XXXVIII IAH Congress

Groundwater Quality Sustainability

Krakow, 12–17 September 2010

Extended Abstracts

Editors:
Andrzej Zuber
Jarosław Kania
Ewa Kmiecik

University
of Silesia
Press 2010

abstract id: **206**

topic: **1**
Groundwater quality sustainability

1.2
Groundwater vulnerability and quality standards

title:

Hydrostratigraphical setting and groundwater quality status in alluvial aquifers: the low Garigliano River Basin (Southern Italy), case study

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keywords: 3D model, nitrate contamination, vulnerability map, risk map

INTRODUCTION

Background

Aquifer characterization is critical to understanding groundwater flow systems, especially when the spatial variability has a significant influence on the hydrogeological structure (Ahmed, 2009). With this in mind, the present study applies a 3D lithologic model to characterize the Garigliano River plain aquifer in central-southern Italy (Fig. 1).

The Garigliano River plain (about 170 km^2) presents a complex geological pattern and geomorphological evolution which have been extensively investigated (Cosentino et al., 2006, among others). The plain holds a major aquifer, the subject of an in-depth study by Nicotera and Civita (1969).

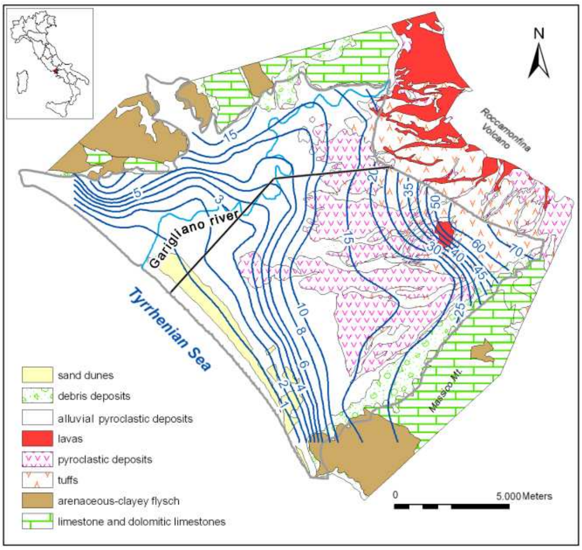

Figure 1. Hydrogeological map of the lower Garigliano river basin showing the study area (red line), the piezometric surface of the aquifer in m a.s.l. (April-May 2009; blue line) and the trace of the hydrogeological cross section of Fig. 3 (black line).

Hydrogeological setting of the study area

The Garigliano River plain is a NE-SW oriented graben filled with upper Miocene-Quaternary infralittoral, deltaic and continental clastic deposits, containing in the uppermost part volcanoclastic sediments from nearby Roccamonfina. The Roccamonfina volcanic district, located NE of the plain, developed between 630 and 53 ka, and has a maximum thickness of the volcanics of about 1000 m (Cosentino et al., 2006). The substratum to the volcanics, also dissected by NW-SE normal faults, is represented by Apenninic platform carbonates, which also crop out along the SE and NW limits of the alluvial plain. Along the SW border two sand dunes run parallel to the coastline. These sand dunes in the past created secluded ponds and coastal lagoons filled by groundwater, runoff and direct rainfall which could not reach the sea.

Stratigraphic reconstruction of the main aquifer was obtained by interpolating stratigraphic data from more than 80 boreholes. The aquifer consists (Figs. 2 and 3) of marine and alluvial deposits, often with peat levels**.** In the NE sector these deposits overlap (or are interbedded with) pyroclastic layers of the Roccamonfina complex. Depending on the stratigraphy and granulometry of the deposits, the aquifer is confined or semi-confined.

MATERIALS AND METHODS

Piezometric setting

The piezometric pattern (defined by the piezometric network consisting of more than 60 sites measured in April-May 2009) shows the groundwater flow directed toward the sea and the Garigliano river (Fig. 1). Along the slopes of the Roccamonfina volcano the piezometric gradients are in the order of 2%, while in the plain they are substantially lower (about 0.1–0.2%). At piezometric levels less than 10 m a.s.l. the hydraulic gradient increases (from 0.2 to 0.4%) due to the presence of less pervious sediments. As this impedes flow towards the sea, the water table rises above ground level creating ponds and marshes behind the coastal dunes (§1.2).

