A Review on Microplastics contamination in Agricultural Soil and Water bodies of Central India

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Abstract : Plastic particles ranging from 1µm to 5 mm in size are known as microplastics. Due to its wide applications in industries and households, it has emerged as a potential environmental contaminant. These are found in freshwater, marine, groundwater, soil, and surrounding vegetation. Due to their bioaccumulation potential, aquatic life is severely threatened, and human health is indirectly in danger. The most utilized MPs are - Polyethylene, Polypropylene, Polyethylene Terephthalate, Polystyrene, Polyurethane, Polyamide and many more. Central Indian states like Madhya Pradesh, Chhattisgarh and Maharashtra, being an important agricultural and industrial belt, have till now focused less research on specific MP pollution compared to the coastal and major river systems. The aim of this review is to conduct a thorough analysis of existing research with regards to MPs in freshwater ecosystems and agricultural soil of central India, focusing on the methods of analysis for detection, and also mitigation strategies. Though localized studies confirm contamination, knowledge gaps still exist on long-term ecological risks and human health effects, and the requirement for region-specific mitigation strategies.

IndexTerms **- Microplastics, Aquatic pollution, Soil pollution, Density separation, Plastic waste management, Bioremediation, Pyrolysis-GC/MS, Polymer identification, Plastic waste management**

INTRODUCTION

Microplastics are defined as plastic particles smaller than 5 mm and are global pollutants originating either from the fragments of larger plastics, known as Secondary MPs, or manufactured as small particles, known as Primary MPs. Plastic pollution has now become a major global problem because of its impact on the environment, as only a tiny fraction of plastics is recycled. India's rapidly growing population and high plastic consumption, combined with a lack of sufficient waste management infrastructure in the country, contribute substantially to environmental plastic pollution (Singh et al., 2024). Aquatic environments in India comprise lakes, ponds, canals, floodplains, coastal water bodies, estuaries, and marine systems. India ranks second globally in terms of fisheries and aquaculture production. With an approximate number of 838 freshwater species, it is also the second most diverse group of aquatic fish in Asia, comprising 5% of the global fish trade and 6.3% of the world's total population (Lloyd et al., 2022).

As MPs are widely found in surface water, the use of such contaminated water for brings MPs to agricultural soil and makes them a long-term MP reservoir (Gupta et al., 2024). Due to its vast farmlands and vast river systems with tributaries, central Indian states, including major rivers like the Narmada and Godavari, have been considered high-risk regions for MP accumulation in the riparian zone and water matrices. MPs interact with the soil's environment and alter its stability, which is directly related to the fertility of the soil and has further indirect disastrous impacts on plant development. They affect plant photosynthesis, ionic homeostasis, and redox regulation (Guo et al., 2022). On the other hand, MP stress in plants is enhanced by using some crop residues like mulch, haplophytes, and biochar (Jia et al., 2023).

According to the 2025 Global Risks Report by the World Economic Forum, MPs are on the top 10 list for risks to the human population. Owing to their pervasiveness and morphological characteristics, MPs directly and

indirectly have the potential to threaten life. They enter food chain through various pathways hence, have potential risks for human health. To overcome the consequences, it is very important to understand the fate and behavior of the MPs present in the environment (Su et al., 2016). The issue of plastic pollution is increasing and is well recognized in India. The Indian government is putting numerous efforts to reduce plastic footprints. The very first step was the implementation of a ban on single-use plastics on ships in 2019. The plastics industry in India has become a significant contributor to the Indian economy, but despite its growth potential, these industries still face multiple challenges, including improper waste management and concerns about negative environmental effects (Neelavannan and Sen, 2023). This study aimed to analyze the existing scientific literature on MPs in the central India region in order to understand their impacts on vegetation and humans.

SOURCES AND PATHWAYS OF MICROPLASTICS IN WATER BODIES AND AGRICULTURAL SOIL

The primary sources and pathways for MP contamination in Central India's environment are interconnected. Traditionally, mulching has been in use in India as well as other countries for water conservation by using dry leaves, trash, straw, etc. The usage of plastic film in mulching is a current development worldwide. The worldwide mulch film market has grown exponentially in the last few years. The extensive use of plastic mulching for increased crop yields in states like Maharashtra is a direct and major source of secondary MPs in the soil and water (Mahesh et al., 2022).

