Environment and Ecology 43 (1A) : 289—295, January—March 2025
Article DOI: https://doi.org/10.60151/envec/DEVO7788
ISSN 0970-0420

Microplastics in Freshwater Ecosystems: Sources, Transport and Ecotoxicological Impacts on Aquatic Life and Human Health

Varsha, Sushil Kumar Singh

Received 7 February 2025, Accepted 7 March 2025, Published on 17 March 2025

ABSTRACT

Microplastics (MPs) are widespread pollutants in freshwater ecosystems, originating from industrial runoff, urban waste, and agriculture. These particles, ranging from nanometers to millimeters, accumulate in sediments and pose risks to aquatic life. Freshwater organisms ingest MPs, leading to reduced feeding efficiency, growth inhibition, and reproductive toxicity. MPs also act as vectors for toxic chemicals, contributing to bioaccumulation and biomagnification, raising human health concerns. Potential impacts include inflammation, oxidative stress, and chemical exposure. This review explores MP sources, transport mechanisms, and ecotoxicological effects, highlighting the need for further research and effective waste management to mitigate their risks.

Keywords Bioaccumulation, Health concern, Freshwater, Ecosystem, Microplastics.

Varsha[1], Sushil Kumar Singh[2]*

[2]Associate Professor
[1]Dept of Botany, Patliputra University, Patna 800020, India

[2]Dept of Botany, A. N. College, (PPU) Patna 800013, India

Email: sushilkumarppu@gmail.com
*Corresponding author

INTRODUCTION

Microplastic (MP) pollution has become a significant global issue due to the growing use of plastic in everyday life, leading to an increase in MPs worldwide (Yu *et al.* 2018). The demand for plastic has driven a massive rise in its production, from 1.5 million tons in 1950 to 367 million tons in 2020 (Da *et al.* 2017). MPs are often directly released into water bodies such as rivers and lakes from water treatment plants (Kurniawan *et al.* 2023). Since the majority of plastics end up in the environment, the increased production rate, not with standing limited recycling and lack of breakdown to harmless particles, became a significant issue. Primary and secondary sources are the two major ways that MPs are found in the environment. The main sources are synthetic plastics made in smaller sizes for a variety of uses, like manufactured feedstock pellets, household cleansers, cosmetics, industrial abrasives for sandblasting, and polyethylene microbeads (scrubbers) in domestic cleaners (Horton *et al.* 2017). A sizable portion of MPs escape filtration systems and end up in terrestrial habitats, even though wastewater treatment has a high efficiency and can remove up to 95% of MPs (Eerkes *et al.* 2015). Fishing nets, bags, microwave containers, and other large plastic items naturally break down biochemically to produce tiny fibers or fragments that enter the environment and become secondary sources of MP pollutants. Most MPs identified in marine habitats are assumed to have secondary origins as their primary sources. Recent research has shown MPs in freshwater habitats, including groundwater, wetlands, streams and estuaries (Du *et al.* 2021). According to Zhang *et al.* (2022a), wastewater treatment technology, urbanization, human activity, and water quality are the prime factors that are responsible for the increased levels of MP contamination in freshwater systems. A significant source of MPs, wetlands are one of the main ecosystems that take in MPs from wastewater from municipal, industrial, and agricultural sources (Kumar *et al.* 2021). Plastic items like Fishery nets left behind, food packets, Wrappers and beverage bottles are among the items that pollute the aquatic environment (Zhou *et al.* 2018). If large-scale human activities are abandoned, many xenobiotic pollutants may be accidentally or intentionally introduced into aquatic environments around the world (Alimba and Faggio 2019). Microplastics (MPs) are widespread across all levels of aquatic ecosystems and present a serious threat to primary organisms (Aragaw 2021). Research has shown that microplastics (MPs) are present in various edible fish species, demonstrating their potential to accumulate through the food chain and ultimately reach humans via biomagnification (Alfaro-Núñez *et al.* 2021). Since fish serve as a vital protein source for humans, MP contamination in aquatic environments may not only impact fish but also pose indirect risks to human health. The present evaluation centers on diverse facets of MPs, encompassing their origin and the consequences of MP contamination in freshwater environment. The primary objectives of this review are to evaluate the impact of microplastics on fish, examine their effects on human health, and identify gaps in knowledge along with strategies for mitigation. It highlights the need for comprehensive studies to understand MP sources, global spread, health risks, and regulatory recommendations for future control.

