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# Microplastics occurrence in high-altitude mountain lakes: Insights from recent research

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**Abstract**

The occurrence of microplastics in high-mountain lakes, once considered pristine and free from human-induced pollution, has emerged as a pressing concern. Recent research has exposed the pervasiveness of microplastic pollution even in these remote environments. This study underscores the urgency to comprehend microplastic pollution in high-mountain lakes comprehensively, emphasizing its global reach and diverse origins. The study serves as a clarion call for collaborative research and concerted efforts to mitigate the consequences of microplastic contamination. The transformation of once-pristine high-mountain lakes into arenas of microplastic accumulation necessitates a multidisciplinary approach involving researchers, policymakers, and local communities. Acknowledging and addressing microplastic pollution stands as a critical step towards preserving these remarkable ecosystems, essential for biodiversity maintenance and the sustenance of ecosystem services. Protecting high-mountain lakes demands effective mitigation strategies to shield them from the adverse impacts of microplastics, thus safeguarding their integrity and contributing to the overarching goal of reducing plastic pollution on a global scale.

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**Introduction**

High-mountain lakes are remote, pristine environments that have long been thought to be free from human-induced pollution (Machate *et al.,* 2023). However, recent research has shown that even these isolated lakes are not immune to the widespread problem of microplastic pollution (Zhang *et al.,* 2021; Paolo *et al.,* 2022). Microplastics are defined as plastic particles less than 5mm in size, and they can originate from various sources, including cosmetics, clothing, packaging, and industrial processes. These tiny particles pose a threat to aquatic ecosystems, and organisms (Ghosh *et al.,* 2023; Malafaia *et al.,* 2023). The occurrence of microplastics in high-mountain lakes is a relatively new area of research, and many knowledge gaps still exist. However, recent studies have revealed that microplastics are present in these environments, and they have been found to accumulate in sediments, surface waters, and biota (D'Avignon *et al.,* 2022; Napper *et al.,* 2022; Nava *et al.,* 2023). Additionally, high-altitude lakes may be particularly vulnerable to microplastic pollution, as their ecosystems are often unique and adapted to extreme conditions.

Microplastics can also be transported to high-mountain lakes through atmospheric deposition, which may be a significant source of contamination in these remote areas (O'Brien *et al.,* 2023). High-mountain lakes are unique freshwater ecosystems that are situated at high elevations, often above the tree line, and are typically fed by snow and glacier melt. Due to their remote locations and lack of direct human impact, they have long been considered as pristine environments that are relatively free of anthropogenic contaminants. However, recent studies have revealed the widespread occurrence of microplastics in these lakes, highlighting the need for further investigation into their distribution, sources, and ecological impacts (Saravia *et al.,* 2021; Liu *et al.,* 2021). Understanding the presence and effects of microplastics in high-mountain lakes is important for several reasons. Firstly, these lakes are important indicators of wider environmental issues due to their high sensitivity to environmental changes and their potential to record changes in climate and atmospheric pollution (Machate *et al.,* 2023; Nava *et al.,* 2023). The presence of microplastics in these lakes can be seen as a reflection of global plastic pollution, and their study provides insights into the extent of this issue in remote, pristine environments. Secondly, high-mountain lakes are often used for recreational activities such as fishing, swimming, and boating, and their ecological health is vital to the local economy and cultural heritage (Saravia *et al.,* 2021). Microplastics have been found to accumulate in the food chain, and their ingestion by aquatic organisms can have negative impacts on their health and survival (Scherer *et al.,* 2020). Furthermore, microplastics can also alter the physical and chemical properties of the lake water and affect nutrient cycling, leading to changes in the structure and function of the ecosystem (Liu *et al.,* 2021). The widespread occurrence of microplastics in high-mountain lakes highlights the need for further research into their distribution, sources, and ecological impacts. Understanding the presence and effects of microplastics in these unique ecosystems is vital for effective management and conservation of these valuable freshwater resources.

