DInSAR ANALYSIS OF AQUIFER COMPACTION DUE TO GROUND WATER EXTRACTION IN THE SEGURA RIVER BASIN

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ABSTRACT

The aim of this work is to analyze the subsidence affecting the whole Segura River Basin (1900 km^2) using Differential Interferometry (DInSAR). This technique is capable of estimating mean deformation velocity maps of ground surface and displacement time series from Synthetic Aperture Radar (SAR) images. The processing of some datasets acquired between 1992 and 2008 from ERS and ENVISAT sensors have allowed to detect the highest rates of groundwater-related subsidence recorded in Europe (>10 cm/yr). These data have been validated against ground subsidence measurements and correlated with subsidence triggering and conditioning factors by means of a Geographical Information System (GIS). Retrieved results have permitted to improve the knowledge of the mechanisms that control aquifer compaction due to ground water extraction and the associated effects in the buildings and infrastructures of exposed urban areas.

1. INTRODUCTION

A major global concern that Earth Sciences should urgently face is the study and understanding of the consequences and risks of forecasted future water resources problems. The problem starts to be evident as glaciated areas have been reduced, river run-offs decreased and, groundwater depletion rate have increased, as well. In particular, groundwater depletion rates have been raised in the recent decades, significant groundwater table drops have been reported in Midwestern U.S., Mediterranean coasts, Middle East, Northwestern India and Northeastern China. In particular, the Peri-Mediterranean coastal areas have been subjected to a rapid development in tourism, residential urbanization and intensive agriculture (Fig. 1). As a consequence, land use change dynamics has been increased water resource demand.

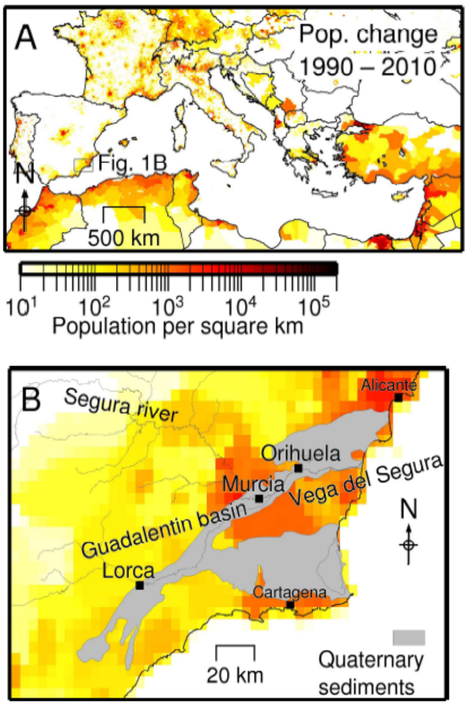

Figure 1. A: Change in population per square kilometer in period 1990–2010 [data source:Gridded Population of the World, version 3 (GPWv3; http://sedac.ciesin.columbia.edu/gpw/)] in peri-Mediterranean area. B: Location of studied areas in southeast coast of Spain drained by Segura River. Locations of the studied localized areas are named as the closest major cities (Murcia, Orihuela, and Lorca) (modified from [1]).

Groundwater resources are of particular interest in arid and semiarid areas (SE Spain) as the extraction of groundwater from shallow aquifers could supply fresh water demand, which is instrumental for an economic development. However, if the extraction rate exceeds the natural recharge, it leads to the aquifers overexploitation. The lowering of the groundwater table is a significant problem in Mediterranean coastal areas, leading to saltwater intrusion, drying-up of wetlands, disappearance of rivers, etc.

The overexploitation of aquifers has been considered a big concern for the management of the water resources, due to the irreversible destruction of the total aquifer storage, and also due to possible associated land subsidence. In this study, we present InSAR studies focused in capturing the detailed spatial distribution of land subsidence in SE Spain. We focused on ground subsidence problems along the Segura river basin and its major tributary, the Guadalentin river. Those studies could contribute to a better understanding of the extension of the groundwater extraction subsidence problem in the vast area, and provide critical information for management authorities.

