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Apulian Groundwater (Southern Italy) Salt-Pollution Monitoring Network

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ABSTRACT

The Apulian hydrogeological units are of coastal type and are mainly carbonate rocks of Mesozoic age. The rapid socio-economic growth, which has occurred in the past decades, has led to different hazardous conditions in connection with groundwater quality. Groundwater for domestic, irrigation and industrial uses has been withdrawn in large quantities over the years; the aquifers are also increasingly becoming the ultimate "receptacle" for domestic and industrial waste water. In order to characterize the evolutionary features of increasing saline and human-related pollution, a regionally based continuously operating hydrogeological monitoring network gathered data. It uses more than 100 wells, some of which are hundreds of metres deep, equipped with multiparameter sensors, temperature, conductivity and level gauges set up along the vertical axis and connected to a geo-information system. Water samples are periodically taken from the wells; the samples are analysed by chemical, physical and bacteriological parameters with the aim of detecting any farming and industrial pollutants. The new system, which provides real-time information for groundwater planning, scheduling, and management, is described together with some preliminary results. The impact of sea-water intrusion on water quality at regional level is also discussed.

INTRODUCTION

The rapid socio-economic growth, which has occurred in the past decades, has continued to stress conditions in the Apulian hydrogeological system in Southern Italy, thereby leading to different hazardous conditions. Groundwater for domestic, irrigation and industrial use has been withdrawn in large quantities over the years. The aquifers are increasingly becoming the ultimate "receptacle" for waste water (COTECCHIA, 1991). Apulia is affected by two types of human-related pollution: 1) salt contamination, which is spreading over large portions of land thus reducing the availability of good-quality water (COTECCHIA, 1981; COTECCHIA & TADOLINI, 1993; COTECCHIA et al., 1981; FIDELIBUS & TULIPANO, 1996); 2) chemico-physical and biological pollution, which is mainly confined to urban areas (COTECCHIA & POLEMIO, 1995). In several areas salt contamination of groundwater has reached such a level that many of the wells have been abandoned.

In Apulia there are four hydrogeological units. They exhibit varying geological, structural and morphological features (fig. 1).

Apart from Puglia Tableland (*Tavoliere*), the remaining hydrogeological units share some common features (COTECCHIA & MAGRI, 1966; IPPOLITO et al., 1958; COTECCHIA, 1977; GRASSI, 1983; ZEZZA, 1975). They consist of large and deep carbonate aquifers (of Jurassic-Oligocene and mainly Mesozoic age), the predominant rock material of which is either limestone or limestone-dolomite. Aquifers are affected by karst and fracturing phenomena, also well below the sea level, whereas intruded sea water underlies fresh groundwater owing to a difference in density. In both the Gargano Promontory (*Gargano*) and the low Murge Plateau (*Murgia*) aquifers are under pressure except on a restricted coastline strip. In the Salentine Peninsula (*Salento*), groundwater flow under phreatic conditions is prevailing. The Salentine hydro-

