The Impact of Land Subsidence on Preservation of Cultural Heritage Sites: The Case Study of Aquileia (Venetian-Friulian Coastland, North-Eastern Italy)

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34 The Impact of Land Subsidence on Preservation of Cultural Heritage Sites: The Case Study of Aquileia (Venetian-Friulian Coastland, North-Eastern Italy)

Loredana Alfarè, Sandra Donnici, Mattia Marini, Massimiliano Moscatelli, Luigi Tosi, and Roberto Vallone

Abstract

In the north-western coastland of the Adriatic Sea flooding hazard due to land subsidence and eustasy seriously jeopardizes the many cultural heritage sites present in the area, among which the UNESCO site of Aquileia. Located about 10 km inward from the coastline, Aquileia has recently come to the fore for the severe structural damages caused to its Patriarchal Basilica by differential ground subsidence. This study aims at highlighting the main control factors for subsidence in Aquileia framing it in a regional context. Our investigation is based on the integrated analysis of vertical displacements from Persistent Scatterers Interferometry and levelling surveys from the literature along a N-S transect from Terzo D'Aquileia to Grado. Interpretation of results is based on a geotechnical reference model of the subsoil obtained mainly from borehole data. Beside confirming the regional subsidence scenario affecting the Venetian-Friulian coastland, our study indicates that in Aquileia, differences in subsidence rates between the archeological area and the new city likely relate to diverse consolidation paths induced in the subsoil of the two sites by differential and diachronous man-mad loading over historical time. The smaller scale yet stark variability of sinking rates observed at the Patriarchal Basilica are interpreted to relate to heterogeneities in the shallow subsoil.

Keywords

Land subsidence • Persistent scatter interferometry • Subsoil reference model • Load-induced consolidation • Consolidation history

34.1 Introduction

The north-western coastland of the Adriatic Sea is a subsiding area which during the Holocene high-stand hosted lagoons, deltas and marshes. Many important cultural heritage sites are present along this coastland, some of which are located in lowland areas and seriously jeopardized by flooding hazard due to land subsidence and eustasy (1.2 mm/yr in the northern Adriatic Sea).

Although the impact of such treat has been deeply studied in the past and continuously monitored in major cities such as Venice and Ravenna, there are other sites of great historical and archaeological value that have not been object of specific investigations. Among these, Aquileia is a small city located on the distal reach of the Isonzo fan delta and at the edge of the Grado and Marano lagoons, about 10 km inward from the coastline.

L. Alfarè · S. Donnici · L. Tosi
Istitute of Marine Sciences—National Research Council, Venice, Italy

M. Marini (✉) · M. Moscatelli · R. Vallone
Institute of Environmental Geology and Geoengineering—National Research Council, Rome, Italy
e-mail: mattia.marini@uniroma1.it

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In the antiquity Aquileia was the ninth largest city and one of the most important fluvial harbour of the Roman Empire. Since 1998 It has been inscribed in the UNESCO World Heritage Sites List for its well preserved remnants from the Early Roman Empire and the Patriarchal Basilica Complex from the Middle Age, which still conserves magnificent floor mosaics of the former 4th century basilica. With respect to subsidence-related hazards (i.e. flooding and salt water intrusion), the case of Aquileia has recently drawn the attention of the scientific community for the severe structural damages affecting the Patriarchal Basilica. This threat to the cultural heritage of Aquileia motivated the research action detailed here, which was developed in the frame of the project CHERPLAN (Enhancement of Cultural Heritage through Environmental Planning and Management) under the auspices of the South-East Europe Programme.

34.1.1 Aims, Methods and Materials

This study is intended to achieve a better understanding of subsidence in the Aquileia UNESCO site. Nonetheless, to allow framing our data and interpretations in the regional subsidence scenario, the study area has been extended to cover a N-S transect from Terzo D'Aquileia to Grado.

The approach followed in this research is based on integration of datasets of land vertical displacement from both Persistent Scatterers Interferometry (PSI) and levelling surveys (Marchesini 2006 and references therein), and matching of results with a subsoil reference model mostly based on boreholes.

The analysis of present-day land movements was performed through Persistent Scatterers Interferometry (PSI) on ENVISAT images acquired from 2003 to 2010 and provided by Portale Geografico Nazionale (http://www.pcn.minambiente.it/GN/).

