The Research of Medical Science Review
ISSN: 3007-1208 & 3007-1216 Volume 4, Issue 3, 2026

MICROPLASTIC POLLUTION IN PAKISTAN'S FOOD CHAIN: HEALTH RISKS, EVIDENCE, AND MITIGATION CHALLENGES

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DOI: https://doi.org/10.5281/zenodo.18871754

Keywords
Microplastics, Pakistan, Food Chain, Human Health Risks, Waste Management, Oxidative Stress, Environmental Toxicology.

Article History
Received: 06 January 2026
Accepted: 19 February 2026
Published: 05 March 2026

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Abstract

Microplastics the tiny plastic particles, have become a widespread environmental pollutant with serious consequences to ecosystems and human health. Their wide distribution is a result of the growing plastic production and chemical misuse, forming microplastics through industrial producers or natural fragmentation processes and consumers use. These particles are now also distributed in the air, soil, freshwater and marine environments, where they present an environmental risk by being taken up by organisms of different trophic levels and entering food webs. In Pakistan, where poor waste management, rapid urbanization and excessive use of single plastic has further aggravated microplastics pollution issues in terrestrial as well as aquatic ecosystems. The contamination of microplastics are found at high frequency in Pakistan freshwater ecosystem like Rawal Lake and Swat River, as well marine coastal region. Different types of polymers like polyethylene, polypropylene and polystyrene have been present in surface waters, sediments. Microplastics serves as a vector for as it absorb toxic substances, including harmful chemicals, heavy metals, and disease-causing microorganisms. Oxidative stress, inflammation, organ damage, and disruption in endocrine and reproductive system are serious health effects caused by microplastics ingestion through contaminated food and portable water. This review highlights the potential sources of microplastics, its distribution across the ecosystem, and effects of microplastics especially within Pakistan, focusing on the country's aquatic ecosystems, the trophic transfer in food web, and the health risks to human. Furthermore, this review will demonstrate how improved waste management, appropriate policies, and educated societies will combat microplastics. In Pakistan, refined research techniques and the newly integrated environment-related policies will microplastics concerned the health of humans and the ecosystem.

INTRODUCTION

Microplastics are tiny plastic fragments ranging in size from 1µ to <5 mm in diameter, are water-soluble, and can be either primary and secondary microplastics. as they are initially created in small

sizes and then develop further due to plastic degradation. There is an average of 360 million tons of plastic produced annually all over the world and only 7 percent are recycled resulting in most of the waste being deposited in the environment and a great risk in the shape of microplastics. (Thacharodi et al., 2024). Plastic use has increased manifold since the 1950s due to its wide variety of uses (Viel et al., 2023). Microplastics Microscopic plastic less than 5 mm in diameter, also known as microplastics, are found in most places and can have multiple sources. The most common causes are the weathering of larger plastics, the manufacturing of plastic, the use of microbeads in personal care products, and the release of microplastic fibres when synthetic clothes are washed (Bhat et al., 2022; Habib et al., 2022). Vehicle tires, poorly managed plastic waste, and other industrial, agricultural, and fishing activities cause the deterioration of materials into microplastics. This is worsened by marine habitat, coatings and urban runoff. The size of microplastics poses a threat to ecosystem health, animals, and human beings because it is found in soil, freshwater bodies, seas, and even in the air. Microplastics can be dispersed throughout the three most vital spheres of our environment during their lifecycle, i.e. in the atmosphere, soil, and water (Bhat et al., 2023). The possible sources of polymeric particles in the atmosphere are industrial Pollution, particle resuspension and other anthropogenic activities such as traffic, construction works and urban facilities. The atmospheric deposition of microplastics is considered to be the cause of the potential environmental contamination. Microplastics in the atmosphere can form a source of air pollution in both the aquatic and soil environment (Bhat et al., 2023). The marine and aquatic organisms, including fish, birds, marine mammals and invertebrates, wrongly treat it as a food and inhale them. Obstruction within the gut may lead to a reduced efficiency of feeding and malnutrition. There is also the risk of animals being entangled in larger microplastics and causing them damage, making movement or reproduction more difficult. There is also the entry of micro plastics into food web, starting with primary producers (e.g., phytoplankton and algae) and further at a higher trophic level (Ma et al., 2020).

