Modeling land subsidence caused by groundwater extraction and revealed by geodetic InSAR measurements in the Leuven area.

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Groundwater extraction can induce land subsidence and have many impacts (e. g., building damages (Floris et al., 2014), aggravation of flooding (Wade et al., 2018), reduction of the capacity of aquifer water storage (Holzer et al., 2005)). However, it is often difficult to prove the link between pumping and surface deformation as part of the consolidation process can be delayed. Indeed, most of this consolidation occurs in compressible low permeability layers interbedded in or overlying/underlying the aquifer and the pore pressure variations propagate slowly in clays. To prove this link, modelling approaches can be helpful tools (Fernandez-Merodo et al., 2021).
In the Leuven area in Belgium, two areas of significant land subsidence have been identified over 30 years in the North of Leuven using Interferometric Synthetic Aperture Radar (InSAR) measurements. These two subsidence bowls are related to the Quaternary valley of the Dyle river. From 1992 to 2001, the ERS 1/2 satellites acquisitions detected localized subsidence in the village of Wijgmaal, Belgium. This surface deformation is changing to the opposite as a rebound is identified by ENVISAT ASAR imagery during the interval 2003 to 2010 (Figure 1). During the same period, another localized subsidence is observed in the North of Leuven, where large pumping activities are recorded. This subsidence is still observed with Sentinel-1A starting in 2016. To verify that this ground motion can be related to pumping activities, a 3D groundwater flow model associated with a 1D geomechanical model are under development.

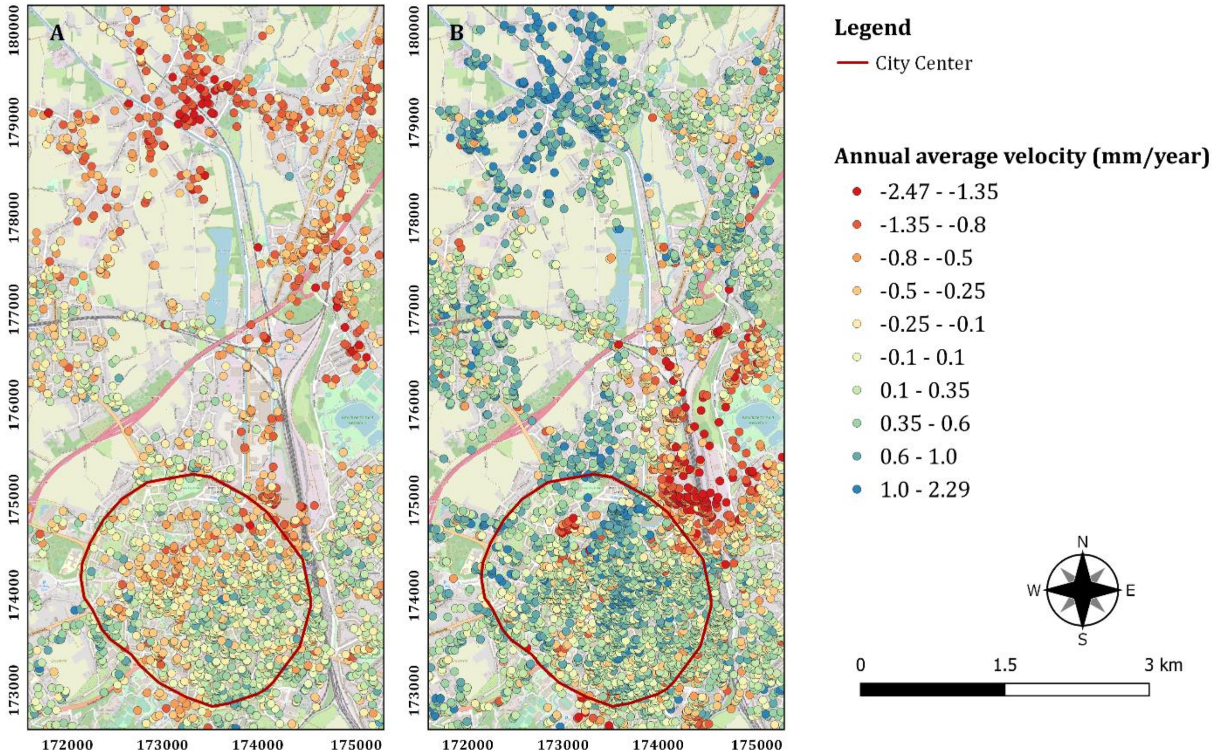

Figure 1: LOS velocity map over Leuven region during the: a) ERS 1/2 and b) ENVISAT ASAR spanning time. The boundary of the city center limits is highlighted on the maps. These maps are part of more global maps. The reference point considered for the interpretation of InSAR data is located in Uccle, not shown in this figure.

