LAND SUBSIDENCE IN THE VENETIAN REGION, ITALY ANALYSIS OF ITS MULTIPLE ASPECTS FOCUS ON RECENT INVESTIGATION

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Abstract

A short review is given of the three major factors responsible for the about 23 cm of relative land subsidence occurred in the Venice area over the XX century. Further developments of study have been addressed outside the Lagoon and to the entire Region improving the knowledge of the complex subsidence process which still today affects wider areas, and to the monitoring techniques.

Keywords: *Venice - Italy, Geological subsidence, Anthropogenic -geomechanical and geochemical - subsidence.*

INTRODUCTION

In-depth experimental and theoretical studies about the relative land subsidence of the city and the of lagoon Venice, and its hinterland (Fig. 1) have been performed starting in 1970 at the Venice CNR (National Research Council of Italy). Land subsidence is the result of a variety of subsurface displacement mechanisms, both natural and man-induced, developing on different time scale, that also involve regional areas.

The foremost result referred to Venice, was to quantify the role played by three factors, i.e. anthropogenic subsidence, natural land subsidence and sea level rise, which have induced a land elevation loss over the XX century of about 23 cm. In other words, the Adriatic Sea level *has risen* by 23 cm with respect to the ground level, definitely altering the relationship between land and water (Gatto and Carbognin, 1981). More recent research topics (Carbognin et al., 2005) deal with: splitting geological subsidence into short- and long-term components, a deeper analysis of the cause-and-effect relationship, the monitoring techniques

with a new strategy to control wide-area vertical land displacements analysis (*see the paper on monitoring by the same authors in this volume*).

GEOLOGICAL SUBSIDENCE

Land subsidence has forever been occurring in the Venetian area at variable rates depending on the geological events. The average long-term subsidence rate (≤ 0.5 mm/yr) reflects mainly tectonic processes (Kent et al, 2002), while the natural consolidation of sediments (average rate of 1.3 mm/yr) has played the major role in the successive periods (latest Pleistocene and Holocene), and mostly after the lagoon birth occurred nearly 7000 years BP. The average rate of 1.3 mm/year, fell over recent centuries, reaching the current figure of approximately 0.4 mm/year (Gatto and Carbognin, 1981). This rate refers to the city of Venice and its closest hinterland, whereas a certain sinking at the furthermost northern and southern boundary areas and along stretches of the coastline is still in progress. This can be attributed to different local situations among which the more active consolidation process acting in these areas (e.g. Carbognin et al., 1995a; Brambati et al, 2003).

Figure 1 - ASTER image of the Venice Lagoon and its surroundings. Main localities are indicated.

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ANTHROPOGENIC SUBSIDENCE

Geomechanical subsidence. *Geomechanical subsidence refers to the sediment compaction as the result of subsurface fluid removal.*

Groundwater withdrawal

Subsidence induced by groundwater withdrawals became a Venetian problem with the industrial boom after the 2nd World War. It has mainly been the result of progressive and intensive depletion of artesian aquifers of the six artesian aquifers, located in the upper 350 m of the 1000 m thick unconsolidated Quaternary formation. This process has been deeply studied, the cause-and-effect relationship quantified (e.g. Carbognin et al., 1984), and a 2-D and a 3-D simulation models were developed and verified in time (e.g. Gambolati et al., 1974; Gambolati and Teatini, 1996). Groundwater withdrawal peaked in the 1950-1970 period, together with the subsidence it caused; the maximum rates of 17 mm/yr and 10 mm/ye were recorded between 1968–69 over the industrial zone and in Venice respectively. Following to the closure of artesian wells and the diversification of water supply, a general improvement occurred quickly for both the processes. The 1993 and 2000 regional surveys confirmed the arrest of subsidence as a widespread phenomenon due to groundwater pumping (e.g. Carbognin and Tosi, 2003), and the stability of Venice and the adjacent mainland has also been verified by an integrated monitoring system (*see the paper on monitoring by the same authors in this volume*).

Gas Withdrawals

Land subsidence has also been expected as a consequence of the gas production planned from the *Chioggia Mare* field, whose gravity center is about 25 km far from Venice and 10 km from the southern littoral. Reassuring results were obtained by a very accurate study (Teatini et al., 2000). In any case the planned project is to date precluded.

Geochemical subsidence. *Land sinking induced either by peat soil oxidation and by salinisation of clayey sediments has been studying for the last decade.*

Peat oxidation

Land subsidence involves peaty areas in response of drainage for agricultural purposes. Agricultural reclaimed lands characterized by the presence of soils with high organic content are located in the south-eastern part of the Veneto Region (see Fig.4). An overall local settlement of about 1.5 m has occurred during the last fifty years (Fig.2). The present average subsidence rate caused by organic soil oxidation is between 2 and 3 cm/yr (e.g. Gambolati et al, 2005).

Saltwater intrusion

The Northern and central areas of the Lagoon seem not to be significantly involved by the phenomenon. On the contrary the southern catchment of the Venice watershed is threatened by salinization of shallow aquifer and sediment (*see the paper by Tosi et al. in this volume*).

SEA LEVEL RISE

The relative land subsidence of the city is associated with sea level rise, as previously mentioned. Time series analyses were computed on century-long tide gauge records (1896-1993) at Venice and Trieste; the extent of the historic series was sufficient to average the internal short period climatic variation. The average linear eustatic rate resulted equal to 1.13 mm/year, and the existence of a non-unique secular trend for Venice due to the influence of anthropogenic subsidence (Fig. 3) was proven by statistical analysis (Carbognin and Taroni, 1996).