As observed in all other developing countries, Pakistan is facing challenges related to treatment of plastic pollution causing multi-environment compartment pollution by microplastics (Paray et al., 2024). Poor practices of waste management, frequent open dumping and lack of regulation towards plastic products production and disposal make the situation worse (Hossain et al., 2020). Microplastics have been detected in various water bodies, sediments and organisms of Pakistan, activating concerns related to the environment and public health (Aarushi et al., 2025). The widespread contamination affects ecologically and raises the concern to humans through contaminated food and water (Zhang et al., 2023). Due to rapid industrialization and inefficient waste management, Asian countries like Pakistan are heavily contributing to microplastic pollution (Aarushi et al., 2025). Inefficient waste management, combined with the high production of plastics, has serious public health and environmental impacts (Aarushi et al., 2025; Zhang et al., 2023). Research identifies microplastics, including polyester, polypropylene, polystyrene, polyethylene terephthalate by fibres and fragments in the water supply throughout Asia, including Pakistan (Aarushi et al., 2025).

Khan et al., (2022) analyzed microplastic contamination in the sediments and water samples from the coast of Pakistan and confirmed that fibers constitute the highest percentage of microplastic contamination. It also confirmed the necessity of developing methodologies to assess total microplastic contamination and the potential risks to ecosystems and human health in Pakistan (Aarushi et al., 2025; Hussain et al., 2023). This also applies to freshwater systems such as lakes and rivers, which provide water for human consumption and support diverse biological communities; thus, the accumulation of microplastics in such systems is of great concern (Aarushi et al., 2025). Rawal Lake, for instance, which supplies water to the cities of Islamabad and Rawalpindi, is heavily contaminated with

microplastics in both sediments and surface waters (Aarushi et al., 2025). Other important rivers and lakes in Pakistan, which support irrigation and aquatic life, are also likely to be heavily contaminated with microplastics due to the current state of plastic pollution and inefficient waste disposal practices (Wagner & Lambert, 2017), as is the case with lakes and rivers (2024). Indiscriminate disposal of about 200,000 tons of plastic waste by coastal communities and inhabitants of the Indus. According to Rifa and Hossain (2023), Rivers create additional environmental challenges for Pakistan. The large contribution of plastic waste increases the concentration of microplastics in the ocean which can harm aquatic life and can be further be a threat to humans through the consumption of contaminated seafood (Ahmed et al. 2023).

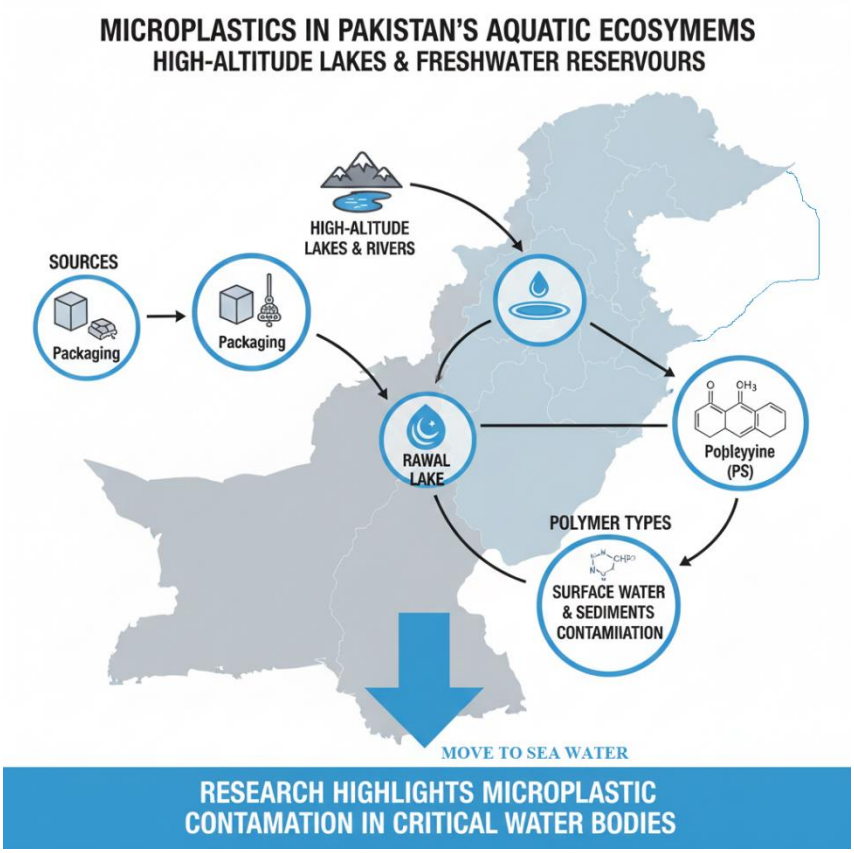

Figure 1: Microplastics contamination in Pakistan's Aquatic Ecosystems.