From the hydrogeological point of view, the Leuven area lies on a multilayer aquifer system called Brulandkrijt, interbedded with some aquitards. In total, three aquitards and five aquifers are considered in this study. The sandy Quaternary aquifer is the shallowest one, followed by the clayey Boom Aquitard, the sandy Oligocene Aquifer, the clayey Barton Aquitard, the sandy Brussels Aquifer, the clayey Ypresian Aquitard, the sandy Paleocene Aquifer and the deepest one, the chalk Cretaceous Aquifer. As the Boom Aquitard, the Oligocene Aquifer and the Barton Aquitard only appeared in the North of the studied area and both have high-clay content, they will be considered as a unique layer with low permeability.

A multilayer 3D regional groundwater flow model is developed using MODFLOW-2005 and the interface GMS. Firstly, a steady-state model is built and calibrated based on mean data from the 1990s. This model simulates the spatial distribution of the groundwater head (Figure 2) and provide initial conditions for a transient model. This transient model is developed to simulate the changes in groundwater pressures over the period 1990-2020 for which InSAR measurements and groundwater abstractions data are available. The result in terms of pressure is associated with a 1D geomechanical model to understand the ongoing consolidation processes.

First geomechanical calculations show that the subsidence observed locally can be explained by the drawdown in the sandy formation close to the surface, the clayey part of the Paleocene Aquifer, and the clayey Ypresian Aquitard.

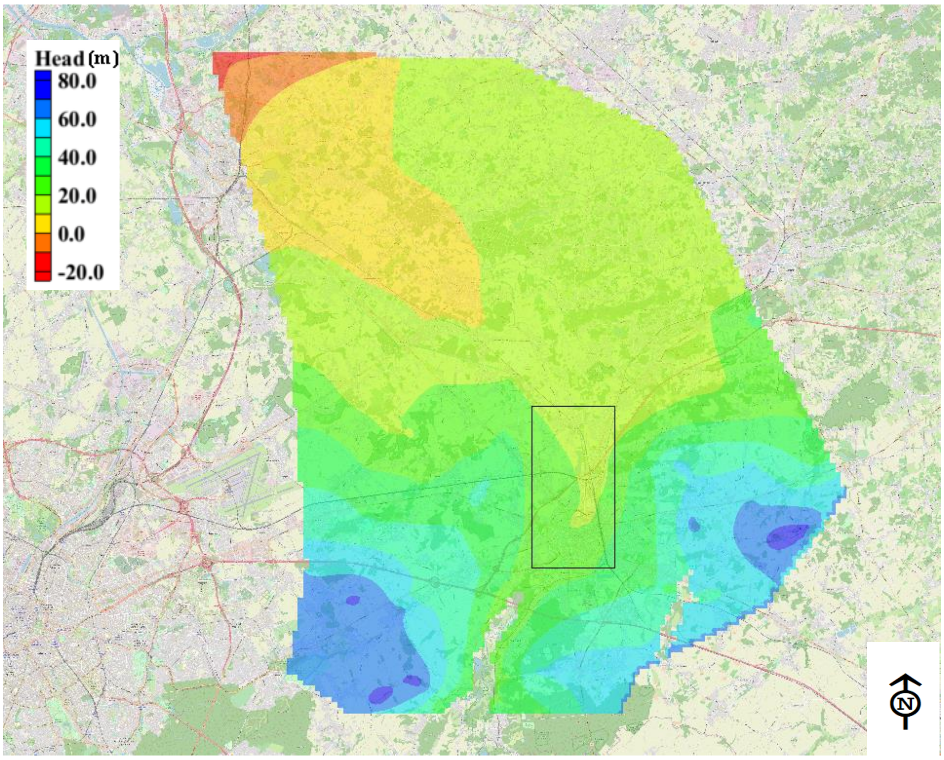

Figure 2: Computed groundwater levels in the Brussels Aquifer, in steady-state. The Leuven area, as shown in Fig. 1, corresponds to the black rectangle.

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