國立中央大學
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Graduate Institute of Applied Geology

SubRISK + Final Workshop

The importance of hydrogeological models in land subsidence simulations

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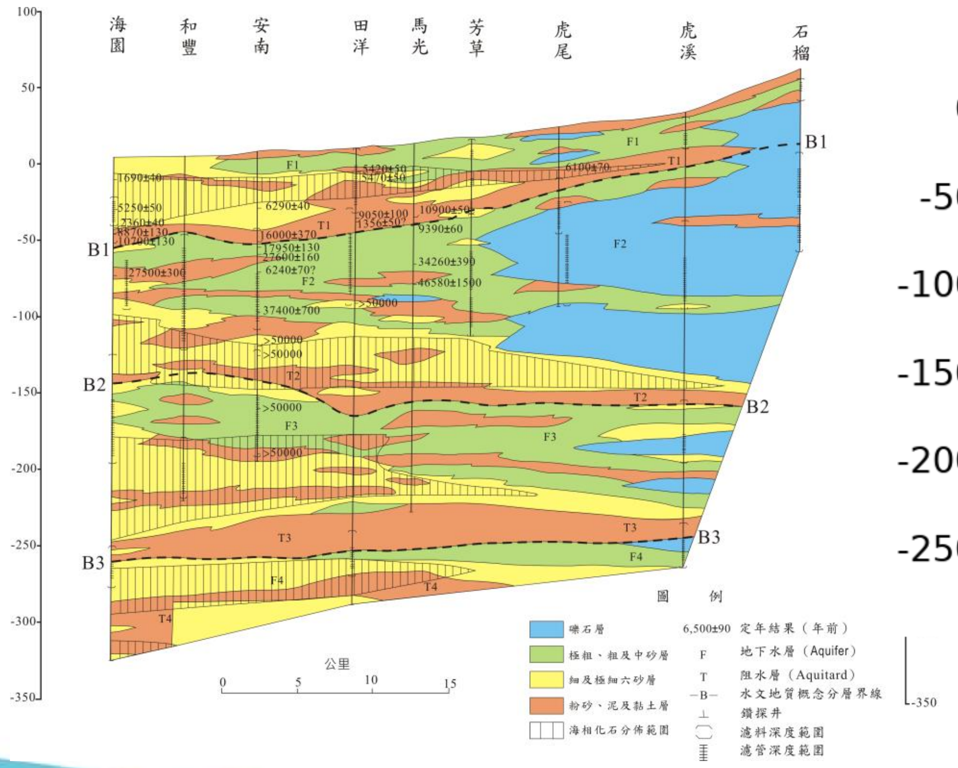
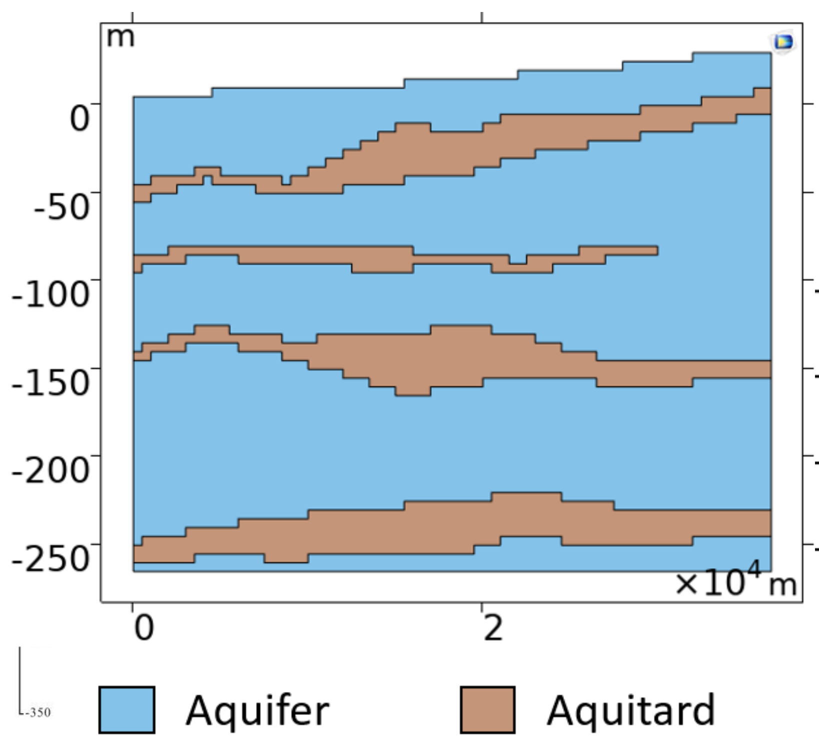
2026/02/27

Introduction – Various Hydrogeological Models

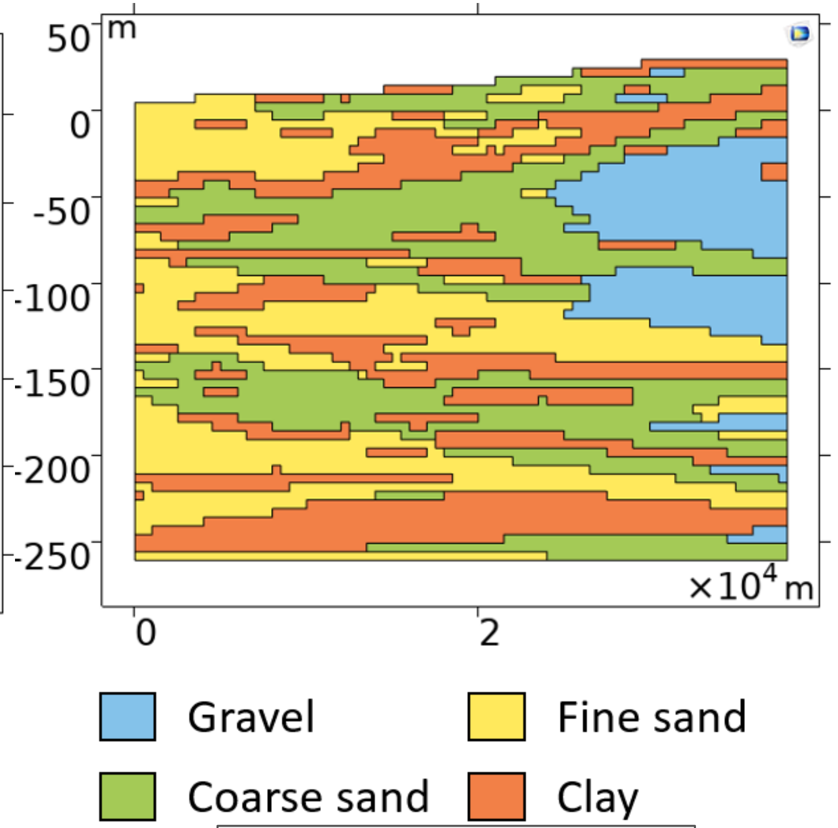
- For groundwater resources assessment, a simplified hydrogeological model is sufficient. However, the characteristics of subsidence are mainly affected by the distribution of geological materials and vary with local geological conditions and geological framework (Liu et al., 2004; Bozzano et al., 2015).



A hydrogeological profile in Yunlin. (GSMMA, 1999)