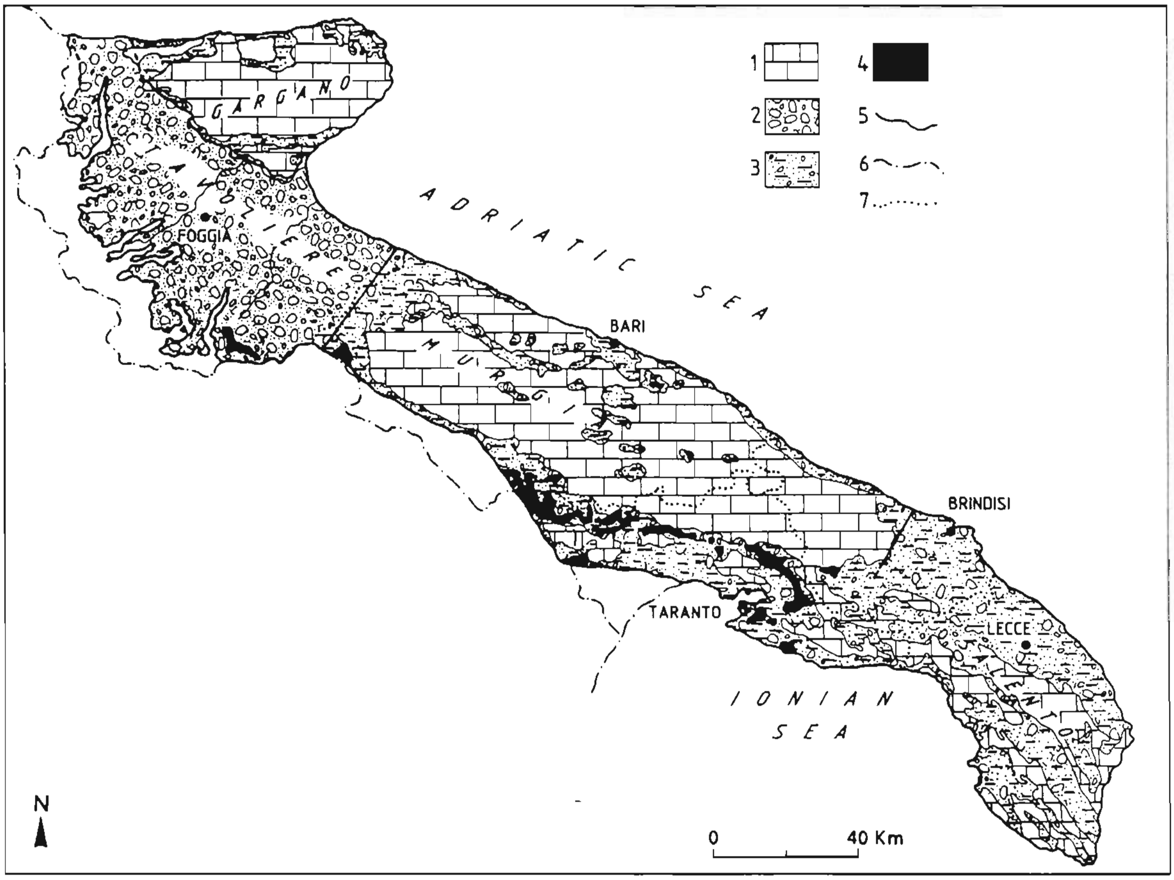

Figure 1. Apulian hydrogeological units. 1) Carbonate rock outcrops of Gargano Promontory (*Gargano*), Low Murge Plateau (*Murgia*) and Salentine Peninsula (*Salento*) units; 2) Puglia Tableland (Tavol*iere*) unit, mainly conglomerate and sands; 3) shallow aquifers and permeable lithotypes, calcarenites, clayey sands, sands, gravel, or conglomerates; 4) low permeable lithotypes, blue marly clays; 5) hydrogeological unit boundary, dashed where uncertain; 6) regional boundary; 7) provincial boundary.

geological unit is the only unit that is lapped by the sea on both sides.

Maximum piezometric heads are about 50 m asl in the Gargano Promontory, 200 m asl in the Murge Plateau and 5 m asl in the Salentine Peninsula (SPIZZICO & TADOLINI, 1997). Puglia Tableland hydrogeological unit consists of a large porous aquifer (Pleistocene-Holocene) within a conglomerate sandy-silty succession, less than sixty metres deep with a clayey impermeable bottom. Only in the vicinity of the coast the aquifer is deep enough to allow sea-water intrusion. Groundwater flows under phreatic conditions in the most internal and upstream portion of the hydrogeological unit, whereas it flows under pressure in the remaining part of the unit; maximum piezometric levels reach 300 m asl.

Along the borders between the Puglia Tableland and the Gargano Promontory or the Murge Plateau, the sinking of the carbonate platform, which makes up these two last hydrogeological units, is observed. A deep succession of clays, marly clays, sandstones and sands of Plio-Pleistocene age underlies the Tableland hydrogeological unit. NW.-SE. oriented oblong aquifers are predominantly reported in the sandy layers of this succession (BALDUZZI et al., 1982). Groundwater flowing in these "intermediate" aquifers is generally of artesian nature and is subjected to high pressure due to the confining action of the clayey layers (COTECCHIA et al., 1995). This succession overlies a third deep carbonate aquifer; it is the sunken carbonate platform. Inland, the Tableland border corresponds to outcropping impermeable clayey formations.

