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Characteristics of Microplastic in Commercial Aquatic Organisms

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ABSTRACT: This study aims to review the occurrence of microplastics in some commercial aquatic organisms. Microplastics are small plastic particles with a diameter of less than 5 mm. Effluent, stormwater, agricultural, and surface runoff introduce microplastic to freshwater basins. Hydrodynamics and hydrology encompass microplastics. River flow speed can cause turbulence and riverbed instability, increasing microplastic concentrations. Fish, shellfish, and crustaceans ingest microplastics in proportion to their quantity in freshwater and marine environments. Human activities cause variations in the form, color, and size of microplastics in the biota. Animals absorb microplastics through trophic transfer. Increased microplastic residence time before ingestion promotes trophic transmission. Lower food concentration and aggregation enhance microplastic retention in zooplankton guts, increasing transmission to higher-trophic-level species. Most studies show that microplastics in biota are discovered in fish and crustacean intestines and bivalve tissues. Microplastic buildup can disrupt live organisms' growth and reproduction, induce oxidative stress, obstruct the digestive system, and damage the intestine. Microplastics may harm people's health if they eat contaminated seafood that contains them, but more research is needed.

KEYWORDS: Microplastic contamination; crustacean; health impact; source and fate

1. Introduction

Rapid urbanisation and industrialization, coupled with escalating population density, have caused massive use and manufacturing of plastics for food packaging, textile clothing, and automotive parts, owing to the properties of plastics which are durable, lightstrongrength, formed from long polymer chains. In addition to the high resistance of plastics to degradation, the ineffective waste management system and uncontrolled discharge of wastewater contaminated by plastic waste contribute to the persistence of plastics in the environment, resulting in plastic pollution [1]. The mass use and disposal of single-use face masks and personal protective equipment (PPE) have exacerbated the plastic waste issue and pollution ever since the coronavirus disease (COVID-19) outbreak began. This disposed medical plastic waste can be found in the aquatic and marine environment due to ineffective waste management practices in place and littering habits, contributing to more secondary microplastics from the degradation process [2]. Plastic production in Asia exceeds 50% of global plastic production, where the production of plastic resins in Asia is around 82Mt. It is thought that 1.15 to 2.41 million tonnes of plastic waste flow from rivers into the ocean every year [3].

Microplastics are small plastic particles with a diameter of less than 5 mm and are categorised into primary and secondary microplastics, where primary microplastics are manufactured in the form of pellets for plastic manufacturing, microbeads for the manufacturing of cosmetic and personal care products, or shredded microplastics from textile clothing washing and tyre abrasion. Secondary microplastics are fragmented from larger plastic debris due to degradation by ultraviolet radiation and physical abrasion. The occurrence and abundance of microplastics in the water and sediments of marine and aquatic environments have been widely studied [4–6]. In recent years, a lot of studies have also focused on microplastic contamination in living biota, including fish, bivalves, crustaceans, and other vertebrates, to study the abundance and accumulation of microplastics within the organisms, including the gastrointestinal tract and other tissues or organs [7–9]. The ecotoxicological effects of microplastics on these organisms through microplastic ingestion include oxidative stress, neurotoxicity, and genotoxicity, which affect their life functions and survival. Concerns have been raised about the pervasiveness and persistence of microplastics in the environment and in living organisms as a result of the potential effects and induced toxicity on the organisms caused by microplastic ingestion. Both direct and indirect ingestion of microplastics by the organisms can occur when microplastics are misidentified as their prey and via trophic transfer, where the predators prey on lower trophic organisms contaminated with microplastics [10]. Combined with microplastics, absorbed environmental contaminants, including POPs and heavy metals, can threaten living creatures. Bioaccumulation and biomagnification of microplastics in organisms, notably seafood, can harm human health through seafood consumption [11].

Crustaceans, especially bottom dwellers, might operate as bioindicators for detecting microplastic contamination due to their feeding behaviours, including detritus feeding and filter-feeding. Due to the comparable size of microplastics and their food, this can increase their susceptibility to ingestion and accumulation [12]. As there is no study on microplastics in commercial crustaceans in Malaysia, they were chosen as the study's target species. Crustacea, including shrimp, crabs, and lobsters, are important seafood commodities in Malaysia. They provide protein, fatty acids, vitamins, and minerals to Malaysians. Average fish and seafood consumption is 44.53 kg per capita per year, whereas coastal Malaysia consumes 51.9 kg per capita per year [13]. When consuming seafood as a whole, humans are at a higher risk of ingesting microplastics, as shrimp are frequently eaten without proper and complete removal of the gastrointestinal tract, implying potential health risks to humans due to the effects of microplastics combined with toxic effects of absorbed contaminants [14].

2. Source of Microplastic

Microplastics are classified into primary microplastics and secondary microplastics. The sources of primary microplastics include the microbeads in personal care products such as toothpaste, facial scrubs, and other cosmetic products, as well as the resin pellets used for the production of virgin plastic [15]. Primary microplastics include the shredding of microfibres from textiles and fishing nets, as well as dust generated by tire abrasion [16]. These primary microplastics will eventually end up in the aquatic and marine environment through the discharge of household and industrial wastewater effluent. Secondary microplastics are sourced from the fragmentation and degradation of plastic waste and debris as a result of weathering. Photo-degradation of the plastic debris occurs with bond cleavage due to long-term exposure to ultraviolet radiation from the sun, coupled with the abrasive action of the ocean waves, leading to the disintegration of plastic debris and consequently increased secondary microplastic formation [15].

Rapid urbanization and industrialization with increasing population density have exacerbated the microplastic contamination in the freshwater and marine environments due to anthropogenic activities on land. It is speculated that the entrance and input of plastic debris into the ocean is around 4.8 to 12.7 million metric tons, where land-based sources of plastic debris account for 80%. The input of plastic debris In most of the developing countries in Southeast Asia and Asia, the poor development of stormwater drainage systems and sewers can result in the direct discharge of domestic wastewater into freshwater bodies instead of passing through a wastewater treatment plant for removal of microplastics, leading to a high level of microplastics concentration in the freshwater. Wastewater treatment plants (WWTPs) are one of the main sources of microplastics in the freshwater environment as they act as the main receptors of domestic and industrial wastewater [17]. Over 90% of the microplastics removal rate can be achieved through wastewater treatment plants. The microbeads found in the wastewater originate from the usage and manufacturing of personal care and cosmetic products (PCCPs) containing microbeads that act as exfoliating agents, including facial scrubs, toothpaste, shampoos, and soaps, while microfibers are shredded from textile clothing during domestic washing activities and textile manufacturing [18]. Praveena reported that the mean microplastic abundance in the household laundry water in Kuala Lumpur, Malaysia, is around 0.068 g/m^3, where fibers and fragments are detected [19]. The dominance of fibrous microplastics among other shapes in the discharged WWTP effluents is commonly observed, and the high length-to-width ratio and smooth surface of fibers make their removal more difficult. According to Zou et al. [20], the WWTP effluents in Guangzhou, China, contain an average of 1.719±1.035 microplastics per litre, with fiber microplastics and polyester dominating.The contamination of microplastics by wastewater treatment plants can be traced back to the low treatment efficiency of wastewater. This happens when the wastewater treatment plant's capacity is exceeded by the flow of incoming wastewater and the biological treatment stage is ineffective or absent during the treatment process [21].

