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The groundwater rise in the urban area of Milan (Italy) and its interactions with underground structures and infrastructures

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ABSTRACT

This paper discusses the effectiveness of different solutions for managing the rise of the groundwater level in the urban area of Milan (Italy). The study area is interested by a regional rising trend of the water table, which can bring about a hydrogeological hazard for the existing underground structures (metro tunnels, stations, deep foundations, etc.). The study was carried out by means of the following steps: (1) monitoring data analysis for reconstructing the regional trend of the water table; (2) calibration of a 3D numerical model of the groundwater flow; (3) scenarios simulation of the aquifer system evolution and evaluation of its effects on underground infrastructures; (4) evaluation of the effectiveness of different solutions for hazard mitigation. In the present day scenario, modelling results pointed out a local increasing of the groundwater levels over wide areas located nearby the tunnels intersections, where the highest increase in water table due to the regional trend is observed (about 10 m in the last 20 years). Results obtained for the future scenarios pointed out a significant increase in water level (from 1 m in short term scenarios to 10 m in the most pessimistic long term scenario), as well as an increase in water thrusts acting on the structures and flow velocity below foundations, bringing about important issues related to their static stability in the long term. Finally, the numerical results for different mitigation systems showed that in the long term the problem could be solved only through a superimposition of the effects of several solutions.

1. Introduction

In the last decades, an increasing trend in groundwater level due to the deindustrialization process was observed in urban aquifers all around the world: from Buenos Aires in Southern America to New Haven in Northern America, from Cairo City in Africa to Bangkok and Tokyo in Asia. Many European cities are affected by the same problem: Barcellona (Vasquez-Sune et al., 1997), Birmingham, Nottingham, Liverpool, London (Wilkinson, 1985), Paris (Lamè, 2013), Berlin and Milan (Beretta et al., 2004). The water table rising in these urban areas was the result of a deindustrialisation process, with the related decrease in groundwater pumping, which was not properly managed and therefore caused serious damages to underground structures and infrastructures (Dean and Sholley, 2006).

In this paper, the case of Milan (northern Italy, Fig. 1a) is discussed. By its geographical position, geology and history, Milan has always been considered a "city of water." Actually, Milan lies on an alluvial plain which contains one of the most important Italian aquifer. Moreover, in the past Milan was affected by a dense network of natural and man-made channels having multiple purposes: military defence (in Roman times), irrigation, zootechnical use, motive power, laundries, collector sewer system, and recreational activities. In the late '800s, early '900s, many of these channels were covered and buried, interrupting the hydraulic continuity of the network and preventing a proper drainage of the surface water. Initially this fact did not create any particular problems, because of the presence of big factories located mainly in the north of Milan. Since the early sixties until the early nineties, these factories led a significant groundwater drawdown, by pumping large quantities of water (up to 140,000 m^3/day). However, since the early nineties, the closure of many factories led to a reversal of the trend and the aquifer began to grow, reaching levels close to those of the fifties.

Actually, the history of the groundwater level in Milan passed through a phase of intense exploitation, which triggered land subsidence phenomena and pollutants inflow, followed by a phase marked by the interference of groundwater level with underground structures, due to the decrease of the withdrawals in wells (Fig. 2).