2. MURCIA CITY (VEGA MEDIA DEL SEGURA)

Murcia city is affected by aquifer system subsidence (Fig. 1). Here, we investigated this phenomenon using an advanced differential SAR interferometry (A-DInSAR) called Stable Point Network (SPN). SPN time series of displacement reveal that in the period 2004-2008 the subsidence rate doubled, from 2 to 5 mm/year, with respect to the previous 1995-2005 period (Fig. 2). Ground deformation acceleration is explained by a drought period started in 2006, which produced an average water table depletion of 7 m. Radar displacement time series comparison with the extensometers indicates a good agreement (3.9±3.8 mm). In addition, forward finite element model subsidence simulations using known water table changes compares well (Fig. 3). This result demonstrates the potential of A-DInSAR techniques to validate subsidence prediction models as an alternative to using instrumental ground based techniques for validation [2].

3. ORIHUELA AREA (VEGA BAJA DEL SEGURA)

Subsidence is affecting Orihuela city and nearby areas. Orihuela is located at the Western sector of the Vega Baja of the Segura River Basin (SE Spain, see Fig. 1). Here, we show the deformation data obtained by Differential SAR Interferometry (DInSAR), and more precisely by the Stable Point Network technique (SPN), an algorithm of the Persistent Scatterers Interferometry (PSI) family.

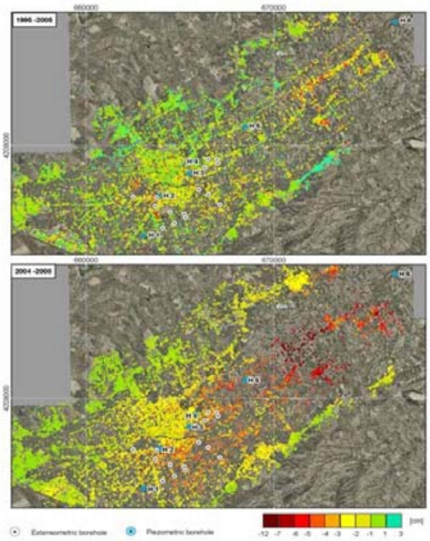

Figure 2. Total deformation estimated with SPN technique between July 1995 and December 2005. Bottom: Total deformation estimated with SPN technique between January 2004 and December 2008. Labels have been placed in those piezometers which were analyzed [2].

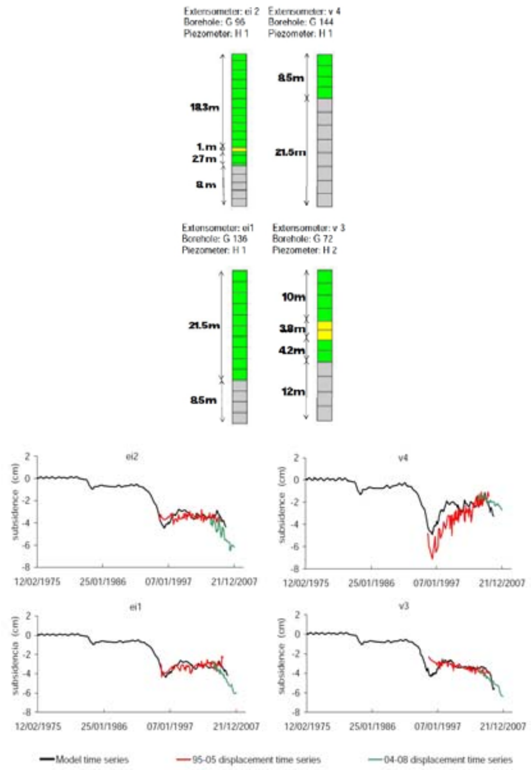

Figure 3. (Top) Finite element mesh of the considered soil columns. Green: clay; yellow: sand, gray: gravel. (Botton) LOS projected time series of the deformation simulated with the model and observed with SPN (modified from [2]).

Two different sets of available images span 1995-2006 and 2004-2008 periods (ERS and ENVISAT satellite sensors). Accumulated deformation maps and displacement time series are analyzed (Figs. 4 and 5). Moreover, subsidence data have been contrasted with subsidence triggering and conditioning factors by means of a Geographical Information System (GIS) interface. The performed analysis shows that there exists a relationship between subsidence and piezometric level evolution in time (Fig. 5). Moreover, the correlations among subsidence and location of pumping wells, distance to the river, geology, and soil thickness have been derived from subsidence analysis for this area [3].

