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Seawater intrusion and groundwater quality in the Southern Italy region of Apulia: a multi-method approach to protection

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SEAWATER INTRUSION AND GROUNDWATER QUALITY IN THE SOUTHERN ITALY REGION OF APULIA: A MULTI-METHOD APPROACH TO PROTECTION

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ABSTRACT

Remarkably fast socio-economic development over the past few decades stressed the Region of Apulia's hydrogeology by originating different hazard sources. Massive groundwater withdrawal increased and aquifers were also increasingly bound to be a sort of ultimate receptacle for domestic and industrial wastewaters. The entire region underwent twofold human-origin pollution caused by saline seawater and chemical-physical intrusion

The importance of impaired natural resources and situation severity called for an approach based on all scientific knowledge available, supplemented by up-to-date investigations on groundwater. The main objective was to identify quality trends, availability degradation and groundwater resource risks, by using different GIS integrated methodologies and developing management tools, the latter to be simple, quick, affordable and as low cost as possible. The proposed approach was based on groundwater vulnerability assessment and use of an automatic hydrogeology monitoring network, the analysis of rainfall, air temperature, river flow yield time series and, more importantly, piezometric level checks to quantify groundwater availability changes, salinity trend analysis to assess changing seawater intrusion effects, groundwater quality schematic mapping with available chemical-physical laboratory data and multi-parameter logging for fast groundwater quality classification. Each tool used is summarised with the main results of applications to Apulia's aquifers.

Key words: groundwater resources, degradation risk, seawater intrusion, pollution, monitoring methods.

INTRODUCTION

Apulia is the south eastern Region of Italy (Fig. 1); it features extremely scarce surface water, groundwater close to the surface giving in fact been the main water supply source in the past for towns, particularly in the Murgia area hinterland. Despite massive water import, Apulia's groundwater now satisfies over 20% of local drinking water demand. Groundwater is the also the only resource available for use in vast areas of the region, as an effect of stream flow incidence, due to the environment's widespread karstic nature. Groundwater thus is the region's main water source.

Apulia's aquifers are Mesozoic rocks outcropping in the Gargano Promontory, hereinafter refereed to as the *Gargano*, in the north, in the low Murge Plateau (*Murgia*) in the centre and Salento Peninsula (*Salento*) in the south (Cotecchia et al. 2004). Apart from the Tavoliere, the remaining hydrogeological structures show some common features (Cotecchia & Magri, 1966; Ippolito et al., 1958; Grassi, 1983; Maggiore & Pagliarulo, 2004). They are large and deep carbonate aquifers, mainly consisting of limestone and dolomite rocks. Carbonate rocks are affected by karstic and fracturing, which also occur well below sea level, whereas intruded seawater underlies fresh groundwater due to different density. Confined groundwater is more widespread in the Gargano and Murgia than the Salento hinterland; groundwater is phreatic along a narrow coastline strip surrounding the region. When the Salento and Gargano are schematized as quadrilaterals, the sea along three sides bound them. The Tavoliere hydrogeological structure features three aquifer types. Starting from the top, the first is a large shallow porous Pleistocene-Holocene aquifer within a less than sixty meters deep conglomerate sandy-silty sequence, with a clayey impermeable bottom. It is deep enough to allow seawater intrusion only close to the coast. Groundwater is phreatic inland and upward, but confined in the remaining aquifer part. The second is a group of NW-SE oblong aquifers within the sandy layers of the deep sequence of Plio-Pleistocene clays, marly clays, sandstones and sands underlying the shallow aquifer and overlying the carbonate platform. The deepest is an aquifer within the sunken carbonate platform, hundreds of meters below ground surface in continuity with the Gargano and Murgia carbonate rocks.