The hydrogeological units are bounded by the coastline and by Pliocene or more recent tectonic lines (faults) (AMBROSETTI et al., 1983). The borders are occasionally clear cut, as those between the Gargano Promontory and the Puglia Tableland and between the latter and the Murge Plateau.

The border between the Murge and the Salentine hydrogeological units is unclear. A gradual shift from the typical Murge high depth to groundwater and low and mildly variable permeability to the Salentine varying types of water flows, permeability, and depth can be observed.

A number of calcarenite and/or sandy aquifers some ten metres deep partially overlie the carbonate hydrogeological units.

Salt contamination of the Apulian groundwater - which flows within hydrogeological units and overlies intruded sea water - is a well-known and thoroughly investigated phenomenon (COTECCHIA, 1977). Nowadays, a strong connection between the increase in salt contamination and the lowering of piezometric levels, which can be ascribed to groundwater overdraft and/or a natural decrease in groundwater recharge, has been recognized in coastal aquifers. The evolution of salt-induced pollution and the gradual shortage of fresh groundwater are largely the result of subsurface water mismanagement (COTECCHIA, 1991).

Despite the massive import of water, the Apulian groundwater supply hardly meets 20% of the local demand for drinking water. Furthermore, groundwater is often the only resource available for diffuse water-demanding production processes in the area (COTECCHIA & POLEMIO, 1995).

The special severity of the situation calls for a rigorous approach based on available scientific knowledge and supplemented by up-to-date investigations of the evolution of groundwater quality. Hence, continuous and systematic monitoring is of paramount importance to ensure a sustainable use of this resource. The collection of chronological and geo-information data, gathered by a monitoring network, will allow the investigation of the phenomena in progress and the safe management of this natural resource (COTECCHIA & POLEMIO, 1997). This is the reason why awareness of the behaviour of aquifers should be fostered.

The Apulian Regional Board has approved this approach. A monitoring network project has been implemented by the *Ente per lo Sviluppo dell'Irrigazione e la Trasformazione Fondiaria*, that we would like to thank for the kind support offered.

In order to characterize the evolutionary features of increasing saline and human-related pollution, data were gathered by a regionally based continuously operating hydrogeological surveying network. It uses more than 100 wells, some of which are hundreds of metres deep, equipped with multiparameter sensors, connected to a geo-information system. Water samples are periodically taken from the wells; chemical, physical and bacteriological parameters are analysed with the aim of detecting any farming and industrial pollutants.

APULIAN HYDROGEOLOGICAL SURVEYING NETWORK

The monitoring network comprises: piezometric and salt-observation wells - for measuring fresh-saline water equilibrium - quality control wells - for assessing human-related pollution - and a Geographical Information System (GIS).

The monitoring network already relies on 118 stations or observation wells. To achieve the required density up to 127 wells will be provided (COTECCHIA & POLEMIO, 1997) (fig. 2).

74 piezometric wells together with those of all different types were equipped with electric piezometric transducers.

28 wells monitor groundwater quality. The control points were mostly located where the withdrawal rate and groundwater contamination hazard were higher; the latter being due to human activity upstream from the observation wells and to the aquifer vulnerability. Each well was equipped for continuously monitoring piezometric level, pH, temperature, electric conductivity, redox potential and dissolved oxygen.

Fourteen wells aimed at controlling the fresh-saline equilibrium were purposely located in those areas where salinization was more likely to endanger groundwater quality. They were sufficiently deep to reach the transition zone between the fresh water and the underlying saline water and were equipped with multiple probes for measuring groundwater temperature and electric conductivity at different depths. The probes were located near to the piezometric surface and at the top and the bottom of the transition zone (COTECCHIA et al., 1974). The standing piezometric level and the atmospheric pressure were also monitored.

Two wells acted as both water-quality control and saline-observation points.Fifty-two percent of the stations are located in the Murgia and thirty-one percent in the Salento. The remaining stations are equally distributed between the Gargano and the Tavoliere. In the latter, wells are located in the three types of aquifers.

