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ADRIANA GALVANI

GraldlediorS

Federica Braga[(1)], Sandra Donnici[(1)],
Pietro Teatini[(1)], Luigi Tosi[(1)], Luca Zaggia[(1)], Xuelu Gao[(2)], Ping Shi[(2)],
Cheng Tang[(2)], Qianguo Xing[(2)], De Wang[(2)], Xiaohu Wen[(2)]

(1) - Institute of Marine Sciences - CNR, Venice, Italy.
(2) - Yantai Institute of Coastal Zone Research - Chinese Academy of Sciences, Yantai, China.

SALT CONTAMINATION PROCESS IN COASTAL AQUIFERS OF YANTAI, CHINA, AND VENICE, ITALY

Abstract: The knowledge of hydro- morpho- geological processes occurring in lagoons and wetlands all over the world is of paramount importance because of the widely recognized buffering function of these unique transitional ecosystems, for biodiversity and for valuable economical resources as agriculture and fisheries.

We present an overview on the salt contamination process affecting the Laizhou Bay (Southern Bohai Sea, Yantai, China) and the Venice Lagoon (Northern Adriatic Sea, Italy), pointing out similarities and differences. Moreover, we report on preliminary results of multidisciplinary surveys and analyses carried out to test an integrated methodology suitable for a better understanding of the fresh-salt surficial water- groundwater interactions in the two study areas.

Keywords: continental-marine groundwater interaction, saltwater intrusion, hydrogeology, Yantai, Venice.

Introduction

The coastlands of the Southern Bohai Sea, China, and the Northern Adriatic Sea, Italy, are precarious environments subject to both natural changes and anthropogenic pressure. Climate changes and stresses induced by human activities, e.g. pollution, engineering interventions for dams, flood control, canalization, urbanization, agriculture and fish farm activities are the main causes of increasing degradation and loss of habitat.

Over the past two decades, seawater intrusion has become a serious environmental management issue. The Laizhou Bay (Yantai) (Fig. 1a) is one of the areas more seriously impacted by saltwater contamination in China, which derives from modern seawater intrusion and fossil brines and salines located in shallow Quaternary sediments. Two major problems are related to the groundwater

contamination by salt: a) effects on the human health (e.g., bone fluorosis, macular teeth) due to fluorine excess in drinkable water, and b) the reduction of agricultural productivity due to soil salinization.

The Laizhou coastland can be divided in four areas on the basis of the salt components in the groundwater (e.g., Meng et al., 2002). The area to the north of Laizhou City is affected by recent seawater contamination, the nearby Baisha River-Jiaolai River mouth plain area and the Weihe River mouth plain area on the northern Changyi county coast are characterized by mixed seawater and fossil saline groundwater intrusion. The contamination of fossil brine prevails in the northern Shouguang plains Recently Han et al. (2011) provided a conceptual model of the relationships between the various water types and their related processes in a spatial context. A hydro geologic sketch for the southern Laizhou Bay is shown in Fig. 1b.

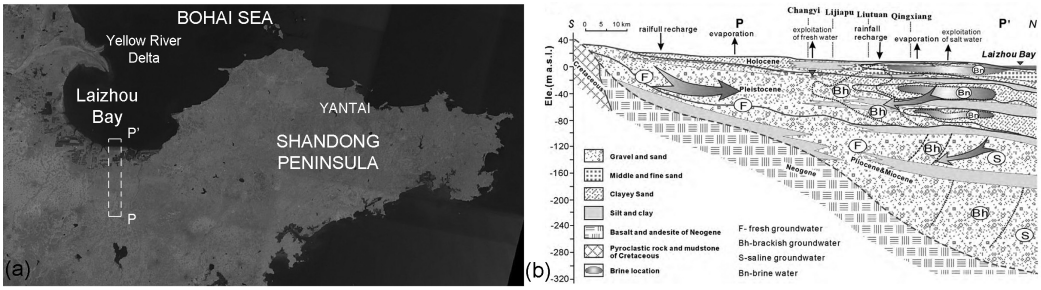

Figure 1. (a) Satellite image of the Southern Bohai Sea and Shandong Peninsula. (b) Hydrogeologic conceptual model along the cross-section P-P' (modified from Hang et al., 2011) which location is shown in (a).

