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Microplastic Impact on Fish Physiology and Ecosystem: *A Review*

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ABSTRACT

Microplastics in aquatic ecosystem has a cumulative effect on the environment, especially fish population, which is directly associated with human health. The impact on fish health differs among the neurological, digestive, and immune systems, as well as behavioral, circulatory, and antioxidant defense systems. This study aims to review previously published studies about the correlation between microplastics and physiological alteration in fish.

تأثير الجسيمات البلاستيكية الدقيقة على فسلجه الأسماك والنظام البيئي: مراجعة شاملة

سهاد حمزه محمد علي   علي كامل وناس   هند ضياء هادي

تُحدث الجسيمات البلاستيكية الدقيقة الموجودة في النظم المائية تأثيرًا تراكميًّا على البيئة، ولا سيما على أعداد الأسماك، وهو ما يرتبط ارتباطًا مباشرًا بصحة الإنسان. ويتنوع تأثيرها على صحة الأسماك بين الجهاز العصبي والجهاز الهضمي والجهاز المناعي، فضلاً عن السلوك والجهاز الدوري وأنظمة الدفاع المضادة للأكسدة. وتهدف هذه الدراسة إلى استعراض الدراسات التي نُشرت سابقًا حول العلاقة بين الجسيمات البلاستيكية الدقيقة والتغيرات الفسيولوجية في الأسماك.

INTRODUCTION

Microplastics (MPs) are plastic Molecules larger than 5 mm that are generated from wide range of causes including decomposition of plastic trash, synthetic textiles besides manufacturing, it is characterized by chemical stability, low decomposition frequency, and ubiquitous dispersion within aquatic environments (Jovanović, 2017; Banaee *et al*., 2024).
Plastic spread over the ecosystem can readily enter into bodies of water, the latest survey from 2020 even states that plastic garbage flows into the ocean at a pace of about eleven million tons every year (PEW, 2022). MPs and Nano plastics (NPs) are global and found extensively in the air (Abbasi *et al*., 2019), land (Guo *et al*., 2020), ocean (Wang *et al*., 2020), rivers (Han *et al*., 2020) as well as in the bottom sedimentary layers of polarized freshwater bodies (González-Pleiter *et al*., 2020). MPs and NPs could be found in several compartments of the environment and affect a healthy environment (Wang *et al*., 2021). MPs from earth-based and airborne sources created by primary or secondary release pathways enter aquatic environments via numerous routes, depending if they were created at that size or broken apart from larger debris (Andrady, 2011; Mo, 2026).The fact that MPs are in aquatic ecosystem poses a particular threat to fish by means of direct ingestion and habitat transmission, which may result in imbalances in the ecosystem and carriage a risk to the health of fish in addition humans by eating seafood (Fred-Ahmadu *et al*., 2024; Wannas and Mohammed, 2025).

In fish, MPs are primarily swallowed, and it is hypothesized that the ingested particles linger in the digestive tract, translocate to other organs and are eventually expelled (Fossi *et al*., 2018). Moreover, MPs tended to adhere to fish skin and migrate to other organs for example liver, gills in addition muscles (Su *et al*., 2019). Wright and Kelly (2017) showed that tiny plastic fragments can cross via cell membranes as well passage through the circulatory system otherwise lymphatic channels, indicating that microplastics might be distributed across the body of the fish.

The objective of this study is to review previous research on the impact of plastics and their risks to fish and the aquatic ecosystem.

CATEGORIES OF MICROPLASTICS

Microplastics are usually grouped into categories (Figure 1):

1. Original-Based

• Primary Sources (micro-sized made)

Include personal care products: Microbeads in facial cleansers, toothpaste and cosmetics slip by filters utilized for wastewater treatment. Industrial pellets, also known as nurdles, are resin pellets used to make plastic. They are often released accidentally into bodies of water by leakage during shipping or handling. Abrasives: The microplastics used in the sandblasting process to eliminate paint and rust from ship hulls and surfaces are released directly into marine ecosystems (Chaukura *et al.*, 2021).