Methodology for data collection

Globally, data have been collected from various research articles published by different scholars and scientists. Some online searching data bases like Google scholar, PubMed are used to gather information regarding impacts MP on aquatic life and human.

Sources of MP in the environment

MPs come from both primary and secondary sources. Primary MPs are intentionally added to product like synthetic textiles (35% from washing), cosmetics (2% from microbeads), and electronics. Other major sources include tire abrasion (28%), city dust (24%), road construction (7%), marine coatings (3.7%), and plastic pellets (0.3%) (Landrigan *et al.* 2023). Secondary MPs form when larger plastics, like bottles, degrade due to UV radiation and wave action (Law and Thompson 2014). Environmental factors like temperature, UV radiation, and plastic properties also cause degradation, though freshwater systems experience less forceful degradation than marine environments (Andrady 2011). High UV penetration and low nutrition in freshwater lakes can accelerate plastic breakdown.

Distribution and occurrence of MPs in freshwater

To understand the impact of MP contamination in freshwater ecosystems, it's essential to examine their sources, spread, types, and effects. MPs in freshwater mainly come from industrial materials, personal hygiene products, and synthetic textiles. A major source in rivers is untreated domestic and commercial sewage. MPs are concerning because they accumulate as their size decreases (Frias and Nash 2019), and their large surface area allows them to carry harmful contaminants like metals and toxins. Recent studies show MPs are a significant threat, especially in drinking water (Li *et al.* 2018). Watershed and river system studies highlight the growing accumulation of MPs. MPs are found in high amounts in river sediments and water, often after rainfall, as they can settle from the atmosphere (Parashar and Hait 2023). The concentration of Microplastics are also affected by the flow rate of river. When rivers flow into the ocean, they contribute MPs to marine ecosystems. Proximity to wastewater disposal sites influences the distribution of MPs in freshwater systems.

Worldwide presence of MP concentration in river system

According to Sofra *et al.* (2010), 13.4 items/L of

MP was found in Greater London (UK) in 2010. In Los Angeles (USA) 2011, river San Gabriel had a 10- 12932/m^3 average number of MPs (Moore *et al.* 2011). Thames River (UK) had a 10-9732/m^3 number of MPs found in river water in 2014 (Morritt *et al.* 2014). Yangtze River's (China) surface water had found an average 8465600/km^2 number of MP (Zhang *et al.* 2015). In Australia, River Brisbane had 10 to 520 items/kg of MP in sediment (He *et al.* 2020). In 2023, Rajan *et al*. (2023) estimated 92.85±50.69 items/m^3 found in the River Ganga, India.

Impact of MPs in freshwater ecosystem

The widespread use of plastics has resulted in significant MP contamination in freshwater ecosystems, Presenting a danger to aquatic species and disturbing ecological food chains. Studies have found MPs in various freshwater species, with ingestion rates as high as 83% in some fish species. MPs can cause digestive issues, reduced energy intake, and bioaccumulation of toxic chemicals, further impacting plant and animal life. These pollutants threaten biodiversity and ecosystem stability, highlighting the urgent need for pollution control and sustainable waste management (Sarijan *et al*. 2021).

Toxic effect of MPs on fish

Fish play a vital role in freshwater ecosystems, serving as key biological components that contribute to ecological balance and biodiversity and is highly demanded all over the world for food and commercial purposes. Developing countries are home to 94% of the world's freshwater fisheries, which provide food and support. For millions of the world's most vulnerable populations while also enhancing national economies through exports, tourism, and recreation (FAO 2007). Because MPs are frequently the same size as their meal, fish may inadvertently swallow them when foraging. Exposure to microplastics (MPs) negatively impacts fish development and quality by inducing the production of reactive oxygen species (ROS), leading to cellular damage, inflammation, immunotoxicity, genotoxicity, behavioral changes, DNA damage, and alterations in gut microbiota (Fig. 1). Furthermore, as nano-scale MPs build in tissues and cross the biological barrier, they may have an additional molecular impact on life (Li *et al*. 2021). These MPs will also alter lipid metabolism. Juvenile perch behavior was observed to be affected by exposure to polyethylene terephthalate MPs, according to Lönnstedt and Eklöv (2016). Wright *et al.* (2020) observed that brown trout exposed to PVC microplastics experienced disruptions in their circadian rhythms, resulting in decreased swimming activity. Such behavioral alterations can significantly impact their survival, reproductive success, and overall ecological role. For example, altered behaviours may disrupt predator-prey interactions and community balance, while reduced feeding and activity can slow growth and reproduction.

