Analysis of a Subsidence Process by Integrating Geological and Hydrogeological Modelling with Satellite InSAR Data

31

Francesca Bozzano, Carlo Esposito, Stefania Franchi, Paolo Mazzanti, Daniele Perissin, Alfredo Rocca, and Emanuele Romano

Abstract

This paper focuses on a multidisciplinary study carried out in an urban area affected by subsidence. The area is located about 20 km east of Rome (Italy) and is affected by dewatering processes mainly linked to quarry activities. Furthermore, compressible soils are locally present immediately below the ground level. Persistent Scatterer Interferometric Synthetic Aperture Radar (InSAR) analyses carried out with different approaches on ERS and ENVISAT data were performed. The so reconstructed time series of ground displacements were then coupled and compared with a detailed geological model and the variations over time of piezometric levels. Such data overlay allowed us to better understand and constrain the relation among ground displacement, piezometric variations, geological setting and geotechnical properties of subsoil.

Keywords

Subsidence • SAR interferometry • Quarry activity • Hydrogeological modelling • Groundwater extraction

31.1 Introduction

The Acque Albule basin is a quite flat area located about 20 km east of Rome affected by a relevant subsidence process (Fig. 31.1), which also damaged some buildings. Several potential predisposing/triggering factors coexist in the study area, such as the presence of compressible soils in the local substratum and a significant groundwater exploitation mainly linked to the quarry activities. The here-presented study aims at defining the recent "time history" of ground deformations by means of Advanced DInSAR (A-DInSAR) techniques, in relation to piezometric variations (both measured and simulated by means of numerical modelling) and the stratigraphic setting (obtained by interpolating data from several available and on-purpose drilled boreholes), in order to better understand and constrain the relationships between subsidence, timing of piezometric level variations and thickness of compressible soils. The here-presented methodologies and results are framed within a research project (PRIN 2010) funded by MIUR.

F. Bozzano · C. Esposito · S. Franchi · P. Mazzanti · A. Rocca
Earth Sciences Department, Sapienza University of Rome, P.le Aldo Moro 5, 00185 Rome, Italy
e-mail: francesca.bozzano@uniroma1.it

C. Esposito
e-mail: carlo.esposito@uniroma1.it

S. Franchi
e-mail: stefaniafranchi84@gmail.com

P. Mazzanti
e-mail: paolo.mazzanti@nhazca.com

F. Bozzano · P. Mazzanti · A. Rocca (✉)
NHAZCA S.r.l. Spin-off of Sapienza University of Rome, Via Cori snc, 00177 Rome, Italy
e-mail: alfredo.rocca@nhazca.com

D. Perissin
Civil Engineering Department, Purdue University, 550 Stadium Mall Drive, West Lafayette, IN 47907, USA
e-mail: perissin@purdue.edu

E. Romano
Water Research Institute–National Research Council, Via Salaria 29, 300, 00015, Monterotondo Scalo Rome, Italy
e-mail: romano@irsa.cnr.it

G. Lollino et al. (eds.), *Engineering Geology for Society and Territory – Volume 5*,
DOI: 10.1007/978-3-319-09048-1_31, © Springer International Publishing Switzerland 2015

