Predictions in Ungauged Basins: Promise and Progress (Proceedings of symposium S7 held during the Seventh IAHS Scientific Assembly at Foz do Iguaçu, Brazil, April 2005). IAHS Publ. 303, 2006.

Groundwater pollution and risks for the coastal environment (southeastern Italy)

MAURIZIO POLEMIO & PIER PAOLO LIMONI
CNR-IRPI, Via Amendola 122/i, 70126 Bari, Italy
m.polemio@ba.irpi.cnr.it

Abstract The quality and quantity of groundwater flow is very important for hydrological and ecological equilibrium where groundwater discharge into the sea and transitional environments is higher than river discharge. This is the case of the Murgia Plateau (Murgia) and of the Salentine Peninsula (Salento), located in the Apulian Region, southeastern Italy, selected as the study area for this research. Data collected by many surveys in which wells and coastal springs were sampled are discussed. Many physical, chemical and bacteriological parameters are considered. A quality classification partially based on Italian and European laws is defined to classify and compare groundwater quality. The groundwater pollution is quite absent only in the inner areas of the Murgia and the Salento, constituting portions of the recharge zone. Groundwater flowing from these areas to the sea is progressively polluted. This pollution load discharges into the sea or into wetlands and lagoons, constituting a huge hazard for the ecological equilibrium of valuable sites.

Key words coastal areas; groundwater; pollution; quality classification; seawater intrusion

INTRODUCTION

The worldwide fresh groundwater discharge into seas and lagoons has been estimated to be about 6% of the world's river discharge. The low percentage of groundwater discharge can be misleading; it is the case of high permeability areas, as in the case of regions dominated by carbonate rock outcropping, especially if highly fractured and karstic (UNESCO, 2004).

Where such conditions exist, the presence of subaerial or submarine springs along the coast sometimes conditioned the development of human settlements. For example, the Roman geographer Strabo describes, about 2000 years ago, the use of a submarine spring of the Mediterranean Sea, tapped with skin tubes from a boat, to supply a city near Latakia, in Syria. Pausanio describes Etruscans who used thermal baths 200 years earlier, thanks to coastal spring waters.

The quality and the quantity of coastal groundwater discharge, especially where it is prevalent, are today remarkable for the effects on the hydrological and ecological equilibrium of humid environments located near the coast (UNESCO, 2004). The effects can be:

(a) in terms of quantity of coastal groundwater discharge, if it increases or decreases the seawater intrusion withdraws (seaward) or advances (inland), respectively;
(b) at the same time, the movement of the seawater intrusion interface affects the salinity of subaerial or submarine spring water discharged near the coast;
(c) the variation of fresh groundwater discharge, of groundwater salinity, that can be due to many causes, or any combination of these two phenomena, very often

affects the chemical characteristics of coastal surface waters, with complex ecological effects, often dramatic for valuable wetlands;

(d) groundwater can transport pollutants and nutrients from inland ground surfaces to surface coastal waters, often modifying the budget of carbon, nitrogen and phosphorus, causing, in these cases, ecological risks such as eutrophication, algal blooms or affecting benthic habitats.

The Apulian region, in particular the Murgia plateau (hereinafter *Murgia*) and the Salentine lowlands (*Salento*), constitute a prime example of a region exposed to these risks. For the selected study area, the Murgia and Salento, the groundwater discharge is greater than twice the surface runoff (De Girolamo *et al*., 2001, 2002), notwithstanding the current overexploitation by wells.

HYDROGEOLOGICAL FEATURES

In the region, the hydrogeological units of the Gargano and of the Tavoliere, and the hydrogeological structures of the Murgia and of the Salento, can be observed. All of these areas are carbonate in nature, except for the Tavoliere, and constitute the largest coastal karstic aquifers of Italy, made up of Mesozoic rocks (Fig. 1). Detrital