• Secondary Sources (Broken down of larger plastics)

Synthetic Textiles: Polyester or nylon clothing release thousands of Fibers per wash and are regularly found in freshwater and marine sediments. Vehicle tire wear leads to mechanical abrasion of the tires and produces particles that are transferred by urban runoff to rivers and coastal oceans. Plastic bags, bottles and packaging degrade under the effect of UV radiation, wave action and oxidation, resulting in irregular fragments. Maritime and fishing activities – Fishing gear (nets, ropes) that is abandoned, lost or discarded (ALDFG) provides Fibers and pieces to the oceans. (Andrady, 2011; Chaukura *et al*., 2021; Cverenkárová *et al*., 2021).

2. Shaped-Based

Microplastics are frequently described in terms of their morphology, which provides an idea of their environmental origin and fate. Researchers generally recognize five major forms: Fibers, pieces, films, beads/pellets and foams. Fibers are threadlike particles, often from synthetic Fibers and fishing lines. Brocken fragments are abnormally shaped that are formed by breakage of large sized plastic products such as bottles or packaging. Films are thin, flat sheets from plastic bags and wrappers. Beads or pellets are round particles, often produced as cosmetic microbeads or industrial nurdles. Foams are porous, lightweight materials, like polystyrene packaging (Hidalgo-Ruz *et al*., 2012).

3. Polymer Type-Based

Microplastics are divided into groups based on their chemical composition, distribution, and industrial use into Polyolefins which include, polyethylene (PE) in bags and bottles, polypropylene (PP) in packaging and textiles. High Density Polymers including, polystyrene (PS) in foams and disposable cutlery, polyvinyl chloride (PVC) in pipes and construction materials, and polyethylene terephthalate (PET) in beverage bottles and fabrics (Hidalgo-Ruz *et al*., 2012; Subaramaniyam *et al*., 2023) as shown in table (1).

The presence of MPs is depending on their densities (Li *et al*., 2020). PE as well PP are found generally at the upper portion of the ocean because of their lower densities, whereas PVC and PET are vertical mixed in the water column (Song *et al*., 2018). The most prevalent MPs are PE, PET, PP, and PVC, which making up 29.1%, 20%, 18%, and 15.3% of worldwide plastics, respectively (Nkwachukwu *et al*., 2013). PP and PE are the most abundant MPs in environments, PP is frequently detected at high level in water bodies, in contrast PE is comparatively high in soils and sediments (Koutnik *et al*., 2021; Orona-Návar *et al*., 2022; Xi *et al*., 2022). PE and PET are the most frequent MPs found in the air (Wang *et al*., 2021a).

Table (1): Classification of MPs Polymers

Polymer Type	Common Abbreviation	Typical Sources	Environmental Fate
Polyethylene	PE	Packaging, plastic bags, microbeads	Low density; floats in surface waters.
Polypropylene	PP	Textiles, ropes, food containers	Low density; floats in surface waters.
Polystyrene	PS	Foam packaging, food containers	Variable; often found as foam or beads.
Polyvinyl Chloride	PVC	Building materials, pipes	High density; sinks to benthic sediments.
polyethylene Terephthalate	PET	beverage bottles and fabrics	High density; sinks to benthic sediments.

4. Size-Based

Microplastics are classed by size, an important characteristic that affects their environmental movement, bioavailability and toxicity. In a study, Hartmann *et al*. (2019), demonstrated that the commonly accepted definition describe microplastics as particles ranging from 1 µm and 5 mm, besides the smaller in size pieces are called Nano plastics with a size less than 1 µm, as a new developing category of concern since they can penetrate biological membranes and accumulate inside cells, mesoblastic between 5 to 25 mm and macro plastics more than 25 mm, that degrade by time via physical, chemical as well biological mechanisms into microplastics.

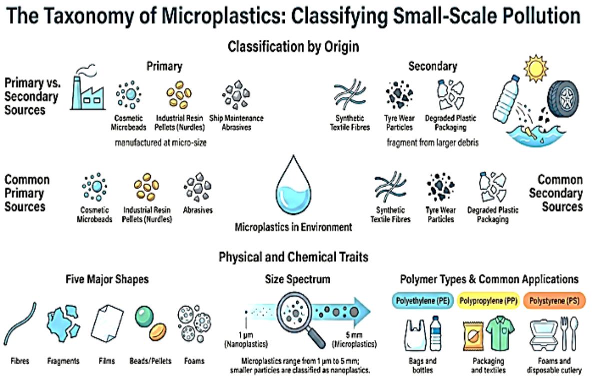

Fig. (1): Categories of Microplastics (Generated by Notebook LM

THE MAIN PATHWAYS OF MICROPLASTICS TO ECOSYSTEMS

Microplastics enter ecosystems through multiple pathways (Figure 2), firstly, wastewater and sewage, where microbeads in cosmetics as well as fibres in synthetic fabrics undergo filtration processes at wastewater treatment plants and are then released straight into rivers and coastal waterways (Roy *et al*., 2022).