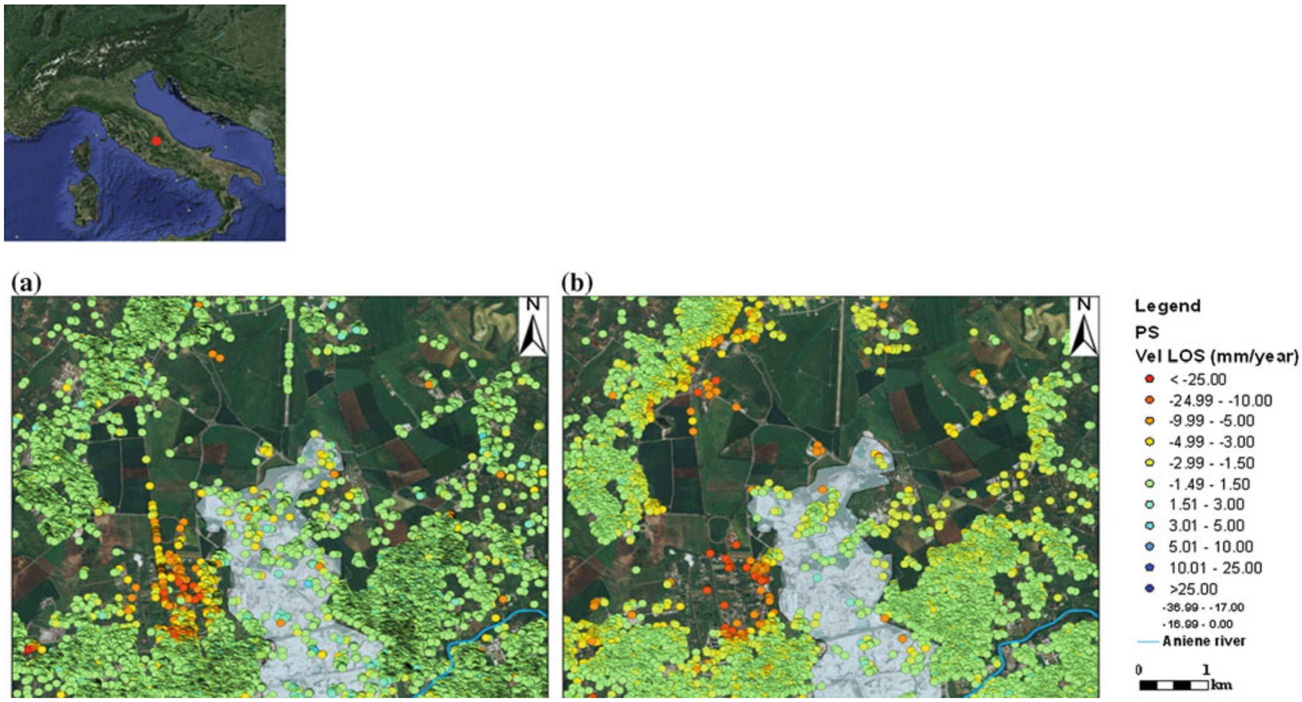

Fig. 31.1 Maps of the mean annual subsidence rate along Line of Sight, (LOS) obtained by processing satellite images from ERS (**a**) and ENVISAT (**b**) descending datasets

31.2 Geological and Hydrogeological Background

The Acque Albule Basin is a morphotectonic depression, whose formation is related to the Plio-Quaternary activity of strike-slip tectonic elements. The so formed depression, whose bedrock is featured by meso-cenozoic limestone, hosted the deposition of Plio-Pleistocene alluvial, lacustrine, and epivolcanic deposits. These deposits are in turn covered by a thick (up to 80 m) stiff and cemented travertine well known since the Ancient Roman age (Faccenna et al. 1994, 2008). The travertine plateau is overlaid by a discontinuous cover of loose, sandy-silty travertine. During Holocene, the development of karst collapses caused the formation of morphological depressions which hosted a lacustrine-palustrine environment with the deposition of sandy silts, clay-loam (with high organic content) and peats. The last two geological units (loose travertine sandy silts and organic clay-loam and peat) are grouped in a “compressible” geological-technical unit whose thickness ranges between few centimeters up to more than 10 meters, as revealed by the geological model interpolated on the basis of available stratigraphic logs (Fig. 31.2).

Strictly related to the quite complex geological setting is the presence of a multi-level groundwater circulation with a deep thermalized aquifer hosted in the Meso-Cenozoic limestone and a surficial aquifer hosted in the Travertine plateau, separated by a clayey-sandy deposits that act as aquitard/aquiclude (Faccenna et al. 2008; Capelli et al. 1987). The travertine aquifer is strongly exploited by human activities: in the frame of a generalized lowering of the water table, a more significant dewatering involves the areas surrounding the travertine quarries where water pumping (on the order of 4 m^3/s) is necessary to exploit deep travertine banks. Such a quarrying activity increased in the last decades, causing a progressive enlargement and deepening of the related cone of depression. Based on hydrogeological monitoring data and hydrodynamic parameters, a detailed hydrogeological 3D numerical model was performed (Franchi 2012) by updating and refining a previous one (Brunetti et al. 2013). Such a model allowed us to reconstruct the “time history” of dewatering over time and space (Fig. 31.2).