6.1 Current Status of Research on Microplastics in Pakistan

Microplastic research has begun in Pakistan (Aarushi et al. 2025) and the first studies have focused on the identification and quantification of microplastics within various environmental mediums in Pakistan. These studies have primarily sought to record the occurrence and assess the types of microplastics present within the country's surface water, sediment, and biota (Aarushi et al. 2025; Mukheed & Khan 2020). For example, microplastic research has been conducted in the Swat River on water, sediment and fish samples (Khan et al. 2022 The research has been conducted to record the occurrence and distribution of microplastics in water, sediment and fish samples. Polypropylene, polyethylene, and polystyrene are typical polymers found in packaging and fishing materials (Aarushi et al., 2025). Additionally, Rawal Lake, an important freshwater reservoir, has been reported to contain a substantial amount of microplastic pollution in

its sediments and surface (Aarushi et al., 2025). The above studies show the need for developing and applying uniform methods for microplastic research in Pakistan so that research findings can be compared and cross regional and ecosystem risk assessments can be done (Bashir & Hashmi, 2022).

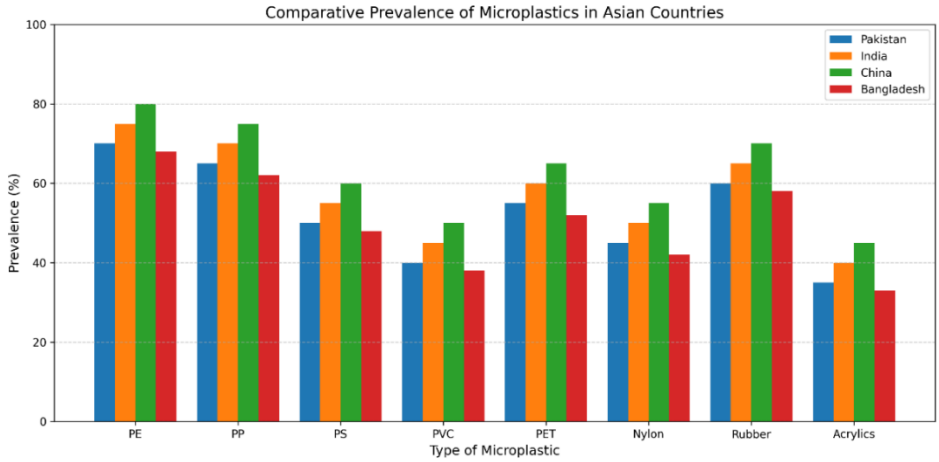

Figure 2: Comparative prevalence (%) of major microplastics polymer types reported in Asian countries.

6.2 Sources of Microplastic Pollution in Pakistan

The microplastic pollution in Pakistan results from the lack of proper waste management systems, overuse of single-use plastics, and substantial industrial and domestic waste into water bodies (Ahmad et al., 2023). Plastic waste from the shipbuilding industry, export units, and local businesses in coastal areas, including Karachi's West Warf, Kemari Jetty, and Manora, is a major contributor to microplastic pollution in the sea (Ahmad et al., 2023). Agricultural runoff containing plastic mulch, tubing, and microplastics in biosolids worsens pollution in soils and freshwater. Microfibers and fragments of polyethylene, polypropylene, and polyethylene terephthalate are the most common microplastics (Bhowmik & Saha, 2025; Miranda-Peña et al., 2023). Secondary microplastics of environmental systems are most abundant, and they result from the breakdown of larger plastic materials due to mismanagement of plastic, and they are transported via river systems to farmlands and sediments of rivers and lakes and to the sea (Ahmad and Azam, 2019).

The distribution underscores the compulsion of understanding the microplastics pathway from land to sea, as these connected systems often serve as critical microplastics transport pathways (Jolaosho et al., 2025). Microplastics originating from urban and agricultural settings flood aquatic environments through rivers, reaffirming the interconnected nature of terrestrial activities and pollution in the sea (Akarsu et al., 2025; Cholewińska et al., 2025). More so, certain polymers like microplastic, polyethene, and polypropylene are often related to agricultural activities, packaging, and domestic refuse, highlighting the unreciprocated relationship between mankind and pollution (Aarushi et al., 2025; Luqman et al., 2023). In high population and Industrialization ratio areas with pressure on the infrastructure, urban and industrial areas add to the microplastic load through storm water runoff and wastewater effluent which significantly reduces the waterways (Cholewińska et al., 2025) The potential of microplastics to be transported over long distances by floods and winds leads to the inundation of even the remotest environments, which demonstrates the far-reaching ranges of one of the numerous global environmental issues (Boahen et al., 2025; Toha et al., 2024).