Fisheries and aquaculture activities are another major contributor to the microplastics in freshwater and marine waters where fishing gear, including fishing nets, lines, floats, and plastic fish crates, is commonly used. The wear and tear of fishing nets and ropes during trawling and dredging can cause the discharge of microplastics into the water environment. Microplastics can be derived from the breakdown and degradation of abandoned, lost, or otherwise discarded fishing gear (ALDFG) and the wear of EPS floats and ropes as a result of UV radiation and abrasion by waves, which causes fragmentation of plastics [22]. In the study by Ma et al., the colored fiber microplastics with the dominance of polypropylene and polyethylene are found in the aquaculture water (and pond influent) of fishponds in the Pearl River Estuary and are possibly sourced from the breakdown and degradation of fishing gear, including fishing ropes and nets made of polyethylene and polypropylene [23]. Other microplastic sources include the shredding of the boat paints and coatings from fishing boats. The issue of microplastics and plastic pollution worsens with the development of tourism industries due to the plastic waste such as plastic bottles and food packaging generated and disposed of by tourists. The direct disposal of plastic waste into the lakes, rivers, and sea and the transport of plastic waste from land to water due to surface runoff results in the consequent breakdown of plastic waste into debris and microplastics. High microplastic abundance in the surface water, sediments and fish at Qinghai Lake in China was detected in the study by Xiong et al., and this can be attributed to the tourists' activities in the area coupled with the ineffective waste management system where there is a lack of facilities for collecting and disposing of rubbish. Polyethylene and polypropylene are dominant in the microplastics samples collected due to the disposal of food packaging waste [24].

The utilization of agricultural plastic mulch films is one of the sources of microplastics in agricultural soils, which can enhance the quantity and quality of the cultivated crops [25]. Yu et al. revealed the prevalence of polyethylene and film-type microplastics in agricultural soils, which are associated with the film residue from the utilization of agricultural plastic mulch films [26]. The addition of soil amendments, including organic fertilizers and sewage sludge, to agricultural soils can improve the agricultural yield by increasing the nutrient content of the soils, but at the same time, this introduces microplastics into the agricultural soils due to the microplastics contained in the sludge and compost. Microplastics in the agricultural soil can be sourced from untreated wastewater used as irrigation water for crops. The farmland application of sludge as fertilizer and the disposal of sludge at landfills can also cause the release of microplastics into the soil environment. The amendment of agricultural soils through sewage sludge application can lead to increased microplastics abundance in the soil, as shown in the study by Yang et al. where the microplastic abundance in the amended soil and unamended soil is 68.6±21.5–149.2±52.5 particles/kg and 40.2±15.6 particles/kg, respectively [27]. Microplastics in the soil are then moved to freshwater bodies by surface runoff caused by rain.

3. Occurrence of Microplastic in Freshwater and Marine Water Environment

There is a high concentration of microplastic fibers consisting of 70% polyester, ranging from 172,000 to 519,000 items per cubic meter in the Saigon River and other urban canals, based on the study by Lahens et al. [28]. This is much higher compared to the respective microplastic abundances in the surface water of the Hanjiang River and Yangtze River of Wuhan, which are 2933±305.5 n/m^3 and 2516.7±911.7 n/m^3 [29]. The mean concentration of microplastics in the river water and sediments of the Ciwalengke River is 5.85 particles per liter and 3.03 particles per 100 g of dry sediment, respectively. A high abundance of microplastics with a smaller size (50 to 100 mm) is discovered in the river water, while microplastics with a larger size (1000 to 2000 mm) are abundant in the river sediments as the settling of the microplastic particles with high density in the sediments occurs [30]. Peng et al. reported a higher mean microplastic abundance in the river sediments in Shanghai, China, which is around 80.2 items per 100 grams of dry weight compared to the microplastic concentration in the Ciwalengke River [30–31]. The occurrence of precipitation and rainfall events during wet seasons can influence the microplastic abundance in the rivers [32–33]. As observed, 37.4±37.0 microplastic particles/m^3 were found in the surface water of Tanchon stream during the rainy season in August, compared to 28.2±22.2 microplastic particles/m^3 detected in Korea's dry season [33]. The occurrence of heavy rainfall events causes increased surface runoff containing microplastics to be discharged into the rivers. Microplastics can also be resuspended from river sediments due to increased flow velocity caused by precipitation [32-33].The microplastics load and abundance in the surface water of Taihu Lake, which is 3.4–25.8 items/l, is similar to the microplastics abundance in Poyang Lake, ranging from 5 to 34 items/l [34-35]. Moreover, high microplastic abundance in rural areas compared to urban areas is demonstrated in the study on East Dongting Lake because there is a lack of effective wastewater treatment plants to control the discharge of wastewater containing microplastics.

The high prevalence of fibers in the water and sediments of rivers and lakes is observed in most of the microplastic studies above, and these fibers are released from domestic washing activities through handwashing and washing machines as well as textile factories. The direct discharge of domestic and industrial waste to freshwater bodies without undergoing proper wastewater treatment causes high microplastic contamination levels [28,30]. Fibers can also be sourced from the breakdown of plastic fishing gear, including fishing nets and lines, as a result of abrasion [6]. However, there is a dominance of fragment-type microplastics in both water and sediment samples in the Tanchon stream, indicating the abundance of secondary microplastics as a result of plastic debris fragmentation and degradation [33]. The estuaries where freshwater connects with marine water are known as microplastics pollution hotspots, acting as temporary reservoirs for microplastics particles as the dynamics of sediment transport and other hydrodynamic conditions can promote the deposition and accumulation of microplastics particles in the estuarine sediments during the process of receiving river water influx, transporting microplastics, and consequently discharging microplastics into the seawater [36]. The study by Oo et al. concluded that there is a higher microplastics abundance at flood tide, which is 5.16 particles/m^3 compared to the abundance at ebb tide, which is 3.11 particles/m^3 at the surface water of the Chao Phraya River Estuary in Thailand, and this can be attributed to the entrance of microplastics debris to the estuary and the leaving of debris from the estuary during flood tide and ebb tide, respectively, under the influence of the tidal current fluctuation [37]. The microplastic concentration in the Chao Phraya River estuary is higher compared to the abundance in the Pearl River estuary, which is around 3.627 particles/m^3 [37-38]. Apart from that, a lower mean concentration of microplastics in the rainy season, which is 200±105 items/kg dry weight, compared to the concentration in the dry season, which is around 450±196 items/kg dry weight, is revealed in another study in the estuarine sediments of Phuket, Thailand, because there is a lesser amount of microplastics deposited in the sediments as a result of increased hydrodynamic forces [39]. Another study by Xu et al. revealed that the microplastics concentration in the sediments at the river mouth of the Liaohe Estuary is the highest, showing a similar trend to the microplastics concentration in the Chao Phraya Estuary, where the declining trend of microplastics concentration from the river mouth to the seawater is observed [36–37]. This is because the sinking and settling of microplastics are facilitated by the hydrodynamic processes and salinity, showing that microplastics originate from the river discharge accumulated at the estuaries. Moreover, similar polymer compositions in the sediments of both the Liaohe estuary and the river are also demonstrated, highlighting the influence of river water inflow on the occurrence of microplastics in the estuary.