31.3 Interferometric Analyses

In this work, ground subsidence measurements were obtained using PS-InSAR technique (Ferretti et al. 2000, 2001; Kampes 2006) and proprietary procedures implemented in SARPROZ software (Copyright 2009, Daniele Perissin, Italy) (Perissin et al. 2011; Perissin and Wang 2012).

ERS and ENVISAT data stacks (covering the period June 1993–August 2010), provided by ESA in the frame of a CAT-1 project (ID: 13097), both in ascending and descending orbital geometry have been processed.

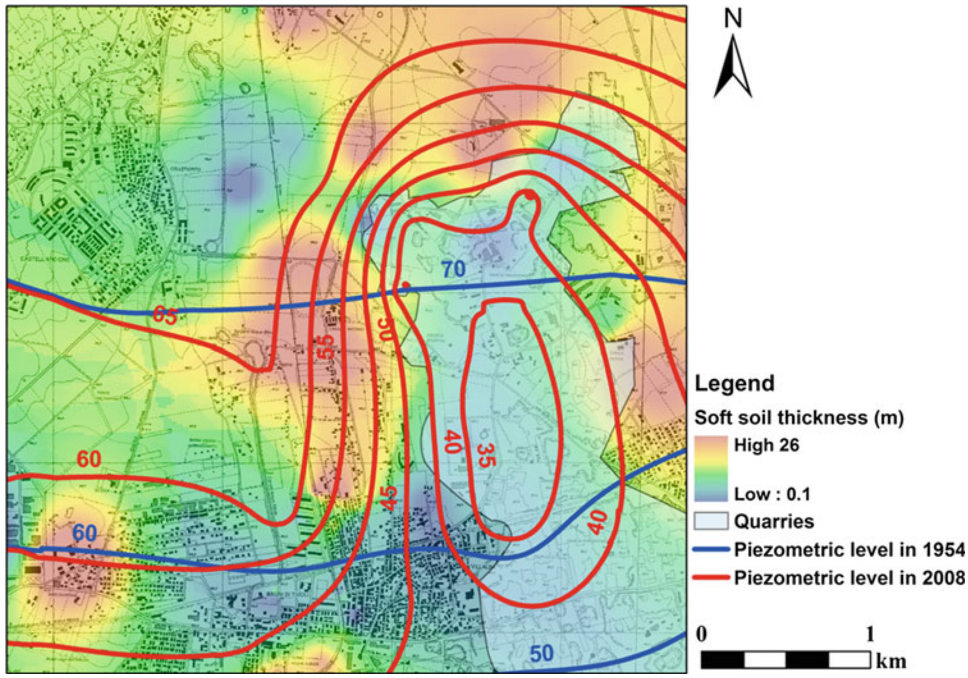

Fig. 31.2 Reconstruction via numerical modelling of piezometric levels within travertine in undisturbed (1954) and disturbed (2008) conditions superimposed on distribution of compressible soils thickness derived from boreholes log interpolation