WRA Model



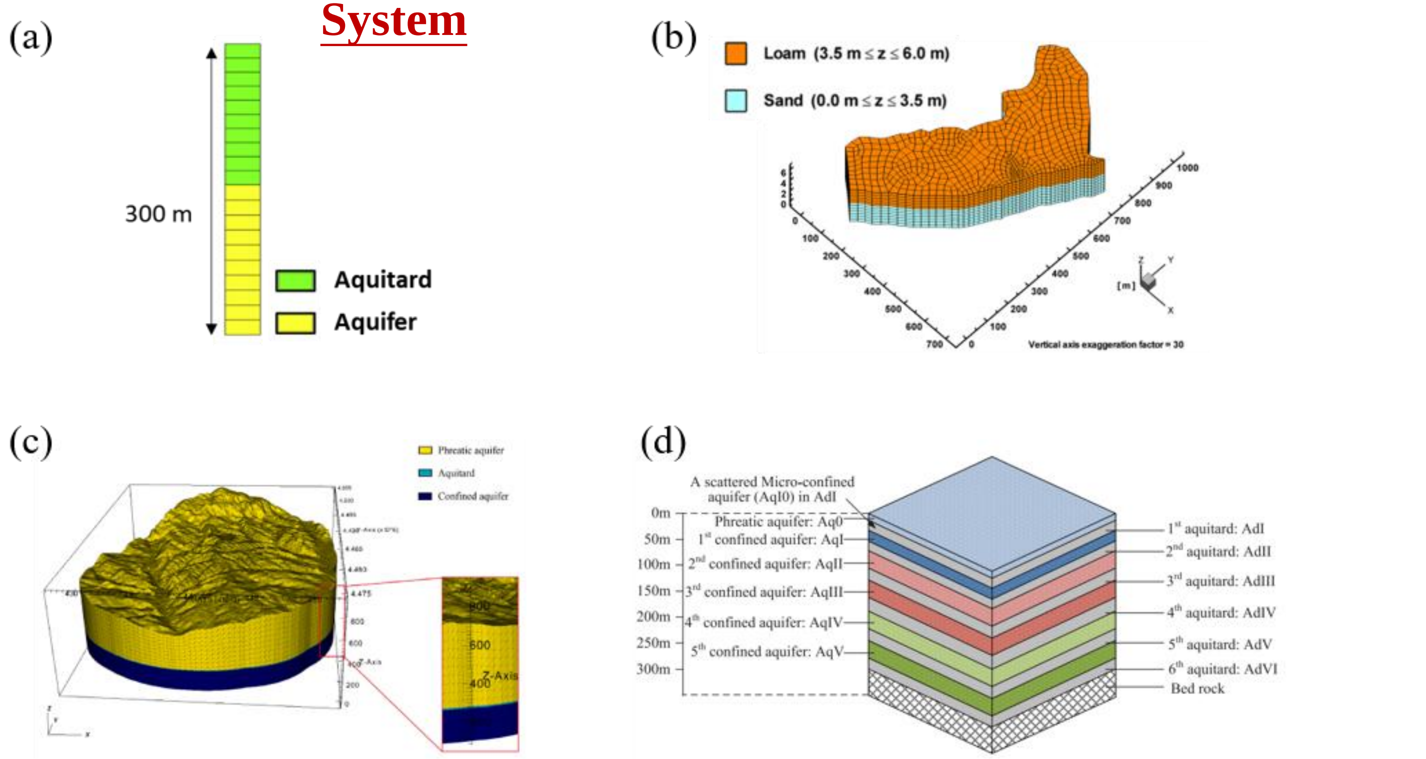
GSMMA Model

Source: Yang and Wang (2023), Master thesis

Introduction – Hydrogeological Model Uncertainty

- The construction of hydrogeological models are usually limited by the measurement methods, the variability and complexity of hydrogeological conditions making it difficult for the hydrogeological structure in the model to fully match the actual hydrogeological conditions.
- There is uncertainty in the hydrogeological model (Moslehi et al., 2015; Dong, 2020).

Aquifer Stratification System



The geological models constructed by previous studies using the coupling model to simulate land subsidence, taken from: (a) Fernández-Merodo et al. (2021), (b) Kihm et al. (2007), (c) Lizárraga & Buscarnera (2020), and (d) Li et al. (2020).

Introduction – Questions?

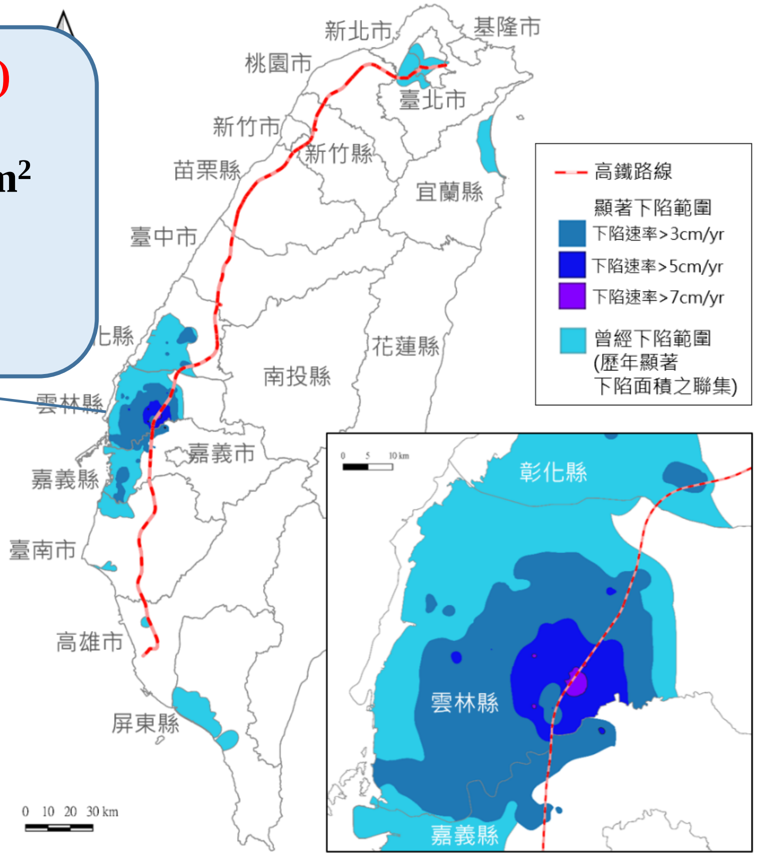
- Can a more precise hydrogeological model provide a better assessment of land subsidence?
- Is a complex hydrogeological model valuable for land subsidence estimation?
- How can we construct a better hydrogeological model, or how should we select a suitable model for assessment?
- How can uncertainty associated with hydrogeological models be quantified?

Spatial transition of land subsidence in Yunlin County

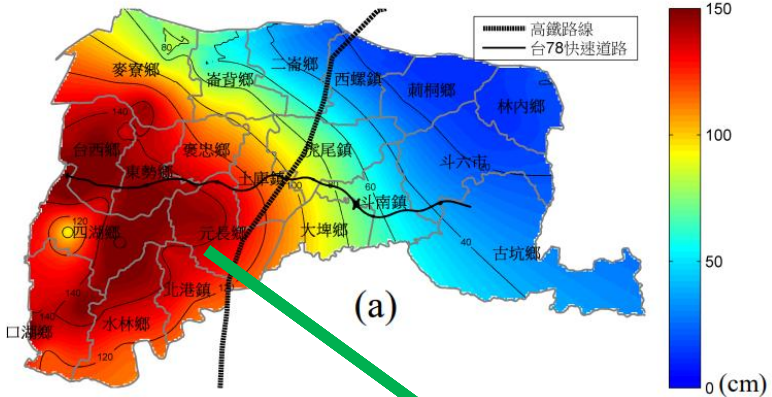
- In the early stage, land subsidence in Yunlin County is mainly located in the coastal areas. However, it is shifted to the central areas and affect the safety of Taiwan High Speed Rail in the current period.

Yunlin County (2021)

- **Area of significant subsidence: 502.7 km^2**
- **Maximum annual subsidence rate: 7.8 cm/yr**



Overview of land subsidence across Taiwan

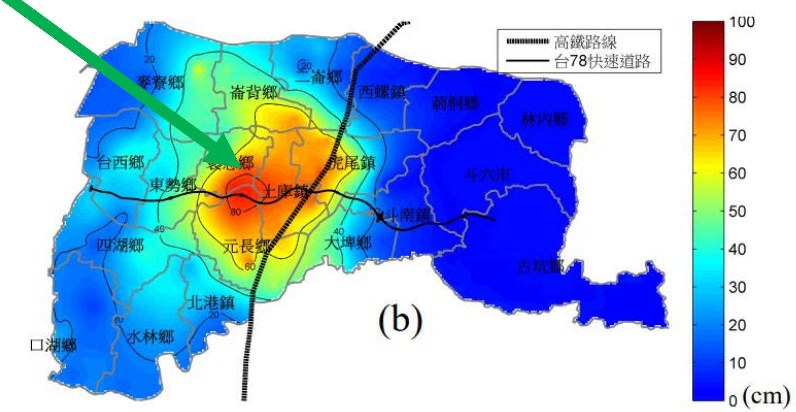


Mechanisms?