There are also many studies conducted on the occurrence and abundance of microplastics in the marine environment, including surface seawater, marine sediments, mangrove sediments, and beach sediments. Based on the study by Nguyen et al. [40], 745 items of microplastics with 99.2% of fibers, referring to an average of 9238±2097 items/kg dry weight, were found in the beach sediments of Da Nang beaches in Vietnam. Higher microplastics concentrations in the upper layer of sediments compared to the lower layer were discovered in both studies on Da Nang beach and in the Bohai Sea, as human activity can further breakdown the plastic debris into more microplastic particles and the exchange of the surface layer with the seawater can increase microplastics retention [40-41]. The beach sand in the Bohai Sea has a lower microplastics concentration, ranging from 102.9±39.9 to 163.3±37.7 compared to the beach sediments of Da Nang Beach [41]. Prarat and Hongsawat reported that the mean microplastic concentration in beach sand and seawater in Rayong province in Thailand is 338.89±264.94 particles/kg of dry weight and 1781.5±1598.4 particles/m^3, respectively, dominated by polyethylene and microplastics with a size of 100 to 500 µm. There is no direct proportionality between the abundance of microplastics in seawater and beach sand, but the percentage of the same polymer composition of microplastics is similar between the beach sand and seawater [42]. The study by Zheng et al. revealed an average of 2.3±1.4 items MPs/50l and 3.1±1.2 items MPs/200g dry weight in the seawater and sediments of Jiaozhou Bay in China, respectively. This study also demonstrated a positive correlation between the microplastic abundance and polymer types in the seawater and sediments of Jiaozhou Bay. Sediment transport trends and the residual current can induce higher microplastic abundance, especially for microplastics with a lower density like polyethylene and polypropylene in the seawater [43]. Dai et al. reported an average microplastics concentration of 2.2 pieces per liter in the surface water of the Bohai Sea and discovered that the microplastics concentration is much higher at the water depth of 5 m to 15 m, which can be attributed to the polymer compositions with different densities where there is the occurrence of polyvinyl chloride at the bottom of the water column due to its high density. The abundance of smaller microplastics increases when the water depth increases, showing the tendency of smaller microplastics to sink [44]. The positive correlation between population density and microplastic abundance has been highlighted in numerous studies. Kwon et al. discovered that there is a higher microplastic concentration in the coastal surface waters in urban areas of Korea, which is around 2.85 particles/m^3, compared to the microplastic concentration in rural areas, which is 1.86 particles/m^3 [45]. Jang et al. also reported higher microplastic abundance in the coastal sediments in urban areas compared to rural areas [46]. Higher microplastic abundance was discovered in urban areas with higher population density compared to rural areas in the Liaohe Estuary study [36].

According to most of the studies on microplastic occurrence and pollution in the marine environment, fiber is predominant in the seawater and sediments, which can be sourced from the discharge of wastewater treatment plant effluent containing synthetic fibers and the abrasion of fishing gear used during fishing and aquaculture activities [45,47]. Furthermore, the abundance of EPS in coastal waters is caused by the breakdown and degradation of EPS buoys, and the abundance of paint particles in coastal waters near shipyards and ports is caused by the shredding of ship paint [45]. Based on the study by Jang et al. [46], EPS aquaculture buoys, fishing nets, and ropes contribute to the abundance of polystyrene and polypropylene in the seawater and sediments.

Microplastics can be easily trapped by the roots and branches of mangroves, especially with the lower water flow velocity in the mangrove forest. Zhou et al. discovered the dominance of foams, microplastics smaller than 2 mm, and polystyrene in the mangrove sediments from mangrove wetlands in Southeast China [48]. However, Deng et al. reported that 68.58% of fibers are predominant in the mangrove sediments of the Jinjiang Estuary in China [49]. There are several factors influencing the microplastics abundance in the sediments of mangrove wetlands, including the intensity of anthropogenic activities, the mangrove forest density and height, and the texture of the sediments [48-49]. More intensive anthropogenic activities like fishing and mariculture can lead to higher microplastic abundance in the mangrove sediments. Besides, the prevalence of fragments, fibers, and foams in the muddy sediments and sand sediments, respectively, is shown in this study [49]. Apart from that, the restoration of mangrove wetlands as well as increased mangrove tree density from planting and elevated heights of mangrove trees can also result in the accumulation and retention of microplastics particles, resulting in increased microplastics concentration in the mangrove sediments as the transfer of microplastics particles from rivers to the oceans is hindered by the mangroves along with the attachment of microplastics to the mangrove tree branches and roots [49]. Table 1 summarizes the occurrence of microplastics in the water and sediments of freshwater and marine environments.

Table 1. Microplastic contamination in water and sediment of freshwater and marine water environment.

Country	Location	Sample type	Abundance	Dominant shape, colour, size and composition	Reference
Vietnam	Saigon River	Surface water	172000-519000 items/m^3	Fiber, 20-250µm, Polyester.	[28]
Indonesia	Ciwalengke River	Surface water and sediments	5.85±3.28 particles/l 3.03±1.59 MPs/100g dry sediments	Fiber, 50-100µm, Polyester.	[30]
China	Shanghai	Freshwater sediment	80.2±59.4 items/100g dry weight	Sphere, White, 100-500µm.	[31]
Korea	Tancheon stream	Surface water	5.3-87.3 particles/m^3	Fragment, 0.1-0.3mm, Polyethylene.	[33]
Korea	Nakdong River	Water and sediments	293-4760 particles/m^3 1971 particles/kg dw	Fragment, 50-150µm Polypropylene.	[32]
China	Dongting Lake	Water and sediments	2.09±0.87 items/m^2 38.5±6.96 items/100g dry weight	Fiber, Transparent, <0.1mm, Polyethylene.	[6]
China	Taihu Lake	Water and sediments	3.4-25.8 items/l 11.0-234.6 items/kg dry weight	Fiber, White and transparent, 333-1000µm.	[34]
China	Poyang Lake	Water and sediments	5-34 items/l 54-506 items/kg dry weight	Fiber, Coloured 0.1-0.5mm, Polypropylene.	[35]
Thailand	Chao Phraya Estuary	Surface water	3.11-5.16 particles/m^3	Fragment, White 335-515µm, Polypropylene.	[37]

Table 1. (Continued)