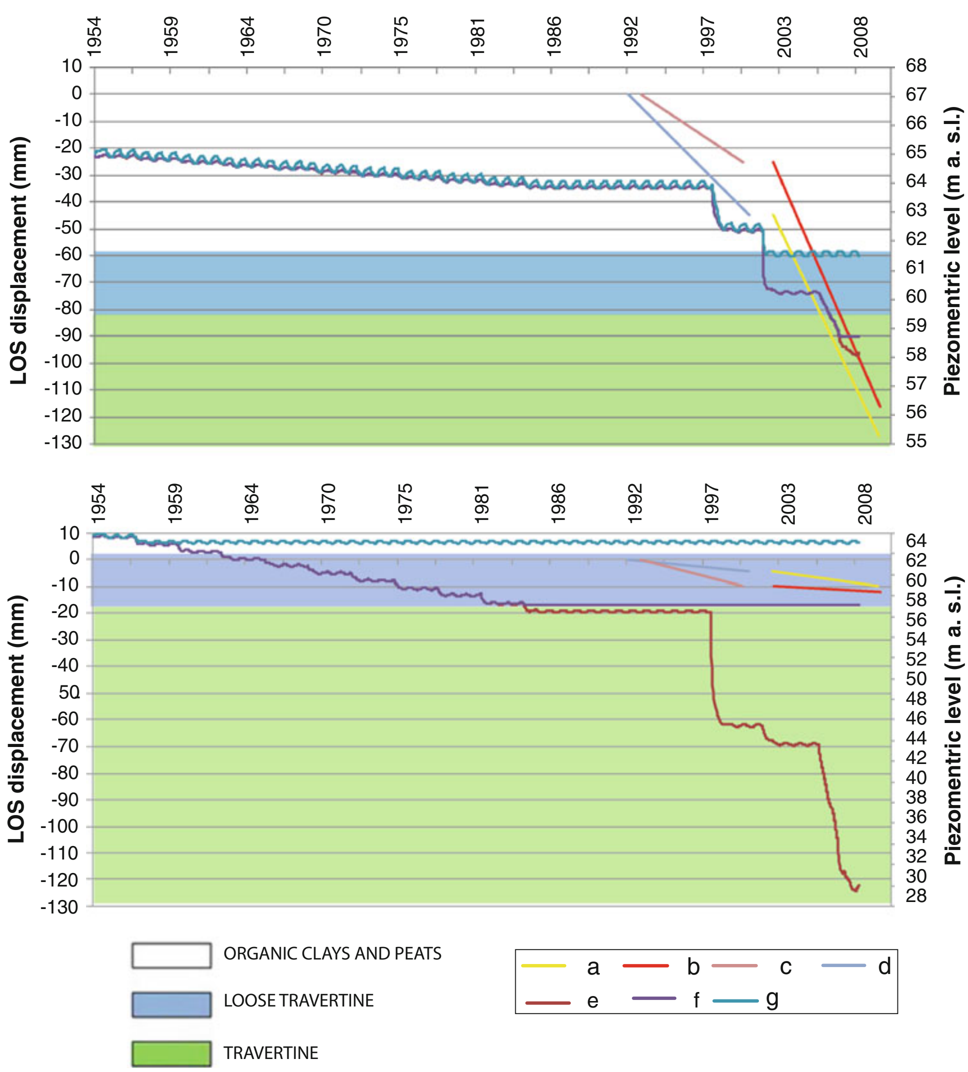

Fig. 31.3 Charts showing the relationships between the time histories of modelled dewatering and LOS displacement in two different stratigraphic settings. Key to legend: **a** ENVISAT descending; **b** ENVISAT ascending; **c** ERS ascending; **d** ERS descending; **e** Simulated piezometric level in travertine; **f** Simulated piezometric level in loose travertine; **g** Simulated piezometric level in organic clays and peats

