Natural Hazards and Earth System Sciences (2005) 5: 127–136
SRef-ID: 1684-9981/nhess/2005-5-127
European Geosciences Union

Geophysical and stratigraphical research into deep groundwater and intruding seawater in the mediterranean area (the Salento Peninsula, Italy)

S. Margiotta and S. Negri

Dipartimento di Scienze dei Materiali, Osservatorio di Chimica, Fisica e Geologia Ambientali, Università degli Studi di Lecce, Italy

Received: 30 July 2004 – Revised: 22 November 2004 – Accepted: 23 December 2004 – Published: 25 January 2005

Part of Special Issue "Natural and anthropogenic hazards in karst areas"

Abstract. Geological, geophysical and hydrological surveys were performed in an area between Lecce to the North and Otranto to the South on the Lower Adriatic coast of Italy in order to verify the "state of health" of the ground water in the deep aquifer, which is characterised by Mesozoic carbonatic formations and is permeable due to fracturing and karstic phenomena. This area was chosen because it is highly urbanised, and contains many wells, some of which were intensively studied from a geological and hydro-geological point of view in 1987. The first phase of the research consisted of a stratigraphical and geological study, based on geological surveys of the surface and the subsoil by direct observation of borehole cores and the collection and analysis of existing stratigraphical data on wells in the area. The stratigraphical and hydrogeological data are kept in the archives of local agencies. The collected data were organised in a single database managed by an appropriate software (ARCVIEW). Numerous geological cross sections of the territory were studied in order to characterise the subsoil. Subsequently, multi-parameter surveys (O_2, pH, temperature, TDS, conductivity) were carried out on the water-column of certain wells selected from those studied in 1987. This was to verify possible changes in the state of the groundwater since 1987. The surveys were carried out in two different periods (May and September) in order to identify potential differences between rainy and dry periods. Moreover, electrical tomography was used to characterise the various subsurface geological formations and possible saline water intrusion where direct information collected from the wells was lacking.

From the research conducted it was possible to effect a stratigraphical characterisation of the subsoil and to verify overexploitation of the water resources resulting from the increasing number of wells, and the consequent deterioration of the aquifer due to saline water intrusion. The research also confirms the validity of geophysical methods for the study of hydro-geological issues.

Correspondence to: S. Negri
(sergio.negri@unile.it)

1 Introduction

The Salento peninsula (Puglia, Italy) (Fig. 1) possesses very few superficial water resources because of its karstic nature; it does have remarkable underground resources however, which have made settlement and the development of productive activities possible across wide areas.

The nature of such underground water resources, the particular phenomena that regulate the outflow and feeding processes and the effects exercised by the sea mean that the correct use and management of underground water resources is essential. Deterioration of underground waters results from both saline contamination and human-generated pollution. The last few years have seen a gradual and constant fall in the volume of underground waters available in the main water-structures of the region (the Gargano, Tavoliere, Murge and Salento areas), consequent of the overexploitation of groundwater resources. This in turn has led to growing salt contamination resulting from the continental invasion of marine waters (Maggiore and Pagliarulo, 2003). Research has shown that the rising salinity levels of the ground water is a more serious problem than the contamination of the soil by various pollutants (Fidelibus and Tulipano 2002; Maggiore and Pagliarulo, 2002, 2003; Tulipano and Fidelibus 1999, 2002). Wasteful uses of water are fundamental causes of desertification and environmental degradation and thus, Puglia, including the Salento, turns out to be one of the regions most threatened by this problems (Glenn et al., 1998; Zito, 2003). Furthermore, the cited literature shows how the karstic nature of the coastal aquifers of the Salento and the Murge consti-