Contaminated river, lake, and even groundwater is used expensively for irrigation, which directly transports aquatic MPs into fields (Anand and Sheel, 2025). Plastic transportation in agriculture could result from many sources, including the washout water from landfills entering the field during rainy seasons. They can also move through the soil systems because of the nature of the soil and quality of MPs. MPs were first identified in the marine environment but they are now also found in terrestrial environments, particularly in soils. They change the structure of the soil, reduce fertility, impact plants growth and damage microbial communities (Chalannavar et al., 2025).

MPs are the most recently discovered of the many air pollutants and are of great concern to both the public and scientists. Humans may inhale roughly 272 particles of airborne MPs in a day, according to Vianello et al. (2019). The size of the MP determines the likelihood of inhaling it. Polyvinyl acetate (PVA), Polyurethane (PUR), Teflon, Polyethylene Terephthalate (PET), Polyethylene (PE), Polyester (PES), Polyacrylonitrile (PAN), Poly (N-methyl acrylamide) (PAA), Rayon, Ethylene Vinyl Acetate (EVA), Epoxy Resin (ER), Alkyd Resin (AR), and natural cotton and wool are the MP types that have been found in the atmosphere so far. The degradation may take place in the atmosphere or in water or in soil (Enyoh et al., 2019). A study performed by Yakovenko et al., 2025 reveals the human exposure to MPs present in indoor air. (Fig.1). Also, Neelavannan & Sen, 2023 conducted a literature review about the MPs contamination in different freshwater sources (Fig. 3).

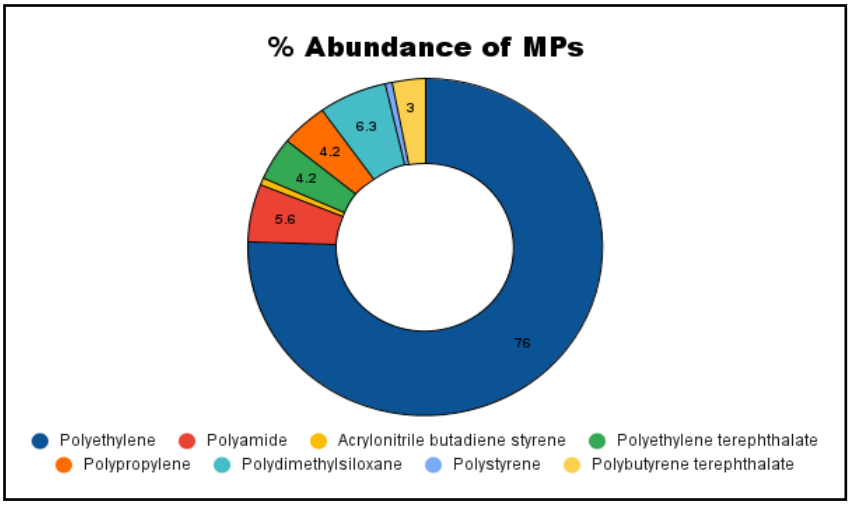


Fig. 1 – Human exposure to PM_{10} MPs in Indoor air (Yakovenko et al., 2025)

