Saltwater contamination in the lowlying coastland of the Venice Lagoon, Italy

Rita Deiana[1], Francesco Morari[2], Pietro Teatini[3], Luigi Tosi[4] and **Andrea Viezzoli**[5]
[1]Department of Cultural Heritage, University of Padova, Padova, Italy
[2]Department of Agronomy, Food, Natural resources, Animals, and Environment, University of Padova, Legnaro (PD), Italy
[3]Department of Civil, Environmental, and Architectural Engineering, University of Padova, Padova, Italy
[4]Institute of Marine Sciences, National Research Council, Venezia, Italy
[5]Aarhus Geophysics APS, Aarhus, Denmark

ABSTRACT

The southern portion of the Venice coastland includes a very precarious environment. Due to an elevation down to 4 m below msl, the Venice Lagoon and Adriatic Sea proximity, and the encroachment of seawater from the mouth of the river network up to 20 km inland, salt contamination of land and groundwater is a severe problem that is seriously affecting the farmland productivity. An interdisciplinary multi-scale research is ongoing with the aim of understanding the contamination process, quantifying the effect of the saltwater intrusion of the crop production, and proposing possible mitigation strategies. A 21-ha representative basin has been selected and deeply monitored from the hydrogeological and agricultural points of view. It has been clearly outlined that in the upper 5 to 10 m mainly the low-permeable soils are contaminated by salt. Conversely, fresh to brackish waters are located in the sandy elongated paleo-channels. This is likely due to the origin of the area which was a salty marshland since one century ago. The freshwater supplied for almost 100 years by the rainfall and leakage from the river and channel beds has been able to reduce the salt concentration only in the highly permeable deposits.

INTRODUCTION

Understanding the hydrogeological processes is critical for a sound management of groundwater resources in coastal areas. Here lie majority of human settlements, industrial production, and fish farming. Human pressure on the coastland environment is constantly increasing, and many studies predict a rising of seawater level in the next 50 years ranging from few cm up to several tens of cm, with expected threatening consequences (e.g., Carbognin et al., 2009). If these are common characteristics of most coastal areas, wetlands, lagoons and estuaries also have often unique flora and fauna depending on the groundwater-surface water processes.

The hydrologic setting of the transitional environments is complicated by their Late Quaternary subsoil architecture. The deposits represents the transition through the fluvial in tide-dominated depositional systems triggered by the sea level changes. In particular, in the Venice area numerous geomorphological features representing i.e. fluvial paleoriver beds, ancient tidal channels, and paleobeach ridges occur (Tosi et al., 2009). These features are generally filled by sandy deposits and can be considered preferential path for the groundwater flow, both in the horizontal and vertical directions.

The area under investigation is part of the coastal plain between the lower stretches of the Brenta and Adige rivers, south of the Venice Lagoon (Figure 1). The coastal plain lies almost completely below the mean sea level. The main hydrogeological problems of this part of the Venice area are the advancing of saltwater contamination into the phreatic aquifer yielding a reduction of the soil productivity (Braga et al., 2012). Geological and geomorphological features can favor or mitigate these processes.

METHODS

The study site (Figure 1) is a ca. 21 ha field located at Chioggia, Venice, Italy (45°10'57"N; 12°13'55'E) along the southern margin of the Venice Lagoon. With an elevation ranging between 1 and 3.3 m below asl, the soil is mainly silt–clay with the presence of peat and sandy drifts (i.e. paleochannels). In particular, two well preserved-paleochannels (i.e. western and eastern), generally characterized by coarse texture, cross the study site in a SW–NE direction (Rizzetto et al., 2003). A pumping station and a dense network of ditches control the depth to the water table (Manoli et al., 2913), which is generally maintained at ~0.6 m during the summer season in order to promote subirrigation.

Both undisturbed and disturbed soil samples were collected in May 2010 at 41 points selected according to an apparent electrical conductivity (ECa)-directed sampling scheme based on simulated spatial annealing. Disturbed samples were taken at 4 depth increments: 0–0.15, 0.15–0.45, 0.45–0.8, and 0.8–1.2 m. Undisturbed cores were extracted with a hydraulic sampler from the upper 1-m profile and then analyzed at 0–0.15, 0.15–0.45, 0.45–0.8, and 0.8–1.00 m for bulk density (Scudiero et al., 2011; 2013).

