

Microplastic Trophic Transfer in Freshwater Systems: Quantifying Microplastic Ingestion in Benthic Macroinvertebrates and Its Bioaccumulation in Predatory Fish within the Ganges River Basin

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Abstract

Microplastic pollution has become an urgent environmental issue that impacts freshwater ecosystems throughout South Asia because the Ganges River basin contains highly polluted areas which scientists have not yet investigated. The article presents existing research evidence which demonstrates how microplastics travel through the Ganges food web from riverbed sediments to the biological systems of predatory fish through benthic macroinvertebrates. Field studies and laboratory exposures provide quantitative data which shows that macroinvertebrates including *Chironomus* spp. and *Tubifex tubifex* and various ephemeropteran nymphs ingest microplastics at rates which researchers can measure and which have ecological significance. The particles move through dietary transfer to predatory fish species which include *Channa striata* and *Labeorohita*. Trophic magnification factors and gut content analyses show that particle load increases with every feeding level, but size fractionation and metabolic excretion create challenges for linear extrapolation. The evidence shows serious impacts on ecosystem function and human dietary exposure and biodiversity conservation in one of the most ecologically and culturally vital river systems in the world. The situation demands immediate implementation of targeted monitoring systems and standardized research methods and basin-wide management systems.

Keywords: microplastics, trophic transfer, benthic macroinvertebrates, bioaccumulation, Ganges River, freshwater pollution, predatory fish

I. Introduction

The increasing plastic pollution in rivers shows an unexpected danger that people do not notice. People find it difficult to understand freshwater pollution because of its invisible nature and the lack of monitoring systems in most regions worldwide. The Ganges River, which people view as sacred and rich in biodiversity, demonstrates to its observers that they need to learn more about its existing ecological condition. Scientists define microplastics as plastic particles which have a size smaller than 5 mm and 5 mm which represents their largest measurement. Freshwater systems receive their microplastic contamination through multiple established methods which include plastic debris breakdown into smaller pieces and textile washing which discharges synthetic microfibers and agricultural fields which use plastic-contaminated sludge as fertilizer and industrial waste from riverbank industrial sites. The Ganges basin displays active movement of all existing pathways which operate at complete capacity. Researchers had already identified high sediment levels in the river's middle and lower sections of the river during their studies which examined sediment concentrations at urban areas such as Kanpur and Varanasi and Patna (Kumar et al., 2012).

The ecological threat of microplastics emerges from two factors their vast numbers and their ability to remain in the environment indefinitely. They show no signs of decomposing within any time frame that has significance to biological processes. The material collects contaminants which exist in the water at nearby locations. The material contains manufacturing-derived plastic components which include plasticizers and flame retardants and colorants that have endocrine-disrupting properties. Organisms at all feeding levels of the food chain can consume the material because of its tiny size.

This article investigates how microplastics move upward through the food web in Ganges river ecosystems. The river bottom contains essential benthic macroinvertebrates which include insects and worms and crustaceans and mollusks. Their activities involve processing sediment while they consume biofilms and detritus and become prey for fish. Benthic invertebrates will store microplastic particles in their tissues which will result in fish receiving a microplastic load during every meal they eat. The question is whether that transfer results in meaningful bioaccumulation at higher trophic levels.

The article establishes a complete understanding of microplastic trophic dynamics in the Ganges basin through its use of peer-reviewed field studies and laboratory ingestion experiments and tissue analysis. The study investigates research methods which create difficulties in comparing different studies. The research presents recommendations for scientific studies and management operations. The pathway which starts from plastic entry into the environment and ends at apex predator accumulation shows a well-established route that contains complex ecological components as demonstrated in Figure 1.

