The experience of southern Apulia (Italy) coastal karst aquifer: indications for the management

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Abstract

Prediction of the salt water intrusion in coastal karst aquifers is a key issue in several regions of the world. Southern Apulia (Italy) hosts a huge aquifer of karstified limestones, that provides 90% of the water demand of this sub-region. The exploitation of the aquifer currently exceeds its natural recharge capacity. The groundwater in wide coastal areas of the sub-region underwent an increase of the salt content. Salinization of the groundwater in such an aquifer cannot be predicted by means of conventional models. An effective model for a quantitative prediction of the fluid flow and transport of solute in the aquifer, aimed at a better understanding of the phenomenon, is therefore needed. This model should account for the discrete nature of the aquifer. In this paper, several situations are reported in order to describe the importance of the inhomogeneities (fracture systems, fault zones, karst conduit, preferential flow levels) in the salinization process of the southern Apulia karst aquifer.

1 Introduction

Southern Apulia (Salento sub-region) is a typical example of karst coastal aquifer. Within the last decades, the total withdrawals have largely exceeded the natural recharge capacity of the aquifer. As a consequence the aquifer has undergone a strong salinization. The prediction of the response of the aquifer to planned exploitations has been generally carried out by means of porous-like medium models or semi-empirical laws, leading sometimes to erroneous evaluations. To help the authorities in the management of the water resource, new tools for the prediction are required.

2 Hydrogeological outline of southern Apulia

Salento is a peninsula of the south-eastern part of Italy. Its basement consists of limestones and limestone-dolostones of Cretaceous age (Fig. 1). These rocks are poorly
to highly permeable, due to fracturation and karstification. In the Upper Cretaceous, the basement was fragmented into uplifted and lowered blocks, later dislocated by high dip faults. The basement crops out mainly in the relief areas, while several Tertiary and Quaternary calcarenitic units form the inland plateaux. The latter units are generally poorly or moderately permeable and host small quantities of groundwater. Quaternary clays locally mark the top of the stratigraphy. The Cretaceous carbonate rocks contain a huge mass of groundwater floating over the salt water of continental intrusion; the passage occurs through a zone of transition which is characterized by an gradual increase in saline content with depth. The deep aquifer is the only drinking water resource available in the Salento Peninsula. The shallow aquifers, used only for irrigation, lie in the Tertiary and Quaternary units and may be locally connected with the main aquifer (Tadolini et al. [1]).

The Salento hydrogeological system discharges into the Adriatic and Ionian sea through numerous subaerial or submarine springs. The fresh groundwater-saline ground-
water relationship is greatly affected by the peculiar discontinuous nature of the aquifer (Delle Rose et al. [2]). Even if some levels of horizontal preferential flow have been identified (Tadolini & Tulipano [3]), the discontinuous nature of the aquifer cannot be neglected at any scale. The groundwater circulation is strongly controlled by the presence of karst conduits, fracture and fault systems, and poorly permeable units. The inhomogeneity of the hydrogeological system is further evidenced by the replenishment of the aquifer. The rain falling on the Cretaceous limestone reaches the aquifer within weeks, while, in absence of karst systems, the water falling on the Tertiary and Quaternary deposits may employ tens of years to percolate into the deep aquifer (Delle Rose [4]). As a result of the above mentioned difficulties, sectors characterized by homogeneous hydrogeological features have not been identified in the Salento peninsula.

The piezometric heads are usually few meters above the sea level, and the salt water is found at shallow depths (Tadolini & Tulipano [5]). This circumstance strongly reduces the availability of the resource, especially in the coastal zones. In fact, there is a big chance to withdraw water of high saline content if the exploitation is not controlled.