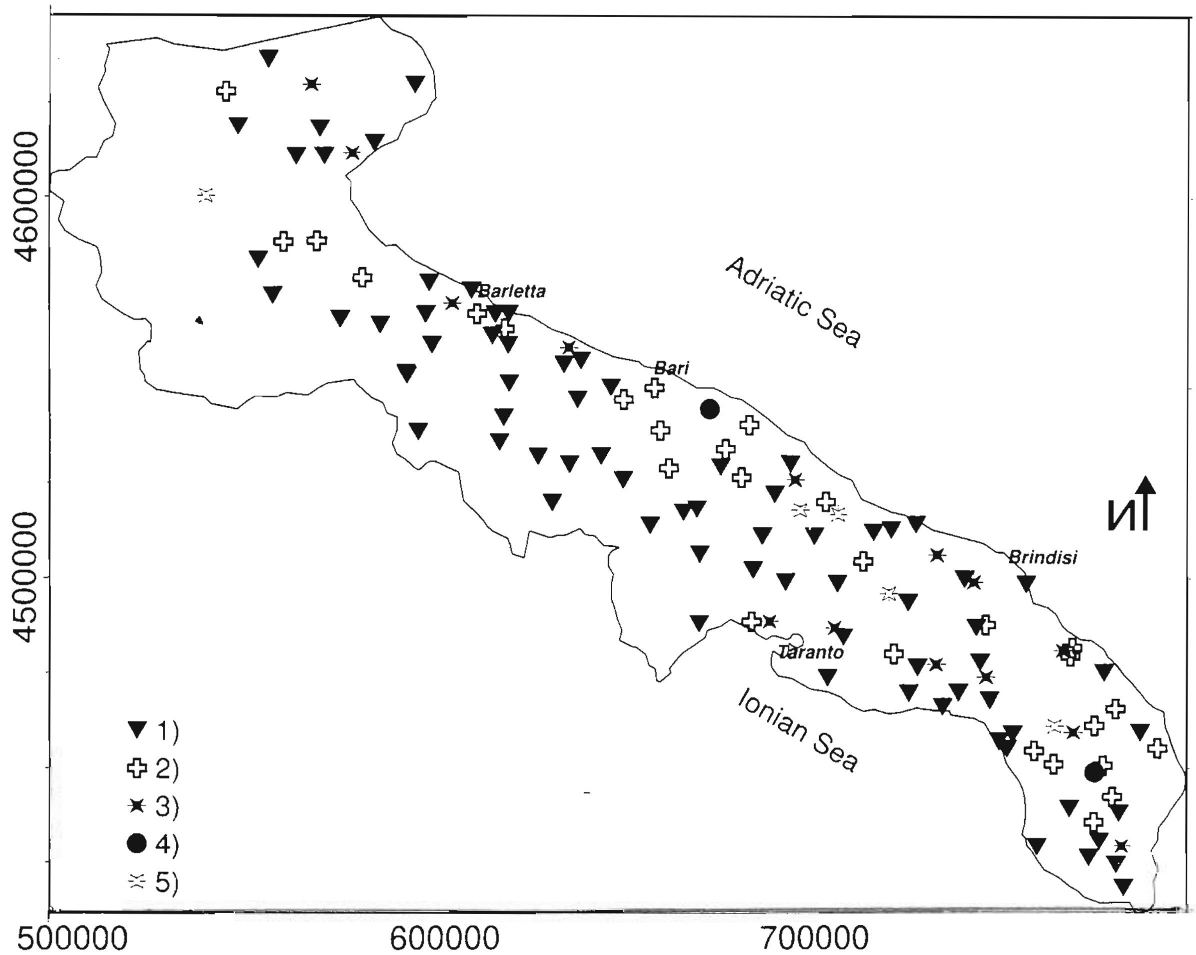

Figure 2. Apulian hydrogeological monitoring network. 1) Piezometric wells, 2) Quality control wells, 3) Sea-water intrusion observation wells, 4) Wells of type 2 and 3, 5) Radio link.