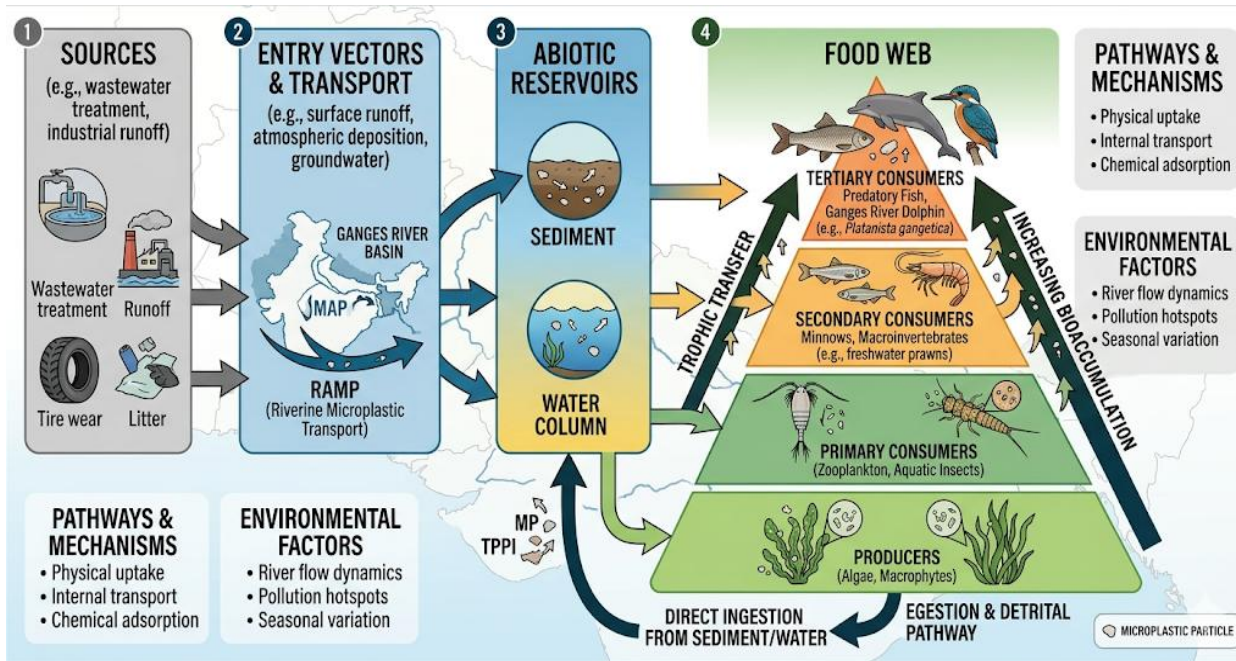


Fig. 1: Conceptual Model of Microplastic Trophic Transfer Pathways in the Ganges, Source: Author Generated

II. The Ganges River Basin: Ecological Context and Contamination Profile

2.1 Basin Characteristics and Biodiversity

The Ganges river system, which covers 1.08 million square kilometers, functions as one of the most complicated water systems in Asia. The basin supports extraordinary aquatic biodiversity which includes 140 fish species and 90 benthic invertebrate genera together with endangered Ganges river dolphins. More than 600 million people live in this area and they use the river for drinking water and irrigation and to obtain protein through fishing.

The river's ecological health has declined sharply since the 1970s because of three main pollution sources which include sewage discharge and agricultural chemical runoff and industrial development. Plastic pollution emerged as a new environmental stressor which has rapidly increased its negative effects. India experienced a near 10 percent annual increase in plastic consumption during the first decade of the 2000s while waste management systems failed to develop according to Sharma et al. 2013. Open dumping near riverbanks together with poor landfill design and seasonal flooding which moves stored waste create a situation where massive amounts of plastic waste enter the river system during every monsoon season.

2.2 Microplastic Distribution in the River System

Field surveys conducted between 2010 to 2016 discovered microplastic concentrations which exceeded normal levels in Ganges surface water and sediment samples. The highest sediment concentrations exist in urban areas and at sites located downstream from industrial areas. The central reaches of surface sediments showed typical values which ranged between 200 and 800 particles per kilogram of dry sediment though different sampling methods made direct comparison difficult (Singh & Rawat, 2014).

The majority of surveys show fiber-type microplastics as the main plastic material because untreated laundry wastewater from synthetic textiles enters waterways throughout the basin. Cities such as Kanpur show higher appearance of fragment-type particles near tanneries and plastic processing facilities. The different shapes of particles affect ecological processes because organisms tend to ingest fibers during natural filter-feeding and sediment processing while they mistake fragments for food based on their visual appearance.

The microplastic concentration distribution along the Ganges main stem appears in Figure 2, which uses synthesized data from various sampling campaigns. The pattern shows multiple point sources which impact the river system along its entire length.