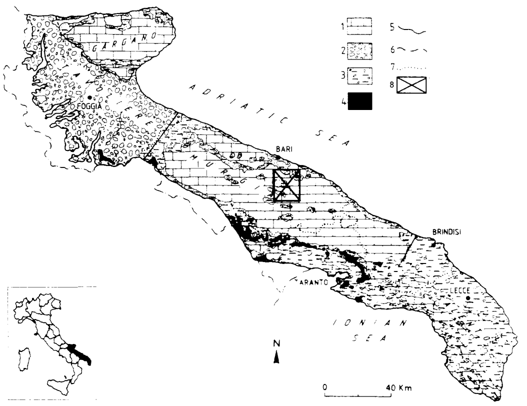

Fig. 1: Apulia's hydrogeology. 1) Carbonate rock outcrops in the Gargano, Murgia and Salento structures; 2) Tavoliere structure, shallow mainly conglomerate and sand aquifer; 3) shallow aquifers and permeable lithotypes, calcarenites, clayey sands, sands, gravel or conglomerates; 4) low permeable lithotypes, blue marly clays; 5) hydrogeology boundary, dashed where uncertain; 6) regional boundary; 7) provincial boundary; 8) Murgia experimental area.

Seawater intrusion-induced salt contamination of Apulia's groundwater is a well-known and thoroughly investigated phenomenon (Cotecchia, 1977; Grassi & Tadolini, 1996). A strong connection between salt contamination increase and t piezometric level lowering attributable to groundwater overdraft and/or natural groundwater recharge decrease, has been recognised today (Polemio & Limoni, 2001,.Polemio et al., 2004). Aquifers have been considered a sort of ultimate receptacle for domestic and industrial wastewaters. The quantity of adequate quality groundwater is decreasing and chemical-physical and biological pollution is gaining importance, mainly due to widespread agricultural origin pollution or phenomena around urbanized areas (Tulipano & Fidelibus, 1993; Polemio 2000). Quality degradation of many pollution sources is noted as being due to outflow from coastline springs above and below sea level.
The importance of impaired natural resources and the severe situation require a strict approach based on all scientific knowledge available supplemented by up-to-date investigations of groundwater quality and availability changes. A multi-methodological approach is proposed to achieve sustainable exploitation of important natural resources such as groundwater. This approach should be based on procedures and as simple as possible technologies to be used not only by all public institutions, associations and professionals but also by as wide as possible number of users and citizens are proposed. The main objective is to identify quality and availability degradation trends and groundwater resource risks by using different GIS-integrated methodologies and developing management tools. These tools should to be simple, quick, affordable and as low cost as possible. The approach proposed is based on: groundwater vulnerability assessment; the use of automatic hydrogeological monitoring network; the analysis of rainfall, air temperature, river flow yield time series and, most importantly, piezometric level checks to quantify groundwater availability changes, salinity trend analysis to evaluate seawater intrusion effect variations, groundwater quality schematic mapping with available chemical-physical laboratory data and multi-parameter logging for fast groundwater quality classification. Each tool will be shortly summarised together with the main results of practical applications.

PROTECTION TOOLS

Groundwater Vulnerability Assessment

The location of any settlement that is a potential source of pollution must be planned based on detailed hydrogeological data and analyses, reported in a clear and straightforward form for use by decision-makers, where wide and vulnerable aquifers are located. The intrinsic aquifer vulnerability map is an effective information tool for this planning activity. These maps quantitatively represent aquifer sensitivity to receiving and transporting pollutants that may degrade groundwater quality (Civita & De Maio, 1997).

Intrinsic aquifer vulnerability was evaluated with the SINTACS method (Civita & De Maio, 1997), an approach that divides the landscape into a grid with regularly spaced cells and assigns scores to selected variables for each cell. The variables used in this method were as follows: depth to water S, actual infiltration or net recharge I, unsaturated zone effect N, soil media effect T, aquifer media features A, hydraulic conductivity C, ground surface slope S. A weight factor was associated to each variable according to its contribution to vulnerability. These weights were defined as functions of the local hydrogeological setting based on many experimental assessments of Italian test sites. The intrinsic vulnerability index for each cell was computed by using the sum of the product of the scores and the weight of each variable.