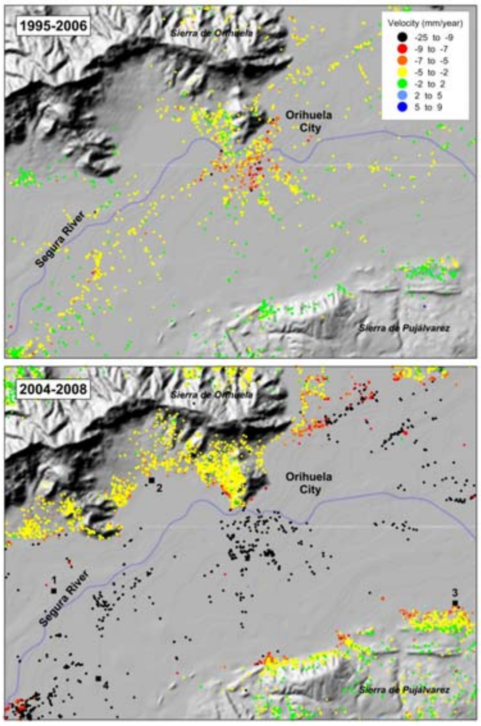

Figure 4. Deformation rates (in mm/year) along LOS for the periods 1995–2006 (Upper) and 2004-2008 (Lower) in the lower part of Segura River basin. Notice the high subsidence affecting the south area of the Orihuela City [3].

4. LORCA (GUADALENTIN SUB-BASIN)

At Alto Guadalentin area, ground deformation data indicates large scale deformation and in particular the discovery of the highest rates of groundwater-related land subsidence recorded in Europe (> 10 cm/yr), affecting the Guadalentin river basin (> 200 km^2), the largest tributary of the Segura river (Fig. 1 and 6).

At Guadalentin basin, the modeling of the ground surface time series indicates that deformation is mainly driven by non-linear time-delayed flow processes in the underneath aquifer. After a drought period (1992-1995), the aquifer responds with an exponential decay of land subsidence, that lasted for a ~8 years period (Fig. 7 and 8), suggesting high permeability and groundwater pore-pressure flows. Such transient groundwater flow processes has been poorly studied using geodetic techniques. Here, we show that multitemporal interferometric analysis and its modeling can be a stimulating way to study non-linear soil mechanics and groundwater flows at aquifers [1].

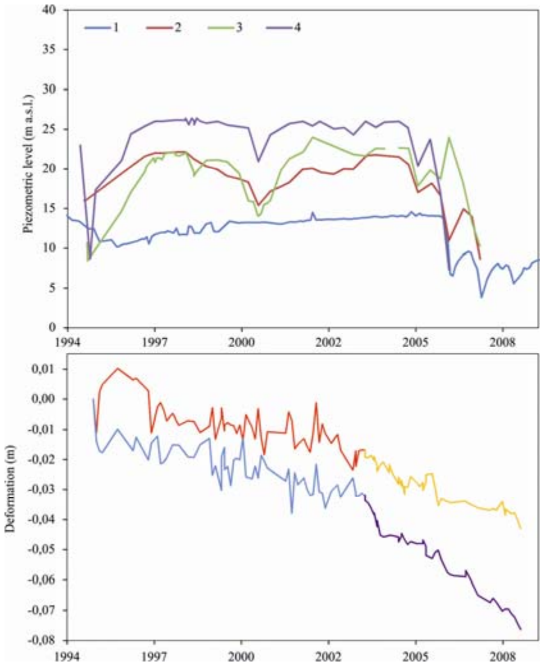

Figure 5. (Upper) piezometric level in several piezometers of the Vega Baja of the Segura River, (Lower) Temporal evolution of two PSs. Piezometer are located in Figure 4. The selected PSs are located in the Orihuela city center (modified from [3]).