(Lin et al., 2016)

Subsidence center shift

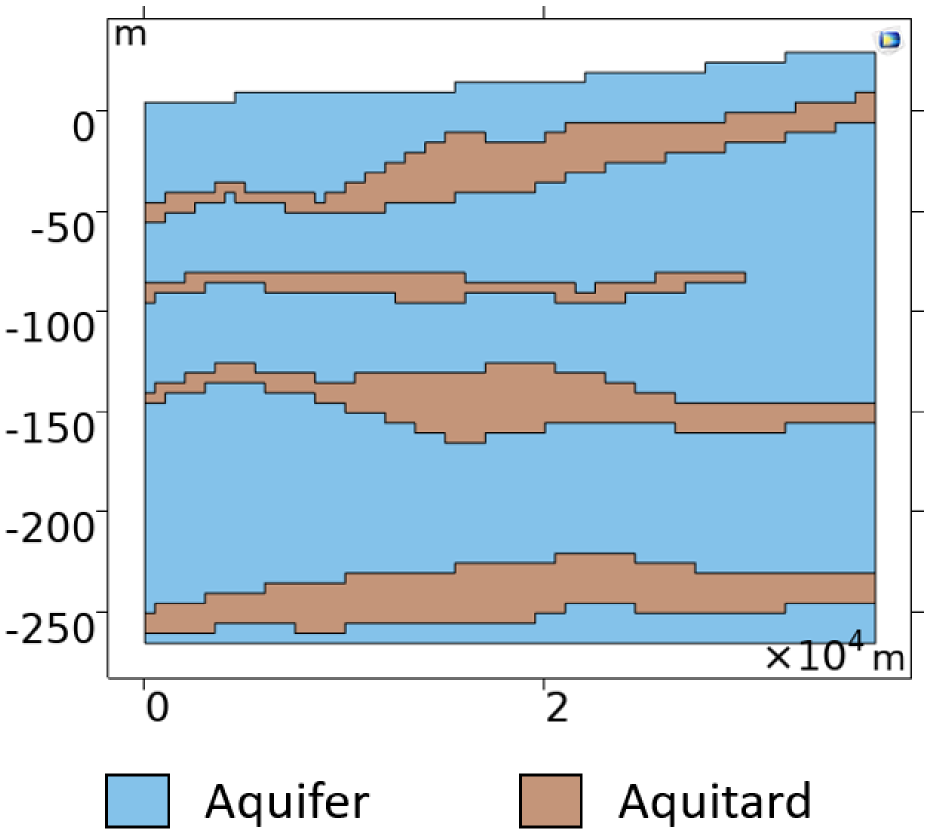
High-speed rail driving safety



Distribution of cumulative subsidence in Yunlin County, detection interval (a)1992-2001 (b)2002-2011

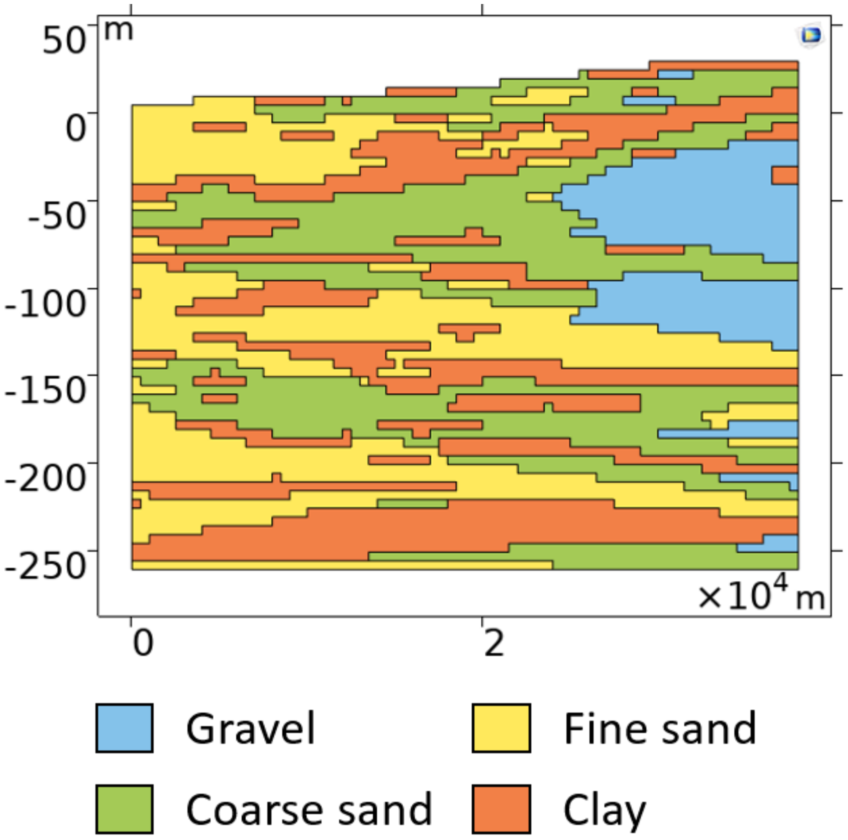
Various complexity of hydrogeological models

WRA Model



36500 m (distance) × 265~290 m (depth)

GSMMA Model



37500 m (distance) × 265~290 m (depth)

Source: Yang and Wang (2023), Master thesis

Historical groundwater level observations

- With reference to the groundwater level observation data of previous years, a total of 50 years were simulated:

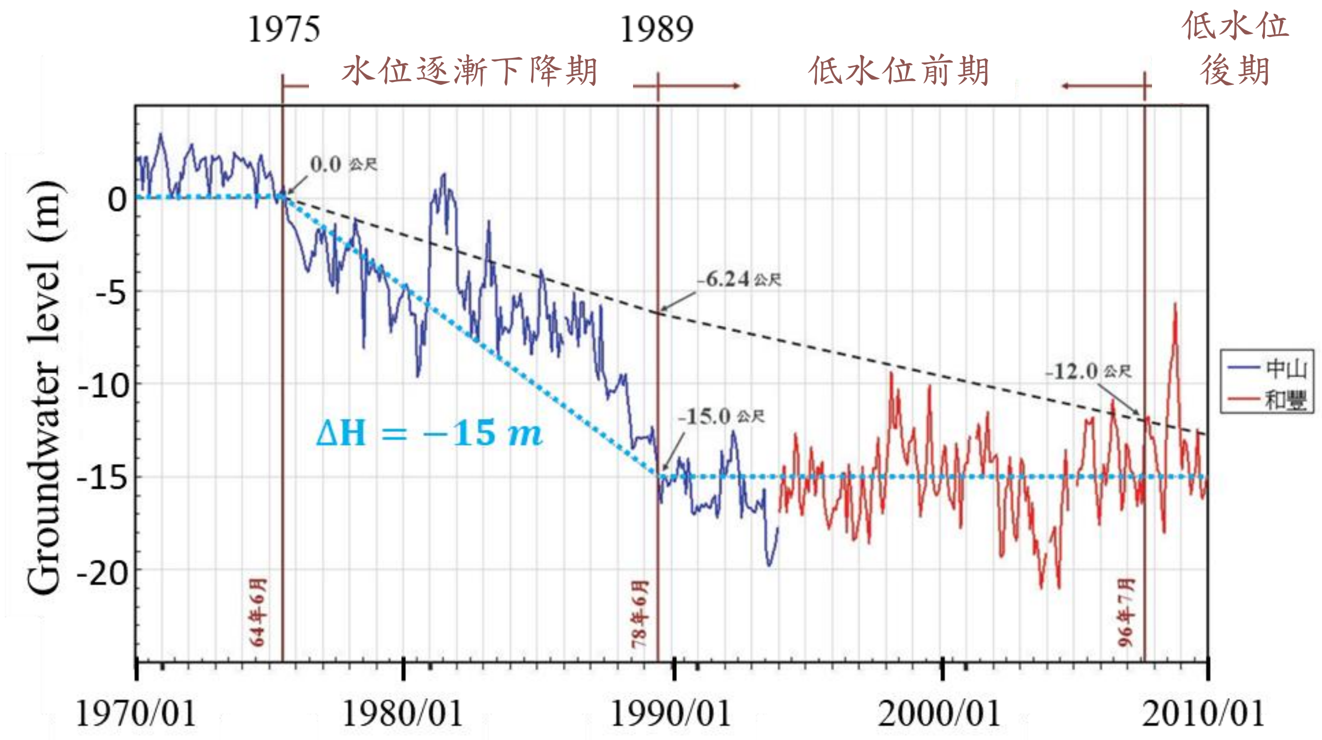


Fig. Groundwater level observation data of Zhongshan Station and Hefeng Station over the years (Jiang, 2011).