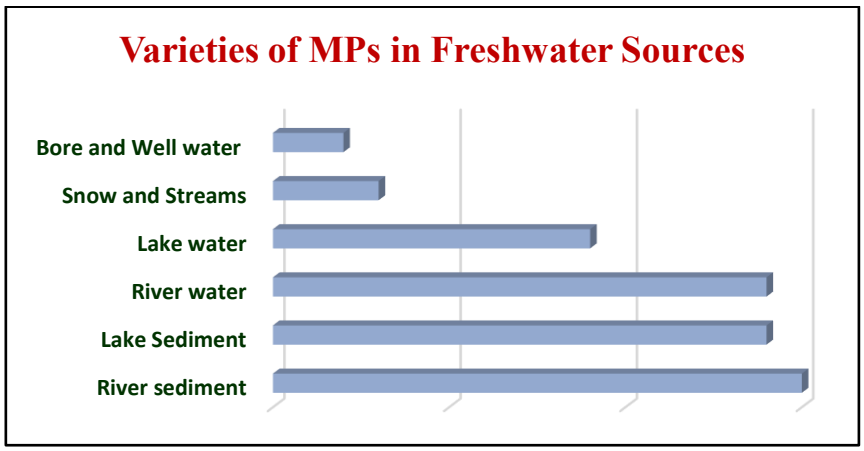


Fig. 2 - Varieties of MPs present in the Freshwater Sources in India. (Neelavannan & Sen, 2023)

ENVIRONMENTAL AND ECOLOGICAL IMPACTS

The presence of MPs in agricultural soil and irrigation water poses risks to the ecosystem and potentially to human health. MPs interfere with the environment across physical, chemical and biological dimensions, acting as a persistent stressor in both terrestrial and aquatic ecosystems.

Table 1- Impacts of MPs on the Environment

Impact category	Impact	Mechanism	Reference
Soil Health	Altered Soil structure and density	MPs, such as films and fragments, change soil bulk density, porosity, and aggregate stability, leading to changes in soil aeration and compaction.	Perez et al., 2022; Mohasin et al., 2025
	Reduced water retention and distribution	The presence of MPs, depend on their polymer type and size, can decrease the water holding capacity of the soil and affect the water availability for crops	Perez et al., 2022; Mohasin et al., 2025
	Disruption of Biogeochemical cycles	MPs interfere with the cycling of essential nutrients like Carbon, Nitrogen, and Phosphorus, which can reduce flora nutrient uptake and ultimately affect soil fertility.	Perez et al., 2022; Mohasin et al., 2025
	Vector for pollutants	MPs have a high surface area that adsorbs co-contaminants such as heavy metals, pesticides and persistent organic pollutants from the surrounding soil/water, increasing their mobility and toxicity.	Vaid et al., 2021; Mohasin et al., 2025
Soil Health	Alteration of Microbial Communities	MPs forms a unique microbial biofilm ecosystem called the plastisphere, which differs from the natural soil microbial community, that has the potential to alter the soil functioning.	Perez et al., 2022; Mohasin et al., 2025

	Pathogen and contaminant distribution	The plastisphere, especially on MPs from wastewater, can harbor and protect human pathogens acting as a vehicle for their spread in agricultural systems	Quilliam et al., 2023
Terrestrial biota	Impact on spoil fauna	MPs can cause slower growth, decrease body weight, and altered eating habits in soil invertebrates like earthworms. MPs that transport through the soil profile is also facilitated by the movement of these organisms.	Yang et al., 2023; Raza et al., 2022
	Toxicity and bioaccumulation	MPs have potential to bioaccumulate in the food web and cause toxicity and physical harm when consumed by different soil biota.	Yang et al., 2023; Mohasin et al., 2025
Vegetation Health	Stunted Growth and Reduced Biomass	Microplastics can interfere with root development and nutrient uptake, apparently causing severe detrimental effects on plant growth and overall crop biomass in species like wheat.	Mohasin et al., 2025; Yang et al., 2023
	Translocation and Food Chain Entry	MPs, particularly smaller ones, can build up in plant roots (like those of cucumbers, lettuce, and wheat) and move to above-ground components like shoots, leaves, flowers, and fruits, from where they can enter the human food chain directly.	Yang et al., 2023; Quilliam et al., 2023
Aquatic Ecosystems	Ingestion and Bioaccumulation in Aquatic Life	Aquatic organisms (fish, filter-feeding bivalves, and crabs) readily consume MPs because they believe they are food. This results in biomagnification up the food chain, metabolic disorders, and internal physical injuries.	Anand & Sheel, 2025; Vaid et al., 2021; Borah et al., 2024
	Habitat Disruption	MPs build up in the sediments of rivers and lakes, disrupting the habitat and activity of benthic organisms, which are essential for the wellbeing of freshwater ecosystems.	Borah et al., 2024; Singh et al., 2024

DETECTION AND QUANTIFICATION METHODS

Detecting and quantifying microplastics (MPs) in complex environmental media is a multi-step process involving sample preparation, separation, and instrumental analysis. The methods employed aim to chemically confirm the polymer identity and accurately count or measure the mass of particles.