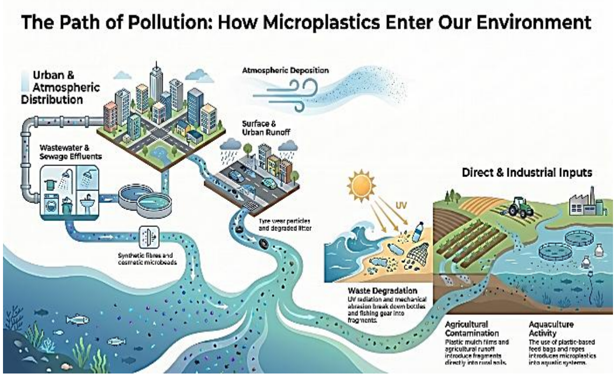

Fig. (2): Pollution Pathway of Microplastics to Ecosystems (Generated by Notebook LM)

Secondly, surface runoff and urban stormwater in which Rain and runoff from agricultural areas wash tire wear and decomposing plastic waste particles into streams and lakes (Hartmann *et al*., 2019). Thirdly, atmospheric deposition microplastics generated by textiles and industrial emissions are transported by wind and deposited in terrestrial and aquatic ecosystems, Detected even in distant areas such as the Arctic (Roy *et al*., 2022). Fourthly, direct littering and mismanaged waste, under the influence of ultraviolet radiation and mechanical wear, plastic bags, bottles and packaging containers are destroyed, their fragments leaching into the soil and water. Fishing equipment additionally contributes greatly to the contamination of marine ecosystems with microplastics (Hidalgo-Ruz *et al*., 2012). Finaly, aquaculture and agricultural inputs, plastic bags for feed, ropes and aquaculture equipment contribute directly to the introduction of microplastics into aquatic systems. Plastic mulch used in agriculture also degrades and disperses into the land and water bodies (Roy *et al*., 2022).

INTERACTION BETWEEN MPS AND ENVIRONMENTAL STRESSOR

The damage from plastics is cumulative, and exacerbated by environmental stressors like lack of oxygen, this causes physiological damage such as reduced immune function and oxidative stress. Fish larvae and juveniles are potentially especially vulnerable to the added stress of low oxygen conditions when they eat microplastics because of their high metabolic rates and undeveloped defensive barriers (Mathew *et al*., 2024; Hu *et al*., 2022; Kaundal and Singh 2025).

Airborne MPs and NPs absorb light and aid in atmospheric warming and could act as 'short-lived climatic forcers' like black carbon (Liu *et al*., 2026). Climate change has resulted in increased UV radiation and harsh weather events, which facilitate the decomposition of bigger plastics into microplastics and their subsequent dissemination within ecosystems (Barletta, 2026; Liu *et al*., 2026). Popular MPs, especially polyolefins, have a strong potential to adsorb hydrophobic organic pollutants such as polycyclic aromatic hydrocarbons (PAHs) (Agboola and Benson, 2021). Spread of MPs influenced by numerous water factors such as temperature, nutrition concentration, suspended components (Ratnasari *et al*., 2024). Temperature and humidity affect the deterioration of microplastics and their transformation into polymers (Pfohl *et al*., 2025), the heat produced via the sun results in methane emissions because of the breakdown of MPs, further leading to the release of greenhouse gases (GHGs) in the atmosphere along with raising the global temperature (Ratnasari *et al*., 2024).The acidification of the oceans is mainly caused by the uptake of atmospheric carbon dioxide, leading to considerable changes in the chemical environment of the marine ecosystem.

