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Groundwater Drought Dynamics and Vulnerability under Climate Change in the Sanjiang Plain, China

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Groundwater is a vital freshwater resource, supporting agriculture, ecosystems, and human livelihoods. However, increasing groundwater scarcity, exacerbated by overextraction, climate change, and land-use intensification, poses significant challenges, particularly in regions like the Sanjiang Plain, China. This study explores the propagation dynamics of groundwater drought and assesses its vulnerability to provide actionable insights into sustainable groundwater management.

The first part of this research investigates how meteorological drought propagates to groundwater systems using standardized indices (SGDI and SPI) and wavelet coherence analysis. Seasonal dynamics show that propagation times are shortest in summer, when irrigation intensifies the impact, and longest in winter. While irrigation buffers drought impacts in some seasons, it accelerates groundwater depletion in summer, particularly in areas with intensive agricultural activity. Nonirrigated regions display heightened drought sensitivity, reflecting the absence of adaptive mechanisms and exacerbating resource stress.

Building on this, we assessed groundwater drought vulnerability using a newly developed Groundwater Drought Vulnerability Index (GDVI). Combining the Analytic Hierarchy Process (AHP) and Random Forest (RF) models, we evaluated nine factors influencing vulnerability, including groundwater exploitation, clay thickness, and precipitation. Future projections under CMIP6 scenarios (SSP1-2.6, SSP2-4.5, and SSP5-8.5) reveal an alarming expansion of high-vulnerability areas, increasing from 30% during the baseline period to over 50% by mid-century. Drivers include rising temperatures, increased evapotranspiration, and rapid paddy field expansion, further straining already limited groundwater reserves.

The integration of drought propagation dynamics with vulnerability assessments highlights the interplay between human activities, land use, and climatic factors. These findings underscore the urgent need for adaptive groundwater management strategies that address both immediate drought risks and long-term sustainability challenges. Future research should prioritize seasonal-scale assessments and numerical modeling to refine groundwater resource planning and drought mitigation efforts.