A Multispectral Approach for Structurally Controlled Groundwater Exploration and Management in the Main Karoo Basin: Integrating Spectral Indices and Machine Learning Models

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Integrating machine learning and spectral indices offers critical insights into structurally controlled groundwater potential in arid regions affected by climate variability. This study evaluates the efficacy of various machine learning models in mapping groundwater potential across the Main Karoo Basin (MKB) during drought conditions. The study leverages groundwater-dependent vegetation and dolerite dikes to identify groundwater recharge zones during the dry season of a drought year. Five machine learning models were tested, with the fast tree decision learning model demonstrating superior performance. It achieved the highest classification accuracy (81.4%) and a high region under the curve (ROC) of 0.84, outperforming other models such as random forest, simple logistic regression, stochastic gradient descent model and multinomial logistic regression model with ridge estimator. Spatial analysis revealed significant clustering of groundwater potential, especially along the Drakensberg Escarpment, the eastern part of the MKB adjacent to the Indian Ocean, and in the arid western part of the MKB, which has localized zones where rivers intercept geological structures such as dolerite dikes and ring structures. These zones exhibit high groundwater potential even during prolonged droughts. Borehole yield data and spring distributions further validate these findings, highlighting the model's ability to predict structurally controlled groundwater systems. The results underscore the value of using AI and machine learning for environmental management in drought-prone areas. By integrating these models with big data analytics, stakeholders can better predict groundwater availability, optimize resource management, and mitigate drought impacts. The findings provide actionable insights for local decision-makers and contribute to long-term strategies for groundwater conservation in South Africa and similar semi-arid regions worldwide.