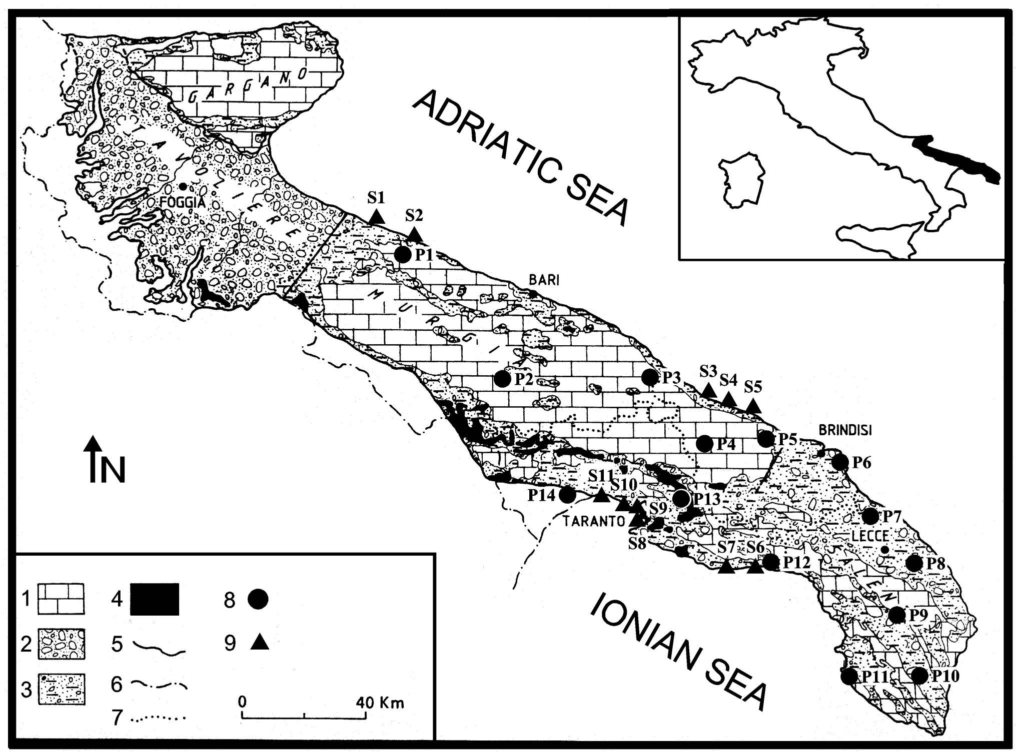

Fig. 1 Apulian hydrogeological units and structures (Cotecchia & Polemio, 1999, Polemio & Limoni, 2001). (1) Carbonate rock outcrops of Gargano, Murgia and Salento; (2) Tavoliere unit, mainly conglomerate and sands; (3) shallow aquifers and permeable lithotypes, calcarenites, clayey sands, sands, gravel, or conglomerates; (4) low permeable lithotypes, blue marly clays; (5) hydrogeological unit boundary, dashed where uncertain; (6) regional boundary; (7) provincial boundary; (8) selected well; (9) selected spring.

organogenic series (Tertiary and Quaternary) fill some troughs or partially overlap the carbonate rocks, in places creating secondary aquifers (Cotecchia *et al*., 2005).

Local groundwater resources, which are the main regional water source (given the lack of a meaningful hydrographic network over most of the area) are deteriorating rapidly and dramatically (Polemio, 2000).

The study area corresponds to two morphological-structural units: the Murgia and the Salento. Their main features are a striking lithological uniformity and a huge diversity from a physiographic and hydrogeological point of view.

The Murgia (maximum height 680 m a.s.l.) is a large asymmetric horst, hit by two direct fault systems (NW–SE and NE–SW), due to neotectonics. Because of these faults, the morphological structure slopes down towards the Adriatic Sea and towards the adjoining regions, including the Salento, by means of a succession of ledges in the shape of steps, bounded by slight fault throws.

In the Salento area, the shelf itself is a sort of lowland (maximum height about 180 m above sea level), bounded by two seas, the Adriatic Sea and the Ionian Sea. The Mesozoic carbonate rocks are relatively more widespread, covered by outcropping Quaternary soils and rocks, even though these outcrops are not very continuous (Fig. 1).

The groundwater flow in the Murgia is generally confined, except along a narrow coastal strip. Faults govern the major preferential flow paths and seawater intrusion in Murgia; they also govern the deep and complex groundwater exchanges along the major hydrogeological boundaries. Maximum piezometric heights are very high, about 50 m a.s.l. The flow path is mainly towards the Adriatic coastline and towards the Salento, secondarily towards the Ionian Sea. The piezometric gradient is high, equal to 1% or greater.