Country	Location	Sample type	Abundance	Dominant shape, colour, size and composition	Reference
Thailand	Phuket	Sediment	200±105-450±196 items/kg dry weight	Fiber, Blue Rayon, and polyester.	[39]
China	Liaohe Estuary	Sediment	120±46 particles/kg dry weight	Fiber, fragment and film.	[36]
Vietnam	Da Nang beach	Beach sediment	9238±2097 items/kg dry weight	15-20µm, Blue.	[40]
Thailand	Rayong	Surface seawater and beach sand	1781.48±1598.36 particles/m^3 338.89±264.94 particles/kg dry weight	Fiber, Blue, 100-500µm, Polyethylene.	[42]
China	Jiaozhou Bay	Seawater and sediment	2.3±1.4 items/50l 3.1±1.2 items/200g dry weight	Fiber, 0.5-1.99mm, Black and blue, Polyethylene terephthalate.	[43]
China	Bohai Sea	Seawater and surface sediment	1.6-6.9 pieces/l 31.1-256.3 pieces/kg	Fiber, White, 100-3000µm.	[41]
Korea	-	Surface seawater	1.12-4.73 particles/m^3	Fiber, Polypropylene.	[45]
Korea	-	Seawater and sediment	0.77±0.88 particles/l 0.94±0.69 particles/g wet weight	Polypropylene, polyethylene.	[46]
China	Jinjiang Estuary	Mangrove sediment	963±175.4 items/500g dry sediment	Fiber, Transparent, 0.038-0.5mm.	[49]
Malaysia	Cherating River	Surface water	0.0042±0.0033 particles/m^3	Fragment, 0.5-1mm, White.	[50]
Malaysia	Klang River Estuary	Surface water	2.47±1.19 partciles/l	Fiber, Transparent, 300-1000µm.	[51]
Malaysia	Baram River Estuary	Water and sediments	0.55±0.071-1.85 ±1.48 mg/l 0.021±0.002-0.057±0.039 mg/g	Fragment, Blue, 0.3-1mm, Polyamide.	[52]
Malaysia	Port Disckson and Kulut	Surface water	2.1-6.8 particles/l	Fiber, Cellophane.	[53]
Bangladesh	Karnaphuli River	Sediment	22.29 to 59.5 items/kg of dry weight	Film, White, 1-5 mm, polyethylene terephthalate.	[54]

4. Occurrence of Microplastics in Biota

Apart from the water and sediments, microplastics are also detected in the biota, such as fish, bivalves, and crustaceans. The number of microplastics consumed by biota such as fish, shellfish, and crustaceans correlates with the abundance of microplastics in freshwater and marine environments [53,55]. The morphology, color, and size of the microplastics present in the body of the biota vary with different point sources and non-point sources of microplastics as a result of human activities. Most of the studies have demonstrated that microplastics within biota are commonly found in the gastrointestinal tract and guts of fish and crustaceans and in the tissues of bivalve species [56-59]. The accumulation of microplastics can have an ecotoxicological impact on these living organisms, affecting their growth and reproduction [60-

61]. Human exposure to microplastics through consumption of seafood contaminated with microplastics may cause health problems, though the health impact of microplastics requires more detailed research and investigation [62].

4.1. Microplastics in fish.

Previous study demonstrated that the mean concentration of microplastics in *Aplocheilus sp.* in the Ciliwung Estuary of Indonesia is 1.97 particles per individual, with 46.1% of fiber type microplastics and 40.68% of microplastics with sizes ranging from 300 to 500 µm. The dominance of microplastics with a size range of 300–500 to 500 µm in *Aplocheilus sp.* highlighted that the smaller size of microplastics promotes microplastic ingestion as they are easily mistaken for food, hence leading to the accumulation of microplastics in the body of the fish [63]. From the study by Park et al., the mean microplastic concentration in 21 fish species is around 17.4±11.9 MPs per individual, and the discharge of treated wastewater containing microplastics from the sewage treatment plants contributes to the higher microplastic concentration within the fish located downstream of the Han River. Where polypropylene and polyethylene are dominant, fragment-type microplastics exceed 95% of all microplastics [33].

Park et al. also revealed that the exposure of pelagic fish species to the prevalence of lightweight microplastic particles like polypropylene and polyethylene in the water leads to higher consumption and accumulation of microplastics in pelagic fish compared to demersal fish in the Han River of South Korea [33]. The study conducted on the microplastics in coastal fish in Thailand by Phaksopa et al. 2021 also highlighted higher microplastics ingestion by pelagic fish compared to demersal fish, and only polyamide was found in demersal fish due to the tendency of polyamide to sink and settle with higher density. The buoyancy force induced by the microplastic density can lead to variations in the microplastics ingested by demersal and pelagic fish [8]. The effect of the feeding habits of fish on microplastic pollution and abundance has also been discovered. A lower concentration of microplastics is discovered in herbivorous fish, which is around 3.56 microplastics per 100 grams compared to carnivorous, omnivorous, and insectivorous fish due to their accidental or indirect consumption of microplastics [33]. However, because herbivorous fish consume more food and have a higher tendency for microplastic accumulation in the gastrointestinal tract from plants, microplastic accumulation in herbivorous fish is much higher than in carnivorous fish [57].

Ding et al. examined the accumulation and distribution of microplastics within the body of a freshwater fish, red tilapia (*Oreochromis niloticus*), and the study results revealed that there is the highest polystyrene-MP accumulation in the fish guts compared to the gills, liver, and brain of the fish, where the translocation of polystyrene-MPs from the fish guts to the tissues of the fish occurs through the increased microplastics concentration in the tissues throughout the exposure period is observed, proving the occurrence of bioaccumulation of microplastics in fish, and factors like food intake, microplastics size, and the time and concentration of microplastics exposure can affect the microplastics bioaccumulation [64]. The study by Pan et al. also showed that there is a higher abundance of microplastics in the gastrointestinal tract of fish compared to the gills, where 351 and 177 microplastics are found in the GI tract and gills, respectively. Pan et al. observed the dominance of fibrous microplastic particles smaller than 1 mm in fish gills, which is associated with the gill structure similar to a comb, allowing for more fiber retention at their gills [57].

4.2. Microplastics in bivalves and crustaceans.

The common use of bivalves as bioindicators for biomonitoring of microplastics is justified as their metabolic activities by enzymes are relatively lower and they are tolerant to a higher concentration of pollutants, including microplastics [65]. The filter-feeding behavior of the bivalves, especially non-selective feeders, increases their susceptibility to a higher risk of microplastic contamination due to the ingestion and accumulation of microplastics through filtration [66]. Based on the study results on targeted bivalves including mussels (*Mytilus edulis*), oysters (*Crassostrea gigas*), scallops (*Patinopecten yessoensis*) and Manila clams (*Tapes philippinarum*) by Cho et al. [59], it is discovered that the average microplastic concentration is around 0.15±0.2 per gram with the dominance of fragment-shaped microplastics. Polystyrene is derived from the EPS floats used in aquaculture farms and is predominant in mussels and oysters cultured on water column surfaces, as well as microplastics in Manila clams and scallops farmed in intertidal sediment. Polyester dominates the bottom of the water column bottom. Depuration of microplastic particles during transport and storage results in lower microplastic concentrations of bivalves in markets when compared to wild and farmed bivalves [59].

