The degradation hazard of groundwater resources of the Metaponto coastal plain (Southern Italy)

Maurizio Polemio[1], Vittoria Dragone[1], Pier Paolo Limoni[1], Donatella Mitolo[1], Francesca Santaloia[1]

Riassunto

Durante il ventesimo secolo, i lavori di bonifica, la costruzione di dighe e sistemi irrigui, le attività produttive, gli emungimenti, le siccità e gli scarichi di reflui hanno profondamente modificato le disponibilità e la qualità delle acque sotterranee della piana di Metaponto. La degradazione quantitativa delle risorse idriche sotterranee e quella qualitativa, in particolare considerata dalla nota, è aumentata nel corso degli anni più recenti, come evidenziato dall'andamento delle caratteristiche fisico-chimiche delle acque sotterranee nel periodo 1990-2003. Lo stato qualitativo chimico-fisico delle acque sotterranee e il relativo trend è stato caratterizzato con riferimento a metodologie standard, definite da vigenti normative.

[Parole chiave: degrado acque sotterranee, inquinamento, classificazione della qualità]

Abstract

During the last century the land reclamation works, the built-up of dams and modern irrigation systems, the farm and industrial activities, and the overexploitation of the wells, associated to several periods of drought, have deeply modified the quantity and the chemical state of the groundwater resources of the Metaponto coastal plain (Southern Italy). The degradation of the groundwater systems seems to be increased with the time as shown by the piezometric trends (1927-1990) and by the chemical-physical data (1990-2003). The chemical-physical state of the groundwater has been defined according to the hydrochemical classification proposed by an Italian legislative decree.

[Keywords: groundwater degradation, pollution, quality classification]

Résumé

Au cours du vingtième siècle, les travaux de bonification, la construction des barrages et des systèmes d'irrigations, les activités productives, les debit, la sécheresse et les déchets des eaux usées ont profondément modifié les disponibilités et la qualité des eaux souterraines de la plane de Metaponto. La dégradation quantitative des ressources hydriques souterraines et celle qualitative, qui est analysée en particulier dans cet article, ont augmentée au cours des années récentes. Cette aggravation est bien marquée par les caractéristiques physiques and chimiques des eaux souterraines pendant les années 1990-2003. L'état chimique et physique des eaux souterraines a été défini sur la base d'une classification hydro-chimique proposée par un décret législatif Italien.

[Mots clef: dégradation des eaux souterraines, pollution, classification de la qualité des eaux]

1. Introduction

The study area rests on the Ionian coastal plain, known as Metaponto coastal plain (Southern Italy), stretching around the middle and the lower valleys of the Sinni, Agri, Cavone, Basento and Bradano Rivers (Figure 1).

Throughout the 20th century, the land reclamation works, the built-up of several dams and of modern irrigation systems, the discharge of wastewaters and the farm and industrial activities, some of which not suitably planned and managed, have deeply modified the quantity and the quality of the groundwater flowing in this coastal plain.

The progressive physical and chemical degradation of the groundwater, occurred during the years, particularly in the recent period 1990-2003, has been inferred from the data of about 250 boreholes while the quantity state of the groundwater has been estimated considering the piezometric levels measured (not always regularly) from 1927 to 2003. This research enhances some results of the activity carried out by authors for the European project "Crystallisation technologies for prevention of salt water intrusion" (Polemio et al., 2005) during which the hydrogeological characterisation of the whole plain was finalised to select a test site for a innovative technology to realise physical barriers to the seawater intrusion. In order to this, data coming

[1] CNR - IRPI - Department of Bari (Italy)

from 1130 boreholes lying in the Metaponto plain were also considered.

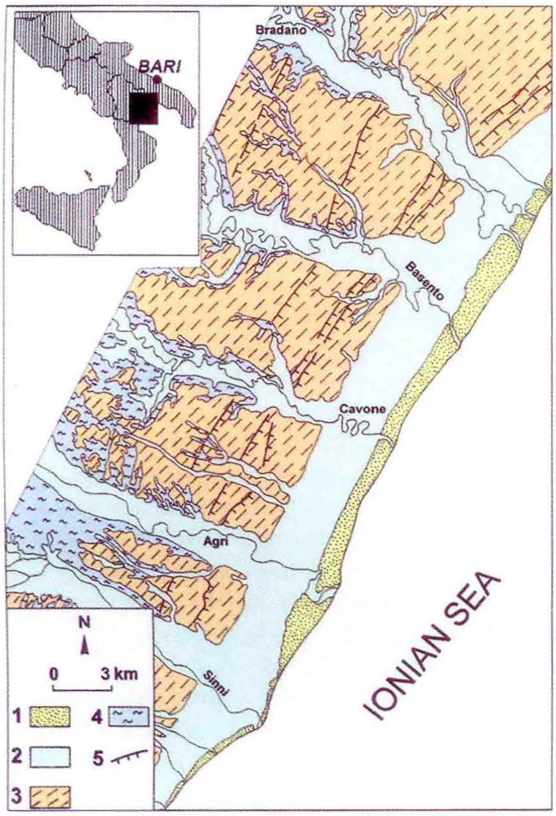


FIG. 1 - *Schematic geological map of the study area: 1) coastal deposits; 2) alluvial, transitional and marine deposits; 3) marine terraced deposits; 4) Subapennine Clays Formation; 5) scarp of marine terraces.*
Mappa geologica schematica dell'area di studio: 1) depositi costieri; 2) depositi alluvionali, di transizione e marini; 3) depositi marini terrazzati; 4) Formazione delle Argille Subappennine; 5) scarpate di terrazzi marini.