There is a gradual hydrogeological change from the Murgia to the Salento (Grassi, 1983; Cotecchia *et al*., 2005). Groundwater heights of the Salento are less than 4–5 m a.s.l. Groundwater flows mainly under phreatic conditions and the depth to groundwater is quite low. The Salento permeability is greater, generally 10 times greater, or even more. The Salento groundwater divide is located along the SE–NW axis, in parallel with the Ionian and Adriatic coastlines, with a greater piezometric gradient, generally equal to 0.2–0.3%, than in the Murgia.

The entire Apulian groundwater has undergone a two-fold pollution, entirely of human origin (Polemio, 2000; Polemio & Limoni 2001): saline pollution evolves progressively as it affects increasingly large portions of land; biological and chemical-physical pollution is gaining in importance and is mainly concentrated around urbanized areas. The latter is due to the circumstance that the aquifers have been utilized to discharge wastewaters (Cotecchia, 1981; Fidelibus & Tulipano, 1996; Cotecchia & Polemio, 1997).

There are widespread carbonate rock outcrops in three areas of the region; in these areas the natural protection of the aquifer by pollution is very low. The intrinsic vulnerability of the main aquifers, spatially variable but everywhere remarkable, expose groundwater to almost direct effects of potential pollution sources due to anthropogenic activities carried out on the ground surface. The natural or intrinsic vulnerability is increased by the custom of using bored wells, karstic pits and dolines to discharge underground wastewaters and runoff from urbanized surfaces.

The Regional Authorities passed a law defining a plan for the safeguard and decontamination called PRA (Apulia Regional Administration 1984), determining the

Fig. 2 Groundwater quality zonation, regulation of groundwater use and known pollution events (Apulia Regional Administration 1984; Giuliano & Corazza, 2000): (1) polluted site, (2) low quality groundwater (forbidden tapping), (3) high quality groundwater (tapping for drinking use).

quality zonation of Apulian groundwater and the regulation of groundwater and aquifer utilization as a function of the risk of groundwater degradation. As an example, new tapping wells were forbidden where the quality was the lowest, mainly due to the seawater intrusion, and strongly regulated where groundwater quality was high enough to permit drinking use (Fig. 2).

Giuliano & Corazza (2000) collected data concerning pollution events of Apulian groundwater from 1982 to 1995 (Fig. 2). The majority of cases are located along or near the coast and is due to saline contamination for the anthropogenic worsening of the seawater intrusion effects; the remaining cases are microbiological, organic or inorganic contaminations. The known pollution events that happened after the PRA promulgation are certainly a low fraction of the whole. At the same time, the inadequate regulation and control of land use, mainly concerning farming activities, together with a progressive weakening of regulation concerning groundwater utilization have thwarted the PRA and triggered a further degradation of the quality of groundwater.

SELECTED WELLS AND SPRINGS AND AVAILABLE DATA

Several surveys have been carried out to detect the chemical-physical-bacteriological characteristics of Apulian groundwater; the most important surveys have considered the coastal springs (Cotecchia & Tulipano, 1989) and wells of the Apulian groundwater monitoring system (Colucci *et al.*, 1998; Cotecchia & Polemio, 1998, 1999). IRPI has carried out research to the end of 2003 on the basis of surveying of wells and springs involved in the above-mentioned surveys.

The analysis of the whole data set constituted by these surveys has recognized the best quality groundwater in some portions of recharge areas of Murgia and Salento. These areas are located, as in the case of the 1984 situation (Apulia Regional Administration, 1984), inland, where the anthropogenic activities are not relevant, and are a portion of the recharge areas of Murgia and Salento. The extent of these areas seems to have decreased since 1984.

The latest IRPI survey has been designed to define the quality modification of groundwater along the flow path from recharge areas to natural discharge areas located along the coastal line. For this purpose, some wells and springs have been selected, since the groundwater quality there is representative of a wide zone (Fig. 1). The temperature, the specific electrical conductivity, the pH and the Eh with the concentrations of ammonia, nitrite, nitrate, chlorine, manganese, iron, mercury, lead, arsenic, cadmium, zinc, arsenic and chromium of groundwater have been, respectively, determined on site and by laboratory chemical analyses. The laboratory determination of the concentration of total coliforms, faecal coliforms and faecal streptococci permits quantification of the bacteriological quality of groundwater, as well.