The monitoring stations allow measurements at varying acquisition and storage frequencies. Data storage may follow preliminary statistical processing of real-time mean, minimum and maximum values within the assigned time lags. The acquisition frequency over constant periods varies according to the local hydrogeological conditions and the parameter under observation. For each measurement the acquisition hour is recorded.

Sea-level measurements are made 48 times a day and 12 real-time values supplemented by the daily peak and well are stored. The same method is applied to monitor the piezometric levels of the wells located along the coast, which exhibit sea level oscillations, and the barometric, thermal and conductivity sensors installed in the wells. This detection method is used to correlate the modifications of piezometric heads and groundwater salt content along the coast, namely in the transition zone, with sea level ranges and air pressure changes.

Inland, the well piezometric level is measured 24 times a day and the minimum, the mean, and the maximum daily values are stored. The same method is applied to the wells that monitor water quality.

All measurements were then stored in an electronic data logging system and periodically transferred by an operator to the data processing centre. The system is also able to transmit data over a long distance in real time, by means of radio links.

All the network wells were used for water sampling as well as for systematic monitoring certain water-quality parameters, which could not be continuously and automatically detected.

The complex issues related to the use and protection of Apulian groundwater and the socio-economic impact thereof call for an advanced data collection and recording process. A system has been devised which gives access to real-time information required for the proper planning, scheduling, and management of groundwater supplies.

The GIS easily performs the above functions. It basically stores historical data gathered by various offices over the years as well as by the monitoring network. It manages available information regarding land type, hydrogeological characteristics, and groundwater quality, and then plots simulations against time and highlights hazards and emergencies.

SALT CONTAMINATION AND GROUNDWATER QUALITY

The results of 516 laboratory analyses carried out on samples taken from 118 stations of the monitoring network were processed. Samplings were performed from January 1995 to July 1997.

The sampling was aimed at identifying significant vertical variations, which require more frequent checking according to the space-time variability of the parameters under study.

Samples were taken under static conditions, using a "Kemmerer" water sampler, which takes water at the selected sampling depth. A submersible pump was used to take samples under dynamic conditions (hereinafter called "static samples" and "dynamic samples"). Static samplings help highlight the "natural" chemico-physical stratification of groundwater as well as the occurrence of hydrogeologically significant geological and structural features. However, little is known about the properties of the water which will be extracted from a given well or area. Withdrawn water is most likely to be that which is found where permeability is higher. Therefore, dynamic samples were also taken during the final stage, once the characteristics of the well were definitely known. Data inferred from dynamic samplings was used to complement and crosscheck data derived from static samplings.

93 % samples were taken under static conditions, at depths ranging from 6 m to 600 m below ground level, 7 % samples were taken under dynamic conditions. The static samples