The high microplastics abundance in the cultured green mussels, *Perna viridis*, from markets in Thailand is shown in the study by Imasha and Babel with an average microplastics concentration of 7.32±8.33 items per mussel (dry weight) and 1.53±2.04 items per gram (wet weight), which is higher compared to the microplastics concentration in the mussels in Korea based on the study by Cho et al. [9,59]. This can be associated with the larger size of the mussels, which are capable of ingesting and accumulating an increased amount of microplastics through the filtration of more water. The dominance of fragment-type microplastics, accounting for 75.4% of microplastics in the green mussels, is also observed, consistent with the study results by Cho et al. [9,59]. Polyethylene and polypropylene are detected in the green mussels due to the cultivation of mussels at the surface of the seawater column, where PE and PP are more abundant due to their low densities [9]. In Patterson et al., they reported an average of 0.81±0.45 items per gram of microplastics in the tissues of Indian edible oysters (*Magallana bilineata*). Higher microplastics abundance is also discovered in oysters with larger sizes, as they are able to ingest more microplastics particles and microplastics particles with different size ranges with their labial palps and gills. Hence, oysters with larger sizes are suitable for biomonitoring of microplastic contamination. In addition, there is a higher resemblance of microplastic abundance and polymer distribution in oysters to microplastics present in the marine water compared to the sediments, which is attributed to the filter-feeding behavior of the oysters [55]. However, the study by Su et al. revealed that the microplastics abundance in Asian clams (*Corbicula fluminea*) correlates more with the microplastics abundance in the sediments compared to surface water due to resuspension of the sediments along with microplastics and the fact that Asian clams are benthic deposit feeders and filter feeders [56]. It is concluded that the mean microplastic abundance in cultivated and wild clams (*Ruditapes philippinarum*) and oysters (*Crassostrea gigas*) at Jiaozhou Bay is around 1.21±1.52 items per gram, which is much higher compared to the microplastic concentration in the study by Cho et al. [59,67]. Oysters have a lower concentration of microplastics than clams due to their sessile behavior, which limits their ability to consume more microplastics. In addition, 37.5% of microplastics with a size of less than 500 m are detected in the shellfish, implying the tendency of shellfish to possess low selective feeding behavior towards the ingestion of small-size microplastics [67].

Crustaceans such as shrimp and crabs can also be used as indicators in biomonitoring the contamination of microplastics. Apart from bivalves, shrimps are also exposed to higher microplastic contamination risk compared to fish, which accounts for their filter-feeding behavior using pereiopods, which have a similar size between microplastic particles and their food, which increases microplastic ingestion [12]. Curren et al. investigated the microplastics present in three shrimp species, including *Fenneropenaeus indicus, Pleoticus muelleri*, and *Litopenaeus vannamei*, and the highest microplastic abundance was discovered in *F. indicus*. The dominance of spheres of microplastics in *F. indicus* and *P. muelleri* shrimp indicates the abundance of microbeads is sourced from personal care and cosmetic products, which are discharged from the sewage treatment plants. The settling and deposition of microplastics due to fouling and agglomeration can facilitate microplastic ingestion by shrimp, which are bottom dwellers [12]. The study by Daniel et al. revealed the mean microplastic abundance of 0.39±0.6 microplastics per shrimp and 0.04±0.07 microplastics per gram wet weight dominated by fibrous microplastics in Indian white shrimp, *Fenneropenaeus indicus*, from coastal waters in Kerala, India. Polyester and polyamide are prevalent in shrimp due to their sinking induced by their higher density, which promotes the ingestion of microplastics by the deposit-feeding shrimp. During the monsoon season, an increased influx of river water, along with plastic debris and microplastics, causes higher microplastics prevalence in shrimp due to increased microplastics bioavailability [68]. Hossain et al. studied the microplastic contamination in the gastrointestinal tract of *Metapenaeus monocerous* (brown shrimp) and *Penaeus monodon* (tiger shrimp), where the average microplastics concentration was 3.87±1.05 items per gram GI tract and 3.4±1.23 items per gram GI tract [58]. Based on the study by Gurjar et al., the shrimp trawled from the Arabian Sea contain an average of 70.32±34.67 microplastics per gram of GI tract of the shrimp, which is much higher compared to the microplastics abundance in *P. monodon* and *M. monocerous* in the study by Hossain et al. There is a positive correlation between the microplastic abundance in the shrimp and the weight of the gastrointestinal tract of the shrimp, as shown in these two studies [58,69]. The predominant microplastic size found in *P. monodon* and *M. monocerous* is between 100 and 250 µm, which is similar to the dominant microplastic size in *P. semisulcatus* from the Musa Estuary [69-70]. These studies also reported the dominance of fiber microplastics in the shrimp species investigated.

Zhang et al. discovered that the mean microplastic abundance in *Dorippe japonica, Charybdis japonica, Matuta planipes*, and *Portunus trituberculatus* is around 5.17± 4.43 items per individual, where microplastics in fiber shape are predominant in the samples. The fiber detected is derived from the use of fishing gear and the possible ingestion of microplastics from the cutoff of fishing nets and lines by the crabs using claws. The microplastics detected in the gills of the crabs are less than the microplastics accumulated in their guts, as the entrance of large microplastic particles into the gills is difficult due to their body structures and cleaning behavior at the gills. The microplastics' ingestion and accumulation in the crabs also vary in terms of their eating patterns. Saprophytic crabs, which are *D. japonica* and *M. planipes*, ingest more microplastics when ingesting other food and detritus at the bottom, causing higher microplastic abundance compared to the predatory crabs, which are *C. japonica* and *P. trituberculatus* [71]. Table 2 summarizes the microplastic research on organisms such as fish, bivalves, and crustaceans.

Table 2. Microplastic contamination in fish, bivalve and crustacean.