2. Hydrogeological set-up

Marine Terraced Deposits (sands, conglomerates and silts), overlaid Subapennine Clays Formation (silty-clayey successions), outcrop in the upland sectors of the study area, while alluvial, transitional, marine and coastal deposits outcrop in the coastal plain and along the rivers (Polemio et al., 2003; Figure 1).
Two main types of aquifers have been distinguished in the study area. The first one encloses the aquifers of the marine terraces and the alluvial river valley deposits. The marine terrace aquifers display medium to high hydraulic conductivity and their spatial extent is regularly broken by the river valleys. The aquifers of the river valleys display generally low to medium hydraulic conductivity and they do not generally allow exploiting groundwater except in the Sinni River valley. The second type of aquifer includes the coastal plain deposits. It is a multilayered aquifer, made up of sandy permeable strata interbedded with clayey strata. The shallow sandy aquifer, characterised by low to medium hydraulic conductivity (mean value 2.28 10^{-4} m/s), is the only one exploited for any kind of practical utilisation. It reaches the depth of 45-50 m below the ground level so its bottom is below the sea level near the coast, allowing so the occurrence of seawater intrusion along the coastal strip (Polemio et al., 2002a). Moreover, the bottom altitude of the shallow aquifer decreases gently from the Sinni to the Bradano River, from SW to NE, so the occurrence of the seawater intrusion becomes progressively more favoured moving along the coast towards the north-eastern direction. Finally the shallow coastal aquifer does not outcrop everywhere due to the widespread presence of an upper almost impervious 3 to 10 meter thick stratum. In particular, where this clayey stratum exists, the aquifer results to be confined, otherwise it is generally unconfined. The recharge of the shallow coastal aquifer is mainly guaranteed by the discharge from the upward aquifers of the marine terraces and from the river leakage (Polemio et al., 2003).

3. Degradation of groundwater resources

The climate of the study area is semiarid, characterised by mean annual rainfall below 600 mm and mean annual temperature close to 17 °C. The minimum of mean monthly rainfall occurs in July and the maximum value is in November while the minimum of mean monthly temperature is in January and the maximum value in July or August.
The piezometric regime of the area has been inferred from the analysis of 60 monthly time series available for two periods, 1927-1940 and 1951-1984 (Polemio & Dragone, 2003; Polemio et al., 2004) during which the wideness of piezometric regime varies from 0.1 m to 4.8 m considering each well or time series (Polemio & Dragone, 2003). The trend of the piezometric time series has been described by the angular coefficient of the regression line through the data available continuously for two periods. A generalised negative trend (80% of the wells) has been observed in the period 1927-1940 with a piezometric decreasing trend equal to -5 cm/year on average. In this period the rainfall trend results to be slightly positive and the groundwater is the only water resource for the agriculture activities. In the 1951-1984, the piezometric trend becomes positive (75% of total available time series) notwithstanding the decreasing trend of the precipitations and of the fluvial discharges (Polemio & Dragone, 2002). Therefore, this piezometric increase seems to be mainly due to the availability of water resources distributed by aqueducts from the dams, built up in the upward area, which has allowed a reduction of groundwater tapping, creating also a sort of artificial recharge, due to over irrigation. Moreover, during 1988-1991 a heavy drought hits the area influencing

so the groundwater availability. The piezometric effects of this drought were serious and widespread, as shown by Figure 2, where the 1990 piezometric map is compared to the piezometric surface of 1953, year of a period in which the groundwater utilisation was quite low. The groundwater availability has resulted strongly influenced by increasing water demand, availability of surface water resources and water crisis due to anomalous and recent drought periods.

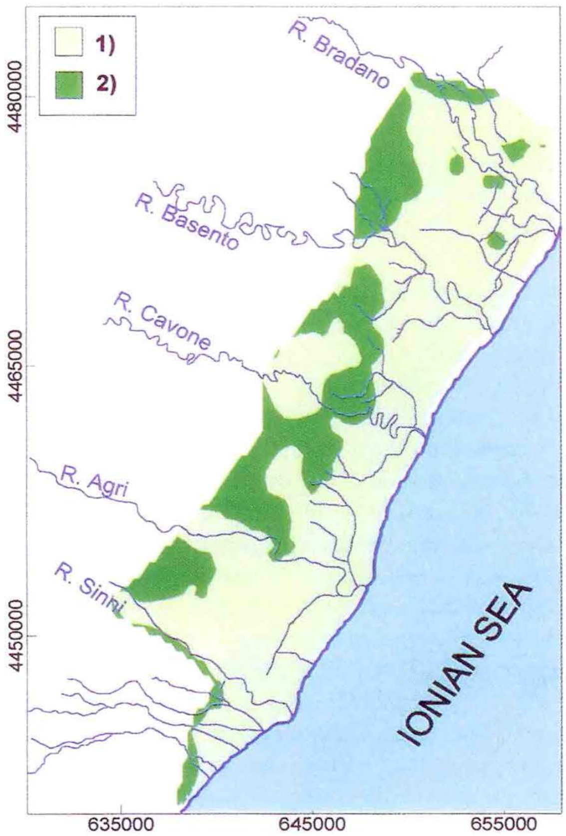


FIG. 2 - *The 1990 piezometric surface compared to the 1953 ones. 1) Negative values or piezometric decrease, 2) positive or increased values.*

Andamento della superficie piezometrica 1990 e variazioni rispetto al 1953. 1) Valori negativi o decremento piezometrico; 2) valori positivi o incremento piezometrico.