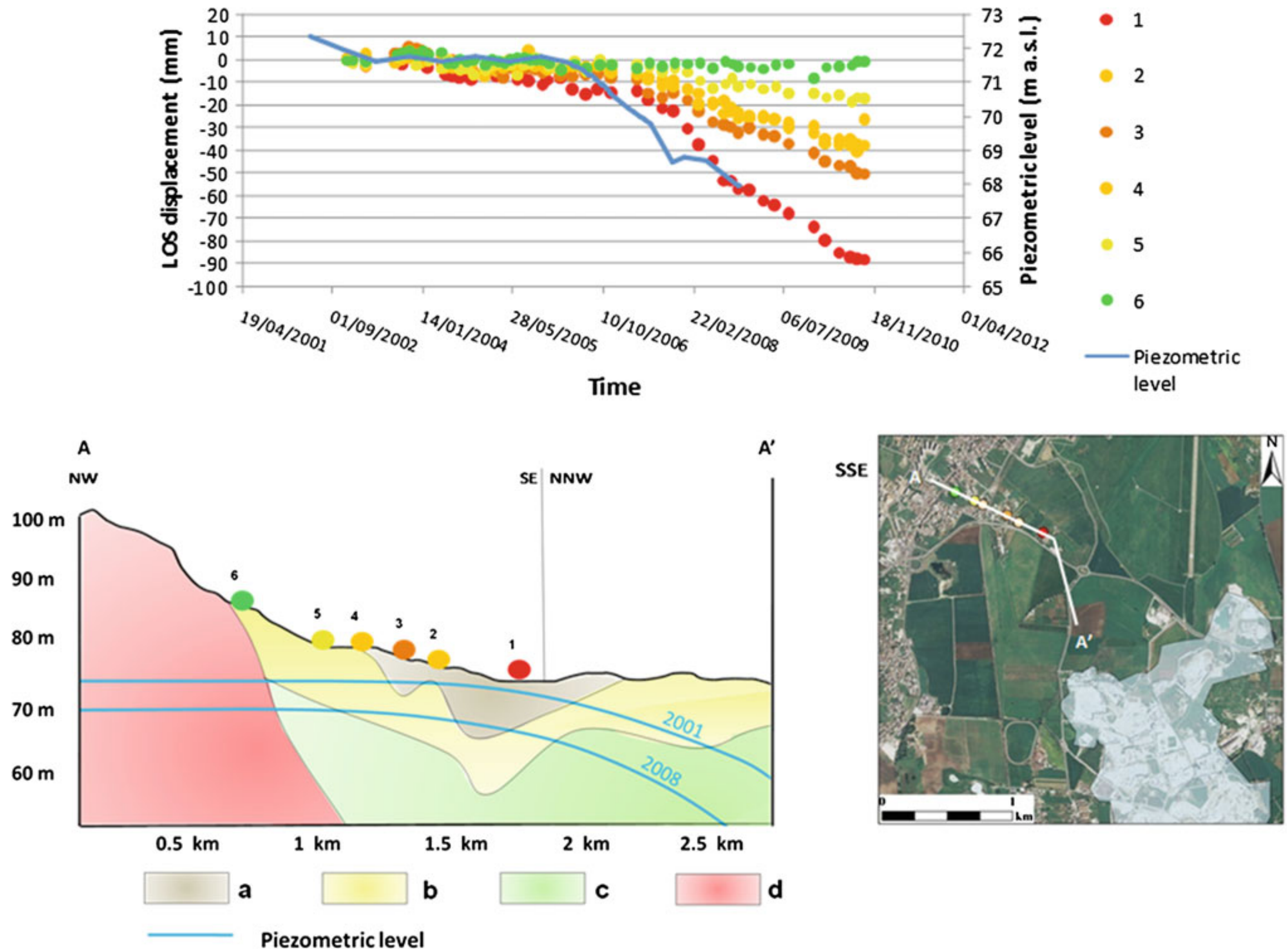

Fig. 31.4 Chart showing the relationships between the time histories of modelled dewatering and LOS displacement of selected PSs along a transect at the NW border of the basin. The stratigraphy associated to the selected PSs as well as their location are reported in the lower left and lower right corners, respectively. Key to legend: **a** Organic clays and peats; **b** Loose travertine; **c** Travertine; **d** Volcanic deposits

Analyses were carried out through two main approaches: full-site processing and local scale processing. Full-site processing allowed us to reconstruct the deformational trend of the entire basin, with the aim of characterizing a large portion of territory in terms of mean annual Line of Sight (LOS) velocity. Additional analyses were performed on a local scale and focused on areas of greatest interest, in order to identify possible non-linear trends correlated with piezometric level variations caused by human activity.

With regard to full-site analyses, a standard PS approach (Ferretti et al. 2001) has been adopted estimating and removing the atmosphere phase screen (APS) from every image phase signal. For each PS, LOS velocity, displacement time series and height were computed (related to a reference point identified in a stable area outside the Acque Albule Basin).

The analysis at locale scale, carried out to highlight non-linear and/or cyclical deformation, was performed on the portion of the basin that was progressively involved in the dewatering. Eight sectors (with an area smaller than 2 km^2) of the basin were analysed separately. This approach does not require the estimation and removal of APS because atmospheric perturbations have a correlation distance less than 1 km. In contrast, non-linear movements are expected to show smaller correlation in space; thus, we assumed to be able to detect such movements via a low pass filter in time domain. The choice of the reference point for each area was performed selecting it in stable areas outside of the basin. For the selected points, height and displacement were estimated and deformation time series were reconstructed.