Some experimental applications show procedure efficiency and clarify the criteria used (Polemio & Ricchetti, 2001). All data are converted into a digital format for implementation in a GIS Geographic Information System for vulnerability analysis, in the case of the Murgia experimental area (Fig. 1). Analysis was accomplished based on a 10 m spatial resolution raster grid (Polemio & Ricchetti, 2001). The data and analysis processes developed to produce the intrinsic vulnerability map are schematically described in the flow chart shown in Figure 2. A semi-variogram for each variable is obtained from point data to define the interpolation function. Then several 10 m resolution raster maps can be computed for the different variables by using kriging. The intrinsic vulnerability map shows the presence of four vulnerability index classes in the study area from 29 to 75% (100% is equivalent to maximum vulnerability); most of the area was classified as highly vulnerable (index over 50%).

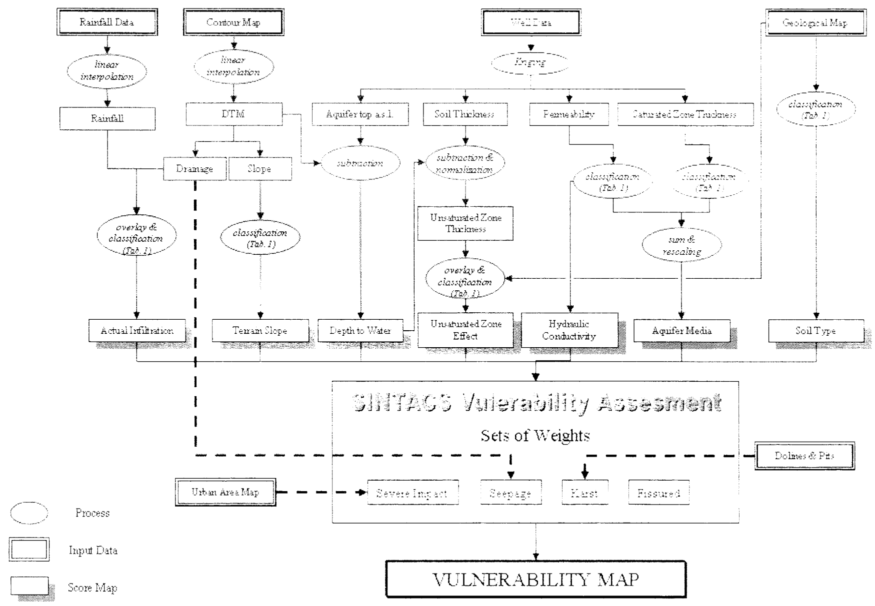

Fig. 2: Vulnerability analysis process diagram (Polemio & Ricchetti, 2001).

Automatic Hydrogeological Monitoring Network

All groundwater resource management and safeguarding activity was based on hydrogeological survey. A system was devised in the case of Apulia's groundwater, accessing the real-time electronic measurements required for proper groundwater supply planning, scheduling and management. Apulia's monitoring network includes: piezometric wells, salt-observation wells for measuring fresh-saline water equilibrium and quality control wells for assessing human-related pollution (Cotecchia & Polemio, 1999). Some 120 stations are currently used (Fig. 3) but plans are to increase the number of wells to 350, also including main coastal springs (Tedeschi, 2004).
Salt observation wells are located along a coastal strip and are deep enough to reach the transition zone between the surface fresh and underlying saline water and are equipped with multiple probes to measure piezometric level, temperature and specific electrical conductivity. Quality control wells are located where

withdrawal rate and groundwater contamination hazards are higher; the probes measure the piezometric level, pH, temperature, specific electrical conductivity and Eh. All data are used by a GIS for easy planning and management. It basically stores historical data gathered by other sources over the years as well as by the monitoring network. It manages information on soil cover type, hydrogeological features and groundwater quality. It then plots simulations against time and highlights hazards and emergencies.