For each persistent scatter (PS), PSI provides the time series of the land displacements along the line-of-sight (LOS) of the satellite, which slopes at 23° from the vertical direction. Since the difference between movements along the LOS and their vertical component is very small, we assume that LOS positive and negative displacement results solely from land subsidence and uplift, respectively (Tosi et al. 2010; Teatini et al. 2012). PS dataset were calibrated using the mean vertical land displacement velocity provided by the permanent GPS stations networks of the Regione Friuli Venezia Giulia and Istituto Nazionale di Oceanografia e Geofisica Sperimentale and levelling carried out by Istituto Geografico Militare Italiano. Finally, the vertical displacement velocities obtained confronting the 2004 and 1997 levelling surveys were utilized as a mean of validation of PSI results (Fig. 34.3).

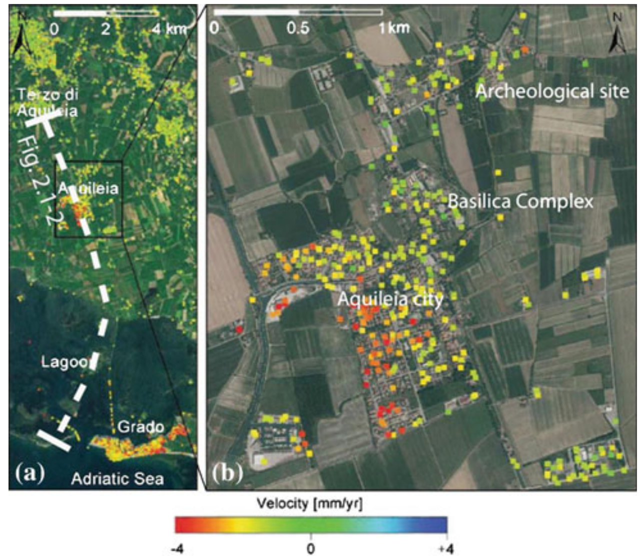

Fig. 34.1 Map of vertical displacement velocity (mm/y) obtained through Persistent Scatter Interferometry on ENVISAT images acquired between 2003 and 2010 for (**a**) the coastland between Terzo di Aquileia and Grado, and (**b**) the surroundings of the city of Aquileia. In (**a**) the dashed line shows the approximate location of Figs. 34.2 and 34.3

The subsoil reference model was obtained correlating a number of boreholes from both the literature (Marocco et al. 1984; Arnaud-Fassetta et al. 2003) and public domain repositories. Palaeo-environmental and genetic meaning of the sedimentary units present in the subsoil were reconstructed by framing them in the Pleistocene-Holocene stratigraphic context with the aid of radiocarbon ages reported by Arnaud-Fassetta et al. (2003). Finally, sedimentary units were converted into geotechnical units basing on dominant lithotypes and the shallow subsurface (depth <5 m from ground surface) detailed compiling penetrometer data from technical reports made available by the Consorzio di Bonifica Bassa Friulana and the Aquileia municipality.

34.2 Results

34.2.1 Subsoil Reference Model

In the subsoil of the Terzo D'Aquileia-Grado transect (Fig. 34.2) from top to bottom two main sedimentary units can be recognized consisting of: (i) recent to present-day barrier-island passing landward to peat-bearing clayey-silty lagoon sediments (<10 m), and (ii) a package of alluvial deposits referable to the distal reach of the Isonzo fan delta. In turn, the latter comprises a relatively thin (<10 m) upper unit mostly made of sands and a lower unit of silts bearing thin peat intercalations.

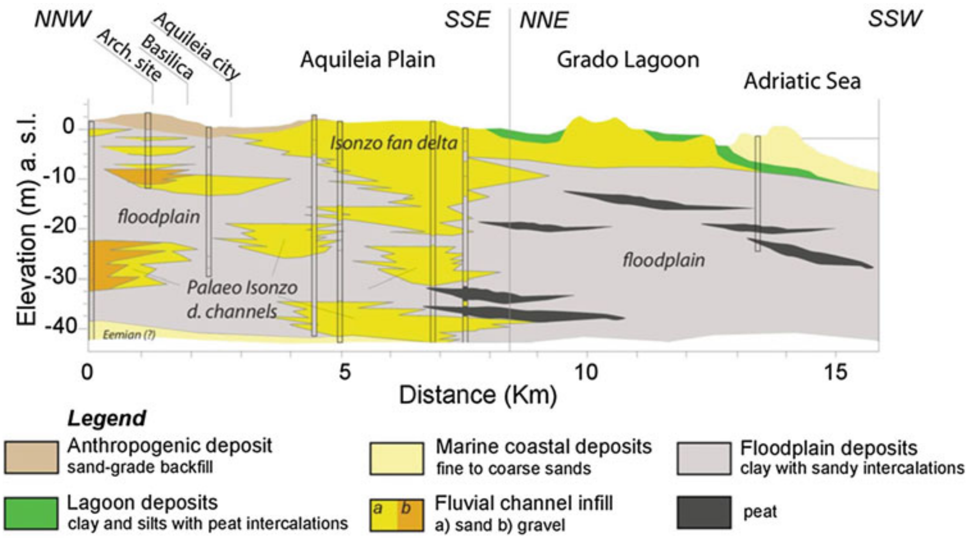

Fig. 34.2 Geological cross section along the Aquileia-Grado transect, modified after Marocco et al. (1984)

