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Geochemical and Mineralogical Assessment of Heavy Metal-Contaminated Soils: Implications for Remediation Based on Magnetic Susceptibility Analysis

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This study assessed heavy metal contamination in soils from a railroad depot in South Korea through total content analysis, sequential extraction, Cu and Zn isotopic, and SEM-EDS analyses. Magnetic susceptibility was also measured to assess the feasibility of physical remediation methods. Site-specific geochemical and mineralogical assessments are essential for developing effective remediation approaches.

Contents of Pb, Zn, and Cu exceeded the worrisome level (Region 1) of soil contamination in the Republic of Korea, with the most contaminated sample containing Pb (7,130 mg/kg), Zn (1,697 mg/kg), and Cu (538 mg/kg). The high Fe content (121,104 mg/kg) suggests contamination from foundry sand and scrap metal. Sequential extraction results indicated that Cu was primarily associated with the organic-bound and Fe-Mn oxide-bound fractions, while Zn and Pb were predominantly bound to the Fe-Mn oxide-bound and residual fractions. The isotopic signatures of Cu (δ^{65}Cu: -0.218 to 2.585‰) and Zn (δ^{66}Zn: -0.145 to 0.332‰) reflect their geochemical behavior and fractionation patterns.

For δ^{66}Zn, values were generally higher in the carbonate-bound fraction (0.332‰), Fe-Mn oxide-bound fraction (0.130‰), and organic-bound fraction (0.035‰) compared to the ion-exchangeable fraction (-0.032‰) and residual fraction (-0.145‰). The calculated bulk isotope ratio was 0.043‰.

For δ^{65}Cu, the highest isotope ratio was observed in the ion-exchangeable fraction (2.466‰), likely due to the desorption of previously adsorbed Cu during oxidative leaching. The isotope ratio was lower in the carbonate-bound fraction (-1.495‰), whereas it was 0.200‰ in the Fe-Mn oxide-bound fraction, -0.401‰ in the organic-bound fraction, and -0.218‰ in the residual fraction. The calculated bulk isotope ratio was -0.206‰.

SEM-EDS analysis identified Zn-bearing Fe oxides encapsulated within the foundry sand mold, primarily composed of a silica matrix, indicating limited extractability. While bulk samples exhibited high magnetic susceptibility, samples after milling indicated a heterogeneous distribution of magnetic materials. The weak correlation between soil magnetism and contamination levels indicated the limited efficacy of magnetic separation.

Given the complex contamination characteristics, conventional soil washing may be ineffective, necessitating alternative stabilization strategies.