Assessing heavy metal pollution and ecological risks in aquatic ecosystems of northern Pakistan: a multiscale perspective

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Sediments are key components in aquatic ecosystem, serving as natural reservoirs and sources for heavy metals, with contaminants accumulating from both dissolved and particulate sources. When exposed to aerobic conditions, sediments undergo chemical transformations, thereby altering metal solubility. Therefore, to understand pollutant behavior and potential environmental risks, it is necessary to examine the extent and origin of heavy metal accumulation. This research examines the spatial distribution, sources, and ecological implications of heavy metals contamination in freshwater sediments across diverse geological settings of northern Pakistan, including the Hunza River, Indus River, Dor River, and Naltar Lakes. Using advanced techniques such as atomic absorption spectrometry (AAS), sediment samples were analyzed to quantify pollution levels, identify contamination sources, and evaluate the ecological and human health impacts of heavy metals and potentially toxic elements (PTEs). The findings reveal that heavy metal concentrations, particularly iron (Fe), cadmium (Cd), chromium (Cr), and nickel (Ni), are influenced by both natural geological processes, such as bedrock weathering and erosion, and localized anthropogenic activities, including agricultural runoff and wastewater discharge. Contamination indices such as contamination factors (CF), pollution load indices (PLI), and ecological risk indices (ERI) indicate moderate to high pollution, with downstream areas showing higher contamination levels. Health risk assessments of sediment contamination identify arsenic and cobalt as significant contributors to potential hazards. Statistical analyses highlight the predominant role of geogenic sources in sediment contamination, while localized human activities further consolidate heavy metal accumulation. This research provides essential insights into sediment contamination dynamics, contributing to a broader understanding of heavy metal transport and deposition in riverine ecosystems. The findings support the development of sustainable sediment management practices to mitigate environmental risks in the region. It also provides essential insights for sustainable ecosystem management and policymaking to protect aquatic habitat and public health, aligning with the United Nations Sustainable Development Goals (SDGs).

Keywords: Spatial Distribution; Sediment; Atomic Absorption Spectrometry; Potential Hazards; Sustainable Development Goals.

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