THE QUALITY CLASSIFICATION METHOD

The selected quality classification method is defined using a shared and quite standard approach, as described by an Italian law (D.L.152/99) which implements some European Directives (1991/271 and 1991/676). This approach could be easily modified to consider the implementation of the European Water Framework Directive 2000/60 and of the draft European Directive on the protection of groundwater against pollution.

The approach distinguishes between two groups of parameters: basic parameters and additional parameters (Tables 1 and 2). The parameters considered have been selected among those suggested by law, considering the nature of pollution sources which are typical of Apulian groundwater. The so called chemical classes, from 1 to 4 in decreasing order of quality, can be thus described: class 1, null or negligible anthropogenic impact, high groundwater quality; class 2, low anthropogenic impact, long-term sustainable impact, good groundwater quality; class 3, considerable anthropogenic impact, good groundwater quality subject to degradation risk; class 4, high anthropogenic impact, low groundwater quality; class 0, null or negligible anthropogenic impact but with at least one parameter from class 4.

Table 1 Quality classification on the basis of basic chemical parameters (D.L.152/99).

Parameter	units	Class 1	Class 2	Class 3	Class 4
Sp. elec. conductivity	μS cm^{-1} (20°C)	≤400		≤2500	>2500
Cl	mg l^{-1}	≤25		≤250	>250
Mn	μg l^{-1}	≤20		≤50	>50
Fe	μg l^{-1}	≤50		≤200	>200
NO_3	mg l^{-1}	≤5	≤25	≤50	>50
SO_4	mg l^{-1}	≤25		≤250	>250
NH_4	mg l^{-1}	≤0.05		≤0.5	>0.5

Table 2 Threshold of the selected additional parameters (D.L.152/99).

Parameter	μg l^{-1}
Arsenic	≤10
Cadmium	≤5
Chrome	≤50
Nitrite	≤500
Lead	≤10

The quality classes are defined according to classes defined by Table 1 for each basic parameter but also considering the threshold values in Table 2. The concentration of one or more pollutants higher than the thresholds of Table 2 determines the classification in class 4, otherwise the water is classified considering the parameters of Table 1; in this case the parameter is defined as Below the Threshold (BT). The final classification of the water sample is equal to the worst class selected by the whole set of basic and additional parameters. If the concentration of a parameter is high enough to attain class 4 but its origin is natural, it is assigned class 0.

The presence of significant concentrations of additional parameters lower than the threshold, except in the case of natural presence, is however a negative signal and unacceptable in terms of groundwater quality. In this case, measures to prevent a further worsening of the quality should be adopted, to remove the causes of pollution, and to reduce the levels of pollution.

It is proposed to complete the method by considering additional bacteriological parameters also classified using the threshold criterion. If total coliforms, faecal coliforms and faecal streptococci concentrations are, respectively, higher than 15, 0, 0 MPN/100 cm^3 the class is 4, otherwise the parameter is considered BT.

The method has been selected because it is a simple one, it is a standard described by a law (except for the bacteriological section), is complete, taking into account the main pollution types, and is widely accepted locally. It is therefore a simple way to evaluate the spatial evolution of pollution due to each parameter and the final effect in the coastal areas of natural groundwater discharge.

DATA ANALYSIS

The highest quality groundwater, not described here for the sake of brevity, can be sampled by wells located in core portions of the recharge areas; the class is often 1 or 2 in these portions of the aquifer.

The mean concentration of each basic or additional parameter is used for the quality classification in each surveying period. The quality classification of the sampled wells is summarized in Tables 3 and 4, in which are reported, respectively, the results concerning chemical and bacteriological parameters, and in Tables 5 and 6, concerning the same parameters but for the sampled springs.