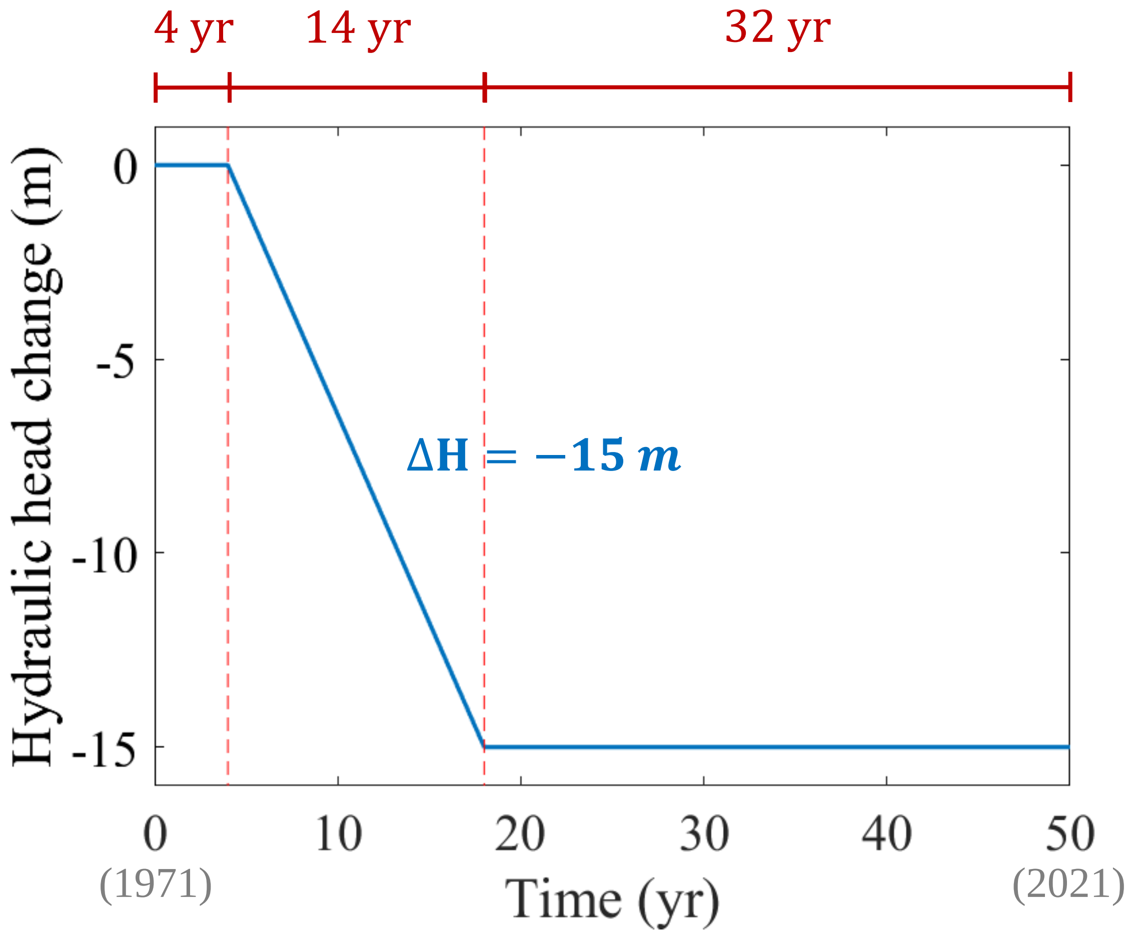
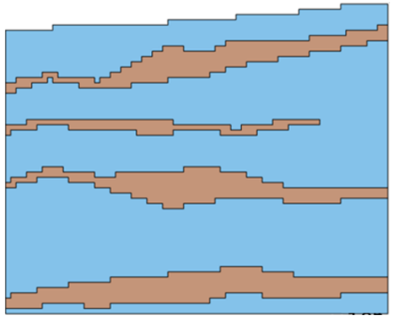
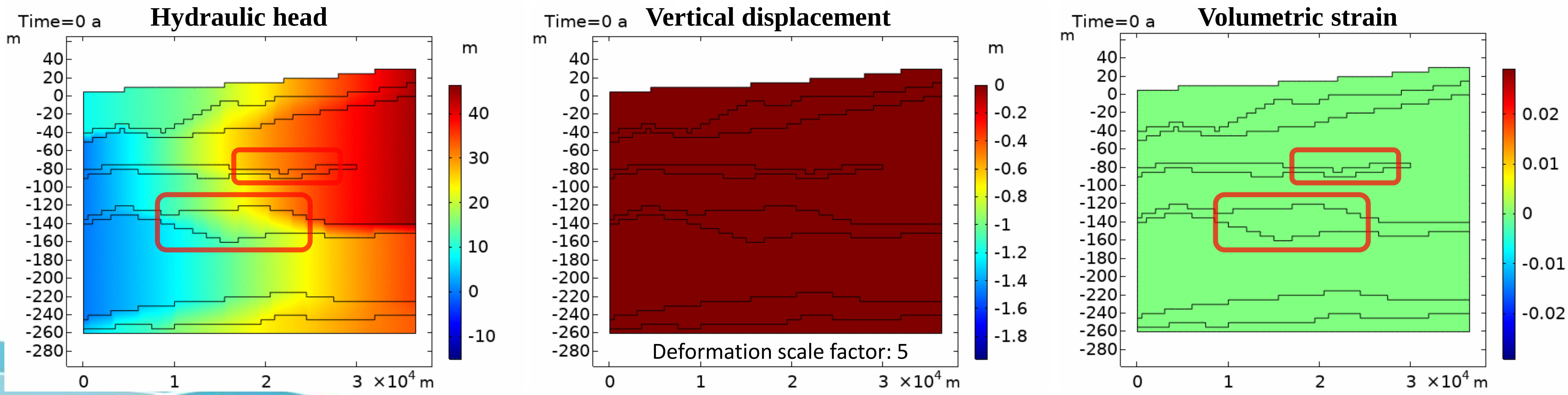


Fig. Scenario of water head change in land subsidence simulation.

Land subsidence under a simplified WRA model

- Cumulative subsidence: Timely subsidence is evenly distributed, while delayed subsidence is mainly distributed in the center of the model.
- Soil deformation: The compressive strain of the aquitard layer is more significant.
- The thickness of the aquitard layer affects its drainage and compaction speed.

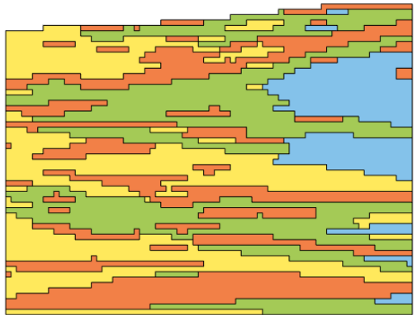


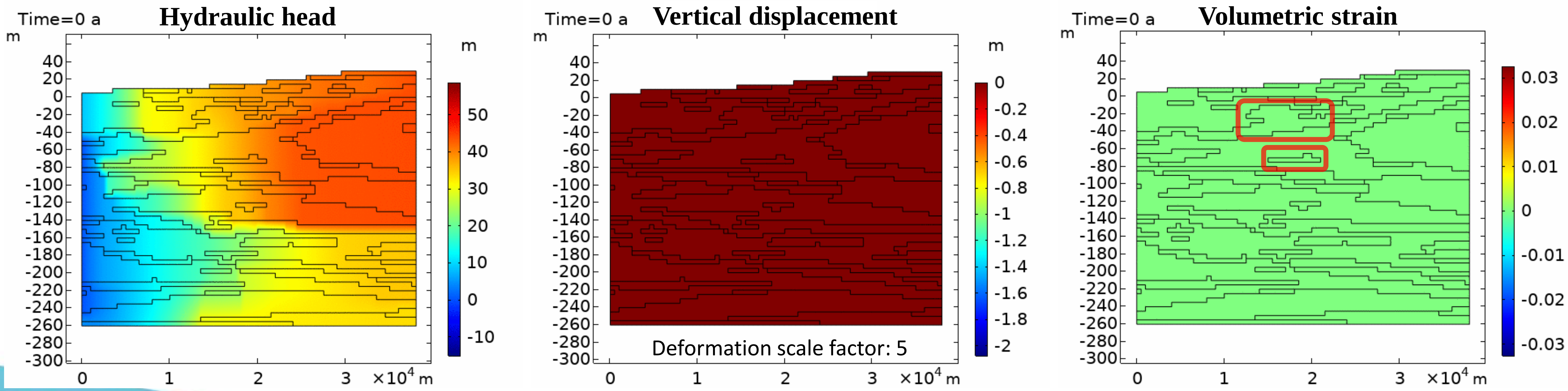


Changes of hydraulic head, vertical displacement, and volume strain over time for the WRA model.