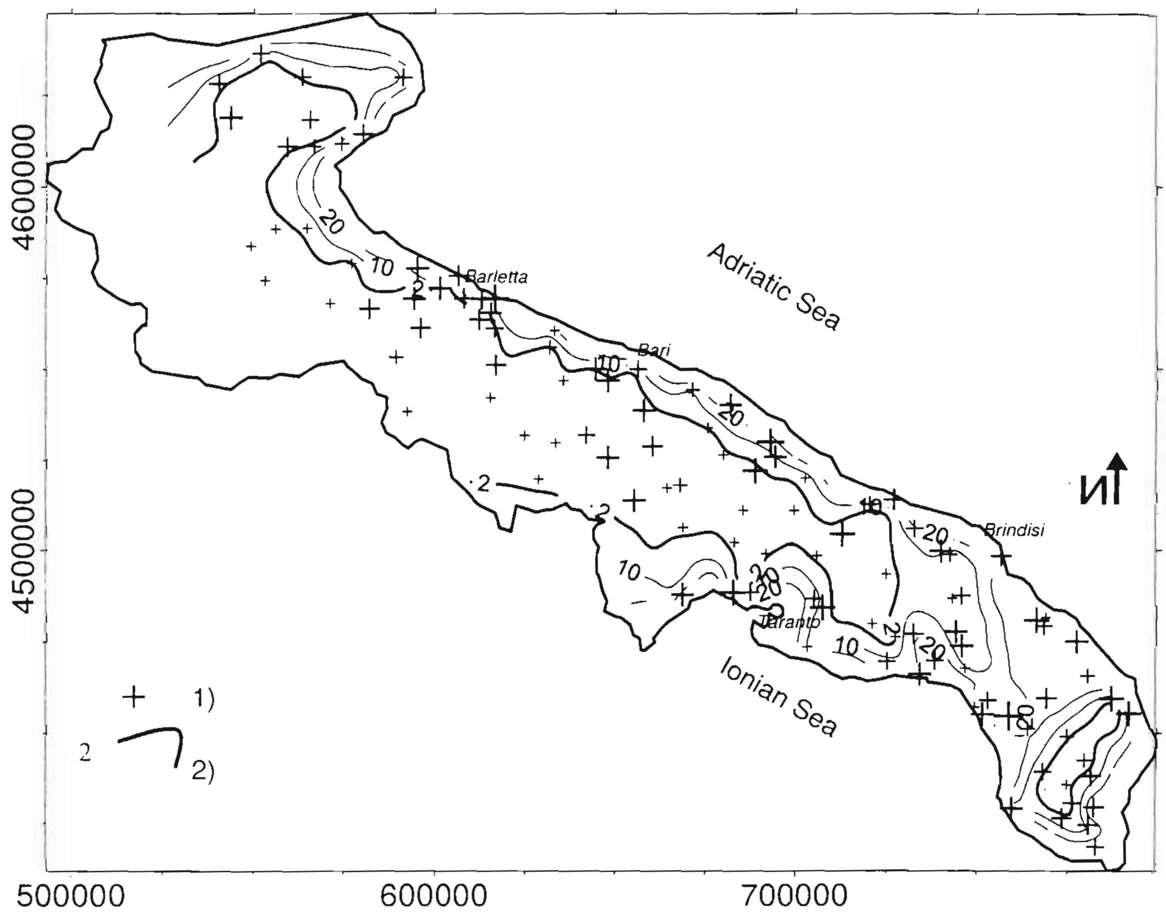

Figure 3. Salinity map (g/l), peak, or the worst concentration along each well. The size of the symbol 1 is proportional to the amount of data available, ranging from 1 to 7, for which the corresponding mean was calculated. 1) Well, 2) Saline contour line (the line corresponding to the drinking-water threshold is thicker).

