryside and small towns are recommended to help curb microplastic pollution. One on one, developing large depots for recycling and accelerating the use of sustainable materials for packing by firms can allay the problem of excessive use of plastics. Also efforts to involve and empower communities, local leaders, civil society organisations such as non-governmental organisations in the removal and management of wastes, particularly plastics should be promoted to reduce dumping in freshwater sources.

Apart from this, one of the most important strategies is to increase people's awareness on the dangers of plastic material to the environment and their health. These microplastics are especially dangerous but many communities in India have no clue on the harm they can cause. The public health phenomena associated with the adverse effects of microplastic pollution to water bodies and the food chain make people change their behavior and reduce their use of plastics. These campaigns could also inform people of such products such as biodegradable packaging material and at the same time could call for change on behavior such as carrying our own bags and containers. Further, regarding the promotion of changes in attitude and behaviour among the public it is stated that, education campaigns in schools and colleges will create awareness and bring permanent changes to them against the use of plastics.

Conclusion

The current literature review focused on assessing the increasing concern of microplastic pollution in freshwater fish in India; abundance, distribution, key drivers in spreading microplastics in water bodies. The review also pointed out that microplastics are now present in freshwater, though their levels are differing between geographically defined regions as well as species. Costa *et al.* explained that the Ganges, Yamuna, and Brahmaputra rivers, and many lakes and wetlands, contain considerable amounts of microplastics, which originate from street and industrial effluents, as well as agricultural operations. Some of the identified Fish species in the mentioned water bodies COM which are *Labeo rohita* (rohu) and *Catla catla* (catla) information suggested that commercial and small fish have ingested micro plastics, the micro particles include fibers, fragments and beads in stomach, gills and muscles among others. The microplastics were detected in the freshwater fishes which agree with the overall microplastic pollution trends identified in Indian rivers. Microplastic density differed across tissues where contamination was significantly higher in the intestinal and gill tissues. This shows that the fish found in places of high plastic pollution or those that feed on other organisms that have ingested more plastics are more likely to intake microplastics. Furthermore, another work showed that fish diet, habitat, and feeding behaviour directly influence microplastic consumption. Fish from areas with more anthropogenic impact or consuming detrus or plankton as their prey, in which microplastic particles have a higher probability of being present, had a higher HMC than those species from less affected zones.

The ingestion of microplastics was also illustrated in this paper to have physiological, ecological and health effects on freshwater fishes including damages to the fish's digestive systems, growth delays and compromised reproductive systems. The occurrence of microplastics in the food web is, therefore, a worry not only to fish stocks but also the whole the ecosystem and humans. Despite this controversy, the available evidence also points to the fact that needs for effective urgent actions to mitigate microplastics pollution in freshwater ecosystems.

Conflict of interest

Authors declare there is no conflict of interest.

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