REGIONAL CAUSES OF LAND DISPLACEMENT

As previously mentioned, studies about cause-and-relationship have recently carried out. Main results are summarized in figure 4.

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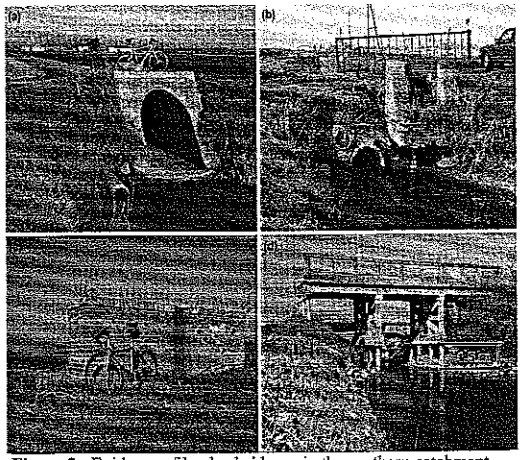
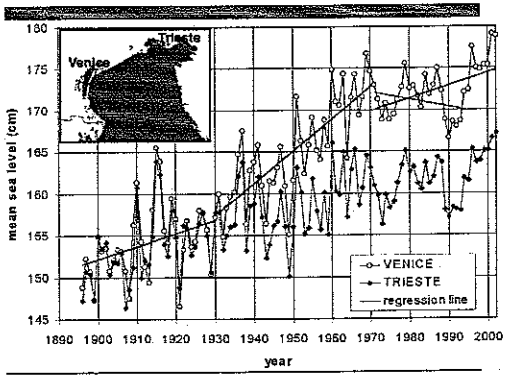
CONCLUSIVE REMARKS

Land subsidence due to groundwater withdrawals has represented one of the most serious problems for the Venice Lagoon over the second half of the XX century.



(a) A bridge has been turned into a useless structure: the left drainpipe helps convey the water of the channel originally flowing through the protruding infrastructure.
(b) An old masonry culvert presently above the water level and substituted by two lower concrete drainpipes, the higher of which already unusable. A qualitative position of the ditch section in the original configuration is sketched.
(c) The protrusion of a sluice wall above the bed of an old disappeared channel.
(d) An old bridge hanging over the canal bank that settled by 1.5 m.

Figure 2 - Evidence of land subsidence in the southern catchment of the Venice watershed.



The increase of m.s.l at Venice in the period 1931-1970 during which anthropogenic subsidence occurred seems to indicate an anomalous rise with respect to Trieste, while no such anomaly is recorded before and after (Carbognin et al., 2004).

Analyses performed clearly suggest that to define a "sea level trend " it is absolutely necessary to handle homogeneous temporal long record (≥ 60 years) from stable sites, as suggested by TAR Scientific Basis that believe 50 years the minimum period suitable to obtain a rather reliable trend.

Figure 3 - Mean sea level at Venice and Trieste vs. time. The location of Trieste with respect to Venice is shown in the inserted map.

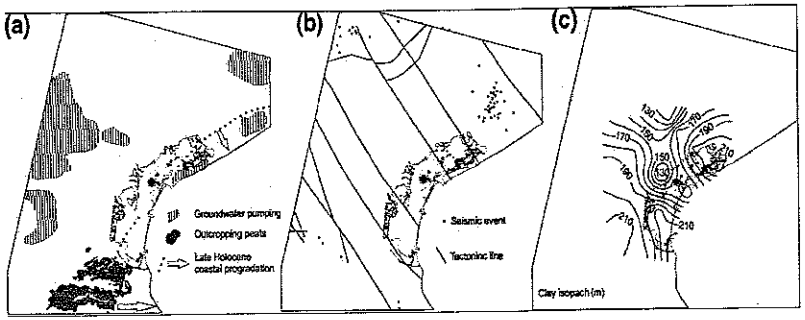


Figure 4 - VENETO REGION: FACTORS RESPONSIBLE FOR LAND DISPLACEMENTS.
(a) areas of groundwater withdrawals and where peat soils outcrop. The dotted line indicates that the coastal progradation occurred over the late Holocene ;
(b) schematic traces of the deep tectonic lines and seismic events recorded between 1990 and 2002;
(c) cumulative thickness (m) of the clayey deposits in the upper 400m depth of the sedimentary sequence (after Teatini et al., 2006).

Once the countermeasures taken, the induced subsidence at Venice and closest areas stopped. The research was then focused on improving the knowledge of the complex subsidence process which involves the Venice Region. Recent analyses, while reassert the stability of Venice, confirm that various processes, both natural and man induced, going from residual sediment consolidation to oxidation of outcropping peat soils and groundwater withdrawals are responsible for land sinking over regional areas, up to 15 mm/yr, and mostly in the northern and southern coastland bounding the lagoon extremities. Moreover, the presence of tectonic lines, the occurrence of recent seismic events, and a larger thickness of clayey compressible deposits in the upper 400 m depth at the lagoon extremities with respect to stiffer sandy formations in the central lagoon can be correlated with differential ground vertical. Studies to improve knowledge are in course.

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