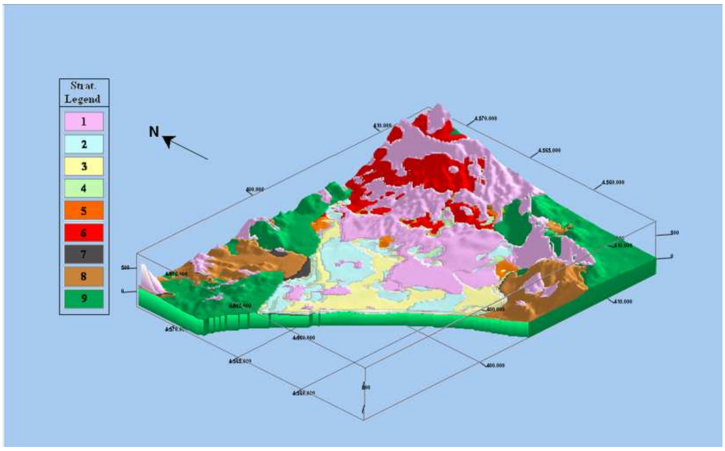

Figure 2. Hydrostratigraphic 3D model of the lower Garigliano river basin: 1) pyroclastic deposits, 2) deposits of fine grain size, 3) deposits of medium grain size 4) deposits of medium-coarse grain size, 5) tuffs, 6) lavas; 7) fluvial-palustrine plio-quaternary unit (SR) 8) arenaceous-marly-clayey torbiditic unit (AM), 9) limestone.

Hydrochemistry

Hydrochemical sampling was conducted in the same wells used for the the piezometric measurements. NO_3 is the most pervasive contaminant, widely exceeding the drinking-water quality guidelines of 50 mg/L (Fig. 4). Close to the Garigliano river, lower nitrate content is related to reducing conditions, testified by low values of SO_4 and high content in Fe and Mn. In the same area there are high fluoride contents (>1.5 mg/L).

3D lithostratigraphic model

3D lithostratigraphic reconstruction of Garigliano river basin model was carried out by using more than 80 borehole stratigraphies. The boreholes, with depth varying between 10 and 318 m, were distributed with greater concentration at the bottom of the Roccamonfina volcano and Mt. Massico; there was a lower borehole density in the surrounding areas. It was necessary to select boreholes on the basis of their reliability and utility. The boreholes were integrated with geophysical information concerning the thickness of the upper aquifer and the depth of the substrate (Nicotera and Civita, 1969).

Stratigraphic succession is very complex and heterogeneous. Therefore, a critical reinterpretation was necessary, with a view to differentiating particle size of deposits rather than their origin and nature. On the basis of these considerations, the conceptual model structure provides:

- the upper aquifer: it has a thickness of 60 m and is the object of the model reconstruction;
- fluvial-palustrine plio-quaternary unit (SR): formed by clay with intercalations of gravel, sand and conglomerate, with a thickness of several hundred meters. The unit, almost impermeable, represents the base of the upper aquifer;
- arenaceous-marly-clayey torbiditic unit (AM): it is not always present. The unit is impervious and in some sectors forms the base of the upper aquifer;
- limestone platform (C): it is always present and represents the bottom of the model.

The software used to create the lithostratigraphic model was Rockworks 2006 (www.rockware.com), which allows a 3D model to be constructed with a detailed geostatistics analysis. The data were organized in a database, imported within Rockworks 2006 and developed by interpolation algorithms, reconstructing a grid model (Fig. 2). The algorithm chosen for modelling is inverse distance because, compared with other methods (e.g. Kriging), it made it possible to obtain hydrogeological cross sections very similar to hand-drawn sections (Fig. 3).