In the analysis of microplastics (MPs), sample preparation and pre-concentration are critical for accurate detection. The most common approach is *density separation*, which utilizes the lower density of plastics (0.9–1.6 g/cm³) compared to inorganic materials (>2.0 g/cm³). By mixing the sample with high-density salt solutions such as NaCl, $ZnCl_2$, or NaI, MPs float to the surface, allowing effective isolation, although high-density polymers like PVC and PET may be difficult to recover (Chalannavar et al., 2025; Thomas et al., 2020; Schutze et al., 2022).

Sieving and filtration are then employed to separate MPs by size-sieving removes larger particles using mesh screens (≥20 µm), while filtration with fine membranes (e.g., glass fiber or aluminum oxide) captures smaller MPs, though issues like clogging and potential MP damage may occur. To remove organic matter that interferes

with analysis, chemical digestion using reagents such as H_2O_2, KOH, or Fenton's reagent is applied, which enhances sample purity but must be carefully optimized to avoid degrading certain plastic types (Rani et al., 2023; Musthafa & Mandal, 2024). There are a number of analytical methods for the identification and characterization of microplastics (MPs), each with unique benefits and drawbacks.

The concentration of elements in a sample is determined using the combustion technique and a *CHN analyzer*. It helps with the development and manufacturing of plastics. It measures the amount of hydrogen, carbon, nitrogen, oxygen, and sulfur in plastics. It classifies the microplastic particles according to their types. But this method time taking process and isn't suitable for smaller particles. (Ebere & Ngozi, 2019).

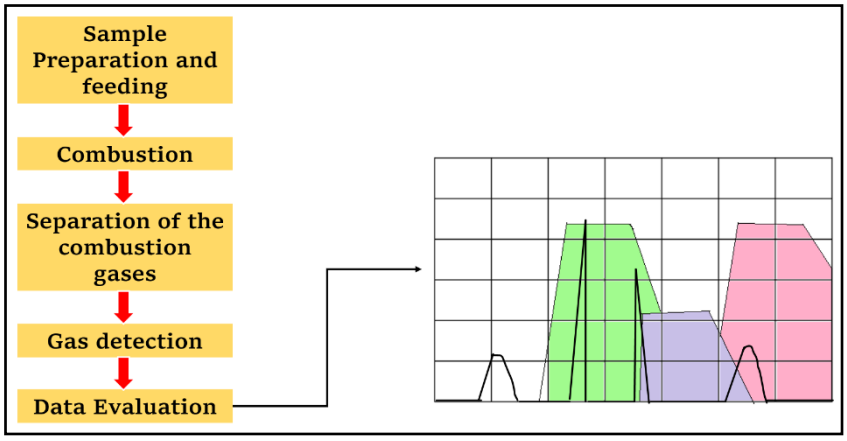


Fig. 3- Schematic representation of a CHN analyzer.

Stereo or optical microscopy allows visual identification of MPs based on their physical characteristics such as color, size, shape, and light transmission. It is one of the simplest and most cost-effective tools for initial detection and assessment of MPs. It is commonly used for counting particles larger than 500 µm. This method is simple, cost-effective, and requires minimal equipment; however, it is particular, labor-intensive, and prone to high error rates, as it cannot confirm polymer composition (Jin et al., 2022).