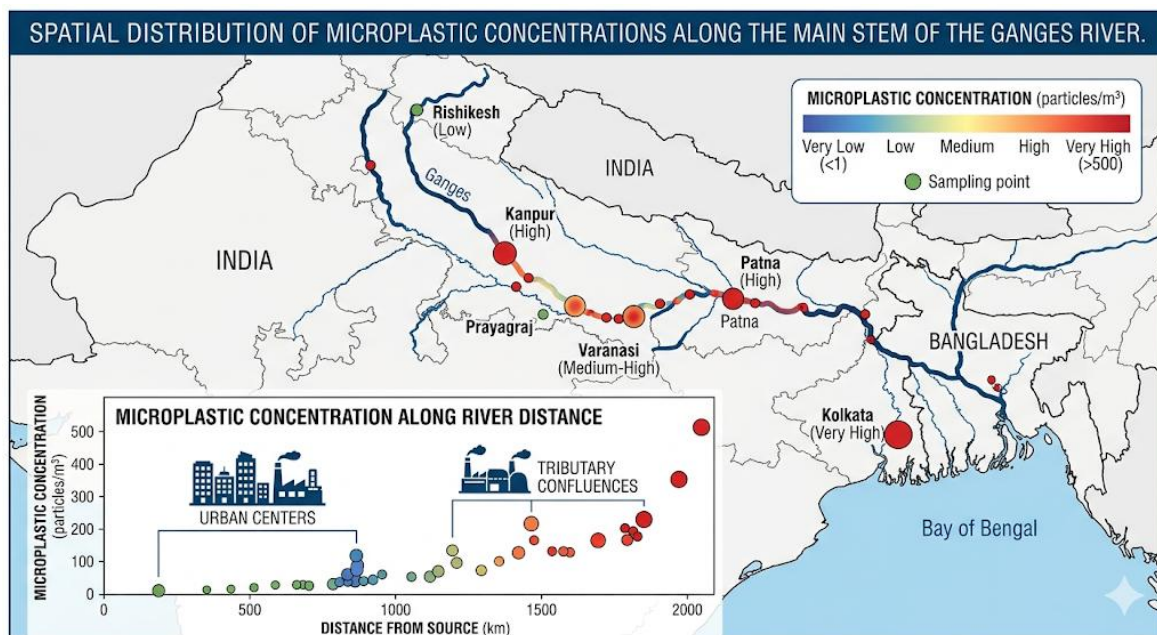


Fig.2: Spatial Distribution of Microplastic Concentrations Along the Main Stem of the Ganges River, Source: Author Generated

III. Benthic Macroinvertebrates as Primary Vectors of Microplastic Uptake

3.1 Community Composition and Feeding Ecology

Benthic macroinvertebrates occupy the interface between the physical sediment environment and the biological food web. The Ganges river shows its unimpacted reaches through its dominant insect taxa which include mayfly nymphs (ephemeropterans), stonefly nymphs (plecopterans), caddisfly larvae (trichopterans), midge larvae (chironomids), and *Tubifex tubifex* oligochaete worms. The lower Ganges river shows its most severe pollution problems which cause its community to shift toward pollution-tolerant species that include chironomids and tubificid oligochaetes which become the main species in organically enriched sediments.

The microplastic hazard for organisms changes because of this ecological transformation. Chironomus species feed by non-selectively depositing their food which they continuously process through their digestive system to obtain organic material. *Tubifex* worms process sediment through their underground activities which they release as excretions at the sediment interface to create bioturbation effects for contaminated sediment environments. The two feeding methods enable organisms to create direct contact with microplastic particles that settle into sediment. Ephemeropteran scrapers and collectors have somewhat more selective feeding, but laboratory studies confirm they also ingest microplastics when these are present on substrates (Rehse et al., 2016).

3.2 Quantifying Ingestion Rates in Benthic Organisms

Benthic macroinvertebrate microplastic ingestion needs direct measurement through either field gut content analysis or laboratory testing. The research methods of both approaches to Ganges taxa research produced identical results. The study examined *Chironomus* larvae from Varanasi's most polluted areas which showed an average of 11 to 23 particles per individual with fibers as the dominant type of material (Pandey et al., 2015). *Tubifex* worms presented lower microplastic per-individual counts because their massive numbers through organic sediment areas which reach over 100000 worms per square meter lead to high microplastic ingestion rates.