3.1. Chemical-physical features and quality of groundwater

The chemical-physical features of the groundwater flowing within the study area have been inferred from the analyses of several water samples taken by hundreds of wells, quite uniformly distributed across the study area. The groundwater temperature (ranging from 12°C to 20°C) and ph (ranging from 6 to 8) tend so to increase close to the coastal area. The variability of the major ions concentrations results to be related to many factors such as the different lithologies of aquifer soils, the seawater intrusion, the mixing with river waters and the impacting factor of intensive farming (Polemio et al., 2003).

As regards the seawater intrusion, it involves a coastal sector up to 2.5 km inland, with an average width equal to 1-1.5 km as highlighted by the spatial trend of the chemical and physical parameters, sensitive to this phenomenon (TDS, groundwater electrical conductivity, chloride, sulphate etc.; Polemio et al., 2002a).

The progressive physical and chemical degradation of the groundwater flowing in the coastal plain, occurred from 1990 to 2003, has been inferred from the chemical data analysis of several water samples taken in 250 wells, located all over the study area. In detail, historical data, collected by many institutions (Polemio et al., 2005) have been compared with recent data collected by authors.

The quality of groundwater has been classified according to the method proposed by the Italian legislative decree 152/1999, afterwards modified by the decree 258/2000. In these decrees, the environmental conditions of groundwater are defined considering the influence of the anthropic impact on the quantity and the chemical characteristics of groundwater. The selected quality classification method is defined considering a shared and quite standard approach which applies some European Directives (1991/271 and 1991/676). This approach could be easily modified to consider the application of European Water Framework Directive 2000/60 and of proposed European Directive on the protection of groundwater against pollution.

The selected method considers five classes (0-4) for the groundwater quality assessment; for each class concentration range of the basic chemical and physical parameters is defined (Table 1).

TAB. 1 - *Quality classification of groundwater based on the basic parameters. Legend: A) specific electrical conductivity at 20°C (µS/cm); B) chloride (mg/l); C) manganese (µg/l); D) iron (µg/l); E) nitrate (mg/l); F) sulphate (mg/l); G) ammonium (mg/l).*

Classificazione della qualità delle acque sotterranee considerando i parametri di base. Legenda: A) Conducibilità elettrica specifica a 20°C; B) cloruri (mg/l); C) manganese (µg/l); D) ferro (µg/l); E) nitrati (mg/l); F) solfati (mg/l); G) ammoniaca (mg/l).

Parameter	Class				
	1	2	3	4	0
A	≤400		≤2500	>2500	>2500
B	≤25		≤250	>250	>250
C	≤20		≤50	>50	>50
D	<50		≤200	>200	>200
E	≤5	≤25	≤50	>50	>50
F	≤25		≤250	>250	>250

These classes are defined according to the following scheme:

- class 1: null or negligible anthropic impact with excellent hydrochemical features of the groundwater;
- class 2: low anthropic impact which is sustainable for a long period of time, good hydrochemical features of the groundwater;
- class 3: remarkable anthropic impact with generally good hydrochemical features of the groundwater, but characterised by with some signs of anthropic influence;

- class 4: high anthropic impact with poor hydrochemical features of the groundwater;

class 0: null or negligible anthropic impact and the high values of the groundwater parameters shown in Tables 1 are of natural origin.

Moreover, for defining the chemical state of groundwater, some supplementary parameters, shown in Table 2, are also considered. If the concentrations of the inorganic pollutants are higher than the threshold values shown in Table 2, the water sample belongs to the class 0 when their origin is natural otherwise the class 4 is identified. The class 4 is also considered for the water samples with concentrations of the organic pollutants higher than the threshold values of Table 2. If the concentrations of all the pollutants are lower than the threshold values of Table 2, the groundwater is classified considering only the parameters shown in Table 1.

Finally, the mean values of the basic and supplementary parameters, with reference to the specified period of time, are considered for classifying the chemical state of the groundwater systems according to the selected classification method.

TAB. 2 - *Quality classification of groundwater based on threshold values for the supplementary parameters considered by the Italian legislative decrees (see the text).*

(1) All the organic compounds used as biocides (insecticides, herbicides, fungicides, algaecides, acaricides, nematocides etc..);

(2) Total polycyclic aromatic hydrocarbons.

Classificazione della qualità delle acque sotterranee considerando i valori di soglia dei parametri aggiuntivi indicati dal decreto legislativo Italiano (vedi testo).

(1) Tutti i componenti organici utilizzati come pesticidi (insetticidi, erbicidi, fungicidi, algacidi, acaricidi, nematocidi etc..);

(2) Idrocarburi totali policiclici aromatici

Inorganic pollutant	μg/l	Organic pollutant	μg/l
Al	≤200	Aliphatic total halogen compound of which:	10
Sb	≤5		
Ag	≤10		
As	≤10	–ethylene chloride	3
Ba	≤2000	Total pesticides(1) of which:	0.5
Be	≤4		
B	≤1000	– aldrin	0.03
Cd	≤5	– heptachlor	0.03
-CN	≤50	– heptachlor epoxide	0.03
Cr tot	≤50		
Cr VI	≤5	Other pesticides	0.1
F^-	≤1500	Acrylamide	0.1
Hg	≤1	Benzene	1
Ni	≤20	Vinyl chloride	0.5
NO_2^-	≤500	PAHs(2)	0.1
Pb	≤10	benzo[a]pyrene	0.01
Cu	≤1000		

The worse class of the whole set of parameters is considered as the reference class of the sample.