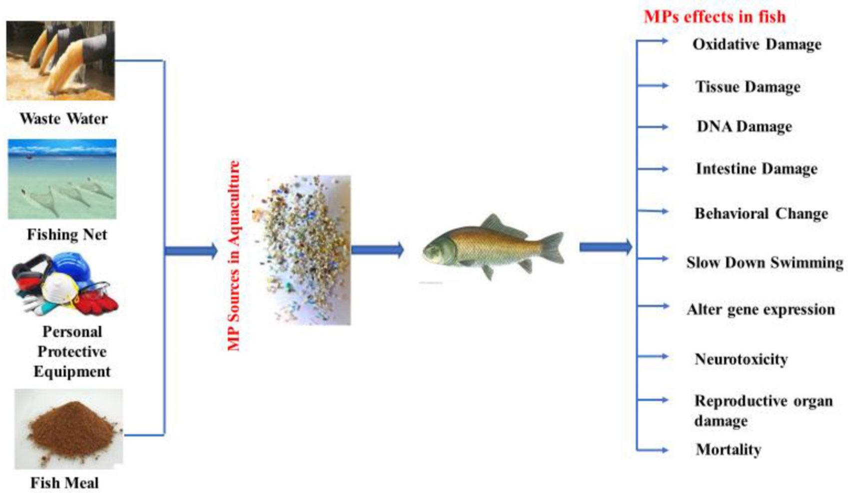

Fig. 1. Toxic effects of MPs in fish.

Toxic effect of MPs through food chain

Plastic often binds to toxic substances in the environment. When ingested by animals, these substances accumulate in their fat and tissues, a process called bioaccumulation. As plastic particles and their associated toxins move up the food chain, their effects become stronger, known as biomagnification. This helps us understand how MPs and their toxins travel across trophic levels. MPs are similar in size and shape to plankton, making them easily ingested by aquatic filter feeders along with various pollutants, leading to bioaccumulation and transfer up the food chain (Desforges *et al.* 2015). Research also indicates that MPs can spread pollutants through food chains by attachment in water or ventilation (Batel *et al.* 2018). Plastics contain hazardous chemicals such as tetrabromobis phenol (TBBPA), bisphenol A (BPA), and polybrominated diphenyl ethers (PBDE), which have been detected in human tissues and bodily fluids. Additionally, di (2-ethylhexyl) phthalate (DEHP) can leach from PVC-based medical devices into patients' bloodstreams (Dong *et al.* 2020). MPs have also been found in seafood, including bivalves consumed by humans (Van and Janssen 2014). Fig. 2 illustrates the accumulation of MPs in organisms and their transfer through the food chain.

Microplastics in human beings

The effects, transport, and distribution of MPs within the human body are still not fully understood. However, research has identified that MPs are found in the digestive systems of various freshwater invertebrates, as well as in both tap and bottled water (Mintenig *et al.* 2019). The effect of MPs is particularly concerning in Shellfish, given the prominence of seafood in human diets. MPs in the digestive tract could potentially spread to other body parts. MPs enter the human body primarily through endocytosis and persorption (Fig. 3).

The toxicological effects of MPs may also impair fish health, raising concerns for human consumers, especially those who frequently eat fish.