This shift in seawater pH alters the surface features of MPs in addition how they interact with contaminants such as heavy metals as well organic compounds (Liu *et al*., 2021; Zhao *et al*., 2022). The interaction of MPs with environmental stresses normally impacts four major biological domains: Growth is substantially negatively impacted; energy is diverted to stress restoration. Reproduction, increased sensitivity Colony size and form decreased. Raised formation of reactive oxygen species (ROS) can cause oxidative stress and DNA damage. Sublethal effects are important, although the combination of stressors does not always lead to a large increase in immediate death than stressors alone (Wang *et al*., 2021b).

MICROPLASTIC AS A CARRIER FOR POLLUTANTS

MPs are now more commonly seen as mobile vectors of pollutants in water-based ecosystems than as inert plastic particles (Gateuille and Naffrechoux, 2022). Their tiny size, high specialized surface region and hydrophobic surfaces allow it to adsorb a broad spectrum of pollutants which include heavy metals, pesticides, pharmaceuticals alongside persistent organic compounds via conventional processes such as hydrophobic partitioning, π–π stacking, hydrogen bonding, electrostatic attraction and van der Waals interactions (Jiang *et al*., 2021). MPs have tiny particle diameters, poor photodegradability, and serve as effective transporters of contaminants. They can absorb, carry, and discharge contaminants in aquatic environments, generating complex binary pollutants by physicochemical reactions (Mousazadehgavan, 2026; Ali *et al*., 2025).

MPs are not enduring sinks, but reactive transporters, where the adsorption-desorption equilibrium is regulated by circumstances (Holmes *et al*., 2012). External causes like ultraviolet radiation and oxidative stress change the chemistry of the plastic surface, raising its roughness and thus increasing the interaction coefficient and adsorption ability (Wang *et al*., 2020). The ability to absorb water of MPs for different pollutants is strongly reliant on the pH, salinity and temperature of the water around them, which may cause the flow of bound toxins returning to the environment, turning microplastics from temporary traps into secondary sources of pollution. For instance, a high pH may facilitate metal binding, whereas elevated salinity may hinder sorption because of competition from background ions (Lu *et al*., 2020), MPs can absorb and transportation chemicals involving heavy metals such as lead (Pb), cadmium (Cd), and mercury (Hg), per- and polyfluoroalkyl substances (PFAS), and persistent organic pollutants (POPs) throughout trophic zones, which raises toxicological effects throughout food chains. The complicated surface chemistry of MPs boosts its contaminant adsorption, an action modified through environmental factors like pH, salinity, as well as pollution levels, whereas aging and structural characteristics also influence their biological absorption and toxicological effects (Pal *et al*., 2025). More acidic environments can enhance the accumulation of metals such as Chromium (Cr) and Lead (Pb) enhancing their affinity towards the microplastic surfaces, ocean acidity can affect the development of the plastisphere (microbial biofilms on the plastic's surface), Because biofilms generally improve adsorption of heavy metals, a decrease in biofilm health caused by acidic conditions in some way diminishes the plastic's ability to transport such metals (Liu *et al*., 2021).

Polymer for instance polyethylene as well polypropylene are able to absorb pesticide ingredients such as organochlorines and organophosphates in water because of to its high surface size besides hydrophobic properties, but this mechanism is age-dependent plastic and environmental alterations that leads to formation of pores on the surface to capture pesticides which in turn affects water-based organisms by the food web where they eventually get accumulated and result in toxicological effects (Wang *et al*., 2018).