Quality data of 1990, 1999, 2002 and 2003 have been so considered and the mean values of each available basic parameter have been estimated. Based on the values obtained for specific electrical conductivity, sulphate and chloride, the groundwater flowing within the coastal plain belongs mainly to the classes 2 or worse.

In order to estimate the quality of the groundwater flowing in the coastal plain and the existence of a degradation trend, the values of the classes recognised for each year and for each selected parameter have been compared with the classes obtained for the reference period 1990-2003, applying GIS methods. Figures 3-5 show examples of the class variations of 1999 and 2003 compared with the class obtained as mean for the so called reference period 1990-2003. A general quality worsening of the groundwater with the time can be so observed (Figures 3-5).

A portion of the whole coastal plain has been selected for more detailed determinations. In the selected area, located on the coastal plain between Agri and Cavone Rivers, a greater amount of parameters and a higher well density are considered. In this area, the coastal sectors seeped by groundwater of classes 3 and 4 have been progressively enlarged with the time, as shown by the classes 2 trend recognised for the specific electrical conductivity (Figure 6). In detail, from 1999 to 2003, the mean values of the sulphate and the chloride concentrations and of the specific electrical conductivity at 20°C change respectively from 98 to 220 mg/l, from 176 to 218 mg/l, and from 1299 to 1828 mS/cm. The groundwater quality degradation and its negative trend is mainly related, concerning these variables, to an increasing effect of seawater intrusion due to an increasing discharge by wells, occurred as an effect of recent, anomalously heavy and frequent drought periods.

The quality degradation is also the effect of other phenomena. Based on the nitrate concentration, the groundwater quality belonging to the classes 2 and 3 is widespread. In detail, the areas mostly subjected to a high nitrate contamination (class 4) are mainly two: the first one is located between the Agri and Cavone River (along the coast between the Agri River mouth and the Scanzano Jonico Village, inland between this village and the Cavone River) and the other is between the Basento and Bradano Rivers (Figure 7). This increase of nitrate concentration is partly due to the higher hydraulic conductivity of the sandy and sandy-silty topsoil outcropping in the previous areas (Polemio et al., 2002b). The effect of nitrate contamination is also worsening with the time, above all in the inland areas, as shown in Figure 7.

The dramatic degradation of valuable groundwater resources of Metaponto coastal plain is not only the effect of the overexploitation and of the excess in the use of fertilizers.

Tables 3 and 4 show the whole quality characterisation of groundwater sampled by 10 selected wells during the 2003 summer. The high concentration of organic pollutants occurring with the time in the study area is a further dramatic signal which calls everyone to pursue the sustainable management of environment, applying clear limits to any kind of polluting activities and pursing the safeguard of groundwater resources and the improvement of groundwater quality.

a)

b)

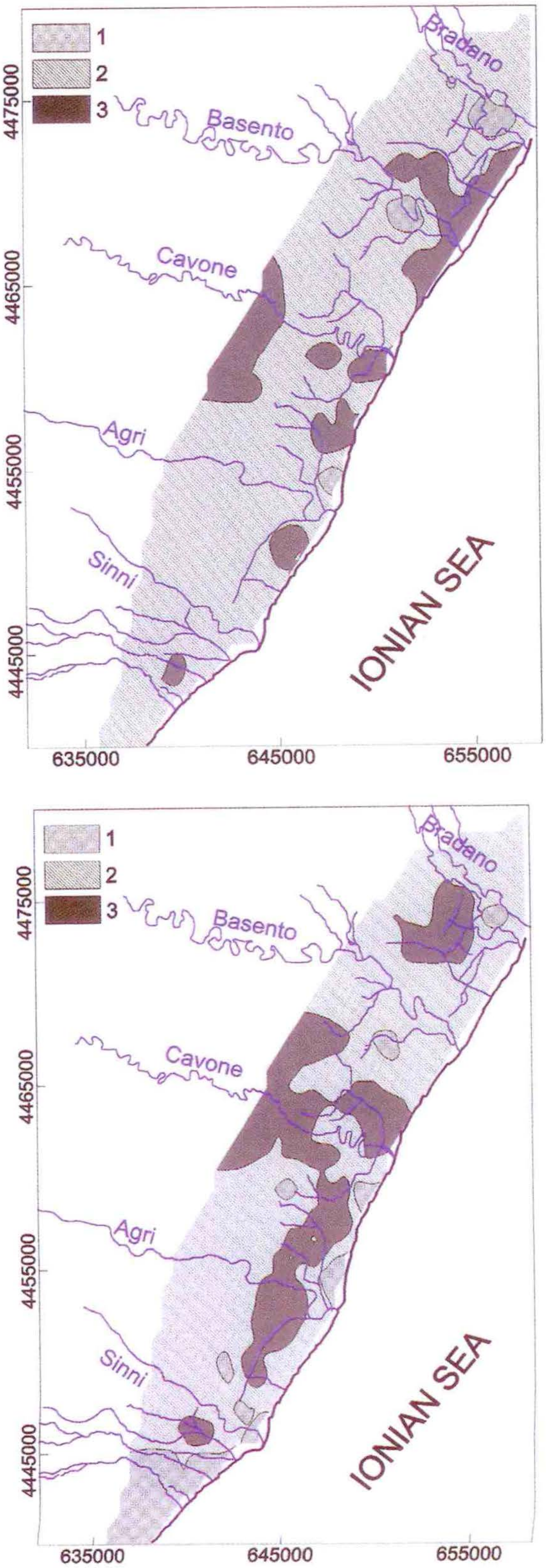


FIG. 3 - *Specific electrical conductivity at 20°C: variations of the 1999 (a) and 2003 (b) quality class compared to the class of the reference period (1990-2003). Legend: 1) class increase, 2) class unchanged, 3) class decrease.*

Conducibilità elettrica specifica a 20 °C: variazione della classe di qualità del 1999 (a) e del 2003 (b) rispetto al periodo di riferimento (1990-2003). Legenda: 1) incremento, 2) costante, 3) decremento.