The groundwater of the selected wells is Class 4 everywhere. In terms of chemical parameters, one well, located in Murgia, is of class 2 (P4, Fig. 1). Belonging to the worst class is frequently determined by the specific electric conductivity and by chlorine, two highly correlated parameters, since the chlorine content depends mainly

Table 3 Chemical classification referred to basic and additional parameters of groundwater samples of wells. BT) Below the threshold.

Well	Sp. el. Cond.	Cl	Mn	Fe	NO_3	SO_4	NH_4	As	Cd	Cr	NO_2	Pb
P1	4	4	1	1	2	2	4	BT	BT	BT	BT	4
P2	2	2	1	1	1	1	1	BT	BT	BT	BT	4
P3	4	4	1	1	2	4	3	BT	BT	BT	4	4
P4	2	2	1	1	2	1	1	BT	BT	BT	BT	BT
P5	4	4	1	1	2	4	3	BT	BT	BT	4	4
P6	2	4	1	1	2	1	4	BT	BT	BT	4	BT
P7	4	4	1	1	2	4	3	BT	BT	BT	4	4
P8	4	4	1	1	2	4	1	BT	BT	BT	4	BT
P9	4	4	1	1	2	4	1	BT	BT	BT	4	BT
P10	4	4	1	1	2	4	4	BT	BT	BT	BT	BT
P11	2	4	1	1	3	2	3	BT	BT	BT	4	4
P12	4	4	1	1	2	4	3	BT	BT	BT	BT	4
P13	4	4	1	1	1	4	3	BT	BT	BT	4	4
P14	4	4	1	1	2	4	3	BT	BT	BT	4	4

Table 4 Bacteriological classification of groundwater samples of wells. BT) Below the threshold.

Well	Total coliforms	Faecal coliforms	Faecal streptococci
P1	4	4	4
P2	4	BT	BT
P3	4	4	BT
P4	4	4	BT
P5	4	4	BT
P6	4	4	BT
P7	4	4	BT
P8	4	4	BT
P9	4	4	BT
P10	4	4	BT
P11	4	4	BT
P12	4	4	BT
P13	BT	BT	BT
P14	4	BT	BT

Table 5 Chemical classification referred to basic parameters of groundwater samples of springs. BT) Below the threshold.

Spring	Sp. el. Cond.	Cl	Mn	Fe	NO_3	SO_4	NH_4	As	Cd	Cr	NO_2	Pb
S1	4	4	1	1	3	4	3	BT	BT	BT	BT	BT
S2	4	4	1	1	3	4	3	BT	BT	BT	BT	BT
S3	4	4	1	1	2	4	3	BT	BT	BT	BT	BT
S4	4	4	1	1	2	4	3	BT	BT	BT	BT	BT
S5	4	4	1	1	4	4	3	BT	BT	BT	BT	BT
S6	4	4	1	1	4	4	3	BT	BT	BT	BT	BT
S7	4	4	1	1	3	4	3	BT	BT	BT	BT	BT
S8	4	4	1	1	3	4	3	BT	BT	BT	BT	BT
S9	4	4	1	1	4	4	3	BT	BT	BT	BT	BT
S10	4	4	1	1	3	4	3	BT	BT	BT	BT	BT
S11	4	4	1	1	2	4	3	BT	BT	BT	BT	BT

Table 6 Bacteriological classification of groundwater samples of springs. BT) Below the threshold.

Spring	Total coliforms	Faecal coliforms	Faecal streptococci
S1	4	4	4
S2	4	4	BT
S3	BT	BT	BT
S4	4	4	4
S5	4	4	BT
S6	4	4	4
S7	4	4	BT
S8	4	4	BT
S9	4	4	4
S10	4	4	4
S11	4	4	4

upon the effect of seawater intrusion under these hydrogeological conditions. The high chlorine concentration or the high specific electrical conductivity, can also be observed far from the coast; it is the result of the high rate of discharge from wells everywhere, in terms of salt pollution by seawater intrusion. In the remaining cases, class 4 is due to nitrite and lead. The parameters for which class 4 is observed for wells are: specific electric conductivity, chlorine, sulphate, ammonia, nitrite and lead.

In terms of bacteriological parameters, one well, located in southeastern Murgia, is not of class 4 (P13, Fig. 1). Belonging to the worst class is generally determined by total coliforms and secondly by faecal coliforms; in this latter case BT is the result only for three wells located in the southeastern portion of the Murgia (P2, P13 and P14). Only well P1, located in the northwestern portion of Murgia, is of class 4 for the whole set of bacteriological parameters.