THE MAJOR PATHS OF MICROPLASTICS TO FISH

Exposure routes of MPs into fish are ingestion, gill absorption, and skin contact, which can lead to internal buildup and toxicity (figure 3). Ingestion is the main pathway, as fish commonly mistake microplastics for food or ingest previously contaminated prey, resulting in trophic transfer through aquatic food webs (Roch *et al*., 2020). Gill absorption can place when suspended particles, such as NPs, pass through the gill membranes throughout respiration and enter the circulation directly (Gao and Tianyu, 2025). These particles can induce gill irritation, inflammation and tissue damage (Guerrera *et al*., 2021) ‹particularly in highly contaminated waters, Dermal contact, where particles stick to or penetrate skin and scales, is less significant but still possible (Papini *et al*., 2026). Early life stages of fish, such as eggs and larvae, can additionally be susceptible to MPs exposure due to their barely developed protective barriers and high metabolism average (Fernandez-Miguez *et al*., 2023). MPs are able to pass in organs for example liver, kidney as well brain, which led to oxidative stress, inflammation and damage to tissues, once inside, these mechanisms collectively underscore the complex dangers of microplastics to fish health and aquatic environments, the level of contamination is influenced by the location, closeness to pollution sources, sorts of habitats (Enyoh *et al*., 2020). The widespread presence of MPs in fish is of great ecological and food safety concern, as fish represents a vital connection between the aquatic ecology and consumption by humans (Bhuyan *et al*., 2020; Al-Emran *et al*., 2025). First, some fish species are known to graze on MPs which resemble their prey (Mizraji *et al*., 2017). Second, MPs may be actively or unintentionally swallowed while looking for food. Third, they can be passed via the food chain (Jovanovic, 2017). The greater cumulative exposure can lead to higher bioavailability, especially in the acidic environment of the digestive system in which metals are more prone to leaching from the plastic matrix (Khan *et al*., 2022).

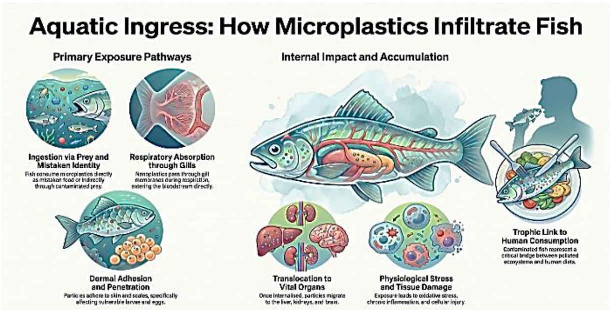

Fig. (3): The main pathways of MPs to Fish (Generated by Notebook LM)

EFFECT OF MPS ON FISH HEALTH

Fish uptake of plastic relies on the abundance and quantity of plastics in the surrounding water, characteristics of the species, period of contact, and eating behaviour (Akhbarizadeh *et al*. 2018). The build-up of MPs in fish causes serious threats to their biological processes such as metabolism, immunity and Reproductivity, MPs act as vectors of contaminants because of its ability to adsorb harmful substances and microbiological diseases, thereby magnifying their toxicological effects (Li *et al*., 2024).

Jovanović (2017) found that MPs caused oxidative stress, tissue damage along with decreased fish development. Ding *et al*. (2018) found that MPs inducing oxidative stress, which is harmful to tissues and inhibits fish development in the freshwater fish, e.g. in red tilapia *Oreochromis niloticus* (Linnaeus, 1758). Limonta *et al*. (2019) stated a decline in floating activities and a rise in anxiety-related behaviours, which indicates neurotoxicity.

MPs of polyethylene and polystyrene were phagocytosed by immune cells. Uptake varied based on polymer type and concentration, Abihssira-García *et al*. (2020) indicating immunomodulatory possibility. polyvinyl chloride Reduced body mass index and developmental rate as showed by Xia *et al*. (2020).

Exposed to MPs and their subsequent bioaccumulation leads to changes in blood markers, reduced red blood cell numbers and haemoglobin concentration therefore compromising oxygen transfer and metabolism, triggering oxidative stress, and causing immunological dysregulation in numerous fish species (Kim *et al*., 2021; Jo *et al*., 2025). Bhat *et al*. (2024) conducted that reduction of the reproductive capacity and alterations in hormones which will influence the fertility of the fish.

A histological analysis by Hamed *et al.* (2021) showed a microvascular congestion in the kidney, immune cell infiltration, reduce basophilia of cytoplasm tubular cells, tubular vacuolization, tubular shrinkage, dilation of tubular lumen, marked tissue disorganization, reduce glomerular size, glomerular cells vacuolation and tubular fatty degeneration. Liver tissue showed vacuolated hepatocyte, hydropic deterioration, focal necrosis, morphological alteration of hepatocytes, nuclear pyknosis, sinusoidal dilatation and congestion. Histopathological examination of pancreatic tissue revealed acinar cell deterioration with nuclear pyknosis, hematic extravasation, focal tissue necrosis, cellular inflammation infiltration, adipocytic infiltration and capillary congestion. Muscle tissue exhibited myofibrillar disintegration, interstitial swelling, necrotic muscle tissue, myofibers fragmentation, and infiltration leukocytes. The gill tissue showed vasodilation as well vascular congestion, lamellar coalescence, detachment of epithelium, structural deterioration and reduction of secondary lamellae, tissue overgrowth and interlamellar MPs aggregate. Effects in the spinal cord and notochord were structural deterioration of meninges, axial deviation of notochord, oedema and depletion of vacuolar cells. Histopathological examination of intestinal tissue showed basement membrane disruption, infiltration of immune cells, thinning of submucosa, condensed nuclei, blood leakage and intracellular vacuoles in mucosa.