Country	Organisms	Species	Abundance	Characteristic	Reference
Indonesia	Fish	*Aplocheilus* sp.	1.97 particles /ind	Fiber, 300-500µm.	[63]
Korea	Fish	*Cyrinus carpio* *Carassius cuvieri* *Lepomis macrochirus* *Micropterus salmoides*	22.0±14.6 particles/fish	Fragment, 0.3-0.6mm, Polytetrafluoroethylene.	[7]
Thailand	Fish	*Stolephorus indicus*	0.20±0.45 items/ind	Fiber, black, polyethylene, terephthalate.	[8]
		Rastrelliger kanagurta	0.13±0.35 items/ind		
		Amblygaster clupeoides	0.11±0.33 items/ind		
		Aurigequula fasciata	0.20±0.45 items/ind		
		Leiognathus equulus	ND		
		Lutjanus lutjanus	ND		
		Lutjanus madras	0.20±0.45 items/ind		
		Sphyraena obtusata	0.17±0.41 items/ind		
		Atule mate	0.22±0.67 items/ind		
		Gerres erythrourus	0.30±0.48 items/ind		
		Nemipterus hexodon	ND		
		Scolopsis taenioptera	0.11±0.32 items/ind		
		Saurida elongate	0.43±0.65 items/ind		
		Saurida undosquamis	0.06±0.24 items/ind		
		Upeneus vittatus	0.10±0.3 items/ind		
		Upeneus tragula	0.20±0.45 items/ind		
		Upeneus sulphureus	ND		
		Platycephalus indicus	0.20±0.45 items/ind		
		Priacanthus tayenus	0.11±0.33 items/ind		
China	Fish	*Clupanodon punctatus* *Clupanodon thrissa* *Siganus fuscessens* *Leiognathus brevirostris* *Alepes djedaba* *Gerres lucidus*	6.6 items/individual	Fiber, White and blue, <0.5mm.	[57]
Korea	Bivalve	Crassostrea gigas	0.07±0.06n/g ww	Fragment, <300µm, Polyester.	[59]
		Mytilus edulis	0.12±0.11n/g ww		
		Tapes philippinarum	0.34±0.31n/g ww		
		Patinopecten yessoensis	0.08±0.08n/g ww		
Thailand	Bivalve	*Perna viridis*	1.53±2.04items/g ww	Fragment, transparent ethylene/propylene, copolymer.	[9]
India	Bivalve	*Magallana bilineata*	0.81±0.45items/g	Fiber, 0.25-0.5mm, Polyethylene.	[55]
China	Bivalve	*Corbicula fluminea*	0.3-4.9 items/g	Fiber, 0.25-1mm, Blue and transparent.	[56]
China	Bivalve	Crassostrea gigas	0.92±0.08 items/g ww	Fiber, Black, <500µm Cellophane.	[12]
		Rudiapes philippinarum	1.51±1.27 items/g ww		
India	Crustacean	*Fenneropenaeus indicus*	0.04±0.07 MPs /g ww	Fiber, red, 500-1000µm, Polyester.	[68]
India	Crustacean	*Metapenaeus monocerous*	3.40±1.23 items/g GT	Filament, black, 1-5mm, Polyamide-6.	[58]
		Penaeus monodon	3.87±1.05 items/g GT		
India	Crustacean	*Metapenaeus monocerous*	7.23±2.63 MPs/ind	Fiber, Black, 100-250µm.	[69]
		Parapeneopsis stylifera	5.36±2.81 MPs/ind		
		Penaeus indicus	7.40±2.60 MPs/ind		
Iran	Crustacean	*Penaeus semisulcatus*	1.51 MPs/g	Fiber, Black and grey, 100-250µm.	[70]
Malaysia	Fish	*Megalaspis cordyla,* *Epinephelus coioides* *Euthynnus affinis* *Thunnus tonggol* *Eleutheronema tridactylum* *Clarias gariepinus* *Colossoma macropomum* *Nemipterus bipunctatus* *Ctenopharyngodon Idella* *Selar boops*	76.8% of plastic particles	Fragment, 149-500µm, Polyethylene.	[72]

5. Fate and Transport of Microplastic

Microplastics enter freshwater basins through effluent, stormwater, agriculture, and surface runoff. Figure 1 shows water microplastic sources and paths. Rivers convey microplastic particles from the land to freshwater, a temporary storage and sink for microplastics, and then to the ocean, the final sink [17,73]. River hydrodynamics and hydrology can impact microplastic movement and entrainment. Greater flow velocity in the river can generate turbulence and instability of the riverbed surface, resulting in higher microplastic concentrations in the river water. Reduced river flow speeds increase the settling and sinking of microplastic particles in sediments, lowering their abundance [17,38]. Increased river channel width reduces flow velocity, which promotes microplastic settling [17]. Microplastics in aquatic and marine environments undergo photodegradation, physical, and thermal weathering. Photochemical degradation is the principal microplastic breakdown mechanism. UV light, temperature, and photo-oxidants like ozone affect plastic trash decomposition [74]. Biofouling of microplastics by microorganisms or algae can promote biofilm development, which increases microplastic density and lowers buoyancy [74].

Density and form impact microplastic transit and dispersion in freshwater systems. PET, PVC, and polyamide tend to settle and sink, while polystyrene, polypropylene, and polyethylene are more buoyant and dispersed by wind and currents [17,75]. Large surface-to-volume ratios of fibrous microplastics contribute to their equal dispersion in the water column, and their inclination to settle with sand particles can lead to a larger abundance of fibrous microplastics in deposited sediments than fragments [17,38]. Compared to sphere-shaped microplastic particles, irregular-shaped ones settle and retain more [38].

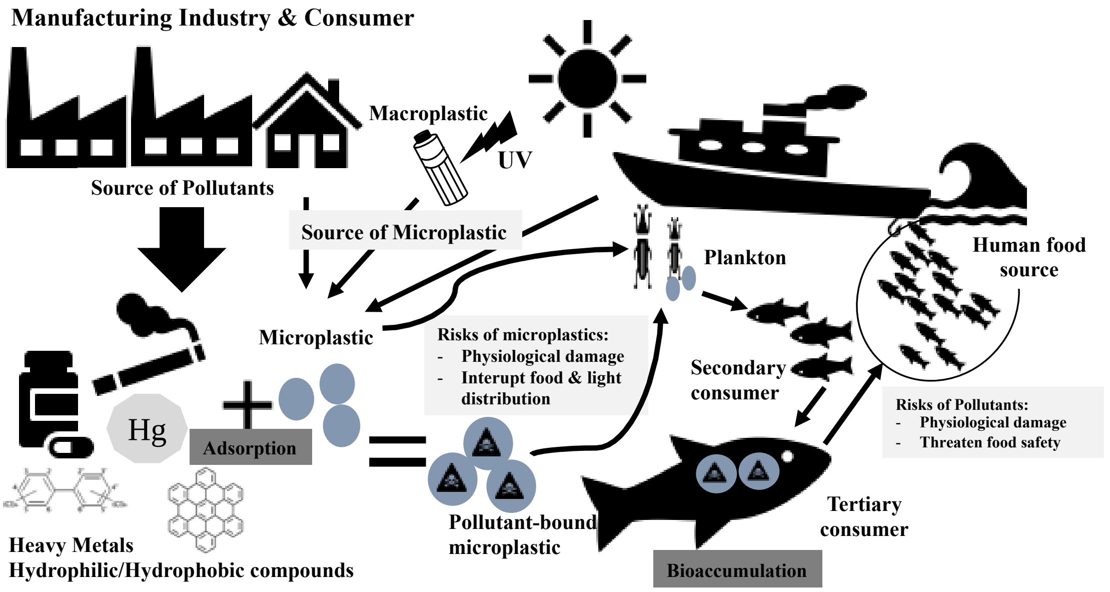

Figure 1. Source and pathway of microplastics.

Aquatic and marine creatures eat microplastics in freshwater and marine water. Marine species excrete microplastics as pseudofeces or translocate them across tissues. *Carcinus maenas* and *Mytilus edulis* ingest microplastics together with fecal pellets [76-78]. Several investigations have shown microplastics in different organs and tissues of organisms [79-80]; in crab hemolymph, gills, hepatopancreas, and ovaries [27]; and in fish liver, gills, and brain

[64,80]. Predation can transmit microplastics from lower to higher trophic level organisms [15]. Microplastics are also a vector for recalcitrant pollutants including heavy metals and persistent organic pollutants (POPs) like polychlorinated bypheniyls (PCBs), dichlorodiphenyltrichloroethane (DDTs), and polycyclic Aromatic Hydrocarbons (PAHs). Hydrophobicity and a high surface-to-volume ratio attract organic and inorganic pollutants with opposing charges and non-polarity [81-83]. Through the intake of microplastics with adsorbed contaminants, hazardous pollutants can bioaccumulate and biomagnify.