3 Groundwater salinization

About 90% of the water demand of the Salento Peninsula is provided by groundwater. It is estimated that 200 millions of cubic meters per year can be provided by the main aquifer, that is yearly replenished by 950 million of cubic meters (Cotecchia et al. [6]). Actually, the need of water for civil purposes is 90 millions $m^3/\text{year}$, produced by the main aquifer with about 120 wells. There is no official value of the water demand for irrigation and industrial use, but it can be estimated in the same order of the water demand for civil use. A critical situation for the aquifer has therefore to be stated. Increasing withdrawal in fact induced a moderate to strong salinization of the water exploited from the wells along the coast (Tulipano & Fidelibus [7]). In order to undertake safeguard and recovery actions, a Regional Water Reclamation Plan (RWRP) was defined in 1984. The RWRP recommended to avoid exploitation within the coastal zones and delimited the safeguard areas for the protection of the water resource. In spite of these recommendations, the exploitation went on uncontrolled, and today groundwater with low saline content (less than 0, 5 g/l) is barely found in the Salento Peninsula.

Given the lack of detailed studies on the local hydrogeological features of the aquifer, the prediction of the evolution of the salinization is rather difficult; this results in a very limited capacity of the authorities to provide a good management. The water demand is increasing, especially for irrigation and civil uses. Programs of highly tourism development, which is considered the major economical activity, contribute to increase the demand. For example, the regional authorities have recently programmed 25 new golf courses. The maintenance of these courses will require about 20 millions $m^3/\text{year}$ of water (European Golf Association [8]), that is nearly a quarter of the actual water demand for civil use of Salento sub-region.

4 Examples of wrong predictions

Four examples of wrong predictions are provided in the following, in order to illustrate the difficulties that generally the authorities involved in the groundwater resource management have to face.
Sustainable Planning and Development

Figure 2: a) Geological section between Lecce and Cesine, b) hydrogeological sketch, c) salinization phenomena.

4.1 Cesine

The Cretaceous basement, sectioned by subvertical faults with throws of tens of meters, contains only salt waters in pressure (Fig. 2). Post-Cretaceous units contain a shallow aquifer utilized for the irrigation. A golf course is the more water demanding activity in the zone, but this has not been considered by the authorities. The shallow aquifer currently is over exploited, while inland a significant increase of salinity has been recently measured in the deep aquifer (Daurà et al. [9]).

Exploitation of the shallow aquifer may produce a strong perturbation in the main aquifer, with the upcoming of the salt water, due to the existence of high conductive bands (fault zones). In this case, a model for prediction of the aquifer response should account for the relations existing between the two aquifers and simulate the role played by the faults as preferential flow paths.

4.2 City of Lecce

The deep groundwater is in pressure and confined several tens of meters below the sea level by impermeable Oligocene unit. The Miocene unit contains few lenses of fresh water. The local authorities released the permission to exploit the main aquifer for maintenance of the city gardens, on the base of economic and social reasons, but in spite of the recommendations of the RWRP (Fig. 2). Moreover, several unauthorized wells insist on the area. Samples of groundwater have been recently taken and a saline content of 4.5 g/l has been measured (Delle Rose et al. [10]). This indicates that the water captured by the wells is salinized. In fact the bottom of such wells is close to the transitional zone where the rock is characterized by low values of vertical conductivity, while the horizontal conductivity is high. The pressure gradient induced by pumping moves the water laterally. Consistent reductions in the thickness of the fresh groundwater lens has actually been already measured in adjacent areas in wells of the Regional Agency Irrigation.

4.3 S. Cataldo

The deep groundwater is generally maintained in pressure by Miocene deposits that are impermeable when not interested by karst conduits (Tadolini et al. [1]). A shallow
coastal aquifer is discontinuously contained in the more recent units (Fig. 3). A project of a golf course has recently been positively evaluated from the town authorities with little attention on the risk of salinization. They have used for the prediction the Ghyben-Herzberg equation which is clearly inadequate, due to strong anisotropy of the aquifer.

On the basis of the water demand of the golf course, consisting of 20 l/s, upconing of the brackish water at the base of the deep aquifer is highly probable, with the consequent salinization of the wells. In addition the brackish water at the base of the shallow aquifer could contaminate the main aquifer.

4.4 Serra Cicora

The project for the construction of a port involves the excavation of a considerable portion of the coastal plain of Serra Cicora (Fig. 4). The seawater will be put in contact with a high permeable zone characterized by several faults and karst cavities. It is predictable a modification of the groundwater circulation, with the reduction of the thickness of the fresh groundwater in adjacent areas, and advancement of the sea intrusion. These consequences could not be adequately considered by the authorities. A heavy perturbation, whose effect can be compared to those provided by a large exploitation in a zone where the RWRF strongly prohibits any withdrawal, could therefore be produced.