Toxicological effects in human health

MPs, when ingested or inhaled, can trigger inflammatory responses in the body, potentially leading to chronic inflammation and contributing to respiratory issues like asthma and gastrointestinal disorders (Galloway and Lewis 2017). MPs often contain harmful additives, such as bisphenol A (BPA) and phthalates, that can leach into the body and disrupt endocrine

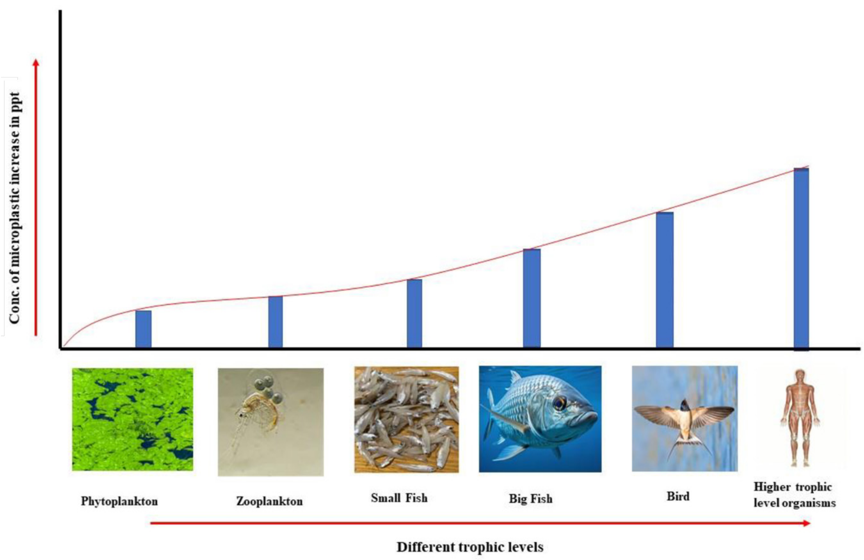

Fig. 2. Graph showing increasing of MP level along with the increase in trophic levels of a particular food chain in ppt (Parts per thousand).

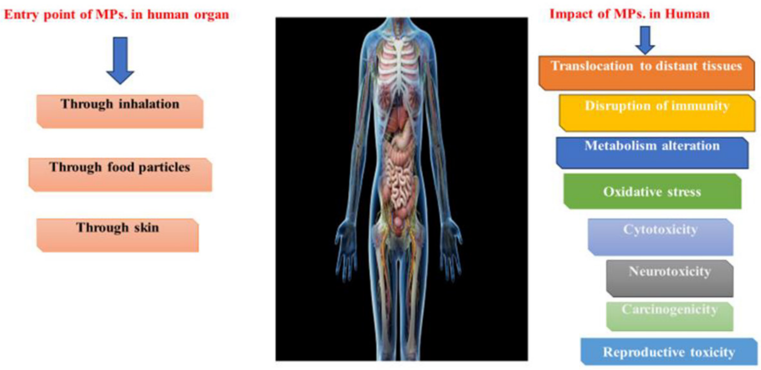

Fig. 3. Entry point of MPs in human organ and its impact on human body.

function, increasing the risk of reproductive issues, developmental delays, and cancers (Koelmans *et al.* 2022). Studies have examined that MPs can adsorb toxic chemicals from the environment, such as heavy metals and persistent organic pollutants (POPs), which, when consumed, accumulate in the body and can damage organs like the liver, kidneys, and heart (Mintenig *et al.* 2019). Furthermore, MPs can cause oxidative stress at the cellular level, leading to DNA damage and cell death, which may increase the risk of developing cancer or degenerative diseases. Ingested MPs can also disrupt gut health, affecting nutrient absorption and disturbing the gut microbiota, which can compromise immune system function and overall health.

Research gap and future prospective

Scientists are increasingly studying the effects of MPs on freshwater environments and organisms, but several research gaps remain. A key area is understanding how MPs are ingested, absorbed, and transported through food chains, including their attachment to gut walls. MPs also act as carriers for contaminants like metals, organic pollutants, and viruses, requiring further investigation into how these toxins are transported and their impacts on fish. Additionally, MPs may amplify toxicity when combined with other pollutants, making it crucial to study these compounded risks at various stages of fish development. Comparing the harmful effects of microplastics in fish with those of other prevalent pollutants, such as heavy metals, is essential for gaining a thorough understanding of the risks to human health. Addressing these knowledge gaps will improve our awareness of both the ecological and health-related impacts of microplastics.

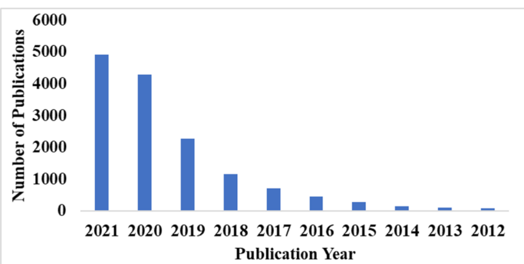

Fig. 4. Year wise publications on MPs effects in fish.