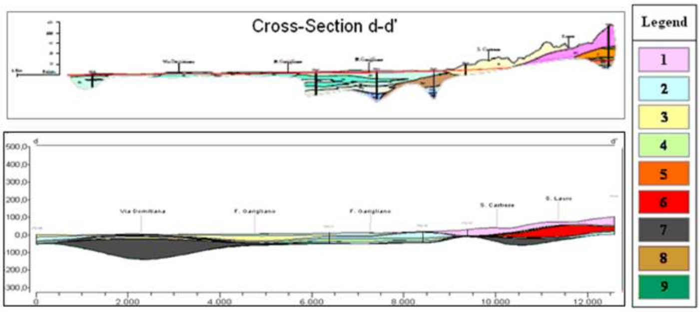

Figure 3. Hydrogeological cross sections constructed a) by hand drafting; b) by the 3D model (inverse distance interpolation): 1) pyroclastic deposits, 2) deposits of fine grain size, 3) deposits of medium grain size 4) deposits of medium-coarse grain size, 5) tuffs, 6) lavas; 7) fluvial-palustrine plio-quaternary unit (SR); 8) arenaceous-marly-clayey unit (AM), 9) limestone. Trace is in Fig. 1.

Potential risk of nitrate contamination

With the purpose of verifying the source of groundwater nitrate contamination the pollution vulnerability map of the aquifer (§ 2.4.1) and the agricultural nitrate hazard map (§ 2.4.2) were drawn up.

Assessment of aquifer contamination vulnerability

The last twenty years have seen the widespread use of point count system methods in evaluating aquifer vulnerability to pollution, such as DRASTIC (Aller et al*.,* 1987) and SINTACS (Civita and De Maio, 2000), based on the most commonly found Italian hydrogeologic settings. Both evaluate vertical vulnerability using the same seven parameters: depth to groundwater (S), recharge action (I), attenuation capacity of the vadose zone (N), attenuation capacity of the soil (T), aquifer media (A), hydraulic conductivity (C) and topographic slope (S). In the Garigliano River Plain, the layers of depth to groundwater, attenuation capacity of the vadose zone and hydrogeological characteristics of the aquifer media were evaluated not for the single boreholes and piezometers, but by the 3D model.

Agricultural nitrate hazard index: IPNOA

Significant experimentation in the risk evaluation of nitrate contamination has been reported worldwide, and some Italian methods have also been applied (Capri et al., 2009; Corniello et al., 2007). In 2002, the agricultural nitrate hazard index (IPNOA — Padovani and Trevisan, 2002) was developed to assess the potential hazard of groundwater contamination by nitrates from agricultural sources at regional and provincial scale, using a parametric approach. IPNOA integrates two categories of parameters: the hazard factors, which represent all farming practices that cause, or might cause, an impact on groundwater in terms of nitrate, and the control factors, which modify the hazard factors according to the site characteristics and agricultural practices. All factors are inter-related after being classified, assigning them an index that characterises the nitrogen load or incidence of the factors involved in nitrate leaching. The potential hazard index (HI) for nitrate contamination from agricultural sources is evaluated by multiplying the different hazard classes (HF) by the control classes (CF). The IPNOA hazard map is then obtained from the HI by classifying the resulting values. Finally, intrinsic vulnerability (evaluated by SINTACS) was linked to IPNOA to assess the potential risk of groundwater contamination.

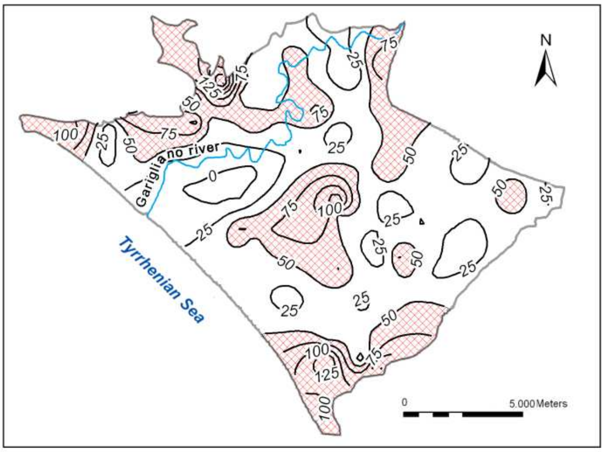

Figure 4. NO_3 distribution in groundwater in mg/L (April-May2009); highlighted areas with nitrate values exceeding 50 mg/L.

