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Searching for pre-collapse precursory deformation in an active sinkhole of the Ebro valley evaporite karst, Spain. High-precision leveling and terrestrial laser scanner

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The dissolution of salt-bearing evaporites in the Ebro valley alluvial karst, subject to intense irrigation, produces sinkholes characterised by very high subsidence rates. Here, numerous large subsidence depressions and sinkholes were filled and used for the construction of human structures (e.g., roads, railways, industrial states) that are currently affected by severe damage. The ground deformation in many of these sinkholes is characterised by progressive sagging, eventually punctuated by the sudden occurrence of nested collapses. The latter events have the potential of causing traffic accidents involving fatalities (e.g. roads, railways). Two critical aspects for assessing the hazard associated with these active sinkholes and managing the risk are the precise delineation of the areas affected by ground deformation, and the assessment of the displacement rates and their spatial-temporal patterns.

This work is focused on the so-called Papiro active sinkhole, which affects the Logroño highway (N-232a), its service road, and some adjacent buildings. The interpretation of old aerial photographs reveals that this sinkhole is nested within a large subsidence depression, which has been progressively buried and is currently traversed by the Logroño highway. The recent occurrence of three collapse sinkholes (2006, 2013, 2021) in this section of the Logroño highway suggests that this is one of the highest risk sites of Zaragoza city area. Subsidence in the Papiro sinkhole has been monitored applying two techniques: (1) high-precision leveling (since 2015); and (2) terrestrial laser scanner (TLS, since 2020). A 108 m long leveling line with a spacing between benchmarks of 3 m was installed along the service road next to the highway. Deformation profiles constructed from measurements taken every three months indicate: (1) a stationary 57 m long deformation zone; (2) constant deformation rates over the monitoring period; (3) a maximum subsidence rate in the central sector of the sinkhole of 1.89 cm/yr; (4) a secondary high-subsidence spot close to the sinkhole edge, coinciding with the location of the 2013 collapse event. The surface displacement models produced by the comparison of point clouds obtained with TLS confidently capture ground deformation with a very high spatial resolution in areas where rates are higher than 4 cm/yr. Interpretation of the consistent displacement data and surface deformations indicates that the sinkhole is characterised by sagging deformation with some displacement accommodated by collapse faults at the margins. The two techniques provide complementary results. High-precision leveling, thanks to its utmost accuracy, allows defining the edges of the deformation zone and resolving small spatial-temporal variations, whereas TLS offers high spatial coverage and resolution. Ongoing monitoring might allow to capture deformation patterns preceding an expected future

collapse, and to gain insight into potential precursory deformation applicable for early warning.