Assessment of potential recharge lakes by absolute gravimetry in regions of severe land subsidence in Taiwan

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Session: Measuring and Monitoring

Reducing groundwater withdrawal and increasing groundwater levels from clay layers can alleviate land subsidence. A sandy aquifer in a clay-dominated region can store groundwater and serve as a recharge lake for water management. However, identifying an appropriate location for constructing a recharge lake can be costly. At a test site, the representative region of existing hydrogeological parameters such as infiltration and storage coefficients is limited to only a few meters around the site. Finding valid hydrogeological parameters for a sufficiently large coverage around a potential recharge lake over a heterogeneous aquifer system can be challenging, but this task is in urgent need in the regions of severe land subsidence in Taiwan.

A microgal-level terrestrial gravimeter is sensitive to mass migration in a near-surface area. Repeated gravity measurements using such a gravimeter can be used to estimate groundwater mass balances in a shallow sandy aquifer. After correcting the environment-induced temporal gravity effects and vertical displacements, time-variable gravity changes at a gravity site reflect the groundwater mass balance. Ground-based gravimetry has several advantages over existing methods, particularly in land subsidence-hit regions. First, ground-based gravimetry can sense the groundwater balance in an unconfined sandy aquifer, where groundwater recharge and extraction result in only small (mm-level) ground deformation. Second, ground-based gravimetry does not require the distribution of storage coefficients in an unconfined aquifer (i.e., specific yield) and groundwater levels for groundwater mass change estimations. Third, gravity changes reflect the average mass change over a region of tens to a hundred meters. Thus, the use of repeat gravity measurements may eliminate the requirements needed in numerous typical hydrogeological tests. In addition, the time of repeated measurements can be manually designed according to events of interest. These advantages are important when constructing recharge lakes in land subsidence-hit regions, especially about the efficiency of acquiring critical hydrogeological parameters.

Groundwater change and vertical displacement lead to gravity changes. Gravity value declines when groundwater is withdrawn or when the surface elevation increases. According to equivalent water height (EWH) used in gravity interpretation, a layer of pure water in thickness of five centimeters can induce 2µgal (10-8 m/s2) of gravity change. Also, one centimeter of vertical displacement leads to 2µgal of gravity change. However, an excessive withdrawal of groundwater is accompanied by compaction of a clay aquifer. In some particular cases, gravity values experience only small fluctuations when the site is subsiding. Therefore, a gravity correction for vertical displacement is required before estimating groundwater storage change by gravimetry.

This study takes advantage of dense, diversified ground deformation measurements at the Choshui River Alluvial Fan (CRAF) in central Taiwan. Continuous GNSS data are used for correcting the gravity effect of land motion at a site, and regional ground deformation is derived from multilayer compaction well (MLCW), leveling, and InSAR observations at different time and space scales. We set up seven absolute gravity sites at CRAF in 2021, five of which are located in regions of severe land subsidence. We measured absolute gravity values in different seasons and focused on capturing groundwater storage change before and after rainy seasons. In 2021, the vertical displacement at the gravity sites of STES and JJES reached -10 cm due to a serious drought in the first half of 2021 in Taiwan. A residual gravity change of 26.6 µgal and a vertical displacement of -4.2 cm (relative to the values in March) in May were detected at STES in 2021. The patterns of the gravity changes at the sites located in the subsidence-hit regions are similar to the gravity change patterns at the sand-dominated aquifers in the proximal region of CRAF, revealing the existence of regional unconfined aquifers (RUAs) in the regions affected by land subsidence.

A site experiencing significant gravity changes can be a site with a high groundwater storage change, and thus can be a potential site to build a recharge lake. A test using gravity changes could be a preliminary test to identify a potential RUA in a clay-dominated aquifer. As such, the measured gravity changes in 2021 can be used to rank the priority of the potential sites for recharge lake construction. In addition, we conducted an electrical resistivity imaging (ERI) survey in 2022 to confirm the existence of a RUA discovered by absolute gravimetry in 2021. We continue to measure gravity changes in 2022 at the sites STES, JJES and TKJH for studies such as detecting interannual changes in water balance of the sandy aquifers and making use of gravity data to assist land subsidence prevention.