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Multiscale geochemical–spectral modelling of acid mine drainage dispersion in an abandoned mine in the Iberian Pyrite Belt (W Spain)

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This study presents an integrated, multiscale framework for geoenvironmental modelling in abandoned mining areas of the Iberian Pyrite Belt (IPB), combining geochemical and mineralogical characterization with spectral reflectance analytics. The approach is applied to the Trimpancho mining system (Huelva, Spain), composed of waste-rock dumps from four medium-sized exploitation sites currently in advanced stages of degradation. The area exemplifies the transboundary dimension of mining-related contamination: acid leachates discharge into the Trimpancho stream and ultimately reach a Portuguese reservoir used for human consumption, generating a multi-contaminant hotspot of regional concern.

A dense sampling network (n = 241) encompassed soils, waste-rock materials, stream sediments, and waters. Major and trace elements (Al, As, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, V, Hg) were quantified by ICP-OES and by a thermal-decomposition mercury analizer, including soluble and extractable fractions, together with sulfates, physicochemical parameters, and grain-size distribution. The alteration mineralogy was characterized and identified using X-ray diffraction (XRD) on samples previously sieved to 2 mm and subsequently ground. These datasets were integrated with high-resolution spectral information derived from drone-based multispectral surveys and laboratory hyperspectral analyses. LiDAR-supported photogrammetry enabled the production of detailed digital terrain and surface models, supporting geomorphological and structural interpretation.

Geomorphological analysis clarified the structural control of the drainage network and identified preferential contaminant transport pathways linking waste-rock dumps to the stream channel. Spectral indices successfully delineated zones enriched in iron oxides–hydroxides and secondary sulfate minerals, consistent with geochemical spatial interpolation results. Peak concentrations reached 450 mg/kg As, 35,000 mg/kg Cu, and 1,325 mg/kg Zn in waste-accumulation zones. Stream-margin sediments recorded up to 241,150 mg/kg Al, 5.5% Fe, 6,000 mg/kg Pb, 5,500 mg/kg Zn, and 25 mg/kg Hg.

Given the limited basin size and the high spatial resolution of the dataset, the resulting indicators enable basin-scale assessment of contamination intensity and dispersion patterns. The identification of preferential runoff corridors and contaminant accumulation hotspots provides a robust decision-support basis for prioritizing remediation measures aimed at pollutant immobilization and mitigating ongoing acid mine drainage transport.