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Data-driven Modeling of Transboundary Aquifers in Conflict Zones: Challenges and Solutions from the GRANDE-U International Collaboration

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Groundwater assessment is critical for addressing global and regional water security challenges, particularly in transboundary areas and conflict zones such as Ukraine. These regions often experience shifting water balance patterns due to excessive groundwater abstraction, damage to water infrastructure, and large-scale population displacement to safer border areas. Modeling transboundary groundwater storage and flows in such contexts is challenging due to uneven data availability across borders, inconsistent hydrogeological descriptions, restricted fieldwork, and limited local capacity to maintain data collection infrastructure. Effective water management in these areas requires pooling global expertise and resources, increasingly leveraging satellite observations, and fostering close collaboration among partner countries engaged in transboundary aquifer modeling.

The Groundwater Resilience Assessment through Integrated Data Exploration for Ukraine (GRANDE-U) project addresses these challenges through an organizational and technological framework uniting researchers from six countries—the U.S., Ukraine, Poland, Latvia, Lithuania, and Estonia. The project integrates physics-based and machine learning models for transboundary aquifers with downscaled satellite remote sensing data. Building on the foundations of the NSF-funded AccelNet Transboundary Groundwater Resilience project and the European EU-WATERRES project, GRANDE-U employs the following methodology:

- Developing a spatial database of water-related indicators for transboundary areas, including geology, water resources, land cover, monthly precipitation, evapotranspiration, runoff, soil moisture, and other characteristics at observation points and a 0.1"-0.25" grids covering the aquifer;

- Creating algorithms to downscale GRACE/GRACE-FO-based terrestrial water storage (TWS)

and groundwater storage (GWS) data to resolutions of 0.25" and finer for specific regions with the best available hydrogeologic data sufficient for GRACE/GRACE-FO adjustment; and

- Developing machine learning models to describe GWS dynamics, utilizing as predictors the monthly averages organized in the spatial database.

Initial results highlight the application of various machine learning models for accurate TWS-GRACE prediction, emphasizing hyperparameter tuning and encoding spatial dependencies. As the database and algorithms evolve, these models aim to improve transboundary groundwater monitoring and management.

An additional novel component of the GRANDE-U collaboration involves analyzing global expertise in transboundary groundwater research. Using a co-authorship network analysis, the project identifies key contributors, emerging topics, knowledge gaps, and collaboration patterns across hydrogeological subdomains and related disciplines. The analysis tracks the formation and evolution of expertise clusters and explores subsets of the network based on environmental, socio-economic, and data-related issues mentioned in publication titles and abstracts. This network analysis is implemented on the SuAVE (Survey Analysis via Visual Exploration, suave.sdsc.edu) visual analytics platform, using OpenAlex, an open-access bibliographic database, to extract and tag relevant publications with keywords and aquifer names. The system provides interactive visualizations of the academic landscape and computes fragmentation and centrality measures for individual researchers and network subsets, offering valuable insights for enhancing international collaboration on transboundary groundwater issues.

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