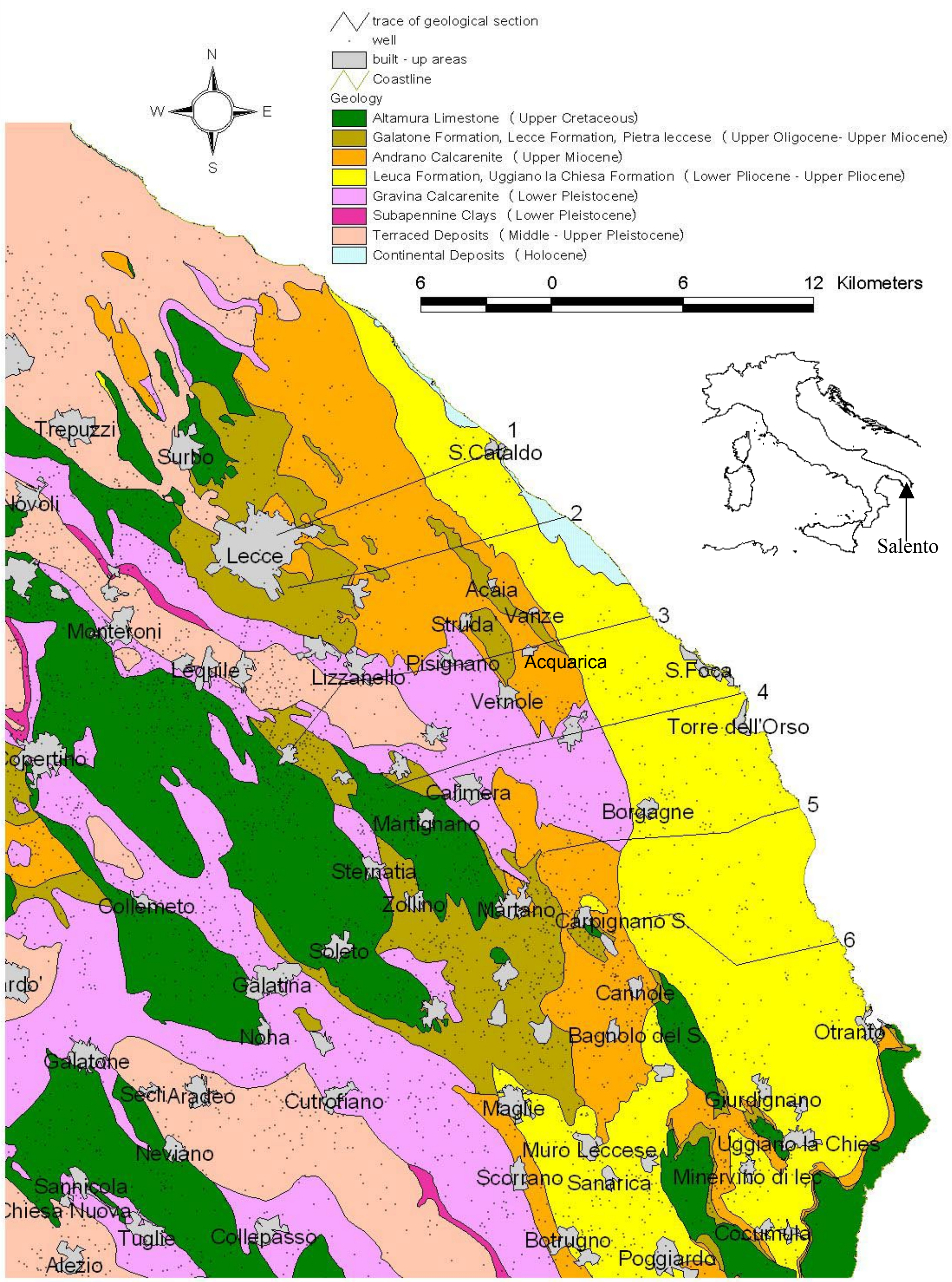

Fig. 1. Location of studied area and geological map.

tutes a important risk factor, since the underground karstic channels may represent routes of rapid and deep saline intrusion. However, in these studies it emerged that the shortage of information, due to the limited number of points of observation, did not allow for a reliable evaluation of the deterioration of underground water resources.

The objective of this work is the physical and stratigraphical characterisation of the subsoil of an Adriatic coastal area located south of Lecce, and to verify "the state of health" of the aquifer holding the deep waters of Salento. This area was characterised in a previous study (Margiotta and Tadolini, 1987), where the authors carried out geological and hydro-geological research, including multi-parameter surveys of the water-columns of many wells pertaining to the land-improvement consortium known as "Consorzio Bonifica Ugento li Foggi" (CBU).

Our study sought to verify possible changes to the state of the groundwater with respect to the earlier surveys. Stratigraphical data on existing wells were collected and analysed in the light of new geological knowledge of the territory. The stratigraphic and geological data are kept in the archives of the following local agencies: “Acquedotto Pugliese, Ente Irrigazione, Consorzio di Bonifica Ugento li Foggi” and “Consorzio di Bonifica dell’Arneo”.

The collected data were organised into a single database managed by an appropriate software (ARCVIEW). In addition, analysis of the rocks was also carried out and numerous geological cross sections of the territory were prepared.

The hydro-geological surveys were carried out in two different periods (May and September) in order to identify potential differences between rainy and dry periods. The wells considered in this study have never been used either for drinking water or irrigation.

In order to test the reliability of electrical tomography and induced polarisation testing as methods for the characterisation of subsurface geological formations and the detection of possible saline water intrusion, geophysical surveys were carried out in an area for which stratigraphical data were already available.

2 Geological and hydrogeological setting

The investigated area represents a complex hydro-geological environment. The Salento is characterised by two aquifers: the first (i.e. the closest to the surface) is made up of Mio-Plio-Pleistocene sediments holding one or more bodies of groundwater. The geometry of the latter is often hard to determine, since they lie in limited intervals of permeable rock in a more general context of impermeable deposits. The second, deep, aquifer is made up of Mesozoic carbonatic formations.