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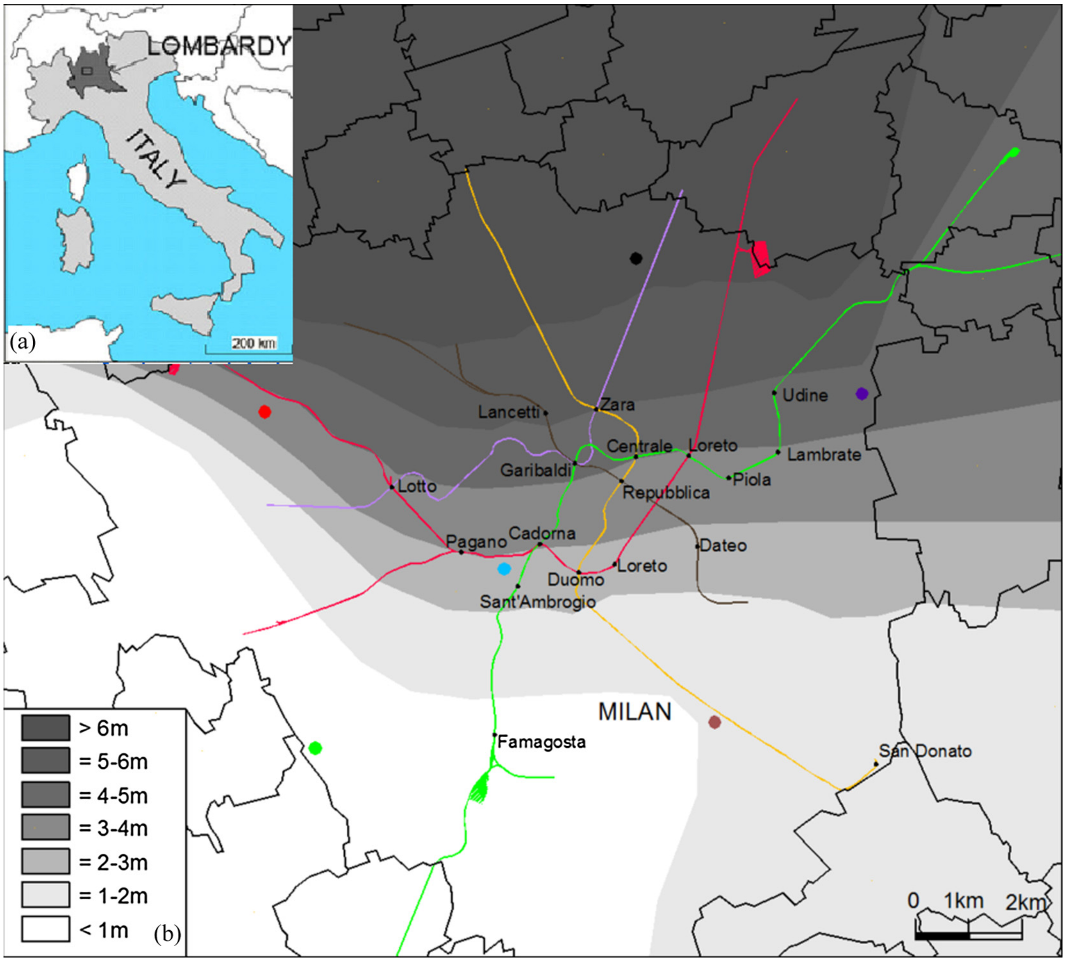

Fig. 1. (a) Location of the study area. (b) Groundwater rising from 2000 and 2014 in the study area. The coloured lines represents the existing metro lines (red, green, yellow and purple) and the suburban railway (in brown). The circles show the location of the monitoring wells, for which the water table trend is shown in Fig. 2 (the colours in the map correspond to the colours in the graph). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

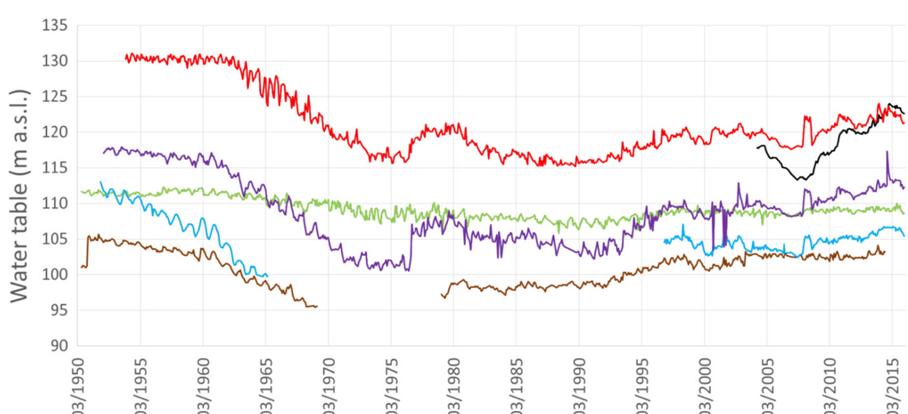

Fig. 2. Monitoring data of the water table in different areas of Milan (see Fig. 1b for the location of the monitoring wells).

The present paper aims at studying the evolution of the phenomenon and therefore identifying medium and long-term solutions in order to hinder the rise of the groundwater level and its interference with underground structures. At this aim, the hydrogeological setting of the area is first described and the monitoring data are analysed in order to reconstruct the regional increasing trend of the water table (Figs. 1b and 2). Afterwards, a 3D numerical model of the groundwater flow system is implemented and then calibrated in steady state with reference to the maximum water table observed in March 2014. Numerical results allow identifying the interferences between the existing underground structures and infrastructures (i.e. metro tunnels and stations, deep foundations, etc.) and the rising water table, pointing out the related hydrogeological hazards. Finally, several scenarios of the groundwater system evolution are defined and simulated in order to reconstruct the possible changes in the groundwater level and