6. Impact of Microplastics

6.1. Bioavailability and microplastics ingestion.

Bioavailability of microplastics to biota depends on density, size, color, and abundance in marine and aquatic environments. Higher-density microplastics, such as polyethylene terephthalate and polyvinyl chloride, settle and become bioavailable to benthic animals, while pelagic creatures, such as zooplankton and suspension feeders, ingest buoyant microplastics with low density [61,83]. Smaller and similar-sized microplastics are more accessible to organisms, enhancing their consumption of microplastics as prey. Because of their lower trophic level, lower trophic level species are more likely to consume smaller microplastics [84]. Organisms also tend to eat microplastics whose hue mimics their prey. Plastic waste degradation increases the bioavailability of microplastics to aquatic and marine biota [83]. The modification of microplastics can also affect bioavailability by altering their distribution in water and sediments. Biofouling and defouling cycles can influence the density and buoyancy of microplastic particles. Microplastics sink owing to biofouling, which enhances their bioavailability to benthic animals, including zooplankton [83,85]. Hydrophobicity-induced microplastic aggregation increases microplastic size and density. Biofouling and microplastic aggregation enhance bioavailability at different water column depths [85].

6.2. Trophic transfer of microplastics.

Trophic transfer is one of the mechanisms marine and aquatic species use to absorb microplastics, and laboratory experiments have been undertaken to explore this process. Increased microplastic residence time within organisms before egestion can boost trophic transmission of microplastics up the food chain [86]. A lower concentration of food and the development of aggregation cause a longer retention period of microplastics in zooplankton guts, increasing the transmission of microplastics to higher trophic level species via consumption [87].The aggregate in *Carcinus maenas'* intestines can slow microplastic digestion [88]. Farrell and Nelson et al. confirmed the trophic transfer of polystyrene microplastics from *Mytilus edulis* to *Carcinus maneas* by detecting fluorescent polystyrene microspheres in *Carcinus maneas* hemolymph, gills, and other organs [89]. Santana et al. [90] demonstrated trophic transmission of PVC microplastics from *Perna perna* to *Callinectes ornatus*. After swallowing microplastics, organisms can release plastic additives and desorb contaminants such as persistent organic pollutants and heavy metals, accumulating and transferring them up the food chain to higher trophic level animals. Microplastics are trophically transmitted to *Danio rerio* after accumulating in *Artemia nauplii*, and zebrafish desorb benzo[a]pyrene [91].

Microplastics are trophically transferred by ingestion, bioaccumulation, and biomagnification [10]. Direct and indirect microplastic ingestion occurs. Different feeding techniques impact marine and aquatic animals' microplastic intake. Microplastics are consumed directly by non-selective feeders such as filter feeders and selective feeders.Most filter feeders unknowingly absorb microplastic particles in the environment through water filtering. Higher trophic level creatures misunderstand and consume microplastics that mimic their food in form, size, and color. Indirect microplastic ingestion occurs when organisms eat lower trophic species that have consumed and accumulated microplastics [10]. Microplastics bioaccumulate in the gastrointestinal organs, gills, and other tissues of organisms, causing persistent toxicity, damaged organs, and behavioral abnormalities. Akhbarizadeh et al. found microplastic accumulation in *Epinephelus coioides* and *Penaeus semisulcatus* muscles [11]. Ding et al. [64] found that red tilapia bioaccumulate microplastics in their gills, intestines, liver, and brain. Biomagnification is the buildup of microplastics in higher trophic level species by lower trophic level creatures. Biomagnification of microplastics is unproven [92].

6.3. Ecotoxicological effects of microplastics on organisms.

Microplastics' influence on creatures, especially ecotoxicology, has been examined. Figure 2 depicts the ecotoxicity of microplastic exposure and ingestion. Microplastics can translocate to the hemolymph of *Mytilus edulis* after being swallowed and accumulating in the intestines, inhibiting hemocytes' abilities to fight pathogens, phagocytose, build bivalve shells, and induce oxidative stress owing to hemocyte mortality [78,87]. High-density polyethylene (HDPE) buildup in the lysosomal system of *Mytilus edulis* can produce granulocytomas and disrupt the lysosomal membrane, illustrating the blue mussel's inflammatory response [79]. Bivalve exposure to microplastics can reduce filtering activity, impacting reproduction and development [93-94], and inhibition of cholinesterase and oxidative stress-induced genotoxicity [94].

The main microplastic exposure pathway for fish is direct microplastic ingestion. Microplastic intake can clog and obstruct the digestive system and tract due to the lack of an enzyme route for microplastic breakdown in organisms. False satiation can cause starvation, which reduces food and nutrient intake, slowing growth and reproduction. Ingested microplastics can potentially cause intestinal damage [10,51]. Zebrafish exposed to polystyrene, polyvinyl chloride, polypropylene, polyethylene, and polyamides develop intestinal injuries [95]. Reduced neutrophil phagocytosis and increased lysozyme activity also influence fish immunity [96-97]. Microplastic particles found in fish GI tracts can harm organs such as the liver. Polystyrene microplastics accumulate in the stomach, gills, and liver of *Danio rerio* (zebrafish), causing oxidative stress, alterations in lipid metabolic activity, and inflammation [80]. Ingesting microplastics increases muscle lipid peroxidation, which disrupts swimming and mobility [97]. Polystyrene produces neurotoxicity in *Oreochromis niloticus* by inhibiting acetylcholinesterase (AChE) [64]. Several studies have explored shrimp and crabs' microplastic intake. Microplastic exposure and ingestion can harm crustacean gills by preventing gas exchange, ammonia excretion, and hemolymph osmoregulation [98]. Microplastics reduce crustaceans' feeding efficiency [99]. Watt et al. observed that *Carcinus maenas*' food intake and growth energy dropped [88]. Microplastic exposure can also generate oxidative stress in crustaceans, despite their antioxidant defense system, at higher doses. At high microplastic concentrations in *Charybdis japonica*'s hepatopancreas, antioxidant defense systems fail to ameliorate oxidative stress, which can produce neurotoxicity due to reduced AChE activity [100]. Han et al. determined that microplastic exposure to *Penaeus vannamei* (whiteleg shrimp) can contribute to cardiac muscle dysfunction [101]. The adsorption of positively charged polystyrene microbeads to the algae Chlorella and Scenedesmus caused by the electrostatic force can block sunlight, leading to decreased photosynthetic activity of the algae as well as the generation of reactive oxygen species (ROS) [102]. Wu et al. discovered that increased exposure concentrations of polyvinyl chloride and polypropylene, combined with a reduction in chlorophyll a content, can inhibit the photosynthetic activities of *Microcystis flosaquae* and *Chlorella pyrenoidosa* [103].