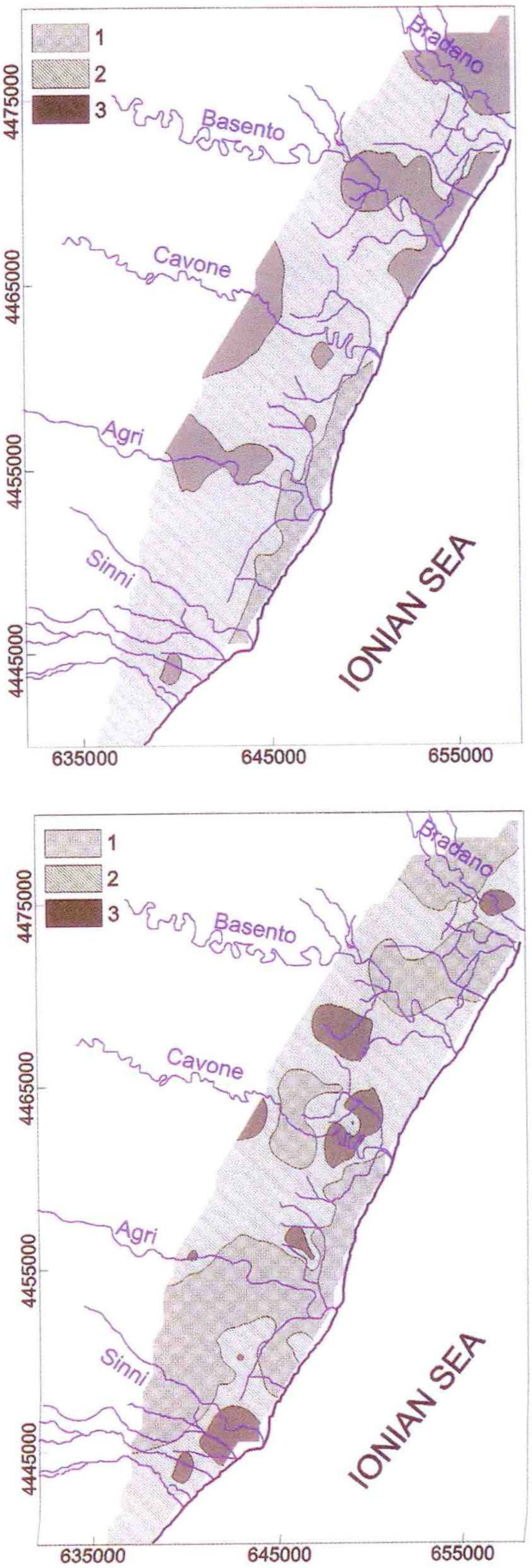


FIG. 4 - *Sulphate concentration: variations of the 1999 (a) and 2003 (b) quality class compared to the class of the reference period (1990-2003). Legend: 1) class increase, 2) class unchanged, 3) class decrease.*

Concentrazione di solfati: variazione della classe di qualità del 1999 (a) e del 2003 (b) rispetto al periodo di riferimento (1990-2003). Legenda: 1) incremento, 2) costante, 3) decremento.

