**Monitoring and Modelling of Hydrological and Geochemical Processes in Large in-situ Waste Rock Leaching Columns**

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A comprehensive in-situ monitoring and geochemical modelling was conducted to investigate the hydrological and geochemical behaviour of waste rock materials, with a focus on addressing environmental challenges posed by potentially acid-forming (PAF) waste. The research evaluated alternative waste co-disposal strategies and the effectiveness of various cover materials. Six large, vertically aligned columns (with a diameter of 1 m and height of 4 m), simulating different configurations of neutral and acid-forming waste types, were instrumented to monitor parameters such as moisture content, suction, oxygen levels, and leachate chemistry over five years. Both Monitoring and geochemical modelling results demonstrated that compacted waste significantly improved moisture retention and reduced oxygen ingress, thereby limiting pyrite oxidation and maintaining near-neutral pH levels in most configurations. Geochemical analysis revealed that calcite dissolution and muscovite weathering were critical in buffering acidity and sustaining alkalinity. Long-term monitoring indicated equilibrium in moisture dynamics and stable leachate hydrochemistry, with pH levels between 6 and 9. The study highlights the importance of material selection, compaction, and cover design in mitigating acid mine drainage, offering valuable implications for sustainable waste management in mining operations.