Land subsidence under a complex GSMMA model

- Cumulative subsidence: Severe subsidence areas include both inland and coastal areas.
- Soil deformation: The compression strain of the clay layer is the most significant, followed by the fine sand layer.
- Thick clay layers also have slower drainage and compression behaviors.





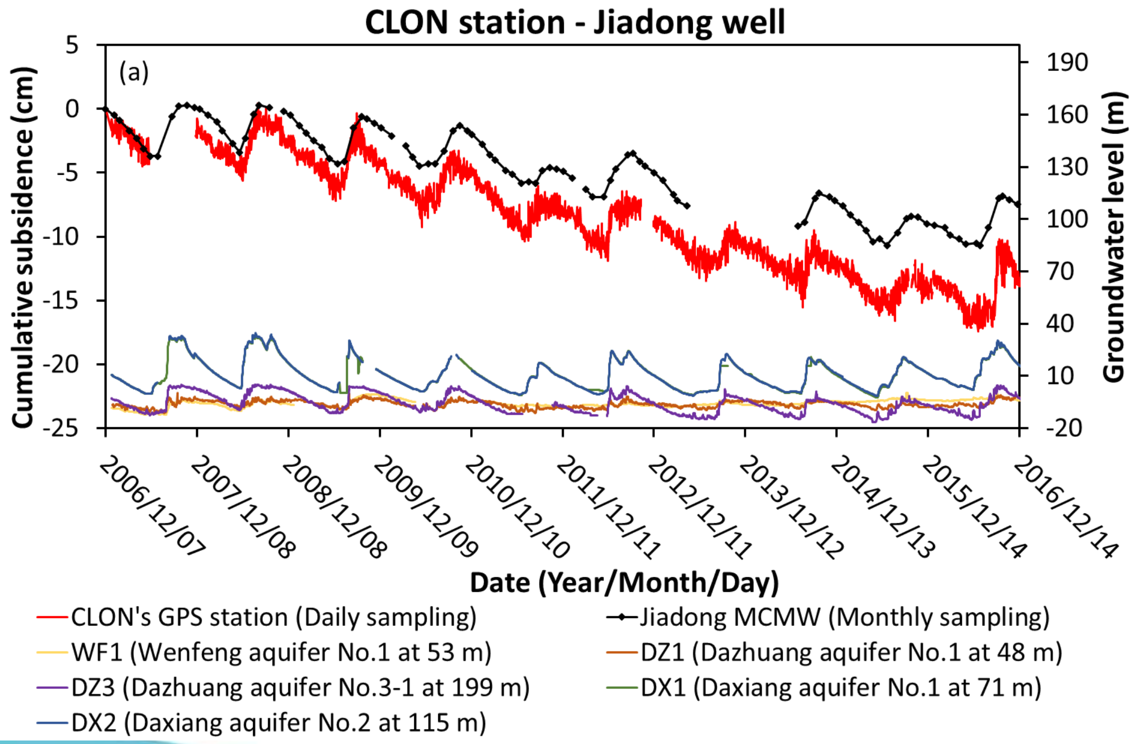
Changes of hydraulic head, vertical displacement, and volumetric strain over time for the GSMMA model.

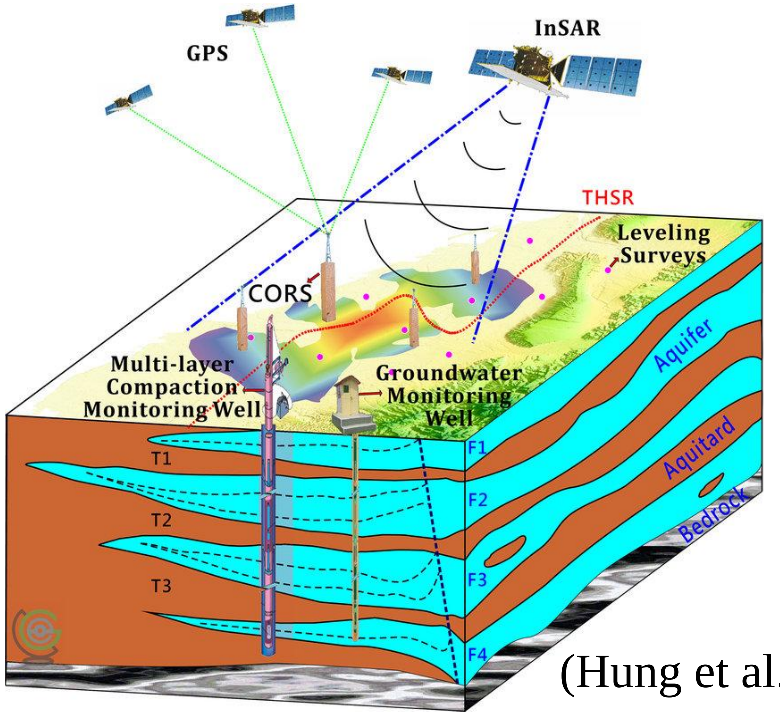
Take home information 1

- A more precise hydrogeological model can provide a better assessment of land subsidence.
  - A coupled hydromechanical model should be adopted.

Deep compression affected by shallow pumping

- From the observations of GNSS and multi-level compaction morning wells (MLCWs), there is discrepancy between them. Deep compression may be caused by shallow pumping or other factors. From traditional layered aquifer system, groundwater in the deep aquifer is not easily affected by shallow pumping.



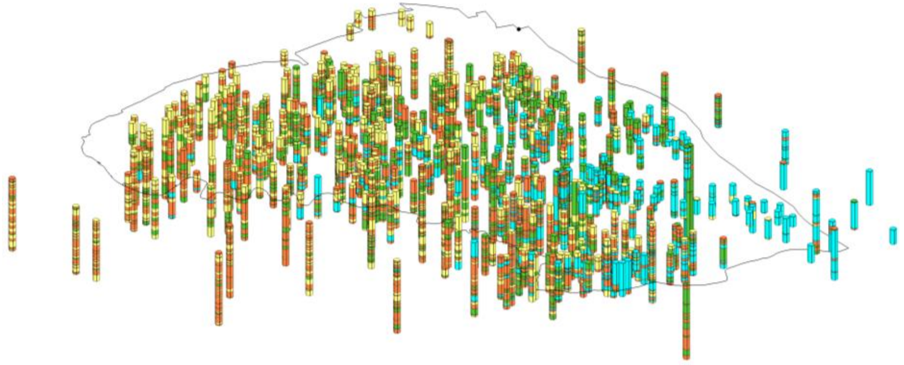


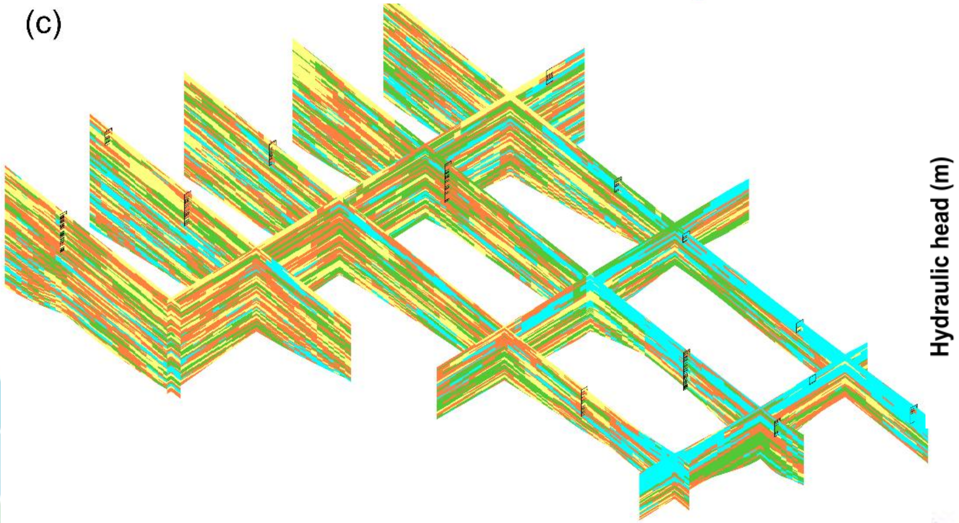
(Hung et al., 2020)

