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Spatiotemporal groundwater predictions using Explainable AI

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Abstract: As the use of machine learning (ML) models in hydrology becomes more widespread, the need for interpretability and transparency is increasingly critical. Trust in these models is essential for their integration into water resource management. This has led to growing interest in Explainable Artificial Intelligence (XAI, Hassinja et al. 2024), a suite of tools and techniques designed to make ML outputs more understandable and actionable. XAI offers a pathway to bridge the gap between complex model outputs and stakeholder comprehension, thereby enhancing the credibility and utility of ML in hydrological applications.

This study investigates the potential of XAI to improve understanding of alluvial groundwater systems in the Murray-Darling Basin in Australia. By applying XAI techniques to an ML model, we explore spatiotemporal variations in groundwater trends and identify key drivers of change over extended periods, including during significant drought events. The analysis reveals how different climatic and anthropogenic factors influence groundwater levels across various subregions, offering insights that would be difficult to obtain using traditional hydrological modelling approaches.

Key results include the identification of groundwater resource development as the most influential variable affecting groundwater levels. This was followed by flood inundation, annual rainfall, and potential evapotranspiration (PET). While increase in the number of extraction bores primarily governed the overall temporal trends, climate variables contributed to more localised responses. Notably, the influence of these drivers evolved over time. Flooding and PET exerting stronger positive influence on groundwater levels towards the end of the study period. The impact of bore numbers became increasingly negative, and drought conditions significantly altered the relationships between groundwater and both climatic and anthropogenic factors.

Regional differences were also evident. In the Condamine region in the north, influence of extraction bores was stronger before the Millennium Drought, while post-drought effects were more subdued. A lack of flooding in recent years emerged as a key factor in declining groundwater levels. In the Namoi/Gwydir region, climate impacts were strongest around 2020, contrasting with other regions where the Millennium Drought had the strongest influence. The southern region (Lachlan/Murrumbidgee/Murray/Goulburn) exhibited persistent climate sensitivity during and post-drought and consistent strong influence from extraction bores. Flooding also played a major role in recharge.

Overall, the integration of XAI into groundwater modelling represents a promising advancement toward more transparent, interpretable, and actionable hydrological insights, paving the way for more informed and sustainable water resource management. Our findings demonstrate that XAI can uncover nuanced interactions between groundwater levels, climate variability, and human activities, providing a more holistic understanding of groundwater behaviour.

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