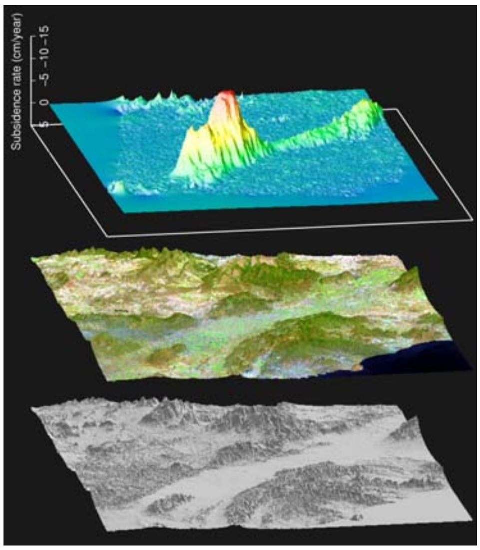

Figure 6. 3D perspective of a Landsat false color composite, shaded relief and the deformation of the Guadalentin basin.

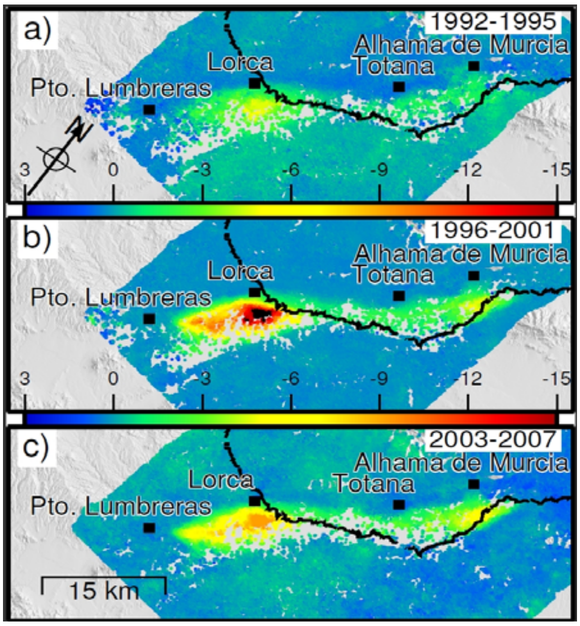

Figure 7. StaMPS/SBAS results in cm/yr. Surface LOS ground velocity for a) the period 1992-1995, b) period 1996-2001, and c) period 2003-2007. Note that the ground deformation follows the deflection of the river valley, a structural direction (EW to ENE-WSW) similar to a geophysical inferred local grabens and horsts [1].

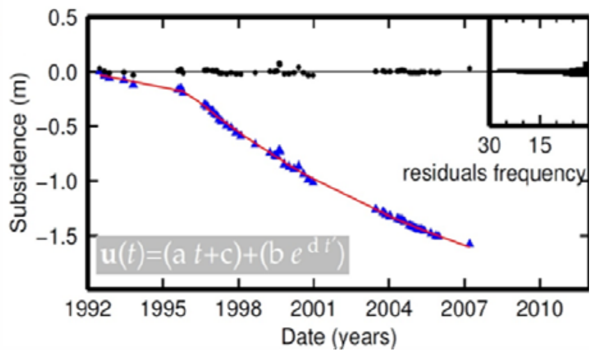

Figure 8. Ground surface deformation time series modeling (ground deformation, y-axis, versus date, x-axis) for the maximum detected subsiding point in the Alto Guadalentin basin. Linear plus an exponential decay model. Blue triangles are data points, red lines are model predictions and black dots are the residuals between data and model. In the upper-right corner of each subplot is a small rectangle containing a residual [1].

5. CONCLUSIONS AND FUTURE WORK

The presented analysis is a first step to a deeper understanding of groundwater related subsidence processes in this high evolving climate and populated region. The derived information (maps and models) could help to the management of the water resource exploitation and land subsidence of unconsolidated coastal and quaternary alluvial aquifers in the region.

Retrieved results have permitted to improve the knowledge of the mechanisms that control aquifer compaction due to ground water extraction and the associated effects in the buildings and infrastructures of exposed urban areas. As a consequence, the deeper understanding of this kind of phenomenon will be helpful to improve the management and control of the aquifer systems located in this part of the South-East Mediterranean, being applicable to any other similar region.

Currently, our processing strategy was based on an heterogeneous analysis of small cropped areas of SAR images. In the near future, we will process homogeneously the large available SAR dataset over the area to map groundwater related subsidence to study the whole basin.

6. ACKNOWLEDGMENTS

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