It is quite simple to appreciate the spatial quality of the variation of groundwater along flow paths to the coast using this approach with a synoptic view, considering each parameter. The groundwater quality gets worse along the flow paths from recharge areas to coastal discharge areas, surface water bodies, such as the hydrographic network, narrow lagoons, and the sea. This spatial trend is not continuous and homogeneous, due to local hydrogeological and, mainly, anthropogenic factors and due to the location of the main urban areas. A greater spatial variability of quality is observed in Salento due to the higher aquifer vulnerability and density of villages, towns and areas of anthropogenic activities. The results show that the coastal springs have become carriers of heavy pollution loads, created inland, abandoned on narrow surface areas, spread over wide agricultural areas, or introduced below the ground surface. The low quality of the groundwater along the whole coastal perimeter should be stressed; the degradation is more serious in Salento.

The groundwater of the selected springs is everywhere of Class 4 (Table 5 and 6). Everywhere, the chemical parameters for which class 4 is observed for springs are specific electric conductivity, chlorine, sulphate, ammonia and, in places, nitrate. A huge worsening is observed in terms of ammonium, nitrate and sulphate concentrations from inland to the coast, not compensated by a low improvement in terms of nitrite and lead concentration, which in some wells only is higher than threshold. These reductions seem to be due to dilution and also, in the case of nitrite, to chemical processes. The dilution happens inland inside fresh groundwater and in proximity to the coast, due to the contribution of intruded seawater.

In terms of bacteriological parameters, one spring, located in northeastern Murgia, is not of class 4 (S3, Fig. 1). Belonging to the worst class is generally determined by both total and faecal coliforms and by faecal streptococci, which are widespread, in this case with the exception of the same Murgia springs, namely S2 in the north and S3, S5, S7 and S8 in the south.

The spring water is generally of worse class and quality; in other words, the spring water is generally more polluted than groundwater tapped by wells, notwithstanding the relevant dilution with intruded seawater.

The analysis of the quality trend, moreover, shows that the trend is widespread negative or decreasing, though it is also unhomogenous and unsteady; the quality worsens over almost the entire Salento and in broad portions of Murgia (Polemio 2000; Polemio & Limoni 2001). This trend implies the real risk that where pollution is low or absent, groundwater degradation could soon be relevant, with serious effects both in terms of availability of good quality groundwater and in terms of its impact on the coastal environments. The traditional problems deriving from overexploitation and seawater intrusion effects are often worsened by the discharge of insufficiently purified wastewater on and below the ground surface. This figure is confirmed by the widespread and serious bacteriological pollution of water sampled by wells and springs.

CONCLUSIONS

The seriousness of the effects of natural and artificial phenomena with an impact in terms of the groundwater resources of Murgia and Salento has been highlighted. Notwithstanding the complexity of phenomena that threaten the groundwater quality, the proposed quality classification highlights, with simplicity, that the quality degradation risks are not only real and serious risks but also that in many places they have already become reality.

High quality groundwater, to be used as drinking water, can be found inland and in the higher portions of Murgia and inland and in narrow areas of the Salento. Groundwater flows from these zones, which are hydrogeologically a portion of the recharge areas, to the coastal areas under the huge effect of a progressive anthropogenic pollution.

Groundwater is loaded with pollutants that arrive at the coastal springs without appreciable attenuation due to the karstic nature of the aquifer. Where the springs are submarine, the contamination is reduced by an appreciable and further dilution as the distance from the spring increases. Where spring outflow becomes inflow to lagoons or valuable wetlands, the ecological equilibrium is subject to serious risks due to continuous degradation of groundwater quality.

REFERENCES

Apulia Regional Administration (1984) Piano Regionale Risanamento delle Acque. *Boll. Uff. Regione Puglia*, XV, 57.

Colucci, V. Limoni, P. P. & Serravezza, C. (1998) La rete di controllo idrometrografico e qualitativo delle falde idriche pugliesi. *Acque Sotterranee* **59**, 55–61.