From the abundant literature on the subject (Cotecchia, 1977; Cotecchia et al., 1983, 1998, 2001; Polemio and Limoni, 1995) it comes out that the groundwater contained in the deep aquifer lies entirely on sea water of continental invasion. In cross section, the groundwater has the form of a lens, with its greatest thickness in the centre of the peninsula. The aquifer is highly permeable, and the gradient of the water table heading towards the sea is extremely low (0.01%–0.02%). Between the fresh and the salt water there is a transitional layer whose thickness declines as it gets closer to the coast.

A stratigraphical and geological study was also carried out in order to characterise the subsoil. The stratigraphical data from Margiotta and Tadolini (1987) were enriched with data from 200 stratigraphies performed on other wells; the resulting integrated database was analysed on the basis of up-to-date geological knowledge of the territory (Bossio et al., 1998, 1999; Margiotta, 1999; Margiotta and Ricchetti, 2002; Margiotta and Varola, 2004). The research and the methodologies applied have made it possible therefore to measure in detail, for the first time in the literature on this region, the horizontal area, depth and thickness of the lithostratigraphical formations.

The following litostratigraphic formations, from the most ancient to the most recent, were recognised (Fig. 1):

- Altamura Limestone (Upper Cretaceous)
- Galatone Formation (Upper Oligocene)
- Lecce Formation (Upper Oligocene – Lower Miocene)
- Pietra Leccese (Lower Miocene – Upper Miocene)
- Andrano Calcarenite (Upper Miocene)
- Leuca Formation (Lower Pliocene)
- Uggiano la Chiesa Formation (Lower – Upper Pliocene)
- Gravina Calcarenite (Pleistocene)

Outcrops of Altamura Limestone are extensive in the area north of Lecce and in the area between Caprarica di Lecce to the north, Zollino to the south-west and Martano to the south-east. These are the highest reliefs in the territory under study. This formation is made up of alternating layers of variable thickness of compact limestones and dolomitic limestones of white and grey colour. The Cretaceous limestones are characterised by folding along a NNW-SSE axis, locally associated with faults. These phenomena have created a system of faults forming small horsts (known as “Serre”) and Grabens (Figs. 2 and 3). Karst was able to develop along these lines of structural weakness. The Mesozoic rocks are always very permeable, due to both fracturing and karst, and hold the deep groundwater of Salento.

Galatone Formation (Upper Oligocene) crop out southwest of Lecce and near Otranto. It is characterised by very thin alternating layers of micritic compact grey-white limestones, marls and sandy clay deposits. On the whole the thickness of the formation varies between 10 m and 70 m. The permeability of Galatone Formation is variable, due to the variable lithological types.

Lecce Formation (Upper Oligocene-Lower Miocene) is characterised by calcarenites varying from white to light brown, with thickness not greater than 60 m. This formation was previously considered as belonging to the “Pietra leccese” formation. Outcrops of this latter are extensive around Lecce, in an area bounded by Strudà, Vernole and Acaia, and in further area between Martano, Zollino and Maglie. This formation is made up of compact and detrital limestones. Its thickness reaches the maximum value of about 80 m, based upon data from wells.

Andrano Calcarenite is made up of marl limestones and calcarenites of grey colour, with a maximum thickness of 50 m. The calcarenite is sometimes fine-grained and compact, while in other cases medium-grained, porous and friable.

Uggiano la Chiesa Formation is detritic and carbonatic and crops out along a strip near the Adriatic sea, with maximum thickness just over 50 m.