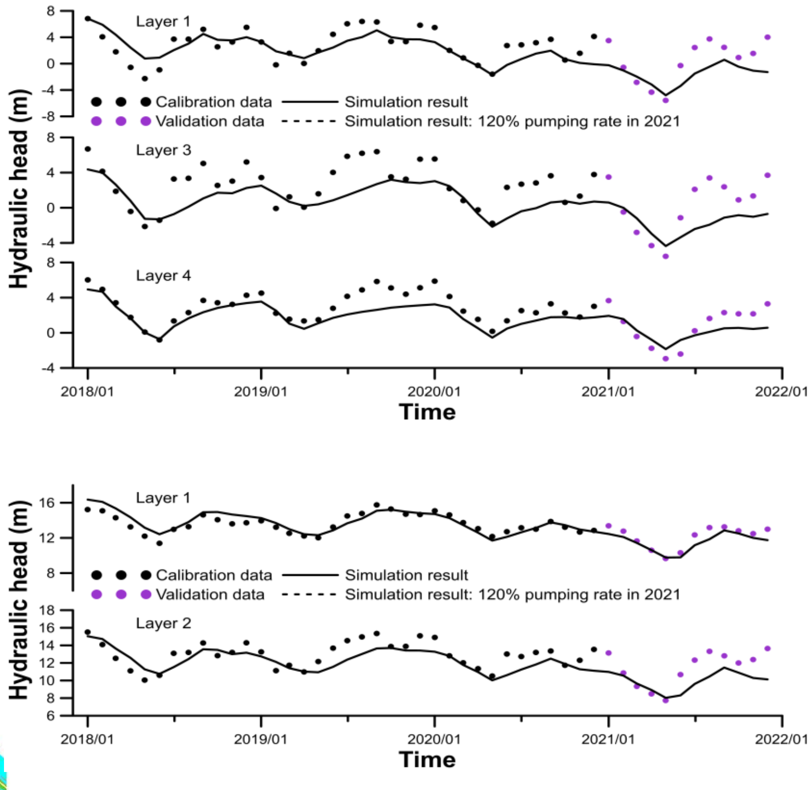
Conceptual model of the multi-stratum subsidence monitoring system in central Taiwan.

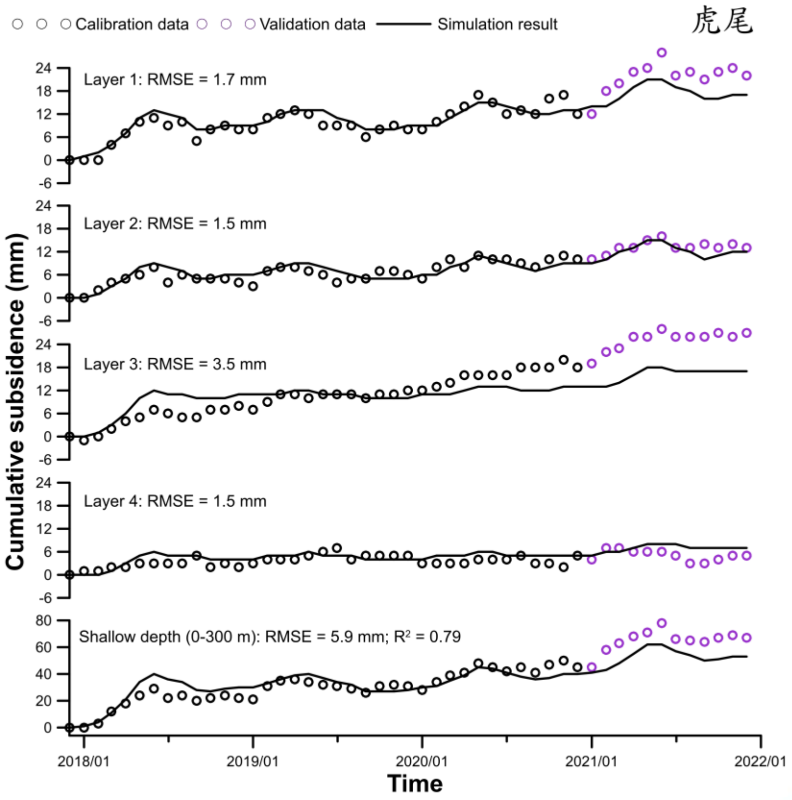
Heterogeneous hydrogeological model

- 472 boreholes with Markov-Chain method was adopted to develop a heterogeneous numerical model. Calibration and validation were implemented within 300 m and then deep compression over 300 m due to shallow pumping was quantified.





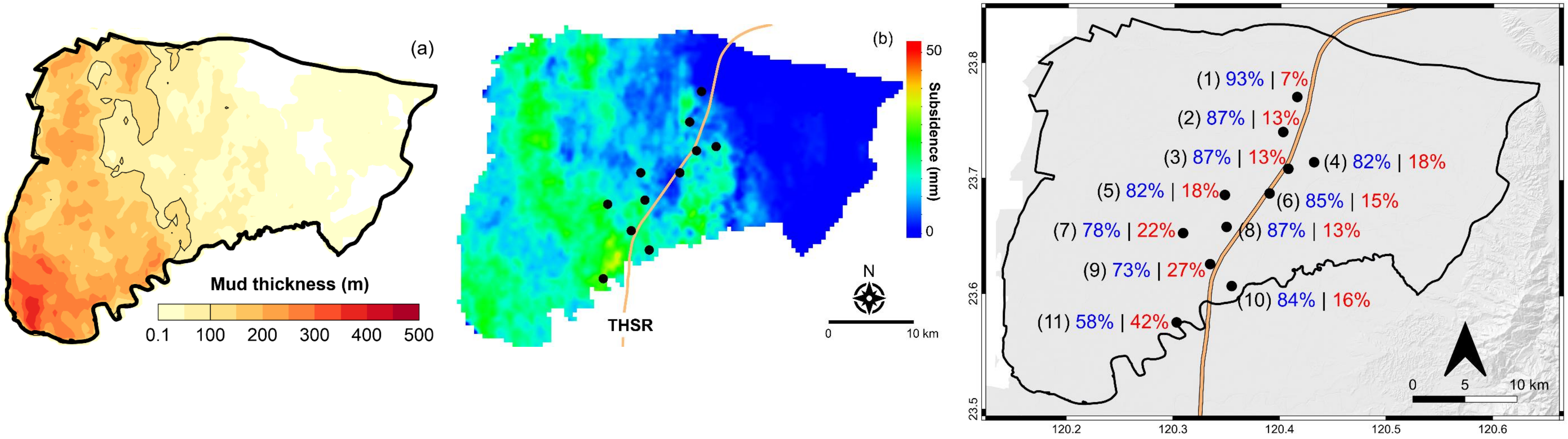




Source: Tran and Wang et al. (manuscript)

Results

- Subsidence distribution is mainly affected by clay distribution.
- Deep compression due to shallow pumping contributes 7-42% of total subsidence around Taiwan High Speed Rail in Yunlin County.

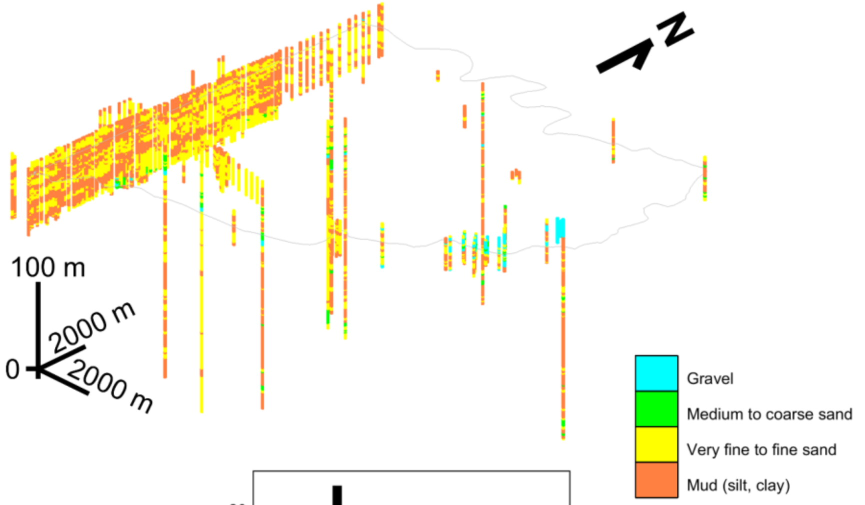


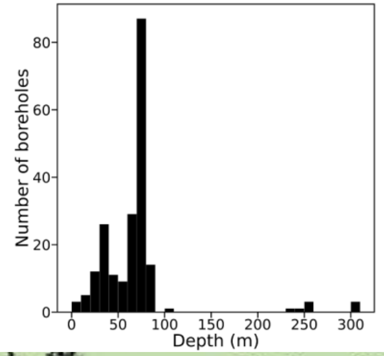
Take home information 2

- A complex hydrogeological model will be able to assess the compression caused by pumping in different depths (layers).

