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Research paper

Seawater intrusion via surface water vs. deep shoreline salt-wedge: A case history from the Pisa coastal plain (Italy)

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ABSTRACT

This study analyses data regarding the quality of surface water in the Pisan plain between the mouth of the Arno river, Pisa and Livorno in order to identify the origin of the high chloride content derived from the sea water in areas far from the coast. We used existing environmental monitoring data from the study area integrated with data from the present study.

The study involved measuring the piezometric levels and electrical conductivity (EC), together with a chemical analysis of the surface water and phreatic aquifer (water table aquifer) samples. Data acquisition through sampling along coastline piezometers, was carried out in 2008. In the summer of 2012 we supplemented data regarding areas further inland with surveys of piezometric levels and EC in the hydrographic network and shallow wells. The distribution of salinity was compared with a three-year monitoring survey carried out at the water sampling points in the Tombolo forest, an area about 5 km from the coastline.

All the collected data show the presence of significant salinisation generated by the sea water, which is carried towards the inner plain through an artificial watercourse (Navicelli channel) and its hydrographic network. In the dry season this channel contains no fresh water from upstream and sea water tends to flow up to the town of Pisa, about 7 km from the coast. The sea water carried by the channel infiltrates into the shallow aquifers directly or through the minor hydrographic network, thus polluting the internal areas of the Pisan plain. Potential hydraulic connections with the intensively exploited deeper aquifers might lead to the salinisation of the same aquifers. This phenomenon could be confused with seawater intrusion from the coast (deep shoreline salt-wedge).

1. Introduction

The northern coastal plains of the Mediterranean are subject to significant human pressure, which often leads to the depletion and deterioration of water resources. One of the most recurring effects is the variation in the natural equilibrium between fresh and sea waters and the consequent advance of the sea water through the coastal aquifers.

Many Italian coastal areas are affected by seawater intrusion (Barrocu, 2003). In Tuscany, several critical situations have been highlighted (Pranzini, 2002; Grassi et al., 2007). The salty waters in the multilayered aquifer system of the Pisan coast have been known about for at least 20 years, and numerous studies have highlighted how the problem affects the environment (Signorini, 2008; Doveri et al., 2010; Butteri et al., 2010; Giannecchini et al., 2010). Seawater intrusion increases especially during the summer months due to the intensive exploitation of civil, industrial and agricultural uses with the consequent deterioration of the qualitative state of the groundwater.

In addition to degrading the quality of groundwater and restricting the agricultural use of the land, increased salinity reduces the diversity of ecosystems (Amores et al., 2013) and leads to the development of halophilic species (Williams, 1987). Sea water contains approximately 35,000 mg/L of dissolved solids, which include about 20,000 mg/L of chloride. These chloride values are normally associated with EC values exceeding 45,000 μS/cm. Fresh groundwater in most coastal areas generally contains less than 100 mg/L of chloride. However, concentrations in excess of 100 mg/L are not conclusive evidence of seawater intrusion because they could be due to airborne sea spray in precipitation, well pumping, local sources of chlorides, including septic systems or animal manure, or to relic seawater in the aquifer. Chloride concentrations higher than a few hundred mg/L can cause adverse effects on many crops (USEPA, 1992; Mara, 1998). In order to provide criteria to assess the chemical status of groundwater

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bodies according to the 2006/118 European directive, Italy (Legislative Decree No. 30/2009, 2009) defined the threshold values with respect to chloride and EC as 250 mg/L and 2500 μS/cm respectively.

Seawater intrusion is the introduction of saltwater into inland freshwater systems. It can move into the freshwater system through both surface water and groundwater connections to the sea. Seawater intrusion via groundwater connection is normally directed along the shoreline as a deep salt-wedge. Human creation of channels and ditches for drainage of freshwater systems encourages saltwater intrusion where channels connect with a saltwater source (Turner, 1997; Day et al., 2000). This is particularly evident when river flows are low and or during high tides or storm surges (Anderson, 2002; Switzer, 2014). Storm surges and strong wind events can push saltwater into freshwater channels encroaching on freshwater coastal systems. Moreover, eustatic sea-level rise is projected to be 1–2 mm/yr, which is the change in sea level rise with a change in the ocean volume due to climate change (Milly et al., 2003). Seawater intrusion can easily propagate in-land along rivers and channels then infiltrate downward to the groundwater zone. In recent decades, the excessive over-exploitation of fresh water resources has exacerbated the situation leading to periods when river flow is reduced to a threshold level beyond which it can no longer prevent sea water from moving inland. The salt water can go back to the lower courses of the rivers for miles, changing the chemical characteristics of the waters of the coastal plains (including groundwater) rendering it too saline for drinking or irrigation water.

Coastal plains are underlain by alluvial aquifers which can be highly heterogeneous sequence of sands and silts. Seawater naturally intrudes into coastal aquifers as a wedge due to density differences. It is very important to distinguish between natural saline wedges in the subsurface and saline intrusion via surface water flow followed by infiltration to the subsurface. How these effects are monitored is, in fact, very different as are the actions required to remove or mitigate the impacts.

