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Persistent Scatterer Interferometry subsidence data exploitation using spatial tools: The Vega Media of the Segura River Basin case study

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SUMMARY

The aim of this paper is to analyze the subsidence affecting the Vega Media of the Segura River Basin, using a Persistent Scatterers Interferometry technique (PSI) named Stable Point Network (SPN). This technique is capable of estimating mean deformation velocity maps of the ground surface and displacement time series from Synthetic Aperture Radar (SAR) images. A dataset acquired between January 2004 and December 2008 from ERS-2 and ENVISAT sensors has been processed measuring maximum subsidence and uplift rates of −25.6 and 7.54 mm/year respectively for the whole area. These data have been validated against ground subsidence measurements and compared with subsidence triggering and conditioning factors by means of a Geographical Information System (GIS). The spatial analysis shows a good relationship between subsidence and piezometric level evolution, pumping wells location, river distance, geology, the Arab wall, previously proposed subsidence predictive model and soil thickness. As a consequence, the paper shows the usefulness and the potential of combining Differential SAR Interferometry (DInSAR) and spatial analysis techniques in order to improve the knowledge of this kind of phenomenon.

1. Introduction

Subsidence is a natural or anthropogenic hazard that produces a downward displacement of the ground surface over wide areas. It can be triggered by the excavation of ground tunnels or mining galleries, soil/rock dissolution, fluid withdrawal (petroleum, water or gas), deep erosion (piping), lateral soil creep, compaction of soil materials or tectonic activity. In this work subsidence due to soil consolidation induced by aquifer overexploitation is investigated. This type of subsidence is mainly due to the consolidation of layers composed of fine lithologies (clays and silts) during prolonged drainage periods, and also to the compaction of coarse fractions (sands and gravels).

Subsidence due to water withdrawal is an extensive worldwide phenomenon affecting large areas and important cities such México City DC (Mexico), Bangkok (Thailand), Po Plain (Italy), Antelope, Santa Clara and San Joaquin Valley (USA), Nobi Plane, Niigata and Suzhou (Japan), Chosui River and Taipei (Taiwan), Shanghai, Tianjin, Beijing (China), Jakarta (Indonesia) among others. In Spain only one case of general subsidence due to water withdrawal has been reported at the Vegas Baja and Media of the Segura River.

The monitoring of this phenomenon is a very important task in order to establish the mechanisms, the causes and the velocities of the subsidence process. This is useful to prevent damages on infrastructures and for land-use and water-resources planning. Moreover, subsidence measurement is necessary in order to determine the affected areal extent, to quantify the deformation or settlement velocities, to identify mechanisms and critical states of failure, and to evaluate the effectiveness of the corrective measures adopted (Tomás et al., 2005a). Murcia City, located in the Vega Media of the Segura River, was the first case in Spain where subsidence induced by piezometric changes due to aquifer overexploitation caused important damages (50 million euros) in human infrastructures (Rodríguez Ortiz and Mulas, 2002; Mulas et al., 2003) during the drought period 1992–1995. From 2004 to 2008 an important piezometric decline affected this area triggering additional subsidence.

This work is focused on the subsidence that occurred during 2004–2008 period in the Vega Media of the Segura River located in SE Spain. We examine the evolution of ground deformation and its relation to the pumping activity in this area generally during

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drought periods, describing the results obtained with the Stable Point Network (SPN) technique. These results will be compared with piezometric measurements, local geology, soft soil thickness, well point distribution, the river distance, the Arab city location, the basement location and the geotechnical Finite Element Method (FEM) model developed by IGME (2000a).

The paper is organized as follows. Section 2 describes the geographical and geological setting of the study area. Subsidence data obtained from interferometry is presented and briefly discussed in Section 3. Then, Section 4 is dedicated to compare this data with other conditioning and triggering factors. A discussion of the results is included in Section 5. The main conclusions are summarized in Section 6.

2. Description of the study area

The Vega Media of the Segura River (VMSR) is located in the East sector of the Betic Cordillera, in the so called Bajo Segura basin (Montenat, 1977; Fig. 1). The materials outcropping along the boundaries of the valley vary with location (Fig. 2). The South border of the VMSR consists mainly of rocks of the basin basement (Permian to Triassic) and slope deposits (Pleistocene). Meanwhile, the Northern border is formed mainly by sedimentary rocks (Upper Miocene to Pliocene) deposited in the basin (marls, sandstones and conglomerates). The valley is filled by recent materials (Holocene at ground surface, Pleistocene to Pliocene at some depth) deposited by the fluvial action of Segura and Guadalentín rivers.

These recent sediments are potentially deformable and the most problematic from a geotechnical point of view. Rodríguez Jurado et al. (2000) and Mulas et al. (2003) made a geotechnical characterization of all these materials for the VMSR showing that the sedimentary rocks protruding at the valley borders, which are also found at some depth within the flood plain, are characterized by low to negligible deformability. Above them, the recent shallow sediments are characterized by moderate to high compressibility.