5 Indications for the management

Local authorities do not perform generally effective predictions of the impact of exploitation on groundwater quality: the models generally used neglect the discrete nature of the aquifer, and do not consider the role played by karst caves, fault systems and variations in permeability of the stratigraphic units. The use of the Ghyben-Herzberg equation, in particular, may lead to erroneous evaluations, especially in a setting such
as the karst of Salento, where: i) the hydraulic head is only few meters from the average sea level and ii) the errors related to measurements of the water table may be in the same order of magnitude of the hydraulic head. With these limitations, adoption of the Ghyben-Herzberg equation could result in authorizing exploitation or pumping deviating from the RWRP.

Effective prescriptions are necessary for the water resources management, but the current laws are often inapplicable. As an example, a regional law already establishes that the concession to exploitation can be revoked in case of salinity increase. Even though new monitoring parameters for the control of the salinization have been recently proposed (the unbalance index by Tulipano & Fidelibus [11]), the weight of an individual well on the saline contamination process is hard to be estimated without performing consistent simulations with an effective model.

For a correct management, new laws imposing thorough studies on the real groundwater potentiality are mandatory. Eventually, the laws should entail the advice of authority also for those projects which do not concern directly the use of the groundwater, but could modify the state of the aquifer. In our opinion, adoption of new tools for the prediction of the likely scenarios are mandatory for the groundwater management in Southern Apulia. It is therefore necessary to establish an operational regional plan consisting of: 1) the definition of a model which accounts for the discrete and anisotropic features of the aquifer; 2) the selection of monitoring wells, in order to follow the evolution of the salinization and to validate the model on the basis of real data; 3) the evaluation of some likely scenarios for management of the groundwater resources.

6 Basics of the model

Assessment of the sea water intrusion in an aquifer is generally based on a physical-mathematical model for the advective/dispersive solute transport (Henry [12]), consisting of the following steps: choice of a conceptual reference model; definition of the representative equations of the phenomenon; direct measurement of some physical quantities; determination of the parameters under discussion; validation and refinement of the model; prediction according to likely scenarios.

The problem of the transport of solute in a fractured and karstified medium (Huyakorn
Figure 5: Guideline for the regional plan of groundwater salinization management.
et al. [13]) can be faced through the adoption of different conceptual models, such as the continuous equivalent model, the discrete model, and the double porosity model. In the continuous equivalent model the fractured mass is considered equivalent to a continuous porous medium. In the discrete model only the fractures are modelled, and the equations can be derived for the single fracture. The double porosity model considers the porous matrix and the network of the discontinuities as two separate media hydraulically coupled and both continuous.

In a karst aquifer, an effective model may be an equivalent medium, together with several distinct bands resembling karst conduits, large fractures and faults (Fig. 5).

The equivalence is obtained linking the hydraulic conductivity of the fictitious porous medium and the dispersion tensor with the hydraulic and geometric features of the dominant system of fractures and conduits (Bear [14], Long et al. [15]). Estimation of the parameters of this model may be rather difficult especially when dealing with the distinct fractures.

Nevertheless, given the importance that even one single preferential flow level or high conductive band might have in controlling flow circulation and salt water transport, sensitivity analysis are recommended in order to assign plausible values to these parameters. The geometry and the geological features of these elements can significantly modify the results.

7 Concluding remark

The actions for management of the salinization of karst aquifers, which is a key issue in several regions of the world, can only stem from a detailed analysis of the local hydrogeological setting.

A plausible physical-mathematical model based on the above mentioned features to correctly evaluate the salinization processes may be defined; this model could also be used to assess the sustainable amount of groundwater resource to exploit.

As regards the specific groundwater management of the coastal karst aquifer in Southern Apulia, due to the present state of knowledge, and the level of available tools, the authorities should pay greater attention to the negative impact of future pumping projects.

Acknowledgments: The authors would like to thank the Regional Agency Irrigation (Regione Puglia) for having provided part of the data about water salinity.

References