MPs in fish can induce a variety of metabolic abnormalities including physiological and oxidative stress, enzyme activity suppression, decrease in growth frequency besides reproductive problems (Mallik *et al*., 2021; Banaee *et al*., 2023). Mbugani *et al*. (2022)

conducted research that showed that polyethylene affects the growth of Wami Tilapia Juveniles (*Oreochromis urolepis*) through damaging the small intestine leading to degeneration of cells and inflammation leading to a decrease in the pace of growth and loss in body weight gaining. Li *et al*. (2022) exposed that MPs altered the configuration of intestinal microbiota, decreased the activity of digesting enzymes, and caused gastrointestinal inflammation.

Physical impacts of high MPs levels on fish include intestinal blockage and reduced food intake, and ecological toxic impact include cellular injury, nervous system toxicity, and inflammation response (Yin *et al*., 2022). Moreover, plastics can contain possibly dangerous chemical additives (stabilizers, antioxidants, pigments or colorants, plasticizers, fillers or flame retardants) throughout the manufacturing procedure, and their large surface area per unit of weight can adsorb different harmful compounds in water, rendering them extremely vulnerable to possible hazards because of chemical damage (Bošković *et al*., 2022; Zeidi *et al*., 2023). Subaramaniyam *et al.* (2023) found that these MPs regulate various signalling routes such as Nrf-2 pathway, JNK cascade, ERK signalling, NF-κB activation, and MAPK pathway and enzymatic antioxidants defence such as SOD enzyme, catalytic antioxidant enzyme and glutathione system.

Lee *et al.* (2023) showed that polyethylene MPs particularly impact blood profile, oxidative stress responses in *Pseudobagrus fulvidraco*, systemic stressful conditions and inflammatory responses.

A study conducted by Ghosh (2024) showed that bioaccumulation of MPs induces a series of physiological disturbances involving alterations in haematological indices like increased liver enzymes (ALP, ALT, AST) and haemolysis, and neurotoxicity due to suppression of acetylcholinesterase activity causing motor and behavioural problems. In addition, induce substantial oxidative stress by generating reactive oxygen species (ROS) and lipid peroxidation, at the same time, increase pro-inflammatory cytokines along with activate inflammatory immune reactions, weak rate of growth due to gut microbial dysbiosis and lower activation of digesting enzymes, and These systemic stressors can lead to severe reproductive disorder, including disturbance of the hypothalamic-pituitary-gonadal (HPG) axis, reduced fertility, delayed sex development, and potential transgenerational effects on healthy offspring.

Hasan *et al*. (2024) showed that MPs cause different neurobehavioral problems in zebrafish influencing social and cognitive functions. Changes in the neurotransmitter are suggested as an important mechanism underlying behavioural changes following MP involvement, also, physiological problems such neurotoxicity, immunotoxicity and oxidative stress have been identified in fishes exposing MPs, these physiological disturbances may have negative effects on the individual health of aquatic animals, causes major damage to the reproductive systems of fish principally by interfering with the hypothalamic-pituitary-gonadal (HPG) axis that regulates basic reproductive processes such as gamete development and the production of steroids.

Nair and Perumal (2024) reported comparable impacts in Nile tilapia (*Oreochromis niloticus*) in contact with polypropylene MPs, with a reduced haemoglobin level, increased levels of reactive oxygen species, and poorer growth efficiency, suggesting metabolic stress and decreased cellular resistance. Yang *et al*. (2024) shown that MPs could decrease the innate immunity in zebra fish larvae.

