Design and application of an open-source 3D/4D geo-database: the case study of the Volturno Plain in Southern Italy

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Introduction

The European Water Framework Directive (2000/60/EC) and Groundwater Directive (2006/118/EC) require member states to identify groundwater bodies and monitor their qualitative and quantitative status. Therefore, a comprehensive knowledge on groundwater bodies characteristics, groundwater quality and groundwater availability should be achieved for a sustainable management of water resources.

In complex hydrogeological settings and in areas characterised by widespread anthropic activities (i.e., agricultural and livestock activities) and urban settlements, such knowledge is usually represented by a huge amount of data, often non-homogeneous in terms of spatial and temporal distribution. Therefore, an appropriate and uniform data collection, storage and management is necessary. The objective of this study is to implement an interactive 3D / 4D hydrogeological geo-database for the optimization of the handling and storage of spatio-temporal data for the Volturno Plain in Campania Region (Southern Italy). An open-source WebGIS version of the geo-database is under development for data visualisation, exploration and query, and it is proposed to water managers and decision-makers for a proper and sustainable management of groundwater resources.

Materials and methods

The 3D / 4D hydrogeological geo-database is implemented for the Volturno Plain in Campania Region (Southern Italy). The Volturno Plain is a coastal plain of about 1340 km² constituted of fluvial, volcanic (i.e., pyroclastic) and marine sediments. It is surrounded by Mesozoic limestone mountains of the Southern Apennines (E), pyroclastic hills of the Phlegrean Fields (SW), adjacent plains (N and SE) and by the Thyrrenian sea (W). The Volturno River crosses the plain from NE to SW. Two main porous aquifers are present (Allocca et al. 2005; Corniello and Ducci 2014): a shallow phreatic one and a deep semi-confined (or confined) one, which are separated by a tuff layer of variable thickness.

The database includes geographical (i.e., base layers), geological and hydrogeological information. Base layers include elevation, hydrography, land cover and land use. Geological data include stratigraphies from more than 400 boreholes. Hydrogeological data include piezometric levels and more than 600 hydrochemical analyses (i.e., physico-chemical parameters, major and minor cations and anions, metals, organic compounds) from 370 wells and piezometers, spanning from 2002 to 2020. At 12 water sampling points, about 60 isotopic analyses on $\delta^{18}O$ and δD for the period 2011-2016 are available. Hydrogeological data were collected by various entities (e.g., Regional Environmental Agency) for different purposes (e.g., monitoring campaigns, remediation activities) and were provided in extremely various formats.

The first step in the realisation of the 3D / 4D hydrogeological geo-database consisted in the collection and homogenisation of the information coming from different sources. Secondly, a quality check on the data was performed to identify errors, missing values and duplicate data. Errors and missing values were flagged, whereas duplicate data were removed from the database. Then, the basic, geological and hydrogeological data were organised in tables, vectorial and raster layers in a geographic information system (GIS) environment, according to the specific information contained in each single database (i.e., borehole stratigraphies, piezometric levels, hydrochemical data). Data formats were adjusted to respect the ISO (International Organization for Standardization) and the OGC (Open Geospatial Consortium) standards to make them accessible on a WebGIS platform. Finally, the 3D / 4D hydrogeological geo-database was tested for visualisation, exploration and query and for furthered data analyses, such as: i) the identification of areas characterised by poor groundwater quality, ii) the evaluation of trends related to both groundwater quantity (piezometric levels) and quality (abundance of specific compounds), iii) the relationship between groundwater quality and geological or anthropogenic conditions.

Results and concluding remarks

The 3D / 4D hydrogeological geo-database summarises all the information collected in the Volturno Plain in the last two decades in a usable and interactive format. The exploration and interpretation of geological and hydrogeological data allow to reconstruct the geological and hydrogeological setting of the plain (Corniello and Ducci 2014; Sellerino et al. 2016), to identify and delineate the groundwater bodies, to recognise the evolution of the hydrogeological characteristics over time, and to highlight missing information in the database.

The hydrogeochemistry of the main aquifers reflects the geological characteristics of the study area, showing waters of calcium-bicarbonate type to sodium-bicarbonate type from the mountains to the seacoast, along the main groundwater flow direction. The high concentrations of As, F, Fe and Mn are strictly related to volcanic sediments and volcanic-related processes, especially in the south-eastern sector of the study area. A specific analysis of the geochemical anomalies allowed to assess the Natural Background Values of these compounds within the groundwater body (Ducci et al. 2016; Sellerino et al. 2019). The spatial and temporal distribution of the main hydrochemical compounds (i.e., Cl^- and NO_3^-), combined with land use and land cover information, highlighted that the extensive presence of agricultural and livestock activities and urban and industrial settlements caused the worsening of groundwater quality in the last 20 years (Ducci et al. 2020): a) coastal areas are affected by marine intrusion; b) several areas of the plain are affected by nitrate contamination, both in terms of high concentration levels and in increasing concentration trends.

A structured and interactive 3D / 4D hydrogeological geo-database, as for the Volturno Plain example, would be a useful support to groundwater managers and decision-makers for a sustainable management of the resource. In particular, it would help: i) exploring and querying the available data, ii) integrating new data, iii) checking the status of groundwater bodies, in terms of water quality and quantity, iv) planning groundwater quality and quantity monitoring campaigns, v) reorganising the monitoring network according to water needs and availability, as well as water quality conditions, vi) keeping the surveillance of the geogenic and anthropic sources of contamination. Lastly, the WebGIS implementation would also allow to interact with the database in a freely and friendly environment.

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