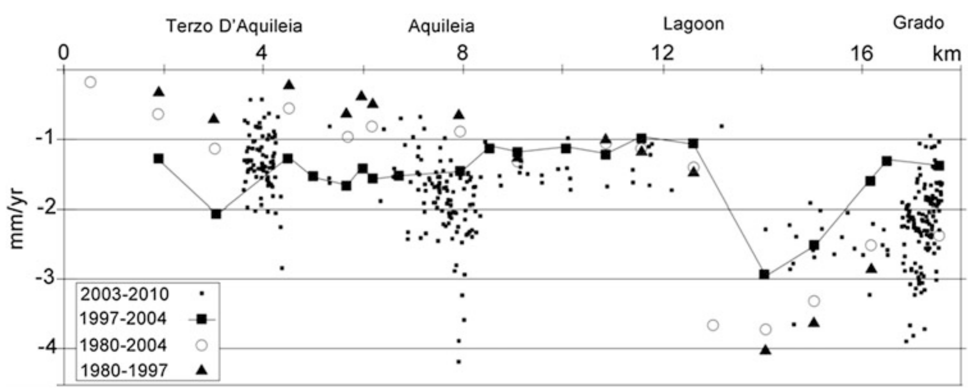

Fig. 34.3 Plot of velocity of vertical displacement (mm/y, negative values indicate subsidence) from levelling surveys (*black triangles*, *empty circles* and *black squares*) and Persistent Scatter Interferometry (*black dots*) along the Terzo di Aquileia-Grado transect (see Figs. 34.1 and 34.2 for location and geological cross section). Modified, after Marchesini (2006)

In the subsoil of Aquileia (Fig. 34.2), four major sedimentary-stratigraphic units can be recognized based on boreholes and radiocarbon dating from the literature (Arnaud-Fassetta et al. 2003).

From top to bottom these are (i) a relatively thin (<5 m) anthropogenic layer of historical age; (ii) a package of Holocene alluvial sediments of the Isonzo fan delta, comprising gravelly-sandy distributary channel infills (up to 10 m thick in the talvegs and 1 km wide), floodplain clays with rare peaty and sandy intercalations and deltaic sands; (iii) 15–25 m of Last Glacial Maximum (LGM) alluvial deposits of the Palaeo Isonzo river comprised of gravelly-sandy channel infill encased in peat-bearing floodplain clays; (iv) a package of sea shells-bearing sands referable to the Eemian interglacial.

34.2.2 Persistent Scatterers Interferometry

Consistently with levelling data (Fig. 34.3), PSI (Fig. 34.1a) indicate an increase in rates of vertical displacements from inland (1–2 mm/yr) to sea (2–3 mm/yr). Moreover, a broad variability (1–4 mm/yr) is highlighted in the urban areas of Aquileia and Grado, which in the former locality allows recognizing two distinct sectors with sinking rates of 1–2 and 3–4 mm/yr (Fig. 34.1b) corresponding to the archaeological site and the new city, respectively. Also, a smaller scale yet stark variability of vertical displacements (0.5–2.5 mm/yr) is observed at the Patriarchal Basilica, which is located halfway between the archaeological site and the new town.

34.3 Discussion and Conclusions

Our comparison of subsidence rates from PSI and levelling data from the literature (Fig. 34.3) confirms the scenario of regional subsidence affecting the Venetian-Friulian coastland and stresses its significance and criticality to preservation of the cultural heritage of the north-western coastland of the Adriatic Sea.

In Aquileia, the difference in subsidence rates between the archaeological area and the new city (Figs. 34.1b and 34.3) is interpreted to reflect the diverse consolidation paths of the dominantly clayey subsoil (Fig. 34.2), induced by differential and diachronous man-made loading over historical time. Conversely, the smaller scale variability of subsidence rates observed at the Patriarchal Basilica Complex would reflect differential ground surface settlements associated to heterogeneities of the shallow subsoil (Fig. 34.2), such as the presence of sandy-gravelly palaeo-channel infills encased in the high-compressibility peaty-clayey soils of the floodplain.

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