31.4 Results and Concluding Remarks

In first instance, by overlaying a classified post map of the full-site PS analysis and the map representing the distribution of compressible soil thickness, it is possible to observe in general terms the relationship among subsidence average rate and geological setting. Furthermore, if the "time history" of some selected PSs is compared to the modelled piezometric level variations over time, an acceleration of the subsidence process corresponds to the main dewatering phases (Fig. 31.3), thus confirming the relevant role of water pumping, which implies a water flow from the topmost compressive soils down to the travertine aquifer. As a result, pore pressure decreases and the soil experiences a consolidation process. At the same time, Fig. 31.4 shows the different behaviour of the PSs as a function of the local stratigraphy, being comparable the dewatering magnitude.

More detailed hints derive from the local scale analysis: in this paper we show the results from an area located at the NW border of the basin, which is particularly significant as: (i) it encompasses a variety of stratigraphic settings; (ii) it has been involved in the cone of depression recently, so that significant piezometric variations can be noted in the investigated time interval (2002–2010). Figure 31.4 clearly shows that the activation time of subsidence is strictly related to the involvement in the cone of depression, while the magnitude of the process is governed by the local stratigraphy. This evidence is testified by the behaviour of some PSs farther away from the pumping "epicenter" that experience greater vertical movements than other points located closer: the associated stratigraphy reveals a thicker layer of compressible soils in the former points with respect to the latter ones. Finally, as expected, PSs located on the outcropping volcanic units are not affected by significant vertical deformations.

The here presented results are encouraging for the final goal of a wider research project which focuses on the back-analysis of factors which control onset and development of subsidence, with the final aim of attempting to forecast subsidence activation and magnitude on the basis of piezometric monitoring coupled with a detailed knowledge of the geological-technical model of the subsoil.

References

Brunetti E, Jones JP, Petitta M (2013) Assessing the impact of large-scale dewatering on fault-controlled aquifer systems: a case study in the Acque Albule basin (Tivoli, central Italy). Hydrogeol J 21:401–423

Capelli G, Cosentino D, Messina P, Raffi R, Ventura G (1987) Modalità di ricarica e assetto strutturale dell'acquifero delle sorgenti Capore: S. Angelo (Monti Lucretili—Sabina Meridionale). Geol Romana 26:419–447

Faccenna C, Funiciello R, Mattei M (1994) Late Pleistocene N-S shear zones along the Latium Tyrrhenian margin: structural characters and volcanological implications. Bol Geofis Teorica Appl 36:507–522

Faccenna C, Soligo M, Billi A, De Filippis L, Funiciello R, Rossetti C, Tuccimei P (2008) Late Pleistocene cycles of travertine deposition and erosion, Tivoli, Central Italy: possible influence of climate changes and fault-related deformation. Global Planet Change 63 (4):299–308

Ferretti A, Prati C, Rocca F (2000) Non-linear subsidence rate estimation using permanent scatterers in differential SAR interferometry. IEEE Trans Geosci Remote Sens 38:2202–2212

Ferretti A, Prati C, Rocca F (2001) Permanent scatterers in SAR interferometry. IEEE Trans Geosc Remote Sens 39(1):8–20

Franchi S (2012) Effetti del depauperamento dell'acquifero principale della piana di Tivoli-Guidonia sulla compattazione dei sedimenti recenti. Tesi di laurea, Università La Sapienza, Roma

Kampes B (2006) Radar interferometry: persistent scatterer technique. Springer, Dordrecht

Perissin D, Wang T (2012) Repeat-pass SAR interferometry with partially coherent targets. IEEE Trans Geosci Remote Sens 50 (1):271, 280

Perissin D, Wang Z, Wang T (2011) The SARPROZ InSAR tool for urban subsidence/manmade structure stability monitoring in China. In: Proceedings of ISRSE 2010, Sidney, Australia, 10–15 April 2011