*Sources and distribution of microplastics in high-mountain lakes*

Over the last few years, research on the sources and distribution of microplastics in high-mountain lakes has increased considerably. Several studies have reported the presence of microplastics in these remote and pristine ecosystems, despite their isolation from human settlements and industrial activities. Recent research has highlighted a variety of sources that contribute to the contamination of high-mountain lakes with microplastics, including atmospheric deposition, runoff from surrounding catchments, and recreational activities such as hiking and camping. Atmospheric deposition has been identified as a significant pathway for the transport of microplastics to high-mountain lakes (Schmidt *et al.,* 2020). Atmospheric deposition of microplastics can occur through a variety of mechanisms, including transport by winds and precipitation. Recent studied

have found that microplastics could be transported over long distances by winds and subsequently deposited onto high-mountain lakes, resulting in high concentrations of microplastics in these ecosystems (Bai *et al.,* 2021; O'Brien *et al.,* 2023; Machate *et al.,* 2023) (Fig. 1). Runoff from surrounding catchments has also been identified as a potential source of microplastics in high-mountain lakes. Studies have shown that microplastics can enter these ecosystems through the transport of contaminated sediments and surface waters from adjacent areas (Liu *et al.,* 2020). For example, a recent study conducted in the Tibetan Plateau reported high concentrations of microplastics in lake sediments, which were attributed to the transport of microplastics from surrounding catchments (Wang *et al.,* 2021). Recreational activities, such as hiking and camping, have also been identified as sources of microplastics in high-mountain lakes. A recent study found that microplastics are present in soils and sediments in areas with high levels of recreational activity, indicating that these activities can contribute to the contamination of high-mountain lakes with microplastics (Mitra *et al.,* 2021).

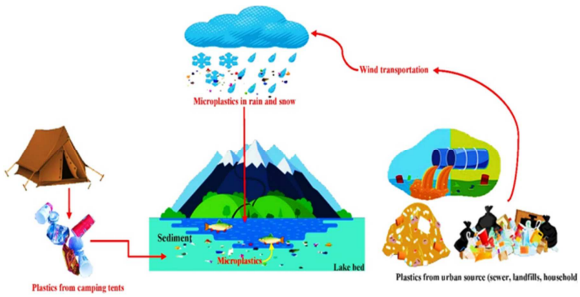


**Fig.1.** MP sources and accumulation in high-altitude mountain lakes.

The sources and distribution of microplastics in high-mountain lakes are complex and multifaceted, involving both natural and anthropogenic pathways. As these ecosystems are highly sensitive to environmental change, it is important to understand the sources and distribution of microplastics in order to effectively manage and conserve these unique and valuable ecosystems. In recent years, there has been a growing concern about the fate of microplastics in high-mountain lakes.

While studies have identified the sources and distribution of microplastics in these ecosystems, the fate of these particles once they enter the lake environment is less well understood. The following section will provide a review of the current knowledge on the fate of microplastics in high-mountain lakes. One important factor affecting the fate of microplastics in high-mountain lakes is their buoyancy. Microplastics that are less dense than water tend to remain suspended in the water column, while those that are denser tend to settle to the lake bottom (Wang *et al.,* 2020). The settling rate of microplastics is influenced by a range of factors, including the size, shape, and surface properties of the particles, as well as the properties of the water column (Li *et al.,* 2022). Once microplastics have settled to the lake bottom, they can become buried in sediment layers, where they may remain for extended periods of time (Yang *et al.,* 2021). Alternatively, they may be resuspended by bottom currents or wave action, leading to their redistribution within the lake environment (Wang *et al.,* 2021). The resuspension of microplastics from sediments may be particularly important in shallow lakes or those with high wind or wave energy (Liu *et al.,* 2021). Microplastics may also interact with other particles and organisms in the lake environment. For example, they may become attached to organic matter or mineral particles, which can affect their transport and fate in the lake (Wang *et al.,* 2021). Microplastics may also be ingested by aquatic organisms, including fish and invertebrates, which can lead to the accumulation of these particles in food webs (Li *et al.,* 2022). The fate of microplastics in high-mountain lakes is also influenced by physical and chemical processes such as photo-oxidation, hydrolysis, and biodegradation (Yang *et al.,* 2021). These processes can alter the size, shape, and chemical properties of microplastics, which can affect their transport, settling, and interactions with other particles in the lake environment (Fig. 1). Overall, the fate of microplastics in high-mountain lakes is complex and influenced by a range of physical, chemical, and biological processes. Further research is needed to better understand the fate of microplastics in these

ecosystems, as well as their potential impacts on the ecology and biogeochemistry of high-mountain lake systems.