Research trends on the impact of MPs in fish and humans

Research by Garrido Gamarro *et al.* (2020) emphasizes that MP pollution is becoming an increasing environmental concern, putting both fish and human health at risk. MPs are present in fish all over the world, and humans can be exposed to them by eating contaminated seafood. There is a growing focus on understanding how microplastics affect both aquatic life and human health (Chae and An 2018). Despite the increasing number of studies, the full extent of their impact is still not well understood. Figures. 4-5 show trends in research, highlighting the rising importance of studying microplastics.

Management and public awareness initiatives

Managing MP pollution in freshwater ecosystems

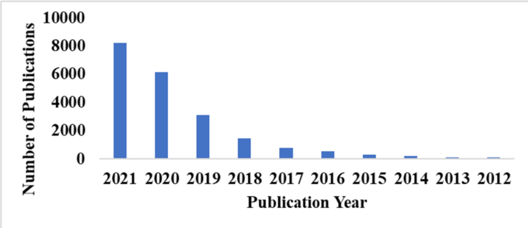

Fig. 5. Year wise publications on MPs effects in human.

requires a combination of preventive and remedial approaches. Reduce the manufacturing and single-use plastics uses, implementing strict waste management practices, and encouraging recycling can significantly curb the amount of plastic waste entering freshwater systems. Upgrading wastewater treatment facilities to filter microplastics more effectively is crucial, as these facilities are often the last line of defence before pollutants reach rivers and lakes. Public awareness campaigns and policies that regulate microplastic pollution, such as banning microbeads in personal care products, can also play a significant role. Additionally, research on bioremediation techniques and eco-friendly materials can provide long-term solutions, minimizing the ecological and health risks posed by microplastics in these environments.

CONCLUSION

Plastic is a widely used material, but MP contamination now affects all levels of aquatic ecosystems from seafloor sediments to surface waters due to improper use and disposal. MPs are ingested by aquatic life, including plankton and fish, which then accumulate these particles in their bodies. When people consume contaminated fish, they too are exposed to these plastics, raising health concerns linked to chronic illnesses. Reducing MP pollution is essential. This requires cutting down on single-use plastics, like bags and bottles, and implementing stricter regulations to improve waste management and recycling. Additionally, innovative methods for breaking down plastics can help create sustainable materials, reducing their impact on ecosystems and human health.

ACKNOWLEDGMENT

We sincerely acknowledge Rajeev Ranjan for his valuable assistance in reviewing and editing the manuscript.

REFERENCES

Alfaro-Núñez A, Astorga D, Cáceres-Farías L, Bastidas L, Soto Villegas C, Macay K, Christensen JH (2021) Microplastic pollution in seawater and marine organisms across the tropical eastern pacific and Galápagos. *Scientific Reports* 11(1): 6424. https://doi.org/10.1038/s41598-021-85939-3

Alimba CG, Faggio C (2019) Microplastics in the marine environment: Current trends in environmental pollution and mechanisms of toxicological profile. *Environmental Toxicology and Pharmacology* 68: 61-74. https://doi.org/10.1016/j.etap.2019.03.001

Andrady AL (2011) Microplastics in the marine environment. *Marine Pollution Bulletin* 62(8) : 1596-1605. https://doi.org/10.1016/j.marpolbul.2011.05.030

Aragaw TA (2021) Microplastic pollution in African countries' water systems: A review on findings, applied methods, characteristics, impacts and managements. *SN Applied Sciences* 3(6): 629. https://doi.org/10.1007/s42452-021-04619-z

Batel A, Borchert F, Reinwald H, Erdinge L, Braunbeck T (2018) Microplastic accumulation patterns and transfer of benzo [a] pyrene to adult zebrafish (Danio rerio) gills and zebrafish embryos. *Environmental Pollution* 235 : 918-930. https://doi.org/10.1016/j.envpol.2018.01.028

Chae Y, An YJ (2018) Current research trends on plastic pollution and ecological impacts on the soil ecosystem: A review. *Environmental Pollution* 240: 387-395. https://doi.org/10.1016/j.envpol.2018.05.008

