Seismology

Potential Relationship between Underground Water and Earthquake

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DOI: https://doi.org/10.15354/si.26.op143
Funding: No funding source declared.
COI: The author declares no competing interest.
AI Declaration: The author affirms that artificial intelligence did not contribute to the process of preparing the work.

The relationship between underground water and earthquakes is an emerging topic in geoscience with significant implications for hazard prediction and water resource management. Subsurface water influences crustal stress, pore pressure, and fault stability, potentially affecting the timing and intensity of seismic events. Human activities such as groundwater extraction, injection of fluids during hydraulic fracturing, and reservoir impoundment have been associated with induced seismicity, highlighting the complex interactions between hydrological and tectonic processes. This article explores the potential connections between underground water and earthquakes, emphasizing both natural and anthropogenic influences. Understanding these dynamics can improve earthquake risk assessment, guide sustainable water management, and inform infrastructure planning. While correlations between water movement and seismicity are observed, causation remains complex, requiring interdisciplinary research. Recognizing the interplay between hydrology and tectonics underscores the need for integrated approaches to predict, mitigate, and adapt to earthquake hazards in water-sensitive regions.

Keywords: Underground Water; Earthquakes; Induced Seismicity; Groundwater; Geohazards

Science Insights, April 30, 2026; Vol. 48, No. 4, pp.2185-2187.

Earthquakes have long been perceived as sudden and uncontrollable geological events, but increasing evidence suggests that underground water can influence seismic activity. The dynamics of water within the Earth's crust—whether in aquifers, faults, or porous rock formations—can modulate stress and pressure, potentially affecting the timing, magnitude, and frequency of earthquakes (U.S. Geological Survey, 2022; Chris H. Scholz, 2019). From deep natural aquifers to human-induced water injections, subsurface water exerts forces on fault systems that can either inhibit or trigger seismic events. Understanding the potential relationship between underground water and earthquakes is critical for hazard assessment, urban planning, and sustainable resource management, particularly in regions where both seismic risk and groundwater exploitation intersect.

The concept that underground water influences earthquakes rests primarily on pore pressure mechanics. Water in subsurface rocks fills pores and fractures, exerting pressure against the surrounding rock matrix. When a fault is near a critical stress threshold, even modest changes in pore pressure can reduce friction along the fault plane, potentially initiating slip and triggering an earthquake (Chris H. Scholz, 2019). This phenomenon is observed in both natural and anthropogenically influenced settings. Groundwater extraction, for example, lowers pore pressure, which can alter stress distribution and lead to subsidence or minor seismic events, whereas fluid injection increases pore pressure and can induce seismicity (U.S. Geological Survey, 2022; Mark D. Zoback & Gorelick, 2012).

Historical cases of induced seismicity highlight the influence of subsurface water on earthquake occurrence. The 1967 Koynanagar earthquake in India (M 6.3) has been widely linked to reservoir-induced seismicity following the impoundment of the Koyna Dam (Gupta, 2002). Similarly, regions in the central United States, particularly Oklahoma, have experienced a surge in earthquakes correlated with the injection of wastewater into deep wells (U.S. Geological Survey, 2016; Keranen et al., 2014). These examples illustrate that human-induced changes in underground water systems can interact with pre-existing tectonic stresses, triggering seismic events that might not otherwise occur.

Natural hydrological processes also play a role in modulating seismicity. Seasonal variations in groundwater levels, snowmelt, and precipitation can subtly affect stress on faults. Observational studies have identified correlations between hydrological loading (e.g., rainfall and groundwater recharge) and shallow seismicity (Saar & Manga, 2003). While these events are generally of lower magnitude, they highlight the sensitivity of the crust to hydrological loading and unloading. The coupling of underground water dynamics with tectonic stresses demonstrates that earthquakes are influenced not only by plate motion but also by local fluid conditions.

Geophysical research provides additional insight into the water–earthquake relationship. Techniques such as seismic tomography, satellite-based interferometry (InSAR), and borehole pressure measurements reveal how fluid movement correlates with fault activity. Water infiltrating faults can reduce effective normal stress and facilitate slip (Mark D. Zoback & Gorelick, 2012). Even small variations in pore pressure can redistribute stress across fault networks, influencing seismic hazard over broader regions.

The interplay between underground water and earthquakes extends to long-term fault evolution. Over geological timescales, fluids promote chemical weathering and mineral alteration, weakening rocks and modifying fault strength (Sibson, 1992). Hydrothermal processes can alter mineral composition and frictional properties, contributing to fault instability and seismic cycles. Thus, water is both an immediate trigger and a long-term conditioning factor in earthquake generation.

Groundwater extraction provides a clear example of anthropogenic influence on fault stability. Excessive aquifer depletion can lead to land subsidence and stress redistribution, as observed in California's Central Valley (U.S. Geological Survey, 2023). While associated earthquakes are typically small, they demonstrate how human water use can influence crustal mechanics. Sustainable groundwater management and seismic monitoring are therefore essential.

Similarly, reservoir impoundment can induce seismicity. The weight of stored water increases stress on the crust, while infiltration raises pore pressure along faults. This combined effect has been linked to earthquakes near large dams such as Koyna (Gupta, 2002) and Zipingpu (Ge et al., 2009). Reservoir-induced seismicity highlights the need to incorporate geophysical assessments into infrastructure planning.

Despite growing evidence, the relationship between underground water and earthquakes remains complex and context-dependent. Fault response depends on geological structure, stress regime, and rock properties (Chris H. Scholz, 2019). Not all fluid injections trigger earthquakes, and thresholds for induced seismicity vary widely. Integrated, interdisciplinary approaches combining hydrogeology, geomechanics, and seismology are required to improve predictions.

Technological advancements are enhancing our understanding of these interactions. High-resolution seismic networks, satellite deformation monitoring, and numerical modeling allow real-time and predictive analysis of hydromechanical coupling (U.S. Geological Survey, 2022). Machine learning approaches are also being applied to large datasets to detect patterns linking fluid changes and seismic activity.

Recognizing the water–earthquake relationship has important policy implications. Regulation of wastewater injection, groundwater extraction, and reservoir operations is critical to reducing induced seismicity risk (U.S. Geological Survey, 2016). Public planning and hazard mitigation strategies must consider hydrological influences, particularly in regions with active fault systems and intensive water use.

In conclusion, underground water plays a multifaceted role in earthquake dynamics. Both natural hydrological processes and human activities can alter pore pressure and stress conditions, influencing fault behavior. While the relationship is complex, it highlights the importance of integrating hydrology and geophysics in hazard assessment. Understanding these interactions enables better risk management, sustainable resource use, and improved resilience in seismically active regions.■

Received: December 16, 2025 | Revised: January 06, 2026 | Accepted: January 22, 2026

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