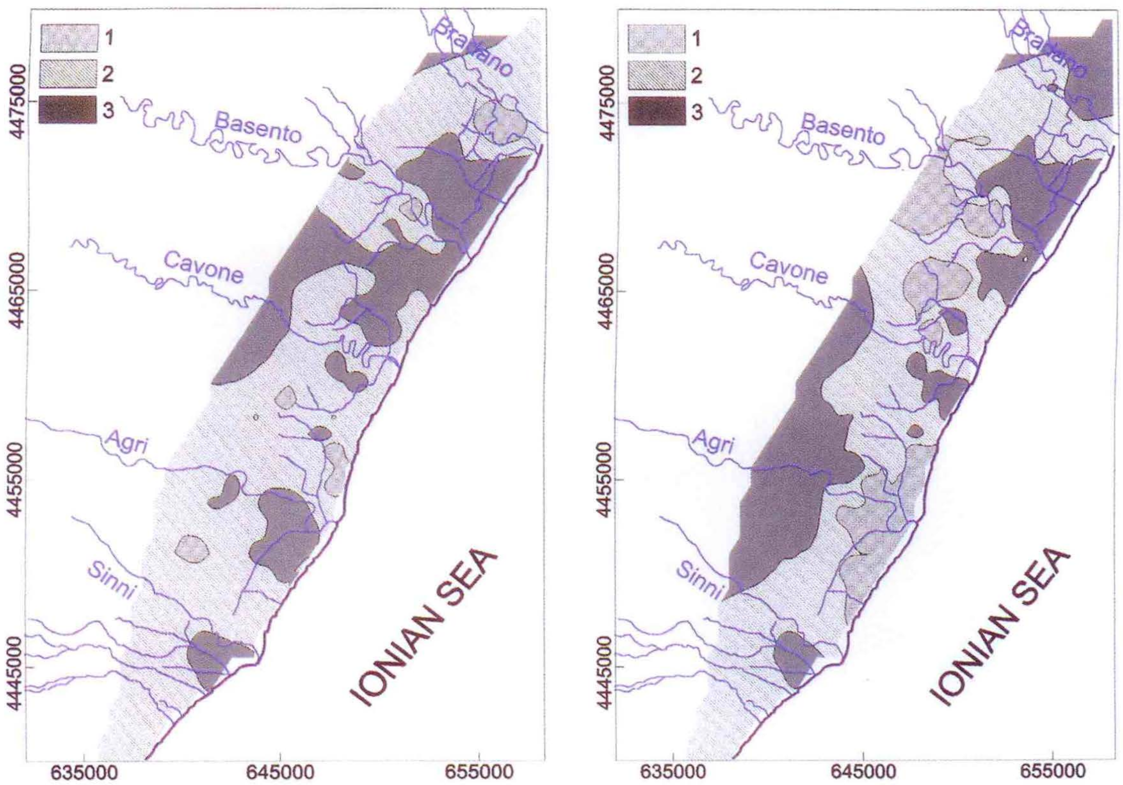


FIG. 5 - *Chloride concentration: variations of the 1999 (a) and 2003 (b) quality class compared to the reference period (1990-2003). Legend: 1) class increase, 2) class unchanged, 3) class decrease.*
Concentrazione di cloruri: variazione della classe di qualità del 1999 (a) e del 2003 (b) rispetto al periodo di riferimento (1990-2003). Legenda: 1) incremento, 2) costante, 3) decremento.

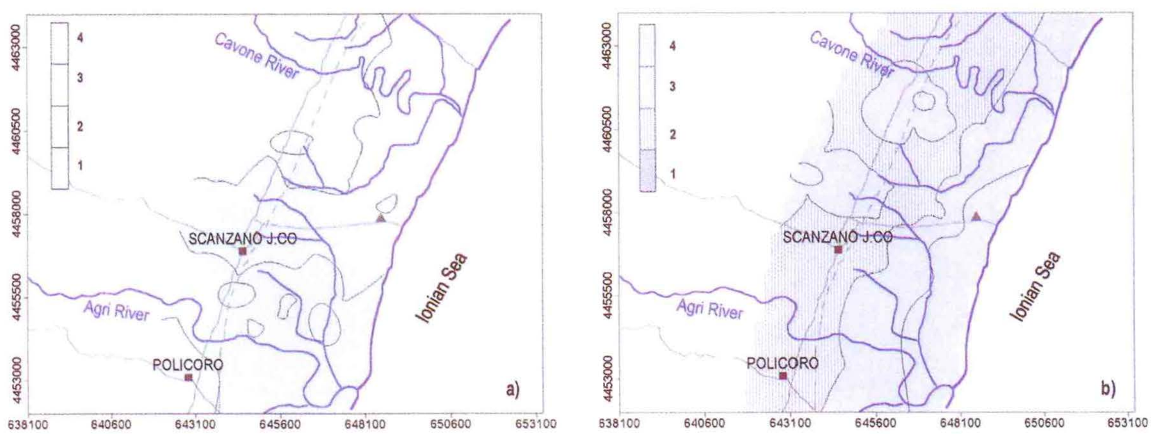
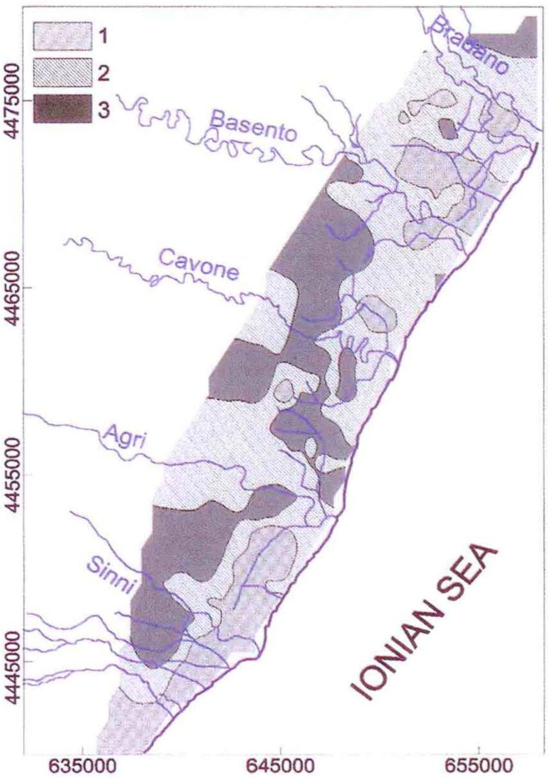


FIG. 6 - *Quality class map of the specific electrical conductivity at 20°C of groundwater: in 1999 (a) and 2003 (b).*
Mappa della classe di qualità della conducibilità elettrica specifica a 20°C delle acque sotterranee: nel 1999 (a) e 2003 (b).

a)



b)