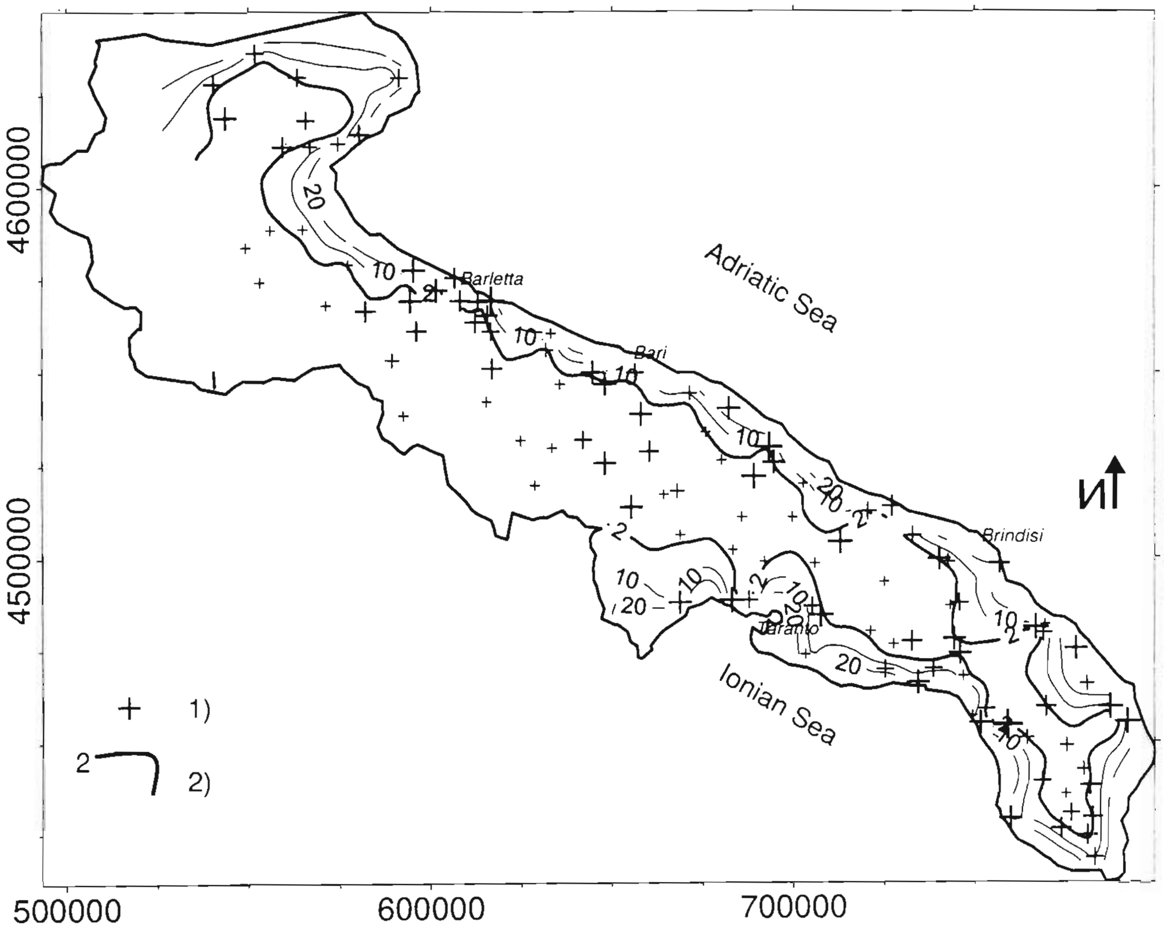

Figure 4. Salinity map (g/l), minimum, or the best concentration along each well. The size of the symbol 1 is proportional to the amount of data available, ranging from 1 to 7, for which the corresponding mean was calculated. 1) Well, 2) Saline contour line (the line corresponding to the drinking-water threshold is thicker).

were taken from each well at varying depths and at various times. A maximum of 15 samples per vertical axis or 5 measuring cycles were obtained.

Despite the effort made to gather and process data, the large size of the investigated hydrogeological units, the natural lack of homogeneity and anisotropy, the frequent withdrawals and frequent use of aquifers for depositing waste water causes impacts that can only be described briefly in this paper. Hence, some parameters were selected in order to assess broadly the quality of groundwater and detect the areas most at risk for salinization problems.

While processing data for mapping purposes, the average concentration of samples taken at the same depth was considered; samples of consecutive depths and very similar averages were unified. Then, in each well, the maximum and minimum mean concentration was selected (hereinafter called the worst and best concentration of the well). Therefore, the selected values provide a more cautious description of the phenomena in progress.

In order to establish a benchmark for groundwater quality, reference was made to the Italian Law (DPR n. 88/236), which includes the EEC directive n. 80/778 about the quality of water fit for human consumption, namely the maximum acceptable concentration of drinking water.

The salinity limit for the law is 1.5 g/l measured as dry residue at 180 °C. Groundwater salinity data is expressed as dry residue at 110 °C. To improve data mapping a limit of 2 g/l at 110°C is referred to.

Assuming some 40-g/l salinity of the Apulian coastal sea water, figure 3 was drawn using the kriging approach. For each well, the mean concentrations were used, at depths where the water was of the worst quality and hence the salinity was higher. This condition generally occurs at maximum sampling depths.

Figure 3 shows that water of acceptable quality, identified by the 2 g/l saline contour line, is found in the Murgia where sea-water intrusion has an impact but on a restricted coastline.

Contrary to what is generally accepted, groundwater in the Gargano Promontory is not exempt from sea-water contamination. The problematical hydrogeological nature of the Tableland, which is made up of many overlapping aquifers and the limited number of wells utilized, prevents the Authors from drawing any general conclusions. The impact of sea-water intrusion is most severe in the Salentine hydrogeological unit. Most of the area has high salt contamination. Hence, the quality of groundwater is well below the drinking threshold.