In the Garigliano River Plain, in order to assess the nitrate contamination hazard using the IPNOA method, the data collected are the following:

- type of animal husbandry;
- climatic and hydrologic factors;
- agricultural activities (obtained from the "CORINE Land Cover 2000 level III" APAT, 2004).

All the data were stored in a geographic database and managed by GIS. The Potential Risk Map (R) was obtained by multiplying in terms of classes, through the GIS, hazard and vulnerability, and then classifying the obtained values into risk classes (see Corniello et al., 2007 and Capri et al., 2009, for the explanation of the scores and crossings).

RESULTS AND DISCUSSION

The Potential Agricultural Nitrate Contamination Risk Map (Fig. 5) shows a prevalent high-very high risk In the north-western and south-eastern sectors of the plain the map reflects the aquifer Vulnerability map (here the aquifer is unconfined, with low depth and high permeability), more than the IPNOA map (prevalent classes: low and very low). In the central sector of the plain the IPNOA values are higher, which suggests for sure that the source of groundwater nitrate content originates in agriculture.

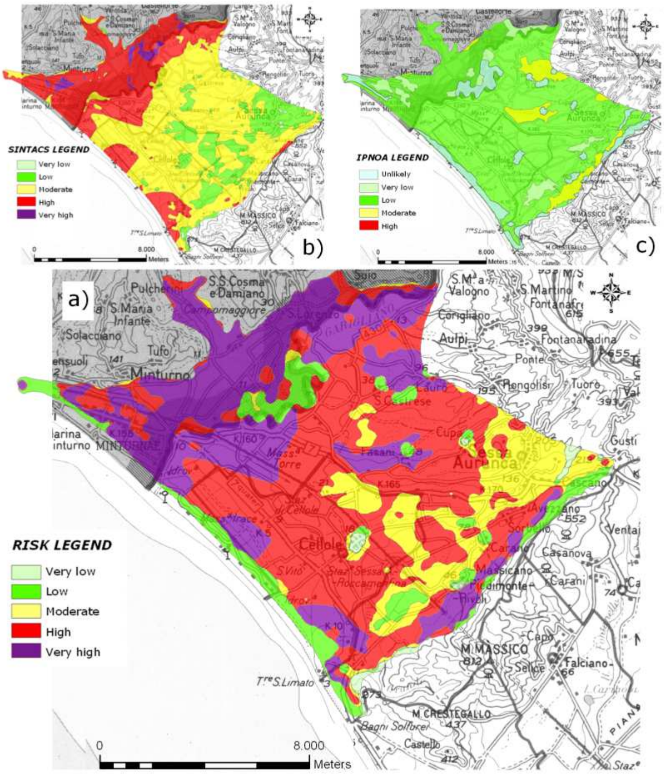

Figure 5. Potential Agricultural Nitrate Contamination Risk (a) derived from the Vulnerability (SINTACS) map (b) and the IPNOA (Agricultural Nitrate Hazard Index) map (c).

CONCLUSION

The risk map presents a good spatial correlation with the nitrate content of the aquifer (Fig. 5), highlighting the sectors most affected by nitrates and supporting the identification of the

source of nitrate contamination. This suggests that the source of the groundwater nitrate is chiefly related to intensive cropping or livestock. However, the authors recommend complementary isotope analysis (δ15N and δ18O), that are now being applied, to verify the hypothesis of the agricultural origin of nitrates and to test the validity of the methods.

This paper highlights the great advantage of using a 3D model of the subsoil of a alluvial plain (Garigliano basin) and the substantial results that can be achieved. Indeed, the author would stress that the originality of this paper lies not in the application of the method to assess nitrate contamination risk, but rather in its application directly from the 3D lithostratigraphic model.

ACKNOWLEDGEMENTS

The study was funded by the research project of national interest (PRIN) “Nitrate Contamination in Groundwater" launched in 2007 (National Project Coordinator, Prof. Alfonso Corniello).

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2-vol. set + CD
ISSN 0208-6336
ISBN 978-83-226-1979-0