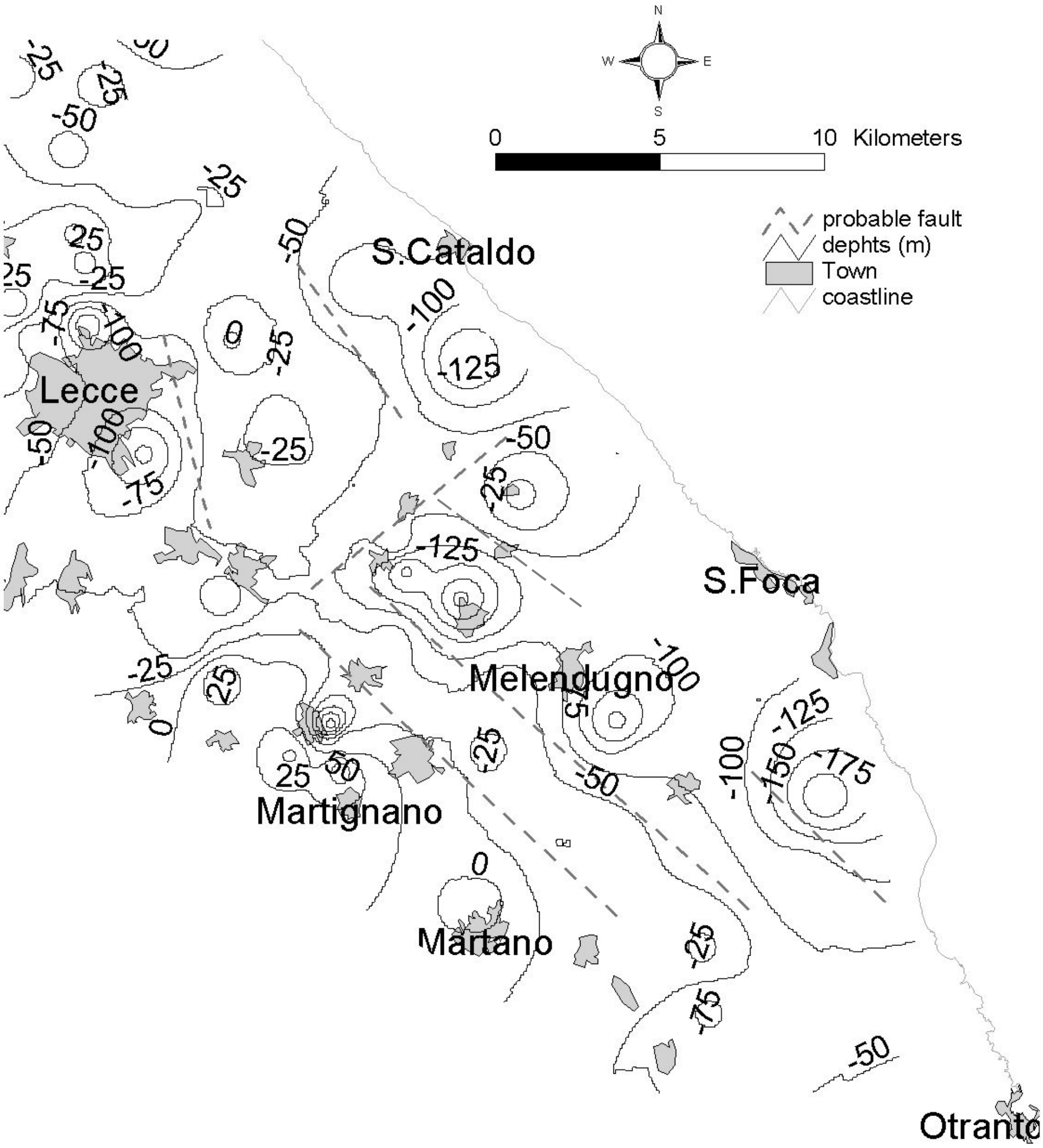

Fig. 2. Top of the carbonatic Cretaceous basement (elaboration with Arcview software).

As already mentioned, the Miocene and Pliocene formations are practically impermeable, although they may present permeable intervals which allow the formation of groundwater bodies relatively close to the surface.

Gravina Calcarenite is characterised by yellow coarse-grained calcarenites, with frequent macro and microfossils.

The stratigraphies collected highlight the following:

– Particularly important, especially in terms of its implications for the hydro-geological features of the site, is the configuration of the Cretaceous formation, the upper surface (Fig. 2) of which rarely rises above sea level. The deep groundwater is thus confined in these Cretaceous deposits by the overlying Miocene sediments (generally impermeable). In the area under study, the Cretaceous sediments contain many faults and form a horst located immediately to the east of Lecce. The top of this horst is 10–20 m above sea level. In adjacent areas, the Cretaceous sediments are delimited by normal faults along a NW-SE axis (Figs. 2 and 3), and form grabens the tops of which lie up to 150 m below sea level.

– In the area bounded by Lecce to the north, Vernole, Lizzanello and Cavallino to the south and the coastline between S. Cataldo and S. Foca to the east, the Oligocene sediments of the Galatone Formation and the Oligo-Miocene sediments of the Lecce Formation reach their greatest thickness (80 m for the continental formation and 60 m for the marine formation); in the same area, the Miocene sediments of Pietra leccese and Andrano Calcarenite also reach significant thickness, about 80 m and 50 m, respectively. Moreover, in the area near the coast, the Pliocene sediments of the Leuca Formation (a