From a hydrogeological point of view, the VMSR belongs to the so-called "Guadalentín – Segura Quaternary aquifer System No. 47" (IGME, 1986). This aquifer is characterized by two units (Cerón and Pulido, 1996; Aragón et al., 2004): (a) a shallow unit that consists of a semiconfined aquifer or aquitard formed by silts and clays with occasional sand intercalations, and (b) a "deep aquifer", consisting on a multilayer aquifer system composed of sand and gravels confined by less permeable layers.

The deep aquifer, scarcely studied, is stratified and comprises several gravels of hydrological interest (CHS, 2007). The upper gravel in the deep aquifer is heavily exploited at about 20 m below the surface, although recent pumping wells drilled in 2004 (CHS, 2007) extract water from the lower gravel too.

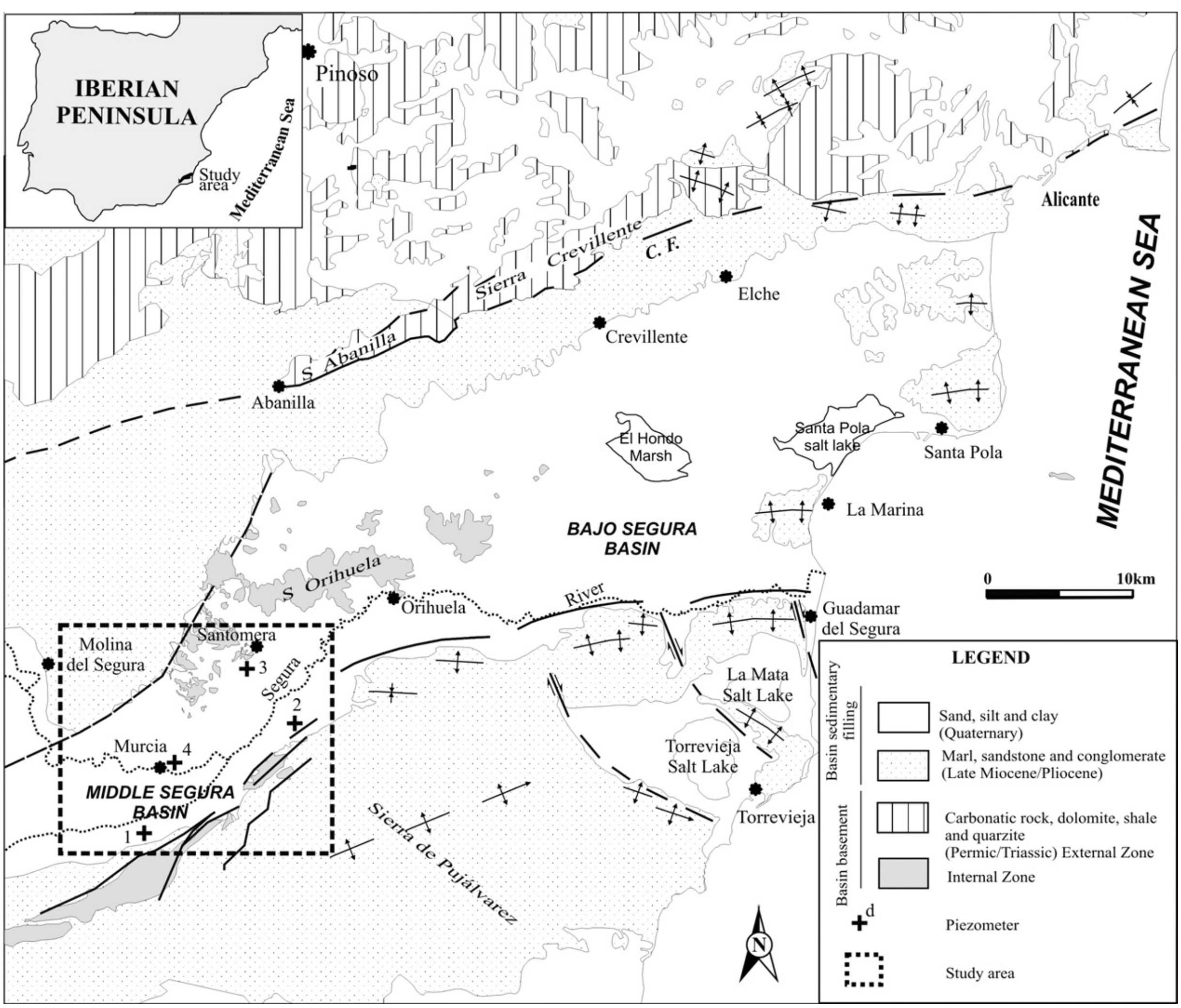

Fig. 1. Geological setting of the Vega Baja and Media of the Segura River Basin (based on Montenat (1977) and Aragón et al. (2004)). Piezometric levels for boreholes (1–4) are shown in Fig. 3a.