In the coastland surrounding the Venice Lagoon (Fig. 2a), the combined effect of sea level rise, land subsidence, and reclamation activities has enhanced saltwater contamination and the related soil salinization with serious environmental and socio-economic effects. The risk of soil desertification and the decline of agricultural activities are major problems in the coastal farmlands.

In the catchment located south of the Venice Lagoon, a serious aquifer contamination due to saltwater intrusion from the sea and the lagoon is inducing a high soil salinization which severely affects crops productivity. The saltwater extends inshore up to 20 km far from the Adriatic Sea coastline and the saltwater plume is observed from the near ground surface down to a depth of 100 m (Fig. 2b).

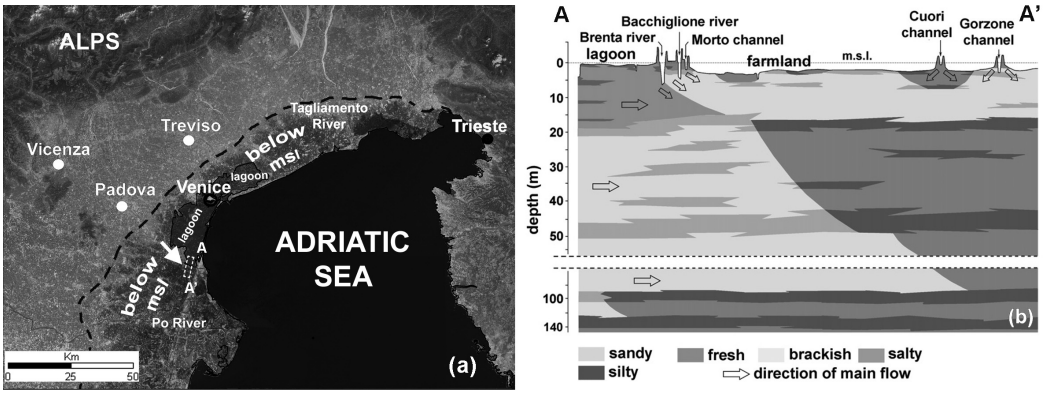

Figure 2 – (a) Satellite image of the northern Adriatic Sea. Black dotted line shows the bounds of low-lying areas. (b) Hydrogeologic conceptual model along the cross-section A-A' at the lagoon margin. The trace of the section is highlighted by the white arrow in (a) (modified from de Franco et al., 2009).

Geological studies pointed out that geomorphologic features and stratigraphic setting can favour or mitigate this process. In particular, well developed paleo-river systems and permeable sediments represent preferential pathways for the communication between waterbodies characterized by different salinity, whereas thick silt-clayey layers can preclude the saltwater/saline contamination from the lagoon and the sea. Changes in river discharge, regulation of phreatic water levels by means of pumping stations, climatic conditions, fresh-water input for irrigation purposes, and riverbed seepage are important factors that affect positively or negatively the saltwater contamination (de Franco et al., 2009). Saltwater is released from the bed of the watercourses into the surrounding farmland when seawater encroaches the river estuary and upstream reaches in dry periods. This process is influenced by the tidal excursion and the river regime. The ground elevation of the territory, generally below the mean sea level up to -4 m, enhances the salt contamination process especially in those sectors where land subsidence, mainly due to the oxidation of peat soils in connection with the agricultural practices, is responsible for a subsidence rate varying between 1.5 and 2 cm/yr.

In both study areas, the occurrence of buried geomorphologic features and land use changes play an important role in salt contamination of groundwater and soil. The presence of sandy paleo-channels enhance the saline groundwater flow landward while land reclamation changes the surface-groundwater exchanges. To better understand this issue, it is crucial to investigate these aspects inland and within the sea/lagoon, wetland/delta, covering both its permanently wet areas as well as the tidal flats.

An integrated monitoring approach for understanding the relationships between continental and marine waters

The Yantai-Laizhou coastland and the Venice Lagoon can be considered two relevant "laboratories" where geophysical, hydrological, and hydrogeological surveys, remote sensing, and geochemical analyses can be tested in various environmental conditions.