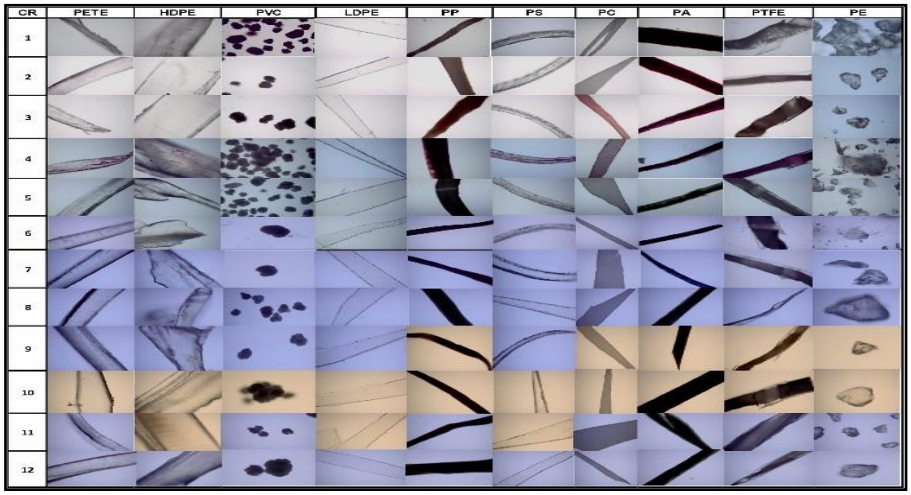


Fig. 4 Optical Imaging of Microplastics observed by Soliz et al., 2024

To enhance visualization, *fluorescence staining* techniques, mainly using lipophilic dyes like Nile Red, have been developed. These dyes selectively bind to plastic polymers, allowing MPs to be detected under a fluorescence microscope. This approach is relatively fast, inexpensive, and suitable for smaller particles, though its reliability varies among polymer types and may produce false positives due to fluorescent organic matter (Spreafico & Russo, 2023).

For identification of chemicals, spectroscopic methods such as *micro-Fourier Transform Infrared Spectroscopy (µ-FTIR)* and *micro-Raman spectroscopy (µ-Raman)* are commonly used. µ-FTIR provides unique spectral fingerprints for polymers based on infrared absorption, offering reliable identification for particles as small as 10–20 µm, though its performance is limited by water interference and low spatial resolution. The main advantages are non-destructive polymer identification and high chemical specificity. This makes FTIR

exceptionally useful for confirming MP presence and type after initial screening by microscopy or fluorescence. However, at a time only one particle can typically be analyzed, also water can interfere with the spectra, and sample preparation can be time-consuming. In contrast, μ-Raman spectroscopy uses inelastic light scattering to expose polymer composition, achieving higher spatial resolution (down to ~1 μm) and reduced sensitivity to water but is hindered by fluorescence interference and slower analysis times (Cabernard et al., 2018).

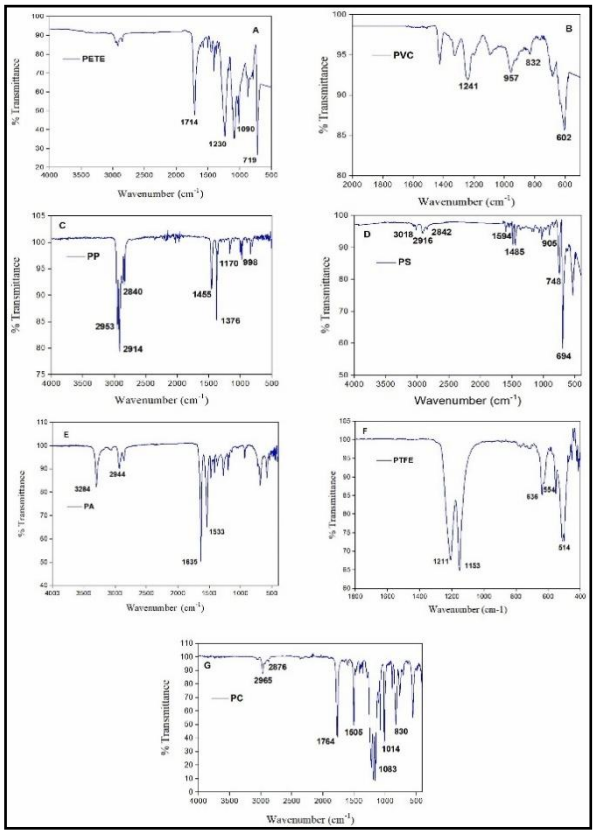


Fig. 5 - IR Spectra of – (A) PETE, (B) PVC (C) PP, (D) PS, (E) PA, (F) PTFE and (G) PC given by Soliz et al., 2024.