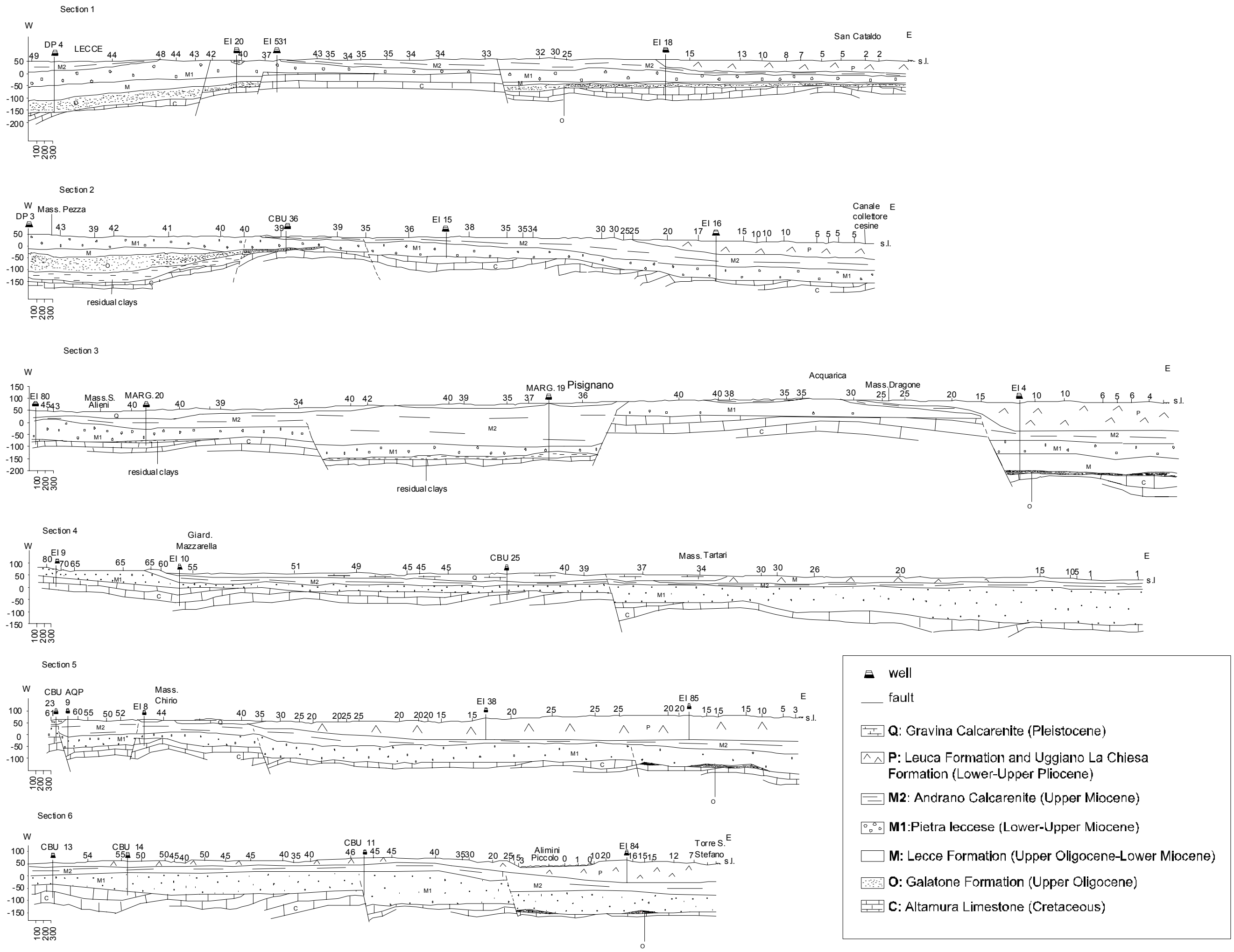

Fig. 3. Geological sections.

few metres) and the Uggiano la Chiesa Formation (up to 50 m) cover the Miocene deposits.

– North of the above-described area, Pietra leccese rests directly in transgression on a Cretaceous basement, with variable thickness.

– In the area between "Otranto" and "S. Foca", the Miocene deposits, resting directly on the Cretaceous limestones, are covered in turn by Pliocene deposits of the Leuca and Uggiano la Chiesa Formations.

In conclusion, the deep groundwater is unconfined in the area north of Lecce where the Mesozoic limestones crop out, and where the outcropping generally impermeable Neogene sediments do not go below sea level. In the rest of the study area, on the other hand, the deep groundwater is generally confined.

3 Hydrological surveying

Fifteen multi-parameter measurements were taken in wells bored in the deep groundwater (Fig. 4) located in the area managed by the Consorzio Bonifica Ugento li Foggi (CBU). Two cycles of measurements were carried out: in May 2003, the period when the recharging of the aquifers is at its height, and in September, at the end of the irrigation season and before the winter rains. In the course of the survey the depth of the piezometric level was also measured.

Separate measurements were taken with 1 m pace, collecting data on various parameters: O_2, pH, temperature, TDS (salinity), conductivity. The probe used was a Hydrolab mini sonde 4 (MS 4). From the hydrological measurements conducted, it emerged that:

1. In many wells the piezometric level is deeper than in 1987 (Table 1). With the exception of the wells 21, 26 and 28, where there was no significant difference, the piezometric level was between 0.3 and 1.45 m lower.

