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The sinkhole area of Bad Frankenhausen: a time-lapse gravity and levelling approach

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Subrosion processes, e.g. the dissolution of readily-soluble rocks, such as rock salt, gypsum, anhydrite and limestone caused by interaction with ground or meteoric water, lead to mass transport and relocation. Therefore, sinkholes (Ø < several 100 m) are generated that pose a severe hazard for infrastructure and inhabitants in urban areas.

Two scenarios of sinkhole evolution are conceivable: Firstly, the mass relocation leads to the development of subsurface cavities. When they reach a critical size and the cover layers cannot be further supported, the surface collapses abruptly. Secondly, the surface subsides continuously in order to compensate for the mass loss. However, subrosion processes, the related surface deformation and the development of sinkholes in space and time are poorly understood until now.

In Germany, sinkholes occur mainly in the central and northern regions due to salt diapirs, limestone and evaporate layers. For this reason, a case study was started in March 2014 in Bad Frankenhausen (central Germany), where subrosion leaches the Zechstein evaporates of the Permian. Here, we installed a monitoring network comprising 15 gravity stations and 130 levelling points covering the main sinkhole areas in the city centre. Until now, 17 measurement campaigns have been carried out in quarter year intervals. Four different gravity meters have been used respectively to collect a statistical significant amount of data and to control the plausibility of the data. The study aims to analyze the dynamic temporal component of mass relocation and surface deformation by time-lapse observations.

We are especially interested in seasonal changes in the soil moisture content. We compare different approaches to determine the influence of seasonally changing soil water balance in the direct gravimeter environment using TDR-measurements and soil sample analyses to determine the gravimetric response to the water content, as well as modelling. We found the influence of seasonal and station-to-station soil moisture changes to be in the single digit up to the lower two-digit μGal range.

After corrections were applied, a change of the gravity acceleration in a range of 0 to 15 μGal over a timespan of four years and a continuous subsidence of 0.2 to 20 mm is observable in the sinkhole-related areas of Bad Frankenhausen, mainly around the leaning church spire.

Combining the time-lapse gravity method with levelling is a feasible approach to improve the knowledge about local surface deformation. Both methods could be part of an early warning system for the prediction of future sinkhole events.