Remote Sensing

Optical and thermal infrared data have been collected for the coastal zone of Laizhou Bay to identify morphological and land use changes at "regional" scale, together with water discharges related to different coastal land-use. Mainly Landsat MSS, TM and ETM+, MODIS-Terra, SPOT-VGT scenes have been acquired. Fig. 3 shows two satellite images acquired in 1979 and 2010, from Landsat-MSS and Landsat5-TM, respectively. The image comparison highlights the main morphologic and hydrologic changes occurred over the last three decades.

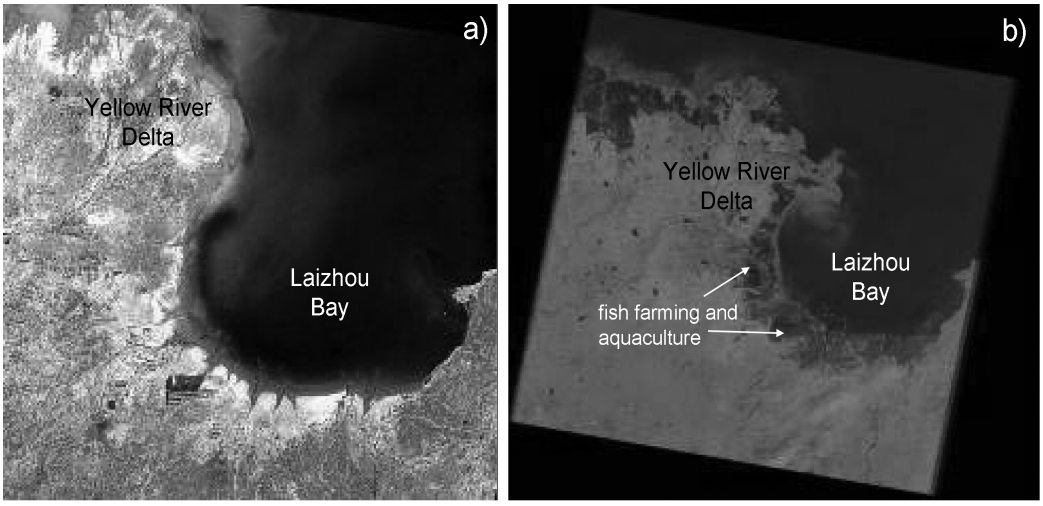

Figure 3 – Satellite images of Southern Bohai Sea. a) 1979 Landsat-MSS, b) 2010 Landsat5-TM.

Hydrochemical investigation

A total of 32 wells, from5 to 40 m deep, located within 10 km from the coastline, have been selected for long-term groundwater level observations and water sampling. Preliminary investigations

on the saltwater intrusion process have been carried out in the eastern Laizhou Bay by Wen et al. (2012). They demonstrated that the three main hydrochemical processes controlling groundwater chemistry is determined by: i) seawater intrusion, ii) chemical weathering water–soil/rock interaction, and iii) nitrate contamination. Preliminary investigation pointed out that the hydrochemical methods are useful tools for interpreting complex water quality data and the origin of groundwater salinity. The obtained information represents a benchmark/basis for future hydrochemical investigations that will be useful for the groundwater management in the study area (Fig. 4).