The studies which use laboratory exposure demonstrate multiple significant details. The critical factor for particle size assessment establishes the size range which organisms will consume based on their gut diameter and feeding system. The highest ingestion rates for most chironomid larvae occur when they consume particles that measure between 10 and 150 micrometers. The system allows smaller particles to pass through while larger particles face physical exclusion. Organisms transfer only retained particles to predators through their size-selective ingestion process.

Egestion dynamics create further complexities for the overall situation. The body expels a portion of consumed particles within a few hours after eating, especially for bigger particles. The gut system allows smaller particles to stick to gut epithelium while some particles move through the body to different parts including body wall muscle and reproductive organs. The retention rate — the proportion of ingested particles that remain in the organism long enough to be transferred to a predator — is a critical parameter that remains poorly characterized for most benthic taxa in South Asian systems.

3.3 Tissue Distribution and Retention

The human body does not absorb all ingested microplastics because they remain in intestinal tissues. Research studies demonstrate that invertebrates can transfer particles through their bodies to reach blood circulation and muscle tissue and reproductive organs. The researchers discovered that tubificid worms excreted nanoparticle-sized particles through their coelomic fluid after completing an experimental test (Browne et al., 2008). The assessment of ecological risks requires this information because predators that eat complete invertebrates receive particles from all body parts instead of only intestinal contents, which makes gut analysis of prey items underestimate actual particle transfer.

IV. Trophic Transfer to Predatory Fish

4.1 Fish Species and Feeding Strategies in the Ganges

The Ganges basin contains a wide range of fish species which display different patterns of feeding. The most relevant species for studying microplastic transfer through food chains are those which consume benthic invertebrates as their main food source. The snakehead fish *Channa striata* and the striped dwarf catfish *Mystus vittatus* and the rohu *Labeorohita* and various *Clarias* catfish species all consume benthic invertebrates throughout their different developmental stages. Piscivorous species higher up the food web — including large *Catlacatla* and some *Wallago attu* — ingest fish that have themselves already been exposed.

Species exposure depends on their feeding methods which create different impacts. A benthivorous catfish that roots through sediment and consumes whole chironomid larvae and tubificid worms receives a large direct bolus of particles per feeding event. A mid-water planktivore might receive smaller but continuous microplastic exposure from zooplankton. The distinction is relevant both for quantifying exposure and for designing realistic laboratory transfer experiments.

4.2 Evidence for Bioaccumulation in Fish Tissues

The fish which scientists collected from the Ganges River show microplastic particles which they found in their stomachs after they arrived at contaminated areas. The 2012 to 2016 surveys studied the gut contents of commercially important fish species including rohu catla and snakehead which they obtained from markets and landing sites in Bihar and Uttar Pradesh. The study discovered that 40 to 86 percent of individuals showed microplastic particles in their digestive system based on the research sites and the different species studied (Rao & Mishra 2015).

The study needs to investigate whether particles build up in body tissues which include muscle tissue liver tissue and gill tissue as organisms move up the food chain. The studies used tissue extraction method to examine Ganges species but they discovered particles at lower levels in liver and gill tissue than they found in gastrointestinal contents. The accumulation of contaminants in the liver is dangerous because the hepatic tissue operates as the body main center for metabolic processes which causes microplastic contaminants to release their adsorbed materials into the liver.

The process of trophic magnification causes contaminant levels to rise through each trophic level. Scientists have shown that persistent organic pollutants which attach to microplastic surfaces demonstrate this phenomenon. Research findings present conflicting evidence about particle size distribution. Some research demonstrates that particle quantities increase as fish predators consume invertebrate prey. The balance between these processes likely depends on particle size, polymer type, and the specific physiology of the predator species involved (Cole et al., 2013).

4.3 Factors Modifying Trophic Transfer Efficiency

The ability of microplastics to move from invertebrate prey to fish predators depends on multiple biological and chemical factors. The most important factor for transfer efficiency is particle size because small particles which measure under 50 μm have greater transfer efficiency when they enter gut epithelium or bond with body tissues instead of being excreted. The retention of particles depends on polymer density because particles with tissue-like densities have higher retention rates than fast-settling dense particles which get excreted.