2. The temperature showed no significant changes (Fig. 5).

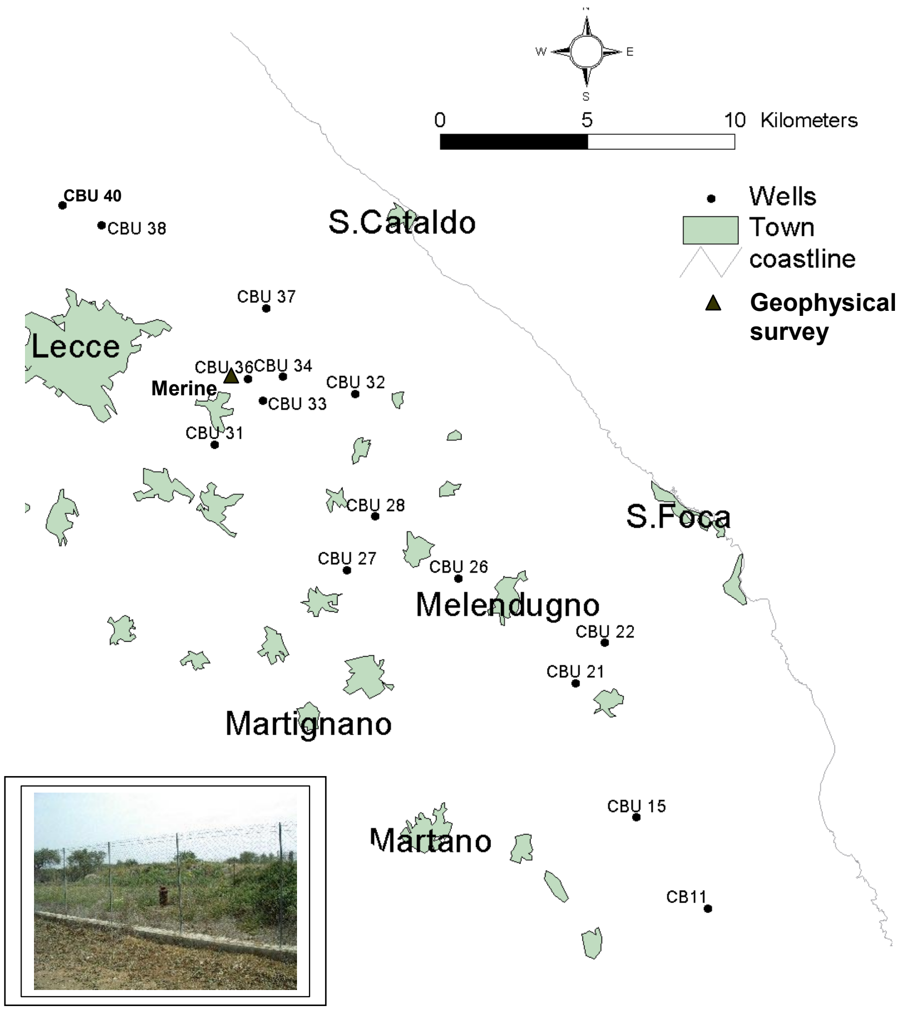

Fig. 4. Location of the investigated wells and of geophysical survey.

Table 1. Piezometric levels measured in 1987 and 2003.

Well	X	Y	Z	P.L.–1987	P.L.–May 2003	P.L.–Sept. 2003
CBU 11	2810575	4452846	43.69	25.38	21.42	21.37
CBU 15	2808157	4455926	33.65	3.64	3.35	3.22
CBU 21	2806105	4460473	34.78	4.61	4.06	3.94
CBU 22	2807075	4461844	26.20	6.21	5.65	5.80
CBU 26	2802113	4463997	46.56	3.18	2.75	2.75
CBU 27	2798364	4464277	39.98	3.72	4.24	4.05
CBU 28	2799323	4466101	37.20	3.55	3.40	3.04
CBU 31	2793894	4468538	46.35	3.26	2.77	2.81
CBU 32	2798657	4470256	39.21	3.33	3.01	2.97
CBU 33	2795511	4470040	42.20	3.23	2.78	2.78
CBU 34	2796200	4470835	36.71	3.17	2.81	2.85
CBU 36	2795007	4470774	40.01	3.16	2.71	2.71
CBU 37	2795643	4473167	35.85	3.57	3.05	3.05
CBU 38	2790052	4475973	35.92	3.44	2.02	2.02
CBU 40	2788720	4476641	34.96	2.32	1.93	2.01

ID	geographycal coordinate						stratigraphy				
CBU 28	X	Y	g.l.(m)	CA	FL	FG	PL	CdA	FU	FdL	CG
	2799323	4466101	37.2				Miocene=37.20 m				
survey of I04-06-87			survey of 02-05-03			survey of 25-09-03					
P.L.(m/gl)	P.L.(m/sl)		P.L.(m/gl)	P.L.(m/sl)		P.L.(m/gl)	P.L.(m/sl)				
33.65	3.55		33.8	3.4		33.8	3.04				