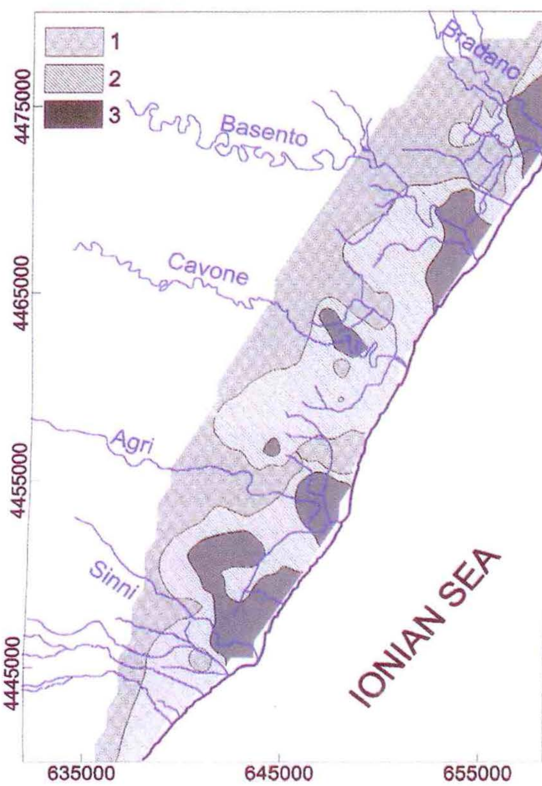


Fig. 7 - *Nitrate concentration: variations of the 1999 (a) and 2003 (b) quality class compared to the class of the reference period (1990-2003). Legend: 1) class increase, 2) class unchanged, 3) class decrease.*
Concentrazione di nitrati: variazione della classe di qualità del 1999 (a) e del 2003 (b) rispetto al periodo di riferimento (1990-2003). Legenda: 1) incremento, 2) costante, 3) decremento.

Tab. 3 - *Groundwater quality classification for the selected wells (2003) based on the basic parameters (Table 1). Legend: A) water electrical conductivity at 20°C (μS/cm); B) chloride (mg/l); C) manganese (μg/l); D) iron (μg/l); E) nitrates (mg/l); F) sulphates (mg/l); G) ammonium (mg/l).*
Classificazione della qualità delle acque sotterranee per i pozzi selezionati (2003) considerando i parametri di base (Tabella 1). Legenda: A) conducibilità elettrica specifica a 20°C; B) cloruri (mg/l); C) manganese (μg/l); D) ferro (μg/l); E) nitrati (mg/l); F) solfati (mg/l); G) ammoniaca (mg/l).

Well	A	B	C	D	E	F
CM5	2	2	1	4	4	4
CM3	2	2	1	4	4	2
CM4	2	2	1	4	4	2
CM7	2	2	1	4	4	4
CM10	2	2	4	4	2	2
FP17	2	2	4	4	2	2
FP10	2	2	1	2	1	2
MGFO	4	4	4	4	1	1
GP3	2	1	1	4	2	2
GP10	2	1	4	4	1	1

4. CONCLUSION

The progressive degradation of the groundwater resources of the Metaponto coastal plain emerges clearly from the hydrogeological, physical and chemical data coming from the groundwater sampled in this area.

The preliminary study carried out on the physical and chemical state of the groundwater has shown a progressive enlargement of the areas with the worse anthropic impact (class 4). As regards the highest values of the specific electrical conductivity of groundwater, the sulphate and the chloride, recognised along the coastline, are related to an increase of seawater intrusion, as an effect of the intense overexploitation of the wells, triggered by a series of drought periods, as shown also by quantity degradation analysis. The influence of the anthropic input on the quality of the studied groundwater systems has been also highlighted by both the increase of nitrate concentration, occurred from 1990 to 2003, and the concentrations of some organic pollutants.

TAB. 4 - *Groundwater quality classification for selected wells (2003), based on supplementary parameters. Legend: *) concentration lower than the threshold values of Table 2, a) PAHs, b) benzo[a]pyrene, c) aldrin, d) dieldrin, e) heptachlor.*
Classificazione della qualità delle acque sotterranee, per i pozzi selezionati (2003) considerando i valori di soglia dei parametri aggiuntivi. Legenda: *) concentrazione inferiore al valore di soglia della Tabella 2, a) Pesticidi Totali, b) benzo[a]pirene, c) aldrin, d) dieldrin, e) eptacloro.

	Inorganic pollutant (µg/l)													Organic pollutant (µg/l)				
Well	Al	As	B	Ba	Be	Cd	Cr(tot)	Cu	Hg	Ni	Pb	Se	Zn	a	b	c	d	e
CM5	*	*	*	*	*	*	*	*	*	*	*	*	*	4	4	*	*	*
CM3	*	*	*	*	*	*	*	*	*	*	*	*	*	4	4	*	*	*
CM4	*	*	*	*	*	*	*	*	*	*	*	*	*	4	4	*	*	*
CM7	*	*	*	*	*	*	*	*	*	*	*	*	*	4	4	*	*	*
CM10	*	*	*	*	*	*	*	*	*	*	*	*	*	4	4	*	*	*
FP17	*	*	*	*	*	*	*	*	*	*	*	*	*	4	4	*	*	*
FP10	*	*	*	*	*	*	*	*	*	*	*	*	*	4	4	*	*	*
MGFO	*	4	*	*	*	*	*	*	*	*	*	*	*	4	4	*	*	*
GP3	*	*	*	*	*	*	*	*	*	*	*	*	*	4	4	*	*	*
GP10	*	*	*	*	*	*	*	*	*	*	*	*	*	4	4	*	*	*