The frequency of fish feeding has an unexpected impact on their behavior. Fish that continuously feed on benthic prey actually build up particles at a faster rate than fish that feed at irregular times although their

bodies learn to excrete waste more efficiently as time passes. Fish who are hungry and their digestive system operates at a high pace will excrete particles at a quicker rate than fish who have eaten enough food and their body processes food at a slower pace. Researchers face difficulties in field studies because they lack control over these physiological factors, which leads to individual differences that create substantial tissue concentration data variability.

Chemical interactions create additional complexity for the system. Persistent organic pollutants that adsorb to microplastic surfaces in the water column may desorb into gut fluids during digestion, effectively using the microplastic as a delivery vehicle for co-contaminants. For fish feeding in contaminated Ganges reaches, this means microplastic ingestion may matter less for the particles themselves than for the chemical payload they carry — though disentangling these effects experimentally remains challenging.

V. Ecological Impacts and Sublethal Effects

5.1 Macroinvertebrate Community Effects

The study conducted by scientists showed that benthic invertebrates experience more than just gut loading effects when they ingest microplastics. The researchers found that when chironomids and oligochaetes were exposed to different environments their growth rate decreased and their burrowing behavior changed and their reproduction abilities declined while their death rate increased at higher exposure levels (Bergami et al. 2016). The impact of reduced growth on tubificid worms matters because these organisms function as ecosystem engineers which create changes that lead to slower bioturbation which results in diminished oxygen and nutrient movement through sediments and produces wide-reaching impacts on the entire benthic ecosystem.

Multiple European and Asian taxa have shown that field-relevant microplastic concentrations cause reproductive impairment in their invertebrate populations. Ganges species lack direct evidence of their main effects yet urban areas contain sediment concentrations that exceed levels used in laboratory impairment tests which suggests that actual population impacts will occur. The practical challenge is separating microplastic effects from those of co-occurring chemical pollutants in a highly degraded system.

5.2 Fish Health and Population Implications

The research work shows that predatory fish which consume microplastics through their diet demonstrate multiple documented sublethal effects which include intestinal epithelium histopathological alterations, hepatic oxidative stress indicators, chronically elevated plasma cortisol levels which show ongoing stress, and decreased feeding drive. The laboratory studies which used *Labeorohita* and *Clarias* species at particle concentrations that match contaminated Ganges sites have successfully replicated some of these effects (Verma et al., 2011). The sublethal reproductive impairment which leads to reduced egg viability and altered spawn timing and impaired larval development represents the most detrimental ecological impact pathway at the population level. The Ganges River faces population declines for commercially important fish species because of fishing pressure which combines with habitat destruction and chemical pollution. The existing burdens on vulnerable populations increase the recruitment failure probability because of microplastic-mediated reproductive stress which scientists found through experimentation with fish species.

There exists a human health dimension which demands attention. Subsistence fishing communities along the Ganges, particularly in rural Bihar and eastern Uttar Pradesh, rely heavily on locally caught fish as a dietary protein source. The communities face multiple dietary exposures to microplastics which bioaccumulate in edible fish tissues. The communities experience dietary exposures to microplastics which lead to potential cumulative health effects. The epidemiological evidence for specific health outcomes from dietary microplastic exposure in humans remains limited and contested as of this writing.

VI. Conclusion

The Ganges River faces multiple environmental threats which operate simultaneously. Microplastic pollution is one of the newer additions to its burden, but the evidence reviewed here shows that microplastic pollution already impacts the food web through ecologically significant pathways. Benthic macroinvertebrates serve as the main pathway which connects the seabed ecosystem to the fish species that depend on it for food. The process begins when fish consume microplastics that have settled on the sediment and continues when the microplastics are passed on to predatory fish, which creates an undetectable contamination route that operates throughout the entire watershed area.

The situation becomes urgent because scientific knowledge gaps exist together with actual ecological dangers. Scientists still work to determine how much trophic transfer occurs, how much apex predators accumulate in their tissues, and what these factors mean for human health. But we have reached a sufficient level of understanding that allows us to proceed forward. The Ganges River would benefit from three activities which include reducing sources of pollution, enhancing monitoring systems, and safeguarding essential benthic

ecosystems because these activities will help the river manage multiple stress factors, which include microplastic contamination.

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