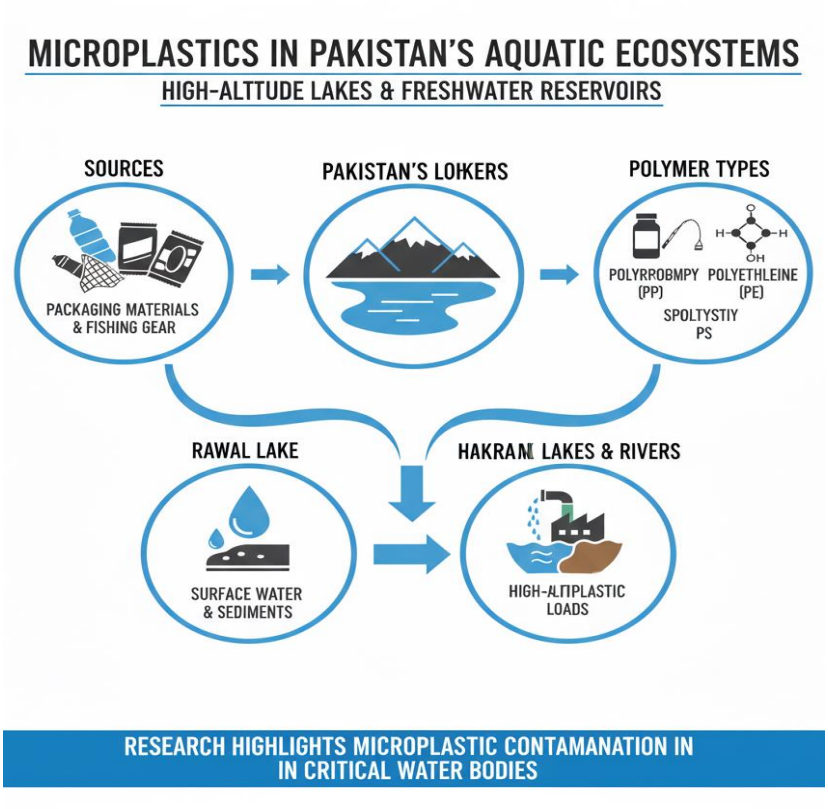

Figure 3: Microplastics in pakistan ,s aquatic ecosystem

Impact on Local Food Chains and Human Health

It has been confirmed that microplastics are present in Pakistan's terrestrial and aquatic environments and have an impact on local food webs as they can be ingested by numerous organisms, including zooplankton, aquatic fish, and terrestrial animals such as livestock. There is an increasing concern over the consumption of microplastics by humans through the food chain as a result of the bioaccumulation and biomagnification of microplastics in these trophic levels through contaminated fish and livestock.

Health risks associated with Microplastics Consumption through food and water

Intake of contaminated food and water result to microplastic ingestion of about 0.1-5 g per week (Jiao et al., 2025). Beyond physical ingestion microplastic serve as users for more toxins, heavy metals, organic pollutants, and additives which increase health risks as these pollutants move along the food chain (Du et al., 2025; Hasan & Tarannum, 2024). Microplastics are present in almost all foods and contaminated water, including fish, chicken, honey, sugar and water, which is harmful due to its chronic exposure (Bilal et al., 2023; Bora et al., 2024). Microplastics exposure could lead to the increase of oxidative stress, inflammation, and cellular damage and could cause organ dysfunction, neurotoxicity, and harmful effects to reproduction (Aarushi et al., 2025). The risk of smaller-sized microplastics is more as they can go beyond biological barriers and accomplish tissues and persist in the organs, Microplastics smaller than 100 nm are the only ones capable of crossing cellular membranes and the blood-brain barrier, which could cause systemic inflammation and result in inflammation (Aarushi et al., 2025). Furthermore, microplastics act as vectors for pathogenic microorganisms and antibiotic-resistant bacteria, introducing further risks to human health through food and water

consumption (Lawal et al., 2025; Malli et al., 2023). Aquatic organisms, particularly fish and shellfish, readily accumulate microplastics, facilitating their transfer to humans through seafood consumption (Zhang et al., 2023). Even lower trophic organisms, such as zooplankton, ingest microplastics, enabling their movement across food webs and reinforcing the potential for biomagnification (Noppradit et al., 2023).