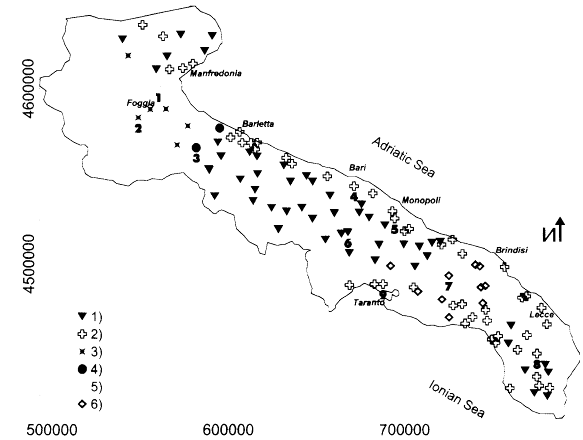

Fig. 3: Well map of monitoring network, logging wells and log types. Log type: 1) A, Inner or recharge area, 2) B, coastal strip or seawater intrusion area; 3) C, shallow Tavoliere aquifer; 4) D transition zone between the Murgia and the Tavoliere; 5) E, transition zone between the Tavoliere and the Gargano; 6) F, transition zone between the Murgia and the Salento.

Time Series Analysis and Groundwater Availability

The availability degradation risk could feature time series analysis of piezometric data, air temperature, well withdrawals, rainfall and river flow yield data, all currently widely available. This approach enable classifying water cycle, hydrology regimes and their variations in time as well. Trend, self-correlation and cross-correlation analyses and forecasting methods should be applied to all variables, as they are quite simple and can be extremely useful to identify available degradation hazards. Simple statistical GIS tools could thus be used to define spatial variation-based groundwater availability changes.
The analysis of Southern Italian monthly rainfall and temperature data time series from 1921 to 2001 highlights a vast decreasing annual rainfall trend at the end of the study period, equivalent: to a drop of 10% of Apulia's mean annual rainfall, with a mean value as low as 644 mm (Polemio & Casarano, 2004). The decrease is higher during the winter, Apulia's aquifer recharge season. The combined effect of annual rainfall and temperature trends and their regime variation is quite dramatic in terms of net rainfall, the trend decrease for which is evaluated as equivalent to 30% of mean annual net rainfall.

Data of 63 wells or piezometric gauges were considered (Polemio et al., 2004) (Table 1).

Table 1: Piezometric trends and data availability for each hydrogeological structure HS. MW) number of monitoring wells, AC) minimum trend (angular coefficient as m/year), MPST) more probable spatial trend at 2002

HS	MW	Data		AC	MPST (2002)
		from	to		
Tavoliere	12	1929	2002	-0,408	Decrease
Gargano	4	1975	1978	-0,036	Low decrease?
Murgia	30	1965	2003	-0,240	High decrease
Salento	17	1965	2003	-0,120	Decrease

Self-correlation piezometric coefficients show a progressively declining trend, starting from values slightly lower than 1. Apulia's groundwater is consequently subject to a consistent memory effect, that is to say the piezometric values recorded in any given month are strongly dependent on previous month values, the link being significant, decreasing the time lag increases, usually not less than a three month time span. This is a typical feature of groundwater of great importance during droughts. Apulia's aquifers show very strong and long-lasting memory effects, as further proof of its excellent hydrogeological potential. The links between piezometric and climatic variables are cross-correlated to a significant degree for a time lag of 1-4 months (Polemio et al., 2004). Rainfall effects are perceptible up to a maximum of 2/3 months, while the best correlation with temperature is felt with a time lag of 4 months, a situation typical of this semiarid area. The results of self- and cross-correlation analyses justify implementing simple and quite reliable piezometric forecasting models such as ARMA, ARIMA and multivariate modelling. The calculated piezometric trend is downward, as there is a widespread tendency, albeit in some cases very slow, towards a piezometric drop. The lowest piezometric decrements occur in the Salento area, with an Angular Coefficient AC of over -0.001 m/month. Minimum AC values occur in the Murgia and Tavoliere, where the lowest values are -0.240 and -0.408 m/year respectively. AC always approaches zero closer to the coastal areas as would be expected. Based on data available and irregular measurements made in 2002/2003, the most likely piezometric trend, ending in the second half of 2002 appears very serious indeed over the entire area (Table 1). Trend and cross-correlation analyses show that the steady and generalized piezometric drop is not entirely due to a rainfall: drop but that resource over-exploitation plays a very clear role in this process. The widespread and long-lasting piezometric decreasing trend implies water resource shortages; effects on seawater intrusion favoured by piezometric decreases and ensuing fresh groundwater salt pollution emphasize this dramatic degradation.