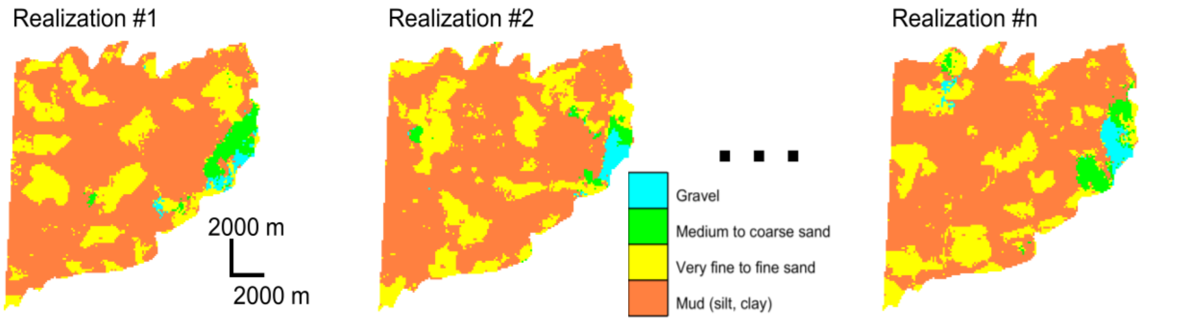
Various hydrogeological models

- From geological setting of the boreholes to construct a hydrogeological model, uncertainty is always embedded. Numerous hydrogeological models match the same geostatistical properties. It is almost impossible to process a calibration step if traditional stochastic simulation (Monte Carlo simulation) is adopted.





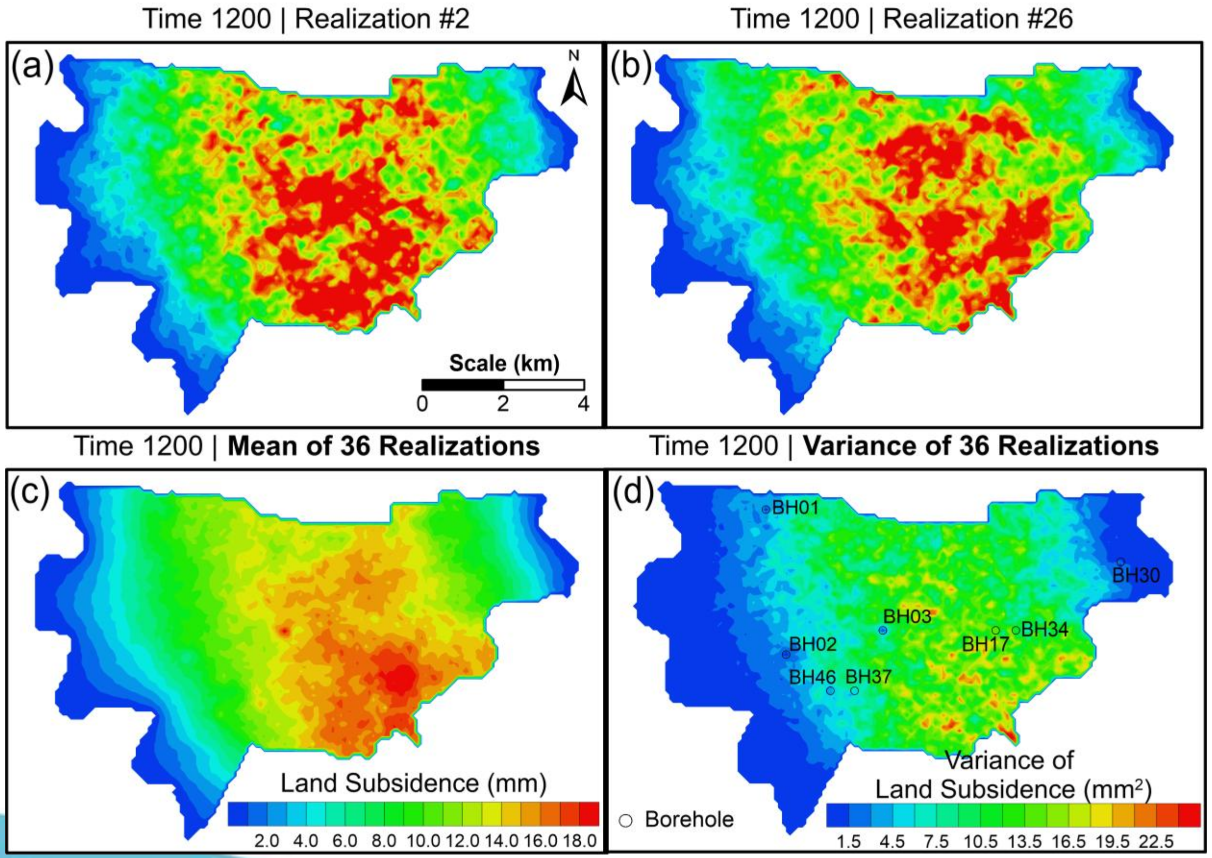
Geological materials	Drilling data volume percentage (%)	Mean Length (m)		
		Vertical	E-W	N-S
Mud (silt and clay)*	59.60	11.91	1241	1179
Fine and very fine sand	34.16	6.96	1372	1078
Coarse to medium sand	3.81	3.13	1263	1626
Gravel	2.43	5.84	885	1053



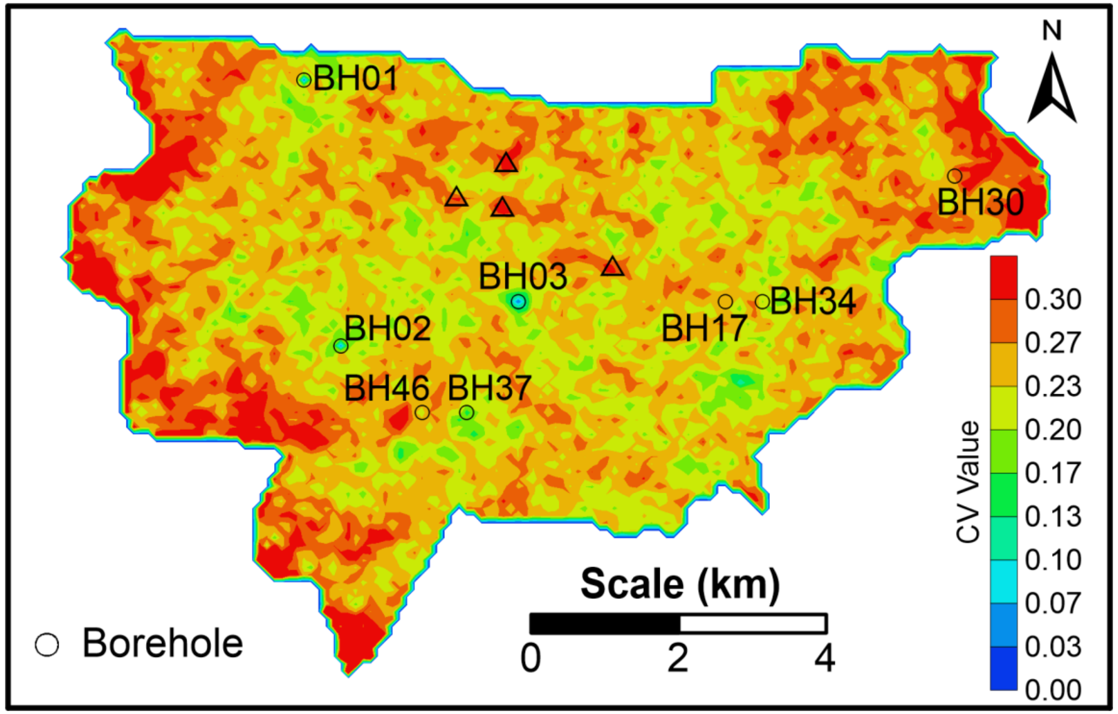
Source: Wang and Tran et al. (2026)

Hydrogeological model uncertainty

- Subsidence distribution is different in different hydrogeological models. Uncertainty assessment can provide a more complete information for the management.



Simulation results of land subsidence distributions.