Cotecchia, V. (1981) Methodologies adopted and results achieved in the investigations of seawater intrusion into the aquifer of Apulia (Southern Italy). In: *Salt Water Intrusion Meeting* (Hannover 15–18 October 1981), 1–68.

Cotecchia, V. & Tulipano, L. (1989) Le emergenze a mare individuate anche con tecniche di telerilevamento, come vettori di carichi inquinanti dagli acquiferi carbonatici e carsici pugliesi all'ambiente costiero. In: *I Workshop Progetto Strategico Clima Ambiente e Territorio nel Mezzogiorno* (Taormina, Italy), 133–144.

Cotecchia, V. & Polemio, M. (1997) L'inquinamento e il sovrasfruttamento delle risorse idriche sotterranee pugliesi. In: *VI Workshop del Progetto Strategico «Clima, Ambiente e Territorio nel Mezzogiorno»*, (Taormina, Italy, Dicember 1995), **I**, 447–484.

Cotecchia, V. & Polemio, M. (1998) The hydrogeological survey of Apulian groundwater (southern Italy): salinization, pollution and over-abstraction. In: *Proc. Int. Conf. on Hydrology in a Changing Environment* (British Hydrological Society, Exeter, 6–10 July, 1998), 129–136. John Wiley & Sons, Chichester, UK.

Cotecchia, V. & Polemio, M. (1999) Apulian groundwater (southern Italy) salt pollution monitoring network. *Flemish J. Nat. Sci.* 197–204.

Cotecchia, V., Grassi, D. & Polemio, M. (2005) Carbonate aquifers in Apulia and seawater intrusion. *Giornale di Geologia Applicata,* 1, "Some Engineering Geology case histories in Italy" Special Issue for 32nd IGC, 219–231, Chieti, Italy.

D. L. del 11 maggio 1999 n.152 (1999) Disposizioni sulla protezione delle acque dall'inquinamento e recepimento della direttiva 91/271/CEE concernente il trattamento delle acque reflue urbane e della direttiva 91/676/CEE relativa alla protezione delle acque dall'inquinamento provocato dai nitrati provenienti da fonti agricole. *G.U. n.124*, Roma, Italy.

De Girolamo, A. M., Limoni, P. P., Portoghese, I. & Vurro, M. (2001) Impiego di tecniche GIS per la valutazione e rappresentazione del bilancio idrogeologico a scala regionale. Applicazione della metodologia alla Penisola Salentina. *L'Acqua,* **2**, 57–70.

De Girolamo, A. M. Limoni, P. P. Portoghese, I. & Vurro, M. (2002) Il bilancio idrogeologico delle idrostrutture pugliesi. Sovrasfruttamento e criteri di gestione. *L'Acqua* **3**, 33–45.

Fidelibus, M. D. & Tulipano, L. (1996) Regional flow of intruding sea water in the carbonate aquifers of Apulia (southern Italy). In: *14th Salt Water Intrusion Meeting* (Malmo, Sweden), 230–240.

Giuliano, G. & Corazza, A. (2000) State of pollution of groundwater used fro drinking purposes in Italy. In: *Water Resources Management in a Vulnerable Environment for Sustainable Development* (ed. by K. Andah), 195–207. UNESCO-Int. Hydrological Programme. Grifo Publishers, Perugia, Italy.

Grassi, D. (1983) Difformità di ambiente idrogeologico promossa in seno alla piattaforma carbonatica appula da una evoluzione tettonico-carsica differenziata. *Geol. Appl. e Idrogeol*. **XVIII**(I), 209–239. Bari, Italy.

Polemio, M. (2000) Degradation risk owing to contamination and overdraft for Apulian groundwater resources (southern Italy). In: *Water Resources Management in a Vulnerable Environment for Sustainable Development* (ed. by K. Andah), 185–194. UNESCO-Int. Hydrological Programme, Grifo Publishers, Perugia, Italy.

Polemio, M. & Limoni, P. P. (2001) L'evoluzione dell'inquinamento salino delle acque sotterranee della Murgia e del Salento. *Memorie della Società Geologica Italiana* **56**, 327–331.

UNESCO (2004) Submarine groundwater discharge. *IHP Groundwater Series n. 5*.