ECa at three different investigation depths (from 0 to 0.75 m; from 0 to 1.50 m; from 0 to 6.00 m) was measured from April 2010 to September 2012 by a ground-based electromagnetic conductivity meter (GEM). We applies an airborne electromagnetic technique (AEM) equipped by a dual moment bandwidths that allow to investigate the soil response from shallow to intermediate depths particularly suitable for our target (Teatini et al., 2011). EM data are then inverted using the Spatially Constrained Inversion (SCI) technique (Viezzoli et al., 2008). The traces of the surveys are provided in Figure 1. Water level and conductivity (ECw) have been systematically measured in a number of boreholes and in the watercourses crossing and bounding the farmland. In addition, five continuous cores have been taken down to 20-m depth for a detail hyrostratigraphic characterization. Finally, a few electrical resistivity tomographies and seismic sections have been acquired crossing the paleo-channels to delineate the geomorphological architecture and the related groundwater salinity.

RESULTS

Geophysical and hydrogeological investigations allowed improving the conceptual model of the processes responsible for the saltwater intrusion. It has been clearly outlined that in the upper 5 to 10 m mainly the low-permeable soils are contaminated by salt. Conversely, fresh to brackish waters are located in the sandy elongated paleo-channels. This is likely due to the origin of the area which was a salty marshland since one century ago. The freshwater supplied for almost 100 years by the rainfall and leakage from the river and channel beds has been able to reduce the salt concentration only in the highly permeable deposits. Below this upper layer, salt concentration is generally very high (ECw ranges between 10'000 and 45'000 mS/cm) in the whole area. Saltwater intrudes from the lagoon bottom, which is 2 to 3 m above the farmland, passes underneath the rivers and canals, and extends landward.

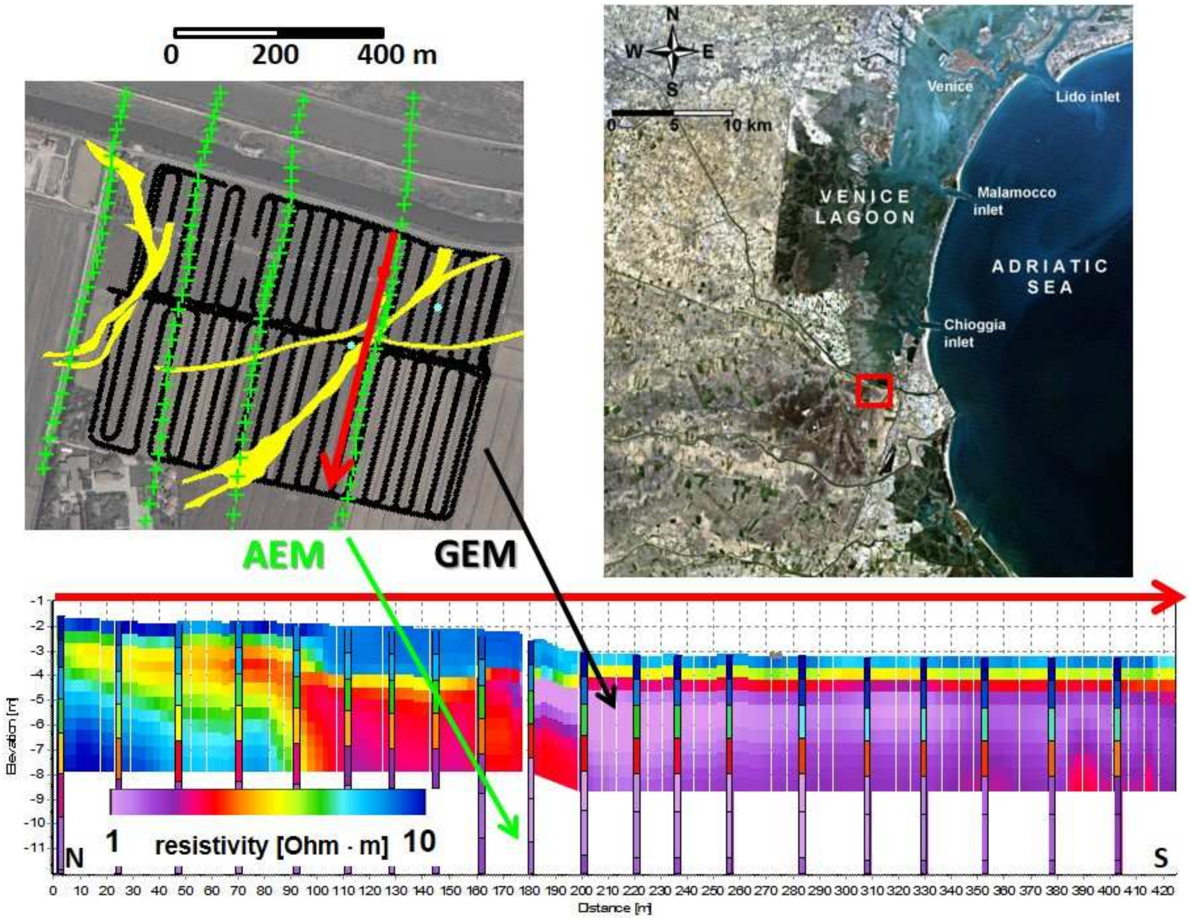

Figure 1. (top right) Location of the study area at the southern margin of the Venice Lagoon. (top left) Study area with the trace of the airborne EM (green) and ground EM (black) surveys together with the trace of the main paleorivers (in yellow). (bottom) North-south resistivity section obtained by AEM and GEM along the red alignment shown above.