RIASSUNTO ESTESO

L'area di studio corrisponde alla piana costiera Ionica, meglio conosciuta come Piana di di Metaponto, che si estende dalla foce del fiume Sinni a quella del Bradano e che comprende anche i fiumi Agri, Cavone, e Basento. Durante il ventesimo secolo, i lavori di bonifica, la costruzione di oltre una decina di dighe o traverse nelle porzioni poste più a monte nei bacini idrografici che attraversano la Piana nonché l'introduzione di reti irrigue servite da acque addotte dagli invasi, lo smaltimento di acque reflue e il carico inquinante dovuto alle attività industriali ed agricole, non opportunamente pianificati e gestiti, hanno modificato profondamente la quantità e la qualità delle acque sotterrane della pianura costiera.
La progressiva degradazione chimico-fisica delle acqua sotterranee, verificatasi nel corso degli anni, specialmente nel recente periodo 1990-2003, è stata caratterizzata analizzando dati di circa 250 pozzi, mentre lo stato quantitativo delle stesse è stato valutato considerando i livelli piezometrici misurati (non sempre regolarmente) dal 1927 al 2003. Questa ricerca riporta alcuni risultati dell'attività effettuata dagli autori per il Progetto di ricerca finanziato dalla Commissione Europea "Tecnologie di cristallizzazione per la prevenzione dell'intrusione marina" (Polemio ed al., 2005), durante la quale la caratterizzazione idrogeologica dell'intera piana è stata finalizzata alla selezione del "test site" per sperimentare una tecnologia innovativa per la realizzazione di barriere fisiche all'intrusione marina.
La qualità delle acque sotterranee è stata classificata secondo il metodo proposto dal decreto legislativo italiano 152/1999, in seguito modificato dal decreto 258/2000. In questi decreti, le condizioni ambientali delle acque sotterranee sono definite considerando l'influenza dell'impatto antropico sulla quantità e le caratteristiche chimiche delle stesse. Il metodo selezionato di classificazione qualitativa è definito considerando un approccio semplice, condiviso e alquanto standard, che applica alcuni indirizzi europei (1991/271 e 1991/676). Questo metodo potrebbe essere facilmente modificato ed adattato alla direttiva quadro europea dell'acqua 2000/60 e alla proposta Direttiva Europea sulla protezione delle acque sotterranee contro l'inquinamento. Il metodo selezionato considera cinque classi (0-4) per la valutazione della qualità delle acque sotterranee; per ogni classe è stabilito un intervallo di concentrazione per i parametri chimico-fisici di base.
La progressiva degradazione qualitativa delle risorse idriche sotterranee della piana costiera di Metaponto emerge chiaramente dai dati idrogeologici, fisici e chimici che provengono dall'analisi dei campioni d'acqua prelevati nell'area in esame.
Lo studio effettuato sullo stato chimico-fisico delle acque sotterranee ha mostrato un allargamento progressivo delle zone ad impatto antropico peggiore. Per quanto riguarda gli alti valori della conducibilità elettrica specifica, dei solfati e dei cloruri delle acque analizzate, rilevati lungo la fascia costiera, essi sono correlati all'aumento del fenomeno dell'intrusione marina, come effetto del sovrasfruttamento dei pozzi, innescato da una serie di periodi di siccità, come indicato dallo studio sulla degradazione quantitativa. L'influenza delle attività antropiche sulla qualità della risorsa idrica studiata è stata anche evidenziata dall'incremento della concentrazione di nitrati, verificatosi fra il 1990 e 2003, e di alcune sostanze inquinanti organiche.

La tendenza diffusa alla degradazione qualitativa delle acque sotterranee indica che il rischio di ulteriore peggioramento della qualità di queste importanti risorse idriche è elevato.

L'approccio metodologico alla classificazione di qualità è risultato essere semplice da applicare e facile da replicare.

Bibliography

D. Lgs. del 11 Maggio 1999 n. 152 - Posizioni sulla tutela 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.154 suppl. del 29 maggio 1999, Roma, .

D. Lgs del 18 agosto 2000 n. 258 – Disposizioni correttive e integrative del decreto legislativo 11 maggio 1999, n. 152, in materia di tutela delle acque dall'inquinamento, a norma dell'articolo l, comma 4, della legge 24 aprile 1998, n. 128. G.U. n. 218, suppl. n. 153/L del 18 settembre 2000, Roma

Polemio, M. & Dragone, V. (2003) - Gli effetti antropici e climatici sulla disponibilità delle acque sotterranee della piana Ionico-Lucana. Atti del I Congresso Nazionale AIGA, Chieti, 603-614.

Polemio, M. Dragone V., Limoni, P.P. Mitolo, D. & Santaloia, F. (2005) - CNR-IRPI, Project CRYSTECHSALIN, first, second and third year of activity, report on work packages 6 and 12. European Commission, V Framework Programme, Brussels, 128 p.

Polemio, M. Dragone, V. & Mitolo, D. (2004) - La siccità e la disponibilità di riserve idriche sotterranee nella piana di metaponto (Basilicata). Accademia Nazionale dei Lincei – Giornata Mondiale dell'Acqua "La siccità in Italia", Roma, 21 marzo 2003, 237-244.

Polemio, M. Limoni, P.P. Mitolo, D. & Santaloia, F. (2002a) - Characterisation of ionian-lucanian coastal aquifer and seawater intrusion hazard. Proc. of 17th Salt Water Intrusion Meeting, Deft, Netherlands, 422-434.

Polemio, M. Limoni, P.P. Mitolo, D. & Santaloia, F. (2002b) – Nitrate content characterisation of Ionian coastal groundwater. Proc. of IAH Eurometeeting, Nitrate in Groundwaters in Europe, Wisła, 4-7 June 2002, 163-176.

Polemio, M. Limoni, P.P. Mitolo, D. & Santaloia, F. (2003) – Characterisation of Ionian-Lucanian coastal plain aquifer. Boletín Geológico y Minero, 114 (2), 225-236.