Table1: Microplastic types, their sources, and health effects in Asian countries (with emphasis on Pakistan)

Type of Microplastic	Source in Asia/Pakistan	Harmful Health Effects	Reference
Polyethylene (PE)	Widely used in packaging, shopping bags, bottled water industry in Pakistan and India	Found in drinking water; linked to oxidative stress, gastrointestinal inflammation	Pervaiz et al. 2025
Polypropylene (PP)	Food containers, textiles, disposable products in Pakistan, Bangladesh, and China	Alters gut microbiota, immune system impairment	Aarushi et al 2025
Polystyrene (PS)	Foam packaging, disposable cups/plates in Pakistan and Southeast Asia	Neurotoxicity, endocrine disruption, carcinogenic potential	Aarushi et al 2025
Polyvinyl Chloride (PVC)	Construction materials (pipes, flooring), synthetic leather in Pakistan	Releases phthalates and heavy metals; reproductive harm, cancer risk	Pervaiz et al. 2025
Polyethylene Terephthalate (PET)	Bottled water, polyester clothing in Pakistan, India, and China	Cardiovascular risks, gastrointestinal inflammation	Springer Longdom Publishing SL
Nylon (Polyamide)	Fishing nets (South Asia), synthetic textiles in Pakistan	Respiratory irritation from inhaled fibers, reproductive toxicity	Aarushi et al 2025
Rubber-derived particles	Vehicle tires, road dust in Pakistan's urban centers	Inhalation linked to lung inflammation, cardiovascular disease	Longdom. (2025).
Acrylics	Paints, coatings, synthetic fabrics in Pakistan and East Asia	Skin irritation, immune dysfunction	Aarushi et al 2025

Mitigation Strategies and Policy Recommendations

In Pakistan, Mitigation strategies along with supporting policies are required for controlling microplastics contamination and its related health hazards. These policies must comprises a multiple interconnected approach with effective solid waste management strategies, reduction in single-use plastics and public awareness sessions to minimize the environmental degradation of microplastics. The number of particles entering the aquatic environment can be limited by effective wastewater treatment plants with systems that are able to capture microplastics. Policy tools such as economic instruments like Extended Producer Responsibility (EPR) should be used to encourage producers to reduce plastics usage, enhance recyclability and minimize microplastics generation. Similarly, in order to ensure public health and to limit the exposure risks, standards for the determination of microplastics in food and drinking water are

critical to be considered. The synchronization of analytical techniques, risk assessment frameworks and setting regulatory limits on microplastic contamination should be implemented by International cooperation also (Aarushi et al., 2025; Abbas et al. 2025). Addressing Pakistan's current problems like waste management and the rapid urban development, implementation and enforcement of policy are particularly important. Scientific evidence and regional level cooperation along with proactive governance, is required to eradicate microplastics contamination and also for maintaining environmental integrity and human health (Aarushi et al., 2025; Sanjeev et al., 2025).

Waste Management and Recycling Initiative

The implementation of effective waste management and recycling programs to reduce pollution with microplastic by means of better collection of plastic waste, sorting, and processing thereof is vital (Zawad et al., 2024; Zhang et al., 2023). The introduction of sophisticated mechanical and chemical recycling systems to support the recovery of different plastic fractions, as well as discourage and encourage the development of the circular economy sphere in an attempt to reduce the consumption and maximize reuse of industrial sectors. Switching to end of pipeline systems to restorative solutions such as better separation of recyclable and compostable wastes and decentralized waste management methods will help reduce leaking of plastic (Jiao et al., 2025). Moreover, the reduction of the nano-plastic entry into the water bodies can be achieved by refurbishing the wastewater treatment plants with microplastic capturing systems. (Feiock, 2020).

Conclusion

Microplastics is a serious environmental dilemma that is rapidly growing, especially in a nation such as Pakistan whereby the pace of industrialization and unregulated urban growth has strained the waste management systems. Their pollution of MPs did not stop at the distance it is an inside out crisis that has affected important fresh water sources such as Rawal Lake and Swat River and the oceanic waters off Karachi. The fact that polyethylene, polypropylene and polystyrene debris dominate such ecosystems indicates great contributions by wastewater effluents of textile washing, run-offs of agriculture and poor recycling of municipal solid waste into the freshwater ecosystem. Besides this, microplastics may serve as carrier of heavy metals and antibiotic-resistant bacteria and its ingestion leads to cellular damage, oxidative stress and neurotoxicity. A shift in policy making of governance and regulatory policies would be necessary to effectively address this multi-dimensional crisis. Pakistan should implement multi stakeholder approach that comprises aggressive enforcement of rules and novel business models like is circular economy. The wholeness of the Pakistan environment and the well-being of people are quickly being fastened to the stake until there is a serious action by the regulatory agencies and standardized control measures.

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