Wang *et al*. (2024) showed that gut microbiota dysbiosis in species. A result conducted by Zhang *et al.* (2024) indicated that MPs could the strongest effect was exerted by the intracellular toxicity followed by oxidative stress, creating oxidative imbalance, generating cytotoxicity, disrupting biotransformation mechanism and impacting lipid metabolism, changing liver shape, causing damage to the liver. Sensitivity of organisms to MPs is higher when exposure time is greater, MPs sizes are smaller and life stage is earlier, the concentration of MPs results in an ongoing rise of many liver markers, such as catalase, glutathione S-transferase, reactive oxygen species and alkaline phosphatase.

Aib *et al*. (2025) demonstrated Fish subjected to a mixture of Pharmaceuticals and microplastics have shown changes in behaviours, liver damage and oxidative stress. MPs have been detected in fish gills, muscles, liver, heart, swim bladders, ovaries, spinal cords and even brains, Ghosh *et al*. (2025) have demonstrated that the presence of MPs in various organs

might have serious deleterious effects, such as fertility, nervous system, endocrine and immune system changes.

Jo *et al*. (2025) established that bioaccumulation of MPs was mostly subsequently in the gut then in the gills as well liver. Haematological studies indicated that haemoglobin and haematocrit levels showed a pronounced decline under elevated MPs exposure. Detected changes in plasma biochemical markers of calcium, magnesium, blood sugar, cholesterol, protein continent, Aspartate transaminase, Alanine transaminase in addition to alkaline phosphatase. With respect to antioxidant reactions, the activities of superoxide dismutase (SOD) and catalase (CAT) were dramatically elevated by MPs, whereas glutathione S-transferase (GST) activity was markedly decreased. The reduction in swimming activity and the increased erratic movement was indicative of neurotoxic consequences in MPs-exposure, such as zebra fish females are more likely to be affected than male fish (Wu *et al*., 2025).

Zhi *et al.* (2025) established that MPs and NPs are toxic, destroying immunological cells and altering gene expression. Importantly, they may react with environmental contaminants (e.g., heavy metals, persistent organic pollutants, and infections) synergistically, which can result in more severe immunological impairment in fish. Siddique *et al*. (2026) showed damage to the gut along with nutrient malabsorption. In the planktivorous bleak (*Alburnus arborella*) the greatest percentages of microplastics were observed in liver and kidneys, with long fibres building up in muscles, fragments in kidneys and small spheres in brain; from this it can infer that the blood-brain barrier in the fish has been penetrated as showed by Papini *et al*. (2026), previous studies shown in Table (2).

Table (2): shown a review of previous studies.

Vital system	Effect	Reference
Circulatory system	Reduced red blood cell numbers and hemoglobin concentration therefore compromising oxygen transfer and metabolism	Kim *et al*. (2021)
	impact blood profile	Lee *et al*. (2023)
	Nile tilapia (*Oreochromis niloticus*) exposed to polypropylene MPs, reduce hemoglobin level	Nair and Perumal (2024)
	Hemoglobin and hematocrit levels showed a pronounced decline under elevated MPs exposure	Jo *et al*. (2025)
Behaviour and nervous system	Reduction in floating activities and a rise in anxiety-related behaviours, which indicates neurotoxicity	Limonta *et al*. (2019)
	Nervous system toxicity	Yin *et al.* (2022)
	Neurotoxicity due to suppression of acetylcholinesterase activity causing motor and behavioural problems	Ghosh (2024)
	Different neurobehavioral problems in zebrafish influencing social and cognitive functions	Hasan *et al*. (2024)
	The reduction in swimming activity and the increased erratic movement was indicative of neurotoxic consequences	Wu *et al*. (2025)
Reproductive system	Reduction of the reproductive capacity and alterations in hormones which will influence the fertility of the fish	Bhat *et al.* (2024)
	Severe reproductive disorder, including disturbance of the hypothalamic-pituitary-gonadal (HPG) axis, reduced fertility, delayed sex development, and potential transgenerational effects on healthy offspring.	Ghosh (2024); Hasan *et al*. (2024)
Development and Growth	Decreased fish development	Jovanović (2017)
	Inhibits fish development in the freshwater fish, e.g. in red tilapia *Oreochromis niloticus* (Linnaeus, 1758)	Ding *et al*. (2018)
	Polyvinyl chloride Reduced body mass index and developmental rate	Xia *et al*. (2020)
	Decrease in the pace of growth and loss in body weight gaining	Mbugani *et al*. (2022)
	Weak rate of growth	Ghosh (2024)
	poorer growth efficiency	Nair and Perumal (2024)
Gastrointestinal system	Altered the configuration of intestinal microbiota, decreased the activity of digesting enzymes, and caused gastrointestinal inflammation	Li *et al*. (2022)
	Intestinal blockage and reduced food intake	Yin *et al.* (2022)
	increased liver enzymes (ALP, ALT, AST)	Ghosh (2024)
	Gut microbiota dysbiosis and lower activation of digesting enzymes	Ghosh (2024) Wang *et al*. (2024)
	Impacting lipid metabolism, changing liver shape, causing damage to the liver	Zhang *et al.* (2024)
	Detected changes in plasma biochemical markers of calcium, magnesium, blood sugar, cholesterol, protein continent, Aspartate transaminase, Alanine transaminase in addition to alkaline phosphatase	Jo *et al*. (2025)