Salinity Trend Analysis and Seawater Intrusion

Two tools based on the use of data collected by private and public bodies are proposed assess seawater intrusion evolution and the ensuing saline contamination in a simple and reliable way.

The former is simple spatial analysis that can be applied if a threshold salinity value between pure fresh and seawater-contaminated groundwater is set for local hydrogeology.
The threshold is equivalent to about 1 to 0.5 g/l for Apulia's karstic and coastal aquifers. Using data measured by hundreds of wells, the threshold contour line can be measured with geo-statistic methods and its changes over the time can be underscored with GIS applications. Spatial evolution over the time was measured using 1981, 1989 and 1997 data (Fig. 4). Three area types were distinguishable. The first was where salinity is always below the threshold. It is an inland type; a vast part of inland Murgia and a restricted strip in the middle of the Salento peninsula were not been polluted so far. The second was linked to the areas where salinity is always greater than the threshold and groundwater saline pollution was found to be a long-standing phenomenon. This type can be identified in large areas along the Adriatic and Ionian shoreline. The third is an intermediate or transitory type; in each point of these areas, salinity is a sensible function of water cycle changes and, mostly, of human capacity to manage groundwater resources. The reference contour line receded gradually in the1981 to 1989 period, for instance, from the coast and groundwater in these areas too, was an effect of a great drought period and consequent greater groundwater over-exploitation. The phenomenon is either stopped or reversed, as in the case of some Murgia and Salento areas, as a consequence of rainy years.
The former tool assumes the existence of very high linear correlation between chlorine concentration and salinity for coastal aquifer groundwater. It should also be remembered that private individuals for several reasons caused chlorine concentration and law in many countries should regulate daily water use, when groundwater is supplied for drinking purpose.
The existence of this good correlation in Apulia's coastal aquifer is testified by 500 analysed groundwater samples, for which the linear correlation coefficient is equivalent to 0.98 (Polemio & Limoni, 2001). The increasing saline pollution of Murgia and Salento groundwater is confirmed by changes to chlorine ion concentration over 30 years in 18 wells. Data show that increased groundwater saline pollution is closely related to overexploitation. No significant concentration increase was reported in most wells before 1980. The phenomenon became apparent in the late 80s after some dry years leading to reduced recharge of aquifers and increased groundwater withdrawal. A clear increasing trend is observed in Salento, where the straight regression line angular coefficient is from 1.7 to 5.1-mg/L year.

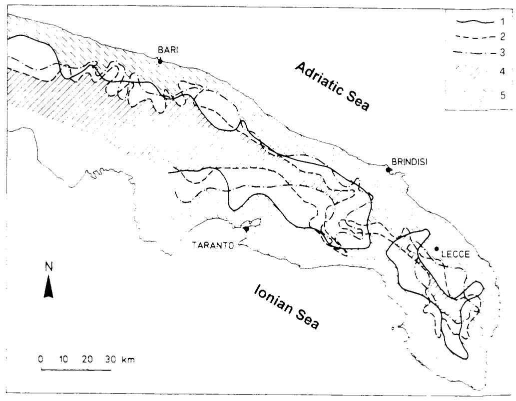

Fig. 4: Time modifications of 0.5 salt contour line g/l. Contour line of: 1) 1997, 2) 1989, and 3) 1981; 4) salinity always: less than 0.5 g/l, 5) greater than 0.5 g/l.

Laboratory Data and Schematic Quality Mapping

Schematic mapping groundwater quality with commonly available chemical-physical data enables defining groundwater quality and its variations starting from the natural features of groundwater as typical of each aquifer system. It is based on using ordinary determined parameter laboratory analysis data due, as required by health or drinking water laws, and from which to extrapolate historical groundwater resource features in time and space. The parameters should be chosen in function of availability in locally available historical data sources, simple laboratory assessment and their importance in connection to the different hydrogeological characteristics of the aquifer considered and potential water source pollution.