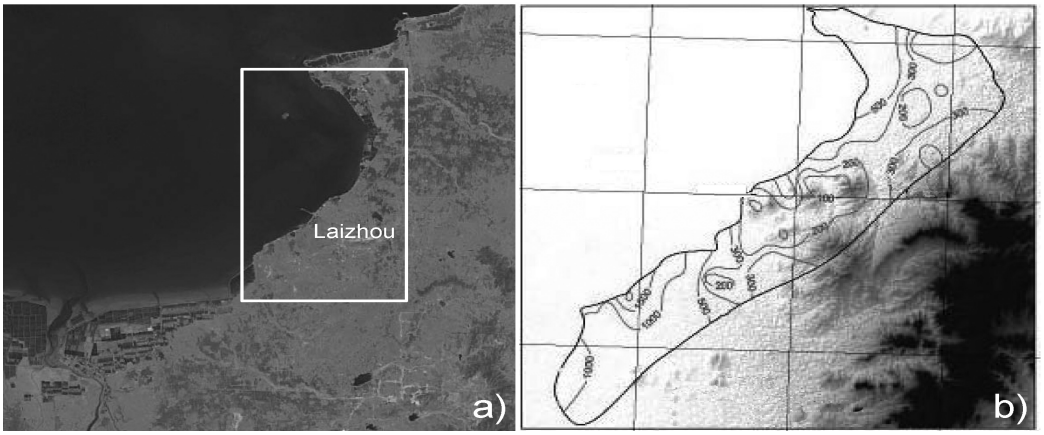

Figure 4 – a) Satellite image of the eastern Laizhou Bay. b) Iso-Cl^-(mg/l) contour map (modified from Wen et al., 2012).

Geophysical surveys

The field activity performed in the Venice case study was focused on the characterization of groundwater and the detection of buried morphological features, such as highly-permeable sandy paleo-channels (Fig. 5a), that can enhance the groundwater flow from the mainland to the sea and/or viceversa. The main goal was the set up of a survey methodology capable to provide both the subsoil architecture and the hydrogeologic setting in very shallow water (about 1 m depth). Very High Resolution Seismic (VHRS) and Continuous Electrical Tomography (CERT) surveys have been carried out and the combined analysis of the two data sets highlighted a correlation between lithostratigraphic discontinuities and heterogeneity in the fluids saturating the deposits (Fig. 5b).

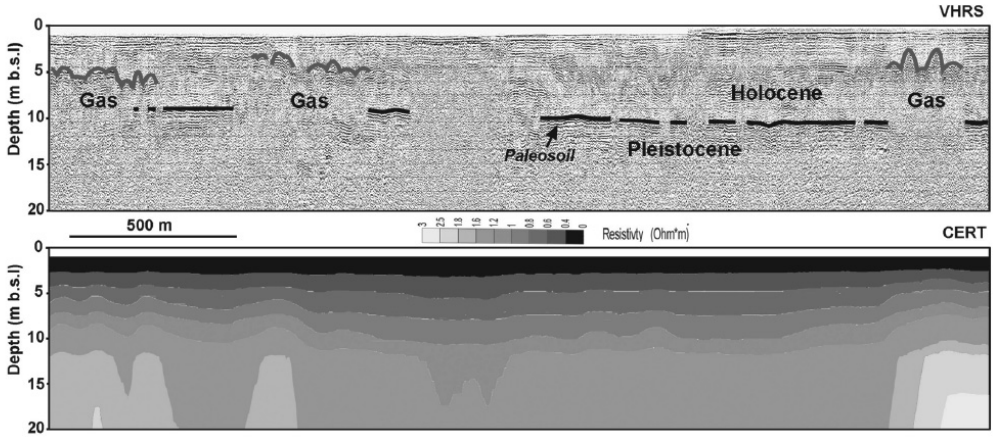

Figure 5 – (a) Example of paleo-channel occurrence in the Venice Lagoon. (b) Preliminary result of the VHRS-CERT test (modified from Tosi et al., 2011).

Conclusive remarks

The investigation performed in the coastal region of the two test areas, Yantai and Venice revealed that a comprehensive quantification/description of surface water–groundwater exchanges in coastlands is still a challenge. The contamination process is due to complex inter-relationships between ground-, surface-, and lagoon-waters combined with the significant heterogeneity of the sediment deposits and soils. In particular, both areas experience a significant saltwater intrusion in the upper aquifer systems as a result of natural processes and human activities. Such occurrence, which is relatively recent, reduces the availability of freshwater resources, the soil productivity, and increases the risk of soil desertification. Just below the upper unit, paleo-brines are generally found in the Laizhou Bay. Conversely, a 200-400 m freshwater multiaquifer system is well developed in the Venice coastland, and brackish paleo-waters are located only below 300-500 m. If brines represent a strong limitation for the development of the Chinese site, with negative effect also on human health because of the high-fluorine content, deep brackish aquifers at present do not negatively affect the Venice coastland because of the freshwater availability in the upper multi-aquifer system and the river network. To increase freshwater availability in northern regions, a project for the derivation of surface water from catchments located at south has been developed by Chinese authorities.

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