非受壓含水層地下水開採引起的地層下陷：實驗與計算流體力學的數值評估

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摘要

地層下陷是一項全球面臨的挑戰，當氣候變遷及其他人為因素發生時，更會加劇含水層的脆弱性。本研究使用計算流體力學(CFD)建模工具進行地層下陷模擬；並評估地下水開採與補注對砂箱實驗含水層中粗砂與細砂垂直變形的影響。透過整合 Navier–Stokes 方程式模擬地下水流動，以及以 Terzaghi 定律模擬砂土的垂直位移來建立模型。使用的邊界條件是隨時間變化的水力坡度，為 Dirichlet 型條件。模型以比儲係數(specific storage coefficient)進行校準。研究結果顯示，平均粒徑為 0.39 毫米的細砂在土壤中產生的下陷速率比平均粒徑為 0.67 毫米的粗砂慢。實驗與數值模擬之間的最大差異可以證實，CFD 適合用來模擬地層下陷，並有潛力同時模擬其他動態。結論與建議考量了最新發展與未來研究方向，以精進非受壓含水層地層下陷之研究。

關鍵字： 土壤壓密、地下水、計算流體力學(CFD)、數值建模、沿海含水層、垂直變形。

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Article

Land Subsidence Due to Groundwater Exploitation in Unconfined Aquifers: Experimental and Numerical Assessment with Computational Fluid Dynamics

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Abstract: Land subsidence is a global challenge that enhances the vulnerability of aquifers where climate change and driving forces are occurring simultaneously. To comprehensively analyze this issue, integrated modeling tools are essential. This study advances the simulation of subsidence using Computational Fluid Dynamics (CFD); it assessed the effects of exploitation and recharge of groundwater on the vertical displacement of coarse and fine sands in a laboratory-scale aquifer. A model was developed by integrating the Navier–Stokes equations to study the groundwater flow and Terzaghi's law for the vertical displacement of sands. The boundary conditions used were Dirichlet based on the changes in the hydraulic head over time. The specific storage coefficient was used to calibrate the model. The findings confirmed that subsidence occurs at slower rates in soil with fine sands with average particle diameters of 0.39 mm than in coarse sands with average particle diameters of 0.67 mm. The maximum discrepancy between the experimental and the numerical reaffirms that CFD platforms can be used to simulate subsidence dynamics and potentially allow the simultaneous simulation of other dynamics. Concluding remarks and recommendations are highlighted considering the up-to-date advances and future work to improve the research on subsidence in unconfined aquifers.

Keywords: soil compaction; groundwater; computational fluid dynamics (CFD); numerical modeling; coastal aquifers; vertical deformation