We studied the surface and subsurface waters in an area of the Pisan plain in terms of geological and hydrogeochemical aspects, with reference to the relationships of feeding and drain between the water table aquifer and the hydrographic network. The study area includes the river Arno and the Scolmatore channel to the north and south respectively, and the coastline to the west. The eastern boundary includes Pisa and the Coltano hills (Fig. 1).

The study area includes the Migliarino-San Rossore-Massaciuccoli Regional Park and has a high environmental value, due to its great variety of natural habitats, ranging dunes to sandy shores and from hygrophilous forests to marshlands. The results provide a tool for managing a network of datasets to help local authorities to improve land management and the monitoring of water resources, and also to prevent possible environmental damage caused by salt pollution.

2. Geological setting

The coastal plain is located in the west of Tuscany, north of Livorno (Fig. 1a). It is bounded by the Pisan Mountains to the NE, the Livorno hills to the south, and the Ligurian Sea to the west. The Arno valley consists of a succession of estuarine clays, subdivided into three, vertically-stacked transgressive-regressive millennial-

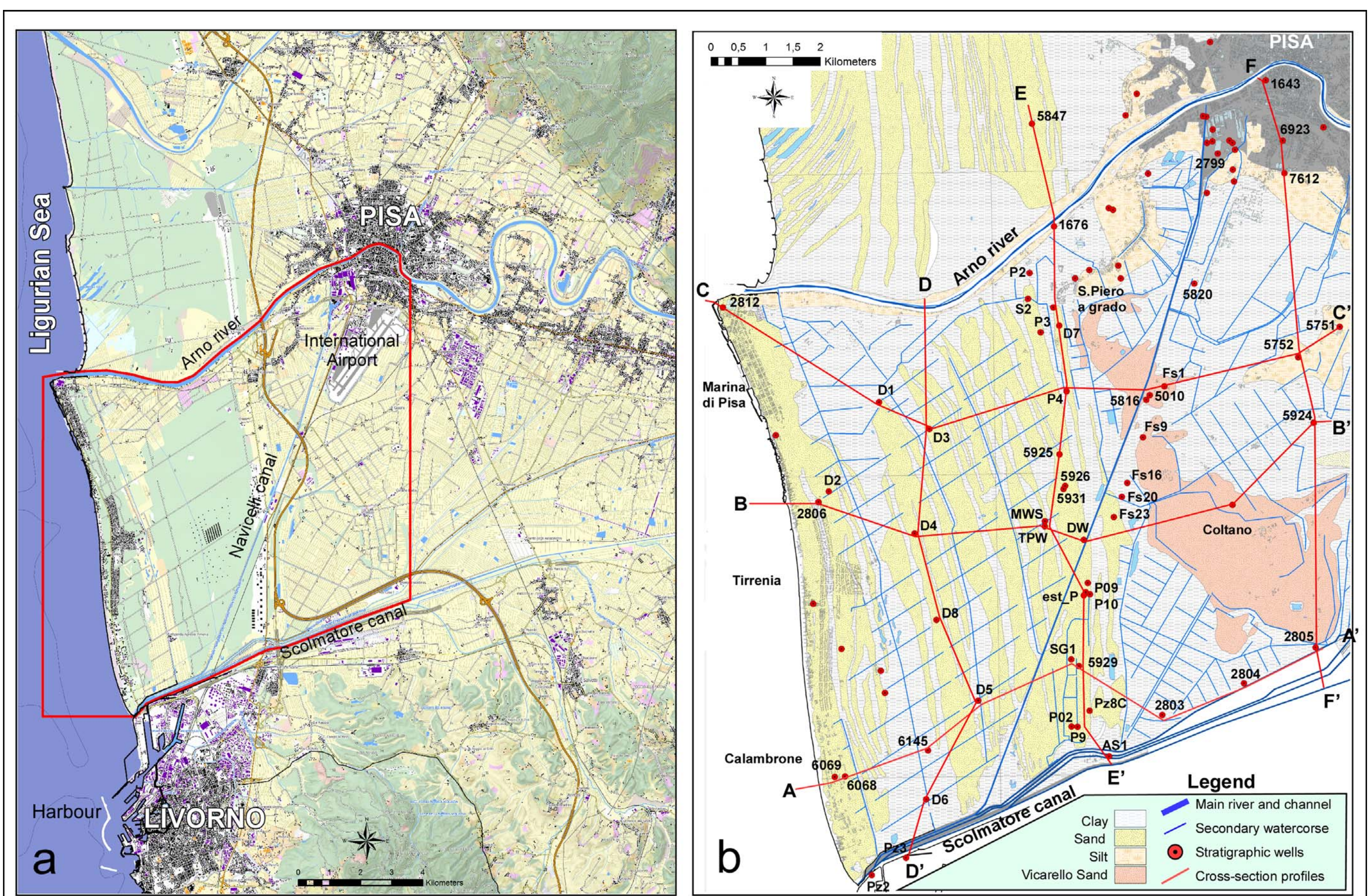

Fig. 1. (a) Location map of the study area (b) Lithological map, derived from the Provincial Administration of Pisa (Provincial administration of Pisa, 2005) geological map. The red lines indicate the section traces of Fig. 5.