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Bridging Geochemical and Spatial Analyses to Assess Heavy Metal Contamination and Health Risks in Industrializing Regions

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Rapid industrialization significantly impacts soil and groundwater quality, leading to elevated heavy metal contamination and potential health risks. Heavy metal (HM) concentrations in groundwater and soil samples of developing industrial areas were assessed using Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES). Heavy metals like Arsenic (As), Nickel (Ni), Mercury (Hg), and Cadmium (Cd). Multivariate statistical modeling, such as Principal Component Analysis (PCA) and Positive Matrix Factorization (PMF), identified industrial effluents, improper waste disposal, and atmospheric deposition as major contamination sources. Spatial analysis using GIS-based Kriging mapped high-risk zones, with As and Cd exceeding safe limits in 47% of groundwater samples and 62% of soil samples. In some locations, Cd concentrations were four times above regulatory standards, posing severe health risks to local communities. Field surveys and stakeholder interviews confirmed that unregulated industrial discharge and inadequate waste management play key roles in contamination. This study highlights the urgency of targeted remediation efforts and stricter environmental regulations to mitigate human health risks in rapidly developing industrial regions.