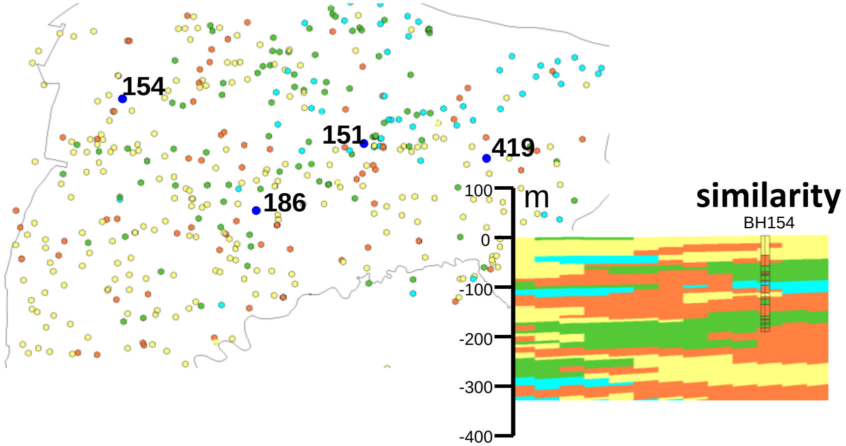


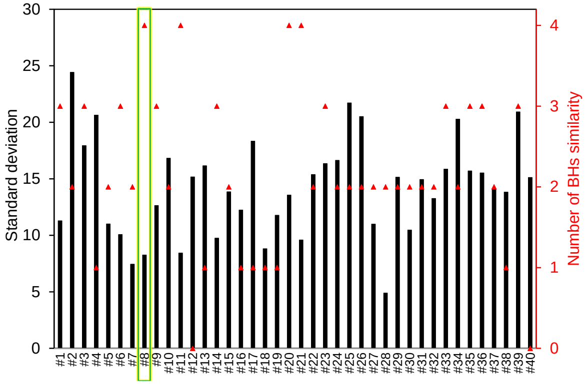
Distribution of CV values of land subsidence for the simulation of 36 realizations.

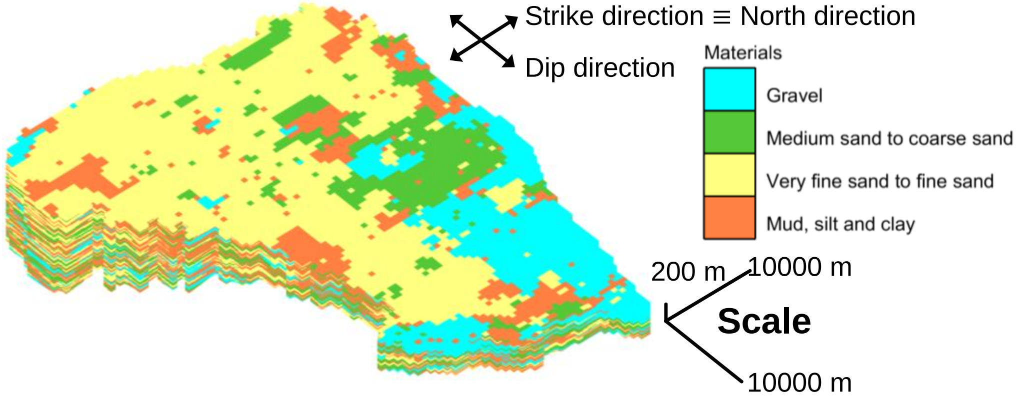
Source: Tran and Wang et al. (2022), Engineering Geology.

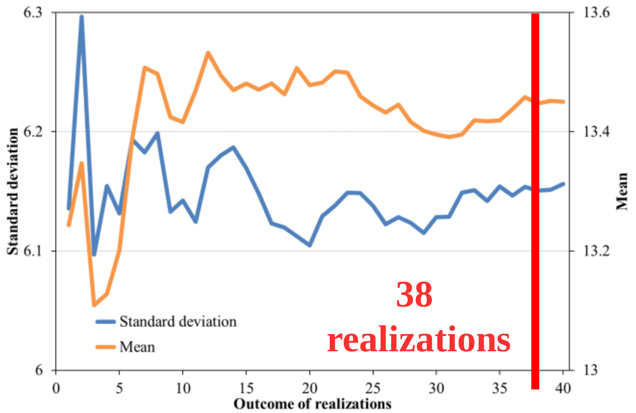
A representative hydrogeological model

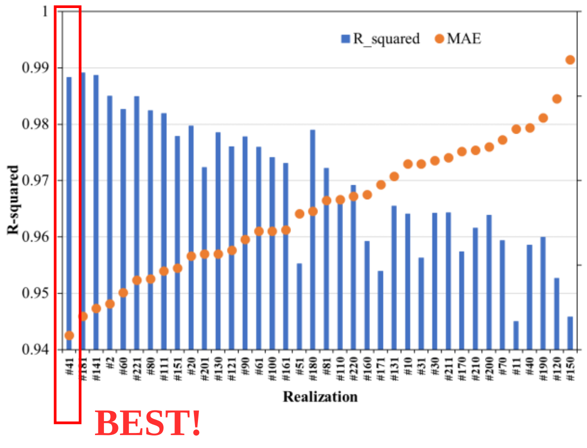
- The hydrogeological model with highest similarity between borehole data and hydrogeological models.
- The hydrogeological model best matches the ensemble mean of groundwater level.

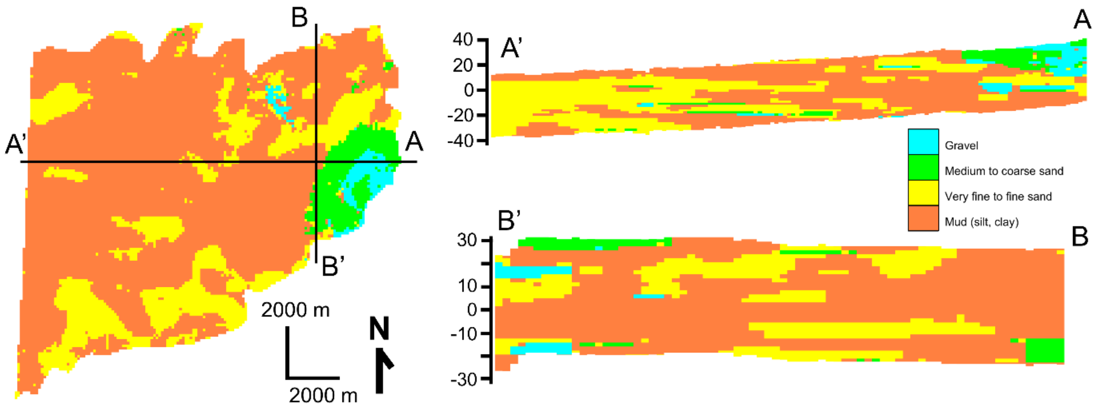












Source: Tran and Wang et al. (manuscript); Wang and Tran et al. (2026)

Conclusions

- The hydrogeological model that conforms to the local situation can reasonably assess the spatiotemporal distribution of land subsidence.
- Hydrogeology in the plain areas is normally a heterogeneous system which should be carefully considered in land subsidence simulation.
- Stochastic simulation can provide further information but the difficulty of calibration increased. Advanced techniques need further investigations.

Q & A

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Special Issue in *Water*

Published Reference

- Tran, D.-H., S.-J. Wang*, and Q. C. Nguyen, 2022, Uncertainty of heterogeneous hydrogeological models in groundwater flow and land subsidence simulations – a case study in Huwei Town, Taiwan, Engineering Geology, 298, 106543. https://doi.org/10.1016/j.enggeo.2022.106543
- Wang, S.-J.*, Nguyen Q.-C., Y.-C. Lu, Y. G. Doyoro, and D.-H. Tran, 2022, Evaluation of geological model uncertainty caused by data sufficiency using groundwater flow and land subsidence modeling as example, Bulletin of Engineering Geology and the Environment, 81(8), 331. https://doi.org/10.1007/s10064-022-02832-7
- Truong, H.-D., S.-J. Wang*, M.-Q. Dang, 2025, Developing a coupled hydraulic-mechanical-chemical model to investigate the influences of geological model complexity in simulating seawater intrusion and land subsidence. Journal of Hydrology, 650, 132505. https://doi.org/10.1016/j.jhydrol.2024.132505
- Tran, D.-H., S.-J. Wang*, J.-J. Dong, 2025. Influence of spatial borehole density on estimation of geostatistical properties and construction of heterogeneous hydrogeological models, Engineering Geology, 350, 107991. https://doi.org/10.1016/j.enggeo.2025.107991

Special Issue in *Water*

Sustainable Groundwater Management and Mitigation of Land Subsidence: Evaluating Environmental Impacts and Resilience Strategies

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Deadline for submissions
31 July 2026