For the analysis of quantity and composition, *Pyrolysis-Gas Chromatography-Mass Spectrometry (Py-GC/MS)* is used, for which samples are thermally decomposed into volatile fragments that are separated and identified, providing definitive polymer identification and quantification. This approach not only confirms polymer type but also quantifies MP content. Despite its high accuracy, this technique is destructive, cannot determine particle morphology, and requires costly instrumentation (Pico & Barcelo, 2020).

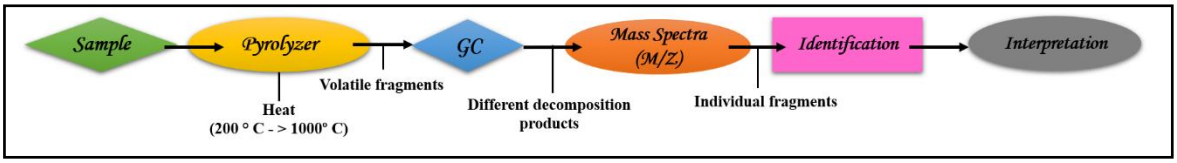


Fig. 6 - Schematic representation of Py-GC/MS

MITIGATION AND REMEDIATION STRATEGIES

MP pollution has emerged as a critical environmental challenge, affecting aquatic and terrestrial ecosystems worldwide. A comprehensive approach and two-pronged strategy are called for the mitigation and remediation of MP pollution, wherein mitigation involves source reduction and remediation involves technologies for removal. The mitigation mainly focuses on upstream solutions such as limiting single-use plastics, encouraging circular economy strategies like recycling and reuse, and creating biodegradable plastic substitutes (Roy et al., 2022).

Biodegradable alternatives offer the view of a supportive role to regulatory approaches by substituting traditional, long-acting plastics with materials capable of natural decomposition by microorganisms and

reducing the long-term accumulation in ecosystems. Biodegradable plastics, such as polylactic acid (PLA) and polyhydroxyalkanoates (PHA), are generally manufactured using renewable feedstock and hence present a sustainable alternative to petroleum-based polymers. Under optimal conditions, microorganisms can degrade these materials into carbon dioxide, water, and biomass (Emadian et al., 2017). However, their degradation rates vary with environmental conditions, and if they are disposed of improperly, they may further produce microplastics (Chamas et al., 2020). In order to contribute effectively for mitigation through biodegradable materials, it necessarily has to be combined with improved waste management.

Improving WWTP operations is another vital line of defense, since the facilities tend to be important entry points for microplastics into aquatic systems. Microplastic discharge can be decreased considerably by increasing the efficiency of the treatment through sophisticated filtration and process optimization (Tang & Hadibarata, 2021). For in-situ removal, remediation technologies such as membrane bioreactors (MBRs), rapid sand filtration and dissolved air flotation have shown great potential, combining biological treatment with fine-pored membrane filtration to achieve removal efficiencies of up to 99.9%, though issues like membrane fouling can hinder long-term operation (Haque, 2025).

Coagulation–flocculation is another cost-effective technique that demonstrates high efficiency by using chemical or natural coagulants, such as alum or plant-based agents (e.g., *Moringa oleifera*, okra extracts), to aggregate and remove microplastics through sedimentation or filtration. Remarkably, natural coagulants have been tested to have the capacity for removing smaller particles of up to 92.6%, outperforming conventional coagulants in some studies (Lapointe et al., 2020). Bioremediation represents a more environmentally responsible and a sustainable approach to tackle the persistence of plastics. Examples include *Bacillus* species and some fungi, which enzymatically break down polymer chains into simpler compounds (Anand et al., 2023). Additionally, under light and with the use of catalysts, Advanced Oxidation Processes such as photocatalytic degradation, ozonation, and Fenton reactions have emerged as feasible and greener chemical methods that can degrade microplastics into less hazardous components. For instance, the efficiency of a TiO2-based photocatalytic system in degrading fragments of polyethylene and polystyrene upon UV light exposure has been shown (Xie et al., 2023). However, they have problems regarding scalability, cost, and practical application on real water treatment systems, even though they work in the laboratory (Shruti et al., 2021). Additionally, research directions on MP pollution should include evaluation of the distribution, prevalence, changes and source discovery of MPs in environmental samples, especially with the micro-invertebrates. When evaluating the ecotoxicological risk of MPs, factors like MP absorptions, exposure times, tropic-level transfers, MP characterization, and gene expression in aquatic species should be taken into account. For the management and assessment of MPs from point sources, a stringent national action plan is also necessary (Onyena et al., 2021).