The situation is improved in figure 4, which records data pertaining to less saline water sampled along the vertical axis. When comparing figure 3 and figure 4, the 2-g/l contour line is shown to stretch on the Adriatic side of the Murge Plateau, in the vicinity of the Salentine Peninsula as well as in the northern part of the Salentine Peninsula. Note also that the shift from the Murgia hydrogeological unit to that of the Salentine Peninsula - geologically marked by the so-called "Soglia Messapica" - is highlighted by the saline contour line 2 on figure 3 and 4. In the first case, the line is interrupted at the southern Murge border whereas, in the second case, the line is somewhat backward versus both coastlines.

In order to assess the impact of salt contamination on farming the distribution of the Sodium Adsorption Rate (SAR), defined by the U.S. Department of Agriculture, was discussed (COTECCHIA & POLEMIO, 1997). The area with excellent quality groundwater encompasses most of the hydrogeological units of the Murgia, the Tavoliere, and the Gargano. Water having the best SAR properties was largely found in the Murge hydrogeological unit. The Salentine hydrogeological unit exhibited a limited amount of best SAR-quality groundwater.

Water quality for farming use is not only related to the alkali hazard. Figure 5 reports the modified Wilcox diagram for the classification of the alkalinity and salinity hazard. The modifications were introduced because of the high conductivity of groundwater in some wells of the network. Most groundwater points show a medium to very high salinity hazard and a low to high alkali hazard. The remaining groundwater cannot be used (C4-S4).

In the few wells in the Gargano area, both water of good quality and highly salt-contaminated water are reported. Best-quality water is reported in the Tavoliere, where no data are classified as C4-S4. The majority of wells in the Murgia provide good-quality water (S1 / 2 - C2 /3). The remaining ones are quite uniformly distributed along a straight line with a C4-S4 orientation. As to the Salento wells, the poorest water detected is also the worst quality groundwater in Apulia and is by far more dangerous than the remaining Salentine groundwater.

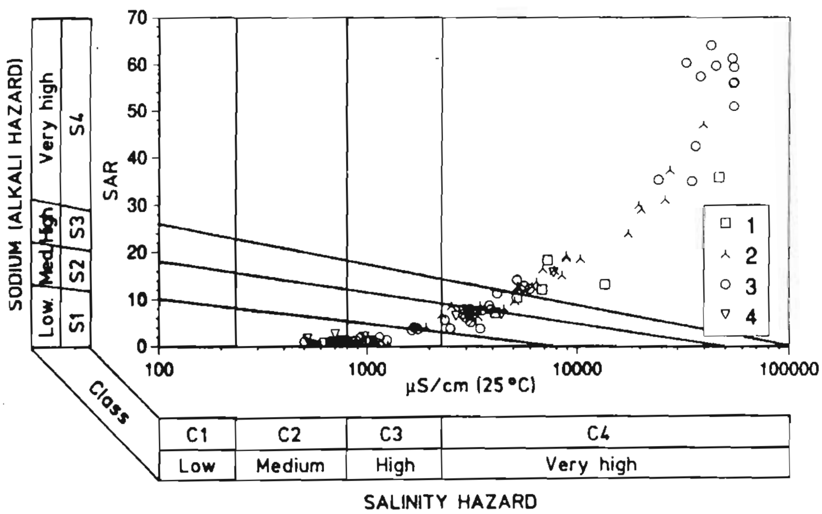

Figure 5. Classification of groundwater for irrigation use. Wells of 1) *Gargano*, 2) *Murgia*, 3) *Salento* and 4) *Tavoliere* hydrogeological units.

CONCLUSIONS

Data, which have been gathered by the Apulian groundwater-monitoring network, highlights the severe saline degradation of groundwater resources.

Water-quality degradation data yielded by the continuously operating geo-information system may provide the basis for protection schemes and sound management plans to address the groundwater problem in general and the Salentine priority in particular.

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