*Impacts of microplastics on high-mountain lake ecosystems*

Microplastic pollution has been shown to have negative impacts on high-mountain lake ecosystems (Pastorino *et al.,* 2023). The small size and persistence of microplastics mean that they can accumulate in the food chain, potentially affecting the health and survival of organisms in these ecosystems (Talukdar *et al.,* 2023). Organisms can consume microplastics, causing physical harm and toxic consequences. In a research study conducted in the Swiss Alps, it was discovered that zooplankton inhabiting high-mountain lakes were ingesting microplastics, leading to detrimental impacts on their feeding rates and reproductive abilities (Velasco *et al.,* 2023). Another study conducted in the Tibetan Plateau found that microplastics were present in the gut contents of fish, indicating that these organisms are also exposed to microplastic pollution (Liu *et al.,* 2021). Microplastics can accumulate in sediments and alter the physical properties of high-mountain lake ecosystems, potentially affecting the health of aquatic organisms. A study conducted in the Rocky Mountains found that microplastics were present in lake sediments, and that their accumulation could lead to changes in sediment properties and decreased oxygen levels (Akdogan *et al.,* 2023). Microplastics can alter the ecological balance of high-mountain lake ecosystems by affecting nutrient cycling and the composition of microbial communities (Nava *et al.,* 2023; Wang *et al.,* 2023). Several other studies found that microplastics were affecting the composition and abundance of microbial communities in high-mountain lakes, potentially leading to disruptions in nutrient cycling and ecosystem processes (Schmeller *et al.,* 2022; Chen *et al.,* 2023). Microplastics can enter the human food chain through the consumption of contaminated fish and other aquatic organisms, potentially exposing humans to harmful chemicals and toxins (Nguyen *et al.,* 2023). A study conducted in the Italian Alps found that microplastics were present in the tissues of fish, indicating that humans who consume these fish may be exposed to microplastic pollution (Siddiqui *et al.,* 2023). The impacts of microplastics on high-mountain lake ecosystems are complex and multifaceted, affecting both the physical and biological aspects of these ecosystems. It is important to continue research on the impacts of microplastics in order to better understand their effects and develop effective management strategies to protect these valuable ecosystems.

**Discussion**

Microplastic pollution in high-mountain lakes is a growing concern due to its potential impacts on these sensitive ecosystems. The presence of microplastics in these remote environments highlights the need for better understanding of the sources, distribution, fate, and impacts of microplastics. The study sheds light on the previously overlooked issue of microplastic pollution in high-mountain lakes, challenging the perception of these remote environments as pristine and unaffected by human-driven pollution. The research underscores the global nature of microplastic pollution and its ability to reach even the most secluded and ecologically sensitive locations. Through a comprehensive review of existing research, this study has emphasized that microplastics, in the form of minute plastic particles, have infiltrated high-mountain lakes from various sources, leading to a widespread distribution throughout these ecosystems. The fate of microplastics in these lakes is also explored, revealing potential impacts on the food web and biogeochemical cycles. Furthermore, the need for further investigation into the potential consequences of microplastics on the unique biodiversity and fragile ecosystems of high-mountain lakes is highlighted. The study raises awareness about the potential implications of microplastics for human health, as these particles can enter the food chain and ultimately reach consumers. This underscores the urgency for continued research and collaborative efforts to comprehensively assess the extent of microplastic pollution in high-mountain lakes and develop effective strategies for mitigation. In light of these

findings, it is evident that high-mountain lakes, once considered pristine havens, are now grappling with the pervasive issue of microplastic contamination.

Addressing this emerging challenge requires a multidisciplinary approach, involving researchers, policymakers, and local communities to collectively develop and implement strategies that safeguard these sensitive ecosystems and ensure the well-being of both their inhabitants and the broader environment. Finally, this study underscores the importance of acknowledging and addressing microplastic pollution in high-mountain lakes as a crucial step toward the conservation and protection of these remarkable and irreplaceable natural wonders. Further research is needed to fully understand the extent and impacts of microplastic pollution in these unique ecosystems and to develop effective mitigation strategies. Overall, the protection and preservation of high-mountain lake ecosystems is crucial for the maintenance of biodiversity and ecosystem services, and the reduction of microplastic pollution is an important step towards achieving this goal. Effective mitigation strategies are needed to address this issue and protect high-mountain lakes from the negative impacts of microplastics.

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