DISCUSSION AND CONCLUSIONS

The study shows the importance of a 3D large-scale view of subsurface water and soil characteristics for the hydrogeological characterization of large fresh-salt transitional environments such as wetlands, lagoons, deltas. Considering the complex physiographic, morphologic and hydraulic setting, this is achieved by an integrated approach combining various methods, i.e. airborne and ground-based electromagnetic acquisitions, electrical resistivity tomographies, seismic surveys, lithological analyses on shallow cores and deep boreholes, piezometric and water conductivity measurements, and lab physical-chemical tests on water and soil samples.

From a general perspective, the integrated approach has a strong hydrogeological relevance both to define conceptual hydrogeological models (e.g. characteristic geometries, boundary conditions, major natural and anthropogenic forcing factors) and to provide the input for the simulation of the groundwater flow/transport by numerical models.

ACKNOWLEDGMENTS

The work has been developed within the Research Programme "GEO-RISKS: Geological, morphological and hydrological processes: monitoring, modelling and impact in the north-eastern Italy", WP4, funded by the University of Padova, Italy. A particular thanks to the Adige-Euganeo Water Reclamation Authority for the substantial help to develop the in-situ activities.

REFERENCES

Braga, F., F. Morari, F. Rizzetto, E. Scudiero, P. Teatini, L. Tosi and Q. Xing. 2012. Characterizing the saltwater effect on soil productivity by WorldView-2 images. The southern margin of the Venice Lagoon, Italy. In: 7th EUREGEO, European Congress on Regional Geoscientific Cartography and Information Systems, ed S. Scappini and S. Zapparoli, Vol. I, 361-362. Centro Stampa Regione Emilia-Romagna Publ.

Carbognin, L., P. Teatini, A. Tomasin and L. Tosi. 2010. Global change and relative sea level rise at Venice: what impact in term of flooding. Climate Dynamics 35:1039-1047.

Manoli, G., S. Bonetti, E. Scudiero, P. Teatini, P. J. Binning, F. Morari, M. Putti, and M. Marani. 2013. Monitoring and modeling farmland productivity along the Venice coastland, Italy. Procedia Environmental Sciences 19: 361-368.

Rizzetto, F., L. Tosi, L. Carbognin, M. Bonardi and P.Teatini. 2003. Geomorphological setting and related hydrogeological implications of the coastal plain south of the Venice Lagoon (Italy). In: Hydrology of the Mediterranean and Semiarid Regions, ed E. Servat et al., 463-470, IAHS Publ. n.278.

Scudiero, E., Deiana, R., Teatini, P., Cassiani, G., Morari, F., 2011. Constrained optimization of spatial sampling in salt contaminated coastal farmland using EMI and continuous simulated annealing. Procedia Environmental Sciences 7: 234-239.

Scudiero, E., P. Teatini, D. L. Corwin, A. Berti, and F. Morari. 2013. Delineation of site-specific management units in a saline region at the Venice Lagoon margin, Italy, using soil reflectance and apparent electrical conductivity. Computers and Electronics in Agriculture 99: 54-64.

Teatini, P., L. Tosi, A, Viezzoli, L. Baradello, M. Zecchin, and S. Silvestri. 2011. Understanding the hydrogeology of the Venice Lagoon subsurface with airborne electromagnetics. Journal of Hydrology 411: 342-354.

Tosi, L., P. Teatini, L. Carbognin, and G. Brancolini. 2009.Using high resolution data to reveal depth-dependent mechanisms that drive land subsidence: The Venice coast, Italy. Tectonophysics 474: 271-284.

Viezzoli, A., A. V. Christiansen, E. Auken, and K. Sørensen. 2008. Quasi-3D modeling of airborne TEM data by spatially constrained inversion. Geophysics 73: F105–F113.

Contact Information: Andrea Viezzoli, Aarhus Geophysics APS, Hoegh-Guldbergs Gade 2, Aarhus DK-8000, Denmark, Email: andrea.viezzoli@aarhusgeo.com