	Damage to the gut along with nutrient malabsorption	Siddique *et al.* (2026)
Inflammatory system	Immunomodulatory possibility	Abihssira-García *et al*. (2020)
	Immunological dysregulation in numerous fish species	Kim *et al*. (2021); Jo *et al*. (2025)
	Inflammation response	Yin *et al.* (2022); Lee *et al.* (2023)
	modification signalling routes of NF-κB activation	Subaramaniyam *et al*. (2023)
	Increase pro-inflammatory cytokines along with activate inflammatory immune reactions	Ghosh (2024)
	Decrease the innate immunity in zebrafish larvae.	Yang *et al*. (2024)
	Destroying immunological cells and altering gene expression	Zhi *et al*. (2025)
Antioxidant system	caused oxidative stress, tissue damage	Jovanović (2017); Ding *et al*. (2018)
	oxidative stress responses in *Pseudobagrus fulvidraco*	Lee *et al.* (2023)
	regulate various signaling routes such as Nrf-2 pathway, JNK cascade, ERK signalling, and MAPK pathway and enzymatic antioxidants defence such as SOD enzyme, catalytic antioxidant enzyme and glutathione system	Subaramaniyam *et al*. (2023)
	Induce substantial oxidative stress by generating reactive oxygen species and lipid peroxidation.	Ghosh (2024)
	Increased levels of reactive oxygen species	Nair and Perumal (2024)
	Rise of catalase, glutathione S-transferase, reactive oxygen species	Zhang *et al.* (2024)
	The activities of superoxide dismutase (SOD) and catalase (CAT) were dramatically elevated by MPs, whereas glutathione S-transferase (GST) activity was markedly decreased.	Jo *et al.* (2025)

CONCLUSION

In conclusion, the widespread introduction of Microplastics (MPs) and Nanoplastics (NPs) into aquatic ecosystems poses a considerable risk to ecological stability, mainly due to their synergistic interactions with other chemical pollutants. This review highlights the resultant oxidative stress, organ damage, and behavioral changes in fish undermine essential trophic levels. Future studies should explore the mechanisms of mixed-pollutant toxicity and the metabolic pathways of plastics in the human digestive system to reduce the cumulative hazards to human health from seafood consumption. In order to establish reliable food safety guidelines and implement effective strategies to protect threatened freshwater and marine ecosystems, it is essential to fill these knowledge gaps.

RECOMMENDATION

Based on the findings of this review, the following mitigation strategies and recommendations to minimize the impact of microplastics on aquatic ecosystems, it is advisable to use alternatives, develop recycling methods, wastewater treatment plants should be equipped with three-stage filtration systems capable of trapping microplastics before discharge into water bodies, enhance awareness within fishing-dependent communities and engage them in the monitoring and reporting of plastic debris, while promoting the utilization of equipment constructed from sustainable materials and restricting the use of equipment containing microplastics, establish systems to monitor and quantify microplastics concentrations in aquatic environments and fish tissue, as well as increase public concern about the dangers of discarding plastic in water, given its harmful effects on the health of living organisms.

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