Education and awareness can play extremely important role in fight against MP pollution. The internet can be utilized as a teaching tool because 80% of search inquiries are meant to retrieve information. Conversely, social media has a greater influence than other information sources and provides opportunities for interaction with information. Analyzing the trends of the terms “microplastics” and “microbeads” on social media and search engines showed how the public’s growing awareness of “microplastics” evolved, as well as the behavior pattern that included the media’s successive news releases, social media sharing, and the search engines’ incitement of information-seeking behaviors, which resulted in an alternative path of active learning and awareness on this environmental issue.

These strategies together provide an integrated framework for addressing the issue of microplastic contamination in soil and water through biological solutions, technological innovation, and prevention (Prata et al., 2019).

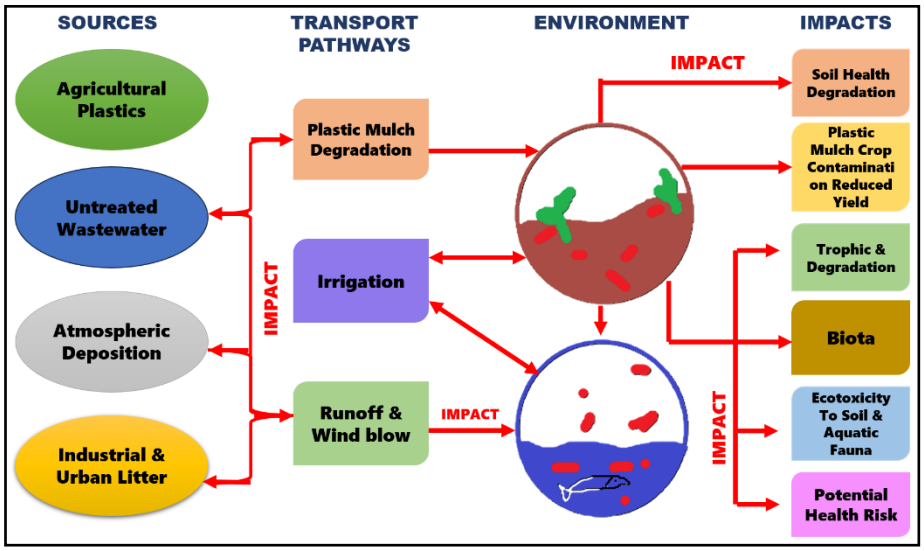


Fig. 7 – Microplastic contamination in Central India

CONCLUSION

Microplastics represent an emerging pollutant of global significance. Their pervasive presence in aquatic ecosystems poses multilayered threats to biodiversity, ecosystem function, and human health. Effective mitigation requires a multidisciplinary approach involving scientific innovation, policy enforcement, and public participation. Strengthening waste management infrastructure and promoting sustainable material alternatives will be key to reducing microplastic contamination in the coming decades. However, the field is in its nascent stage, revealing significant knowledge gaps that must be addressed like there as a lack of standardized methods for MP extraction and quantification across studies, making regional comparisons challenging. Secondly, there is an urgent need for research that could determine the actual ecological risk quotient and ecotoxicological effects of the measured MP levels on native Central Indian crops, soil fauna, and aquatic life. Moreover, the fate and impact of smaller nano-plastics (less than 100 nm), which are harder to detect and potentially more bioavailable, remain completely unexplored in this region. There is a need for the development of region-specific, feasible, and effective mitigation strategies, such as policies for plastic mulch alternatives, improved wastewater treatment, and community waste management. Addressing these gaps is crucial to safeguarding the agricultural productivity, soil health, and food security of Central India.

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