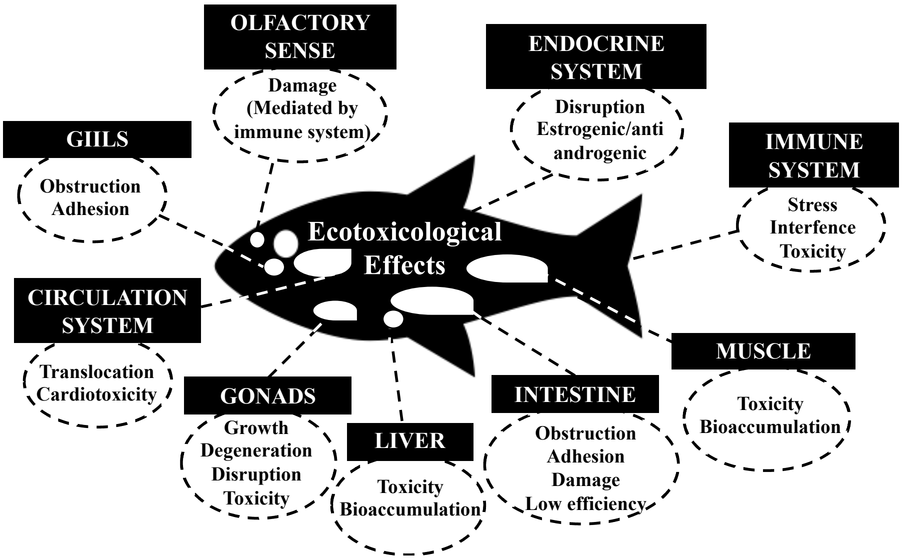

Figure 2. Ecotoxicological effect of microplastic on the organisms.

6.4. Impact of microplastics on human health.

Microplastic bioaccumulation in fish, bivalves, and crustaceans can pose health concerns to people when seafood is ingested. Consuming seafood without eviscerating the GI tract increases the risk of microplastic exposure. Microplastics can cause oxidative stress, cytotoxicity, neurotoxicity, immune system issues, and metabolic disruption [62]. According to lab research, polystyrene exposure can inflame gastric adenocarcinomas and lung cells and promote oxidative stress in human epithelium and brain cells [104-105]. Microplastic buildup in the gut, kidney, and liver of mice caused neurotoxicity, oxidative stress, and decreased energy and lipid metabolism [106]. Microplastics can impair human digestion by blocking and lowering fat digestion, according to Tan et al. [107]. Figure 3 highlights microplastics' health dangers to people.

Microplastics can act as a vector for chemical contaminants because their hydrophobicity and large surface area to volume ratio facilitate the adsorption and accumulation of organic and inorganic pollutants, including heavy metals and persistent organic pollutants (POPs) such as PCBs, DDTs, PAHs, and polybrominated diphenyl ethers (PBDEs). Bisphenol A (BPA), phthalate, and brominated flame retardants (BFRs) are added to plastics to improve their physical qualities and resilience [10,92]. Microplastic exposure and absorption by organisms can cause extra toxicity due to the desorption of ingested chemical pollutants and the leaching of plastic additives into the animals' tissues. Concerns are raised over the joint toxicity of microplastics and associated pollutants, where the chemical contaminants can bioaccumulate and transfer to organisms with higher trophic levels and humans through trophic transfer, posing significant health risks to humans with elevated toxicity levels [92]. Microplastics can leak harmful chemicals such as bisphenol A (BPA), phthalate, and polybrominated diphenyl ethers. These plastic additives are endocrine disruptors that can change human hormone levels and function. BPA exposure can alter organs including the liver and brain, cause cardiovascular disease, reproductive issues, and obesity, while phthalates can cause cancer and asthma [72]. Most available research on the toxicological consequences of microplastics is based on animal studies, and toxicology varies between species. The toxicity mechanism of microplastics and related pollutants such as heavy metals and POPs is unclear [62,92].

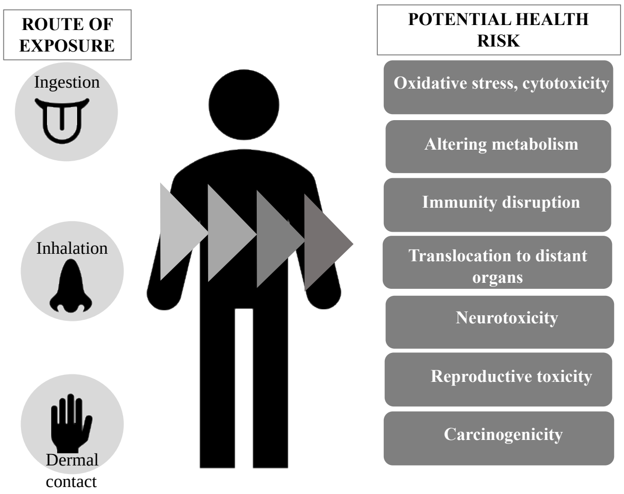

Figure 3. Impact of microplastic on human health.

7. Conclusions

Effluent, stormwater, agricultural, and surface runoff introduce microplastics to freshwater basins. Hydrodynamics and hydrology entangle microplastics. River flow speed can cause turbulence and riverbed instability, increasing microplastic concentrations. Slower river currents help microplastics settle, reducing their number. Photodegrade microplastics. UV radiation, heat, and photo-oxidants destroy trash. Biofouling reduces the buoyancy of microplastics. Bioavailability depends on density, size, color, and amount. Microplastics sink, increasing benthic bioavailability. Zooplankton and suspension feeders eat microplastics. Microplastic bioavailability is affected by water and sediment dispersion. Biofouling impacts microplastic buoyancy and density. Hydrophobicity thickens microplastics. Biofouling increases bioavailability. Trophic transfer absorbs microplastics. Increased microplastic consumption enhances trophic transmission. Lower food concentration and aggregation increase microplastic retention in zooplankton stomachs, enhancing trophic level transmission. Ingestion, bioaccumulation, and biomagnification transmit microplastics. Microplastics are eaten directly and indirectly. The feeding method impacts microplastic ingestion. Nonselective feeders take microplastics like filter feeders. Most filter feeders get microplastics. Selective feeders mistake microplastics for organic food. Lower-trophic animals eat species that contain microplastic. studying microplastics' influence on animals. Microplastics may damage bivalves' filtering activity, development, and life cycles. Microplastic absorption diverts energy to development and maintenance, slowing gametogenesis. Microplastics diminish bivalve cholinesterase and induce oxidative stress. Because organisms lack a microplastic-degrading enzyme, microplastics can obstruct the digestive system. False satisfaction slows growth and reproduction. Ingested microplastics damage the intestines. Zebrafish are killed by polystyrene, PVC, polypropylene, polyethylene, and polyamides. Microplastic ingestion in shrimp and crabs Microplastics hinder gas exchange, ammonia excretion, and blood osmoregulation in crustacean gills.

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Competing Interest

The authors declare that there is no competing interest.

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