Da Costa JP, Duarte AC, Rocha-Santos TA (2017) Microplastics–occurrence, fate and behavior in the environment. Comprehensive analytical chemistry. *Elsevier* 75: 1–24. https://doi.org/10.1016/bs.coac.2016.10.004

Desforges JPW, Galbraith M, Ross PS (2015) Ingestion of microplastics by zooplankton in the northeast pacific ocean. *Archives of Environmental Contamination and Toxicology* 69 : 320-330. https://doi.org/10.1007/s00244-015-0172-5

Dong CD, Chen CW, Chen YC, Chen HH, Lee JS, Lin CH (2020) Polystyrene microplastic particles: *In vitro* pulmonary toxicity assessment. *Journal of Hazardous Materials* 385: 121575. https://doi.org/10.1016/j.jhazmat.2019.121575

Du H, Xie Y, Wang J (2021) Microplastic degradation methods and corresponding degradation mechanism: research status and future perspectives. *Journal of Hazardous Materials* 418 : 126377. https://doi.org/10.1016/j.jhazmat.2021.126377

Eerkes-Medrano D, Thompson RC, Aldridge DC (2015) Microplastics in freshwater systems: a review of the emerging threats, identification of knowledge gaps and prioritisa tion of research needs. *Water Research* 75 : 63-82. https://doi.org/10.1016/j.watres.2015.02.012

Food and Agriculture Organization (2007) The state of food and agriculture 2007: Paying farmers for environmental services. FAO. https://www.fao.org/3/a1200e/a1200e00.htm

Frias JP, Nash R (2019) Microplastics: Finding a consensus on the definition. *Marine Pollution Bulletin* 138 : 145-147. https://doi.org/10.1016/j.marpolbul.2018.11.022

Galloway TS, Lewis CN (2017) Marine microplastics. *Current Biology* 27(11): R445–R446. https://doi.org/10.1016/j.cub.2017.01.043

Garrido Gamarro E, Ryder J, Elvevoll EO, Olsen RL (2020) Microplastics in fish and shellfish – A threat to seafood safety? *Journal of Aquatic Food Product Technology* 29(4) : 417–425. https://doi.org/10.1080/10498850.2020.1739793

He B, Goonetilleke A, Ayoko GA, Rintoul L (2020) Abundance, distribution patterns, and identification of microplastics in Brisbane River sediments, Australia. *Science of the Total Environment* 700: 134467. https://doi.org/10.1016/j.scitotenv.2019.134467

Horton AA, Walton A, Spurgeon DJ, Lahive E, Svendsen C (2017) Microplastics in freshwater and terrestrial environments: Evaluating the current understanding to identify the knowledge gaps and future research priorities. *Science of the Total Environment* 586: 127-141. https://doi.org/10.1016/j.scitotenv.2017.01.190

Koelmans AA, Redondo-Hasselerharm PE, Nor NHM, de Ruijter VN, Mintenig SM, Kooi M (2022) Risk assessment of microplastic particles. *Nature Reviews Materials* 7: 138–152. https://doi.org/10.1038/s41578-021-00411-y

Kumar R, Sharma P, Bandyopadhyay S (2021) Evidence of microplastics in wetlands: Extraction and quantification in fresh water and coastal ecosystems. *Journal of Water Process Engineering* 40 : 101966. https://doi.org/10.1016/j.jwpe.2021.101966

Kurniawan TA, Haider A, Ahmad HM, Mohyuddin A, Aslam HMU, Nadeem S, Chew KW (2023) Source, occurrence, distribution, fate, and implications of microplastic pollutants in freshwater on environment: A critical review and way forward. *Chemosphere* 325: 138367. https://doi.org/10.1016/j.chemosphere.2023.138367

Landrigan PJ, Raps H, Cropper M, Bald C, Brunner M, Canonizado EM, Dunlop S (2023) The Minderoo-Monaco Commission on plastics and human health. *Annals of Global Health* 89(1): In press. doi: 10.5334/aogh.4056

Law KL, Thompson RC (2014) Microplastics in the seas. *Science* 345 (6193): 144-145. https://doi.org/10.1126/science.1254065

