**"Synergistic Soil Remediation Strategies: Investigating the Enhanced Removal Efficacy of Heavy Metals (Cd, Pb, Cu, and Zn) for Sustainable Environmental Management"**

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**Abstract**

The presence of heavy metals in soils, particularly agricultural soils, poses a significant risk to human health and ecosystem health because of their stability, non-microbial degradation, and mineralization. Overall, despite these drawbacks, the adsorption method has a high efficiency of approximately 100% and up to 95% for removing arsenic from water and soil, respectively. This study investigates the possibility of using a soluble humic substance (HS) made from leonhardite to remove copper from soils that have been contaminated. Assessments were conducted on the effects of different washing conditions, including concentration, and washing cycles, on removal efficiency. The findings demonstrated that an ideal removal efficiency of 37.5% for Cu in soil was attained by a single washing with HS solution, and an additional reuse produced an extraction efficiency of more than 30.5%. A two-step soil washing method using a chemical reductant (NH2OH·HCl) in combination with an HS solution (NH2OH·HCl + HS) was used to further improve Cu removal efficiency. This method increased the removal efficiency to 53.0%. Additionally, by 13.6% and 11.4%, respectively, this method greatly decreased the plant availability and bio accessibility of Cu. In contrast to a single NH2OH·HCl washing, by assessing the long-term impacts of the adopted strategies on soil health and biodiversity, the study also takes environmental sustainability into account. The findings of this study provide important new understandings for the development of thorough and long-lasting soil remediation techniques, which influence environmental management strategies and policies. The results have ramifications for how heavy metal contamination issues are handled on a global scale, highlighting the significance of comprehensive and cooperative strategies to attain ecologically sound solutions for sustainable management of soil and ecosystems.