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# Hydrochemical characterization of hot springs in Ollachea, Puno, according to Peruvian environmental standards

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## Abstract

The present study aims to characterize the physicochemical, geochemical, and environmental quality of the thermal waters of the Ollachea Municipal Pool, located in the Puno region, Peru, in order to assess their potential for recreational use and to identify possible risks to human health and the environment. The waters exhibit distinctive characteristics, including a temperature of 83.5 °C and a pH of 11.67, classifying them as hyperthermal and highly alkaline. Geochemical analyses indicate that sulfate ($SO_4^{2-}$) is the dominant anion (269 mg/L), accompanied by moderate sodium concentrations (62.8 mg/L), reflecting the influence of local geological conditions, particularly the quartz sandstones of the Sandia Formation and oxidative processes affecting iron-bearing minerals. However, the assessment of trace metals reveals that aluminum (Al), antimony (Sb), arsenic (As), and lead (Pb) exceed the limits established by the Peruvian Environmental Quality Standards (EQS) for primary-contact recreational waters. Arsenic reached 0.030 mg/L, exceeding the EQS B1 limit of 0.010 mg/L by approximately three times, while lead reached 0.011 mg/L, slightly exceeding the EQS B1 limit of 0.010 mg/L. These exceedances indicate that the waters are unsuitable for recreational or therapeutic use without prior treatment and continuous monitoring. Comparison with thermal waters from the Callejón de Huaylas highlights notable differences in sulfate and sodium contents, suggesting a distinctive hydrogeochemical signature for the Ollachea system. Additionally, organoleptic properties such as color (58.3 UC), earthy odor, and slightly salty taste support the presence of dissolved mineral and metallic constituents. In conclusion, although the Ollachea thermal waters exhibit significant geothermal potential, continuous monitoring and appropriate treatment are required prior to any recreational or medicinal application. Beyond its local relevance, this study contributes to the understanding of hydrothermal spring systems in data-limited Andean regions, where geogenic trace-metal enrichment, recreational use, and limited monitoring capacity may converge as emerging environmental and public-health challenges.