In the case of Apulia's groundwater, the proposal is to use concentration Ci of a group of chemical-physical parameters, total hardness, TDS, sulphates and chlorine, and a group of undesirable substances, nitrates, ammonium, iron and total coliforms. All these parameters play ab important role in identifying general water quality conditions (Civita et al., 1993; Polemio & Limoni, 1999). The former group of parameters should be strongly influenced firstly by natural hydrogeology conditions and secondly by anthropogenic phenomena. The latter group is typical of human pollution. The classification uses European Council Directive 80/778/EEC on the quality of water intended for human consumption, which defines Guide Level and Maximum Admissible Concentration MAC for each parameter, and it identifies 3 decreasing quality levels for each group, from A to C: A if $Ci<GL$ for each parameter, B if $Ci>GL$ at least for one parameter and $Ci<MAC$ each parameter, C if $Ci>MAC$ at least for one parameter. This means that 9 classes of groundwater, AA, AB, and the like can be obtained. Type AB is quality A and B respectively for the former and latter group of parameters. Quality degradation of Apulia's groundwater is summarised by applying the proposed tool, as shown in Figure 5. Quality is so low as to exclude use for drinking in 50% of the wells considered, while, the same treatment is often necessary in the remaining ones.

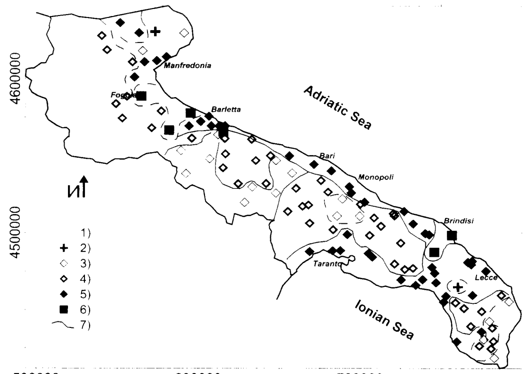

Fig. 5: Groundwater quality classification. Well with groundwater class 1) AA, 2) BA, 3) AB, 4) BB, 5) CB, 6) CC, 7) limit between groundwater classes.

Multi-parameter Logging for Fast Groundwater Quality Classification

Multi-parameter logs monitor some parameters, such as groundwater temperature T, specific electrical conductivity EC, TDS, dissolved oxygen DO and Eh, measured in well water columns. The method is based on identifying the trends of these parameters typical of an aquifer's natural hydrogeology. They are rather recurrent in space and time and enable extensive use of the method suggested, which can be easily applied to hydrogeology preliminary detection when natural or modified by anthropogenic activities, human-related pollution or seawater pollution amount and level. This may prove particularly useful for practical purposes, since these surveys are quite simple, fast and inexpensive.
The method was tested on some 120 wells of the Region of Apulia for one year, with quarterly surveys (Fig. 3) (Cotecchia et al., 1999). 6 typical multi-parameter log trends were identified. The chemical and physical properties of groundwater, as indicated by the tests, could somewhat correlate with the special hydrogeology of the inner: or recharge area type A, coastal strip type B, Tavoliere shallow aquifer type C, transition zone between the Murgia and the Tavoliere type D, transition zone between the Tavoliere and the Gargano type E)and between the Murgia and the Salento type F (Fig. 3). Field research highlighted that multi-parameter logs clearly show some special conditions where human acts cause groundwater degradation or modification, due to pollution or overexploitation. As regards the latter, this tool provides useful data on seawater intrusion evolution and on changes to the transition zone between fresh and saline water.

Conclusions

The complex issues appertaining to groundwater resource use, protection and management and the related socio-economic impact suggest applying an advanced multi-method approach as proposed. Each data collection and geographical processing step should be based on GIS platform. This system will give access to the real-time data required for proper groundwater resource planning and management.

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