Li J, Green C, Reynolds A, Shi H, Rotchell JM (2018) Microplastics in mussels sampled from coastal waters and supermarkets in the United Kingdom. *Environmental Pollution* 241: 35-44. https://doi.org/10.1016/j.envpol.2018.05.038

Li Y, Sun Y, Li J, Tang R, Miu Y, Ma X (2021) Research on the influence of microplastics on marine life. *In IOP Conference Series: Earth and Environmental Science* 631(1) 012006). IOP Publishing. https://doi.org/10.1088/1755-1315/631/1/012006

Lönnstedt OM, Eklöv P (2016) (retracted) Environmentally relevant concentrations of microplastic particles influence larval fish ecology. *Science* 352 (6290) : 1213–1216. https://doi.org/10.1126/science.aad8828

Mintenig SM, Löder MG, Primpke S, Gerdts G (2019) Low num bers of microplastics detected in drinking water from ground water sources. *Science of the Total Environment* 648: 631-635. https://doi.org/10.1016/j.scitotenv.2018.08.178

Moore CJ, Lattin GL, Zellers AF (2011) Quantity and type of plastic debris flowing from two urban rivers to coastal waters and beaches of Southern California. *Revista de Gestão Costeira Integrada-Journal of Integrated Coastal Zone Management* 11(1) : 65-73. http://www.redalyc.org/articulo.oa?id=388340132008

Morritt D, Stefanoudis PV, Pearce D, Crimmen OA, Clark PF (2014) Plastic in the Thames: A river runs through it. *Marine Pollution Bulletin* 78 (1-2) : 196-200. doi:10.1016/j.marpolbul.2013.10.035.

Parashar N, Hait S (2023). Plastic rain—Atmospheric microplastics deposition in urban and peri-urban areas of Patna City, Bihar, India: Distribution, characteristics, transport, and source analysis. *Journal of Hazardous Materials* 458: 131883. https://doi.org/10.1016/j.jhazmat.2023.131883

Rajan K, Khudsar FA, Kumar R (2023) Urbanization and population resources affect microplastic concentration in surface water of the River Ganga. *Journal of Hazardous Materials Advances* 11: 100342. https://doi.org/10.1016/j.hazadv.2023.100342

Sarijan S, Azman S, Said MIM, Jamal MH (2021) Microplastics in freshwater ecosystems: A recent review of occurrence, analysis, potential impacts, and research needs. *Environmental Science and Pollution Research* 28: 1341-1356. https://doi.org/10.1007/s11356-020-11171-7

Sofra C, Calarke B, Calarke GD (2010) September. Microplastics in the marine environment: Investigating possible sources, presence and abundance. In Poster presented at Student Research Meeting, pp 21.

Van Cauwenberghe L, Janssen CR (2014) Microplastics in bivalves cultured for human consumption. *Environmental Pollution* 193: 65-70. https://doi.org/10.1016/j.envpol.2014.06.010

Wright SL, Ulke J, Font A, Chan KLA, Kelly FJ (2020) Atmospheric microplastic deposition in an urban environment and an evaluation of transport. *Environment International* 136: 105411. https://doi.org/10.1016/j.envint.2019.105411

Yu X, Ladewig S, Bao S, Toline CA, Whitmire S, Chow AT (2018) Occurrence and distribution of microplastics at selected coastal sites along the southeastern United States. *Science of the Total Environment* 613: 298-305. https://doi.org/10.1016/j.scitotenv.2017.09.100

Zhang K, Gong W, Lv J, Xiong X, Wu C (2015) Accumulation of floating microplastics behind the Three Gorges Dam. *Environmental Pollution* 204: 117-123. https://doi.org/10.1016/j.envpol.2015.04.023

Zhang T, Jiang B, Xing Y, Ya H, Lv M, Wang X (2022) Current status of microplastics pollution in the aquatic environment, interaction with other pollutants, and effects on aquatic organisms. Environmental Science and Pollution Research, pp 1-30. https://doi.org/10.1007/s11356-022-18504-8

Zhou Q, Zhang H, Fu C, Zhou Y, Dai Z, Li Y, Luo Y (2018) The distribution and morphology of microplastics in coastal soils adjacent to the Bohai Sea and the Yellow Sea. *Geoderma,* 322: 201-208. https://doi.org/10.1016/j.geoderma.2018.02.015