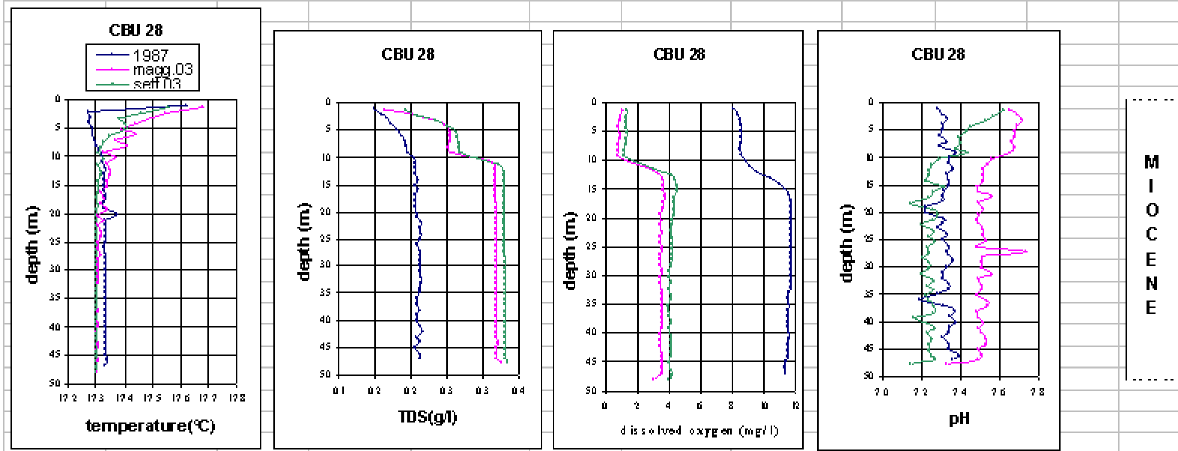

Fig. 5. Results of survey in the well CBU 28.

3. In many wells (11, 15, 21, 22, 27, 28, 34, 37 and 40), the TDS was 0.2–0.5 g/l higher than in 1987, while in some (26, 31, 32 and 36) it was 1–2 g/l higher.

4. The 2003 dissolved oxygen values were lower than in 1987.

5. The pH in many wells rose slightly, up to 8.

These data show that a generalised diminution of the volume of fresh water available in the area under study is in progress. The lowering of the piezometric levels and the rise in salinity unambiguously show the deterioration in both quantitative and qualitative terms of the water resources, driven essentially by over-exploitation and saline contamination. Furthermore, the pH values, together with the diminution of dissolved oxygen, point to the possibility of pollution deriving from substances from the soil. In order to support this hypothesis it would be necessary to conduct specific chemical and bacteriological tests.

4 Geophysical surveying

Geophysical surveys were carried out in an area near the well 36 (Fig. 4). In addition, we carried out thermo-salinometric surveys. This area was thus selected as a site where the electrical methods (electrical tomography and induced polarisation) were tested in order to verify their utility in hydrogeological research.

The following arrays were used for resistivity: pole-dipole, Wenner and Wenner-Schlumberger. Forty-eights, 5m spaced, electrodes were used. The Wenner array was chosen because it better identifies the different subsurface geological formations. The Wenner-Schlumberger array provided horizontal and vertical resolution and the pole-dipole array was used to obtain data from deeper levels. For induced polarisation only the pole-dipole array was used.

To obtain 2D resistivity models the experimental data were inverted using the RES2DINV software (Loke, 1999), which uses the rapid inversion algorithm of Loke and Barker, 1996.

The 2D resistivity model (Fig. 6a) obtained using the pole-pole array showed four electrical layers:

1. A superficial electro-layer with a depth of about 0–13 m and resistivity values of 60–110 ohm.m;

2. An electro-layer with a depth of about 13–40 m and resistivity values of 200–300 ohm.m;

3. An electro-layer with a depth of about 40–50 m and resistivity values of 110–220 ohm.m;

4. An electro-layer with a depth of about 50–63 m and resistivity values of 50–100 ohm.m.

Considering the stratigraphy shown in Fig. 6c, electro-layers 1 and 2 correspond to the Miocene formation; unfortunately there are not stratigraphical data to distinguish which one of Miocene formation. The lower resistivity values in electro-layer 1 are due to infiltration of rainwater. The resistivity values of electro-layer 2 indicate that it is relatively impermeable; it thus forms the bed of a superficial, seasonal groundwater body.

The other third electro-layers corresponds, respectively, to the Galatone Formation, and to the aquifer formed by the Cretaceous limestones.

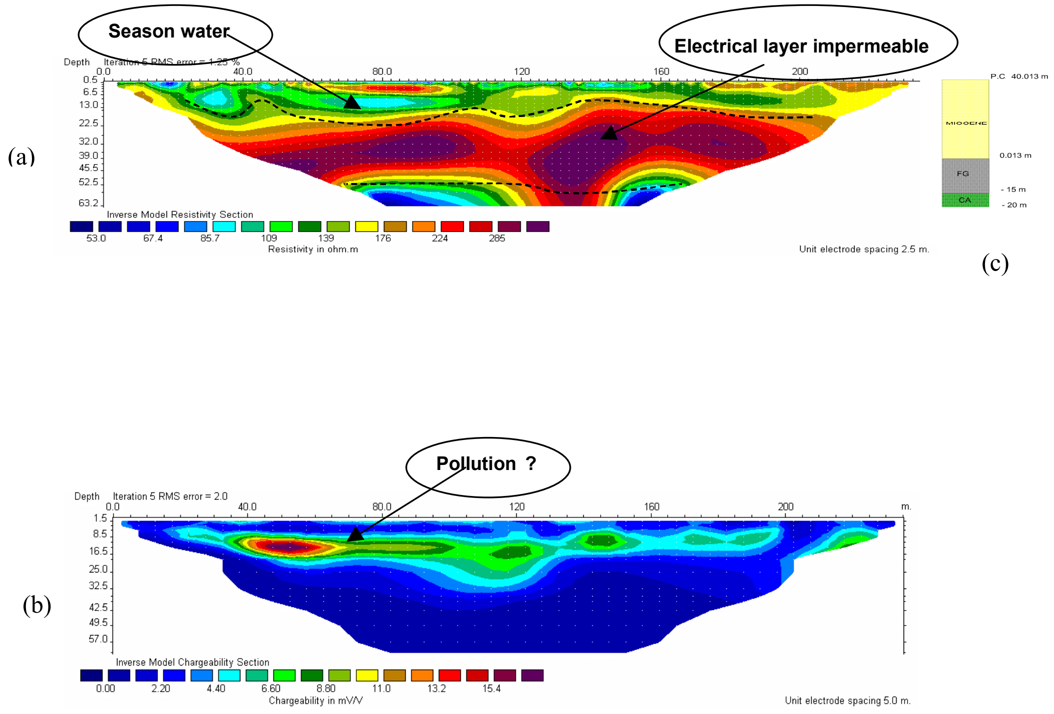

Fig. 6. (a) 2D resistivity model (pole-dipole array); **(b)** 2D chargeability model (pole-dipole array); **(c)** Stratigraphic succession of CBU 36 well.

The 2D resistivity models (Fig. 7) obtained using the Wenner and Wenner-Schlumberger arrays show more clearly the significant difference in resistivity values between the first and the second electro-layers.

The results of the induced polarisation (Fig. 6b) highlights a 8–20 m thick layer with high chargeability values (7 mV/V–16 mV/V). This is probably caused by pollution deriving from infiltration from the surface. The results of the electrical tomography qualitatively indicate the permeability of the various layers and show the piezometric level of the deep aquifer (about 55 m below the surface). These results are in good agreement with the stratigraphies (Fig. 6c). The resistivity values (50–100 ohm.m) also show that the groundwater has low salinity, in agreement with hydrological measurements performed on water drawn directly from the well 36. Moreover the induced polarisation method proved to be useful because it highlighted areas possibly affected by pollution, in agreement with the data for pH values (about 8) and dissolved oxygen (lower values than those recorded in 1987) and with the observation that the well 36 is near an illegal rubbish dump containing dangerous waste. More detailed information on the state of health of the subsoil would require chemical and bacteriological analysis.

5 Conclusions

The surveys conducted for the present study have contributed to characterise the aquifer containing the deep groundwater in the area east of Lecce. They have shown that the piezometric level has fallen in the period 1987–2003 by an average of 0.50 m (maximum 1.50 m) particularly in the area north and east of Lecce. This observation is very important because the surveys conducted have detected a fault in the Cretaceous Limestones and in the Miocene calcarenites, with a slip of 40–70 m, located near the the built-up areas of Strudà and Pisignano (Fig. 2 and Sect. 3 in Fig. 3) at southeast of Lecce. This fault probably constitutes a preferential line of drainage for rainwater and favours the local recharging of the aquifer in the area to the south. The lower values of the piezometric level reflect a fall of several metres in the thickness of the deep groundwater. Moreover, a rise in total salinity has been recorded, due to the intrusion of saline water by continental invasion. This increase has implications for domestic and agricultural water supply. The pH values have risen slightly with respect to the data from 1987 but this parameter is not significant given that the values range from 5.0 to 8.5. However, an increase in the pH and a fall in dissolved oxygen concentrations may indicate pollution from the discharge of dangerous substances into the ground, also supported by the results of the induced polarisation tests. The high pH values recorded for the well 36 are supported by the results of the induced polarisation tests. The results of the electrical tomography surveys are in agreement with the stratigraphies (Fig. 6c) and they provide further information on the differing water content of the various formations. These results also show that the deep groundwater lies 55 m below the surface and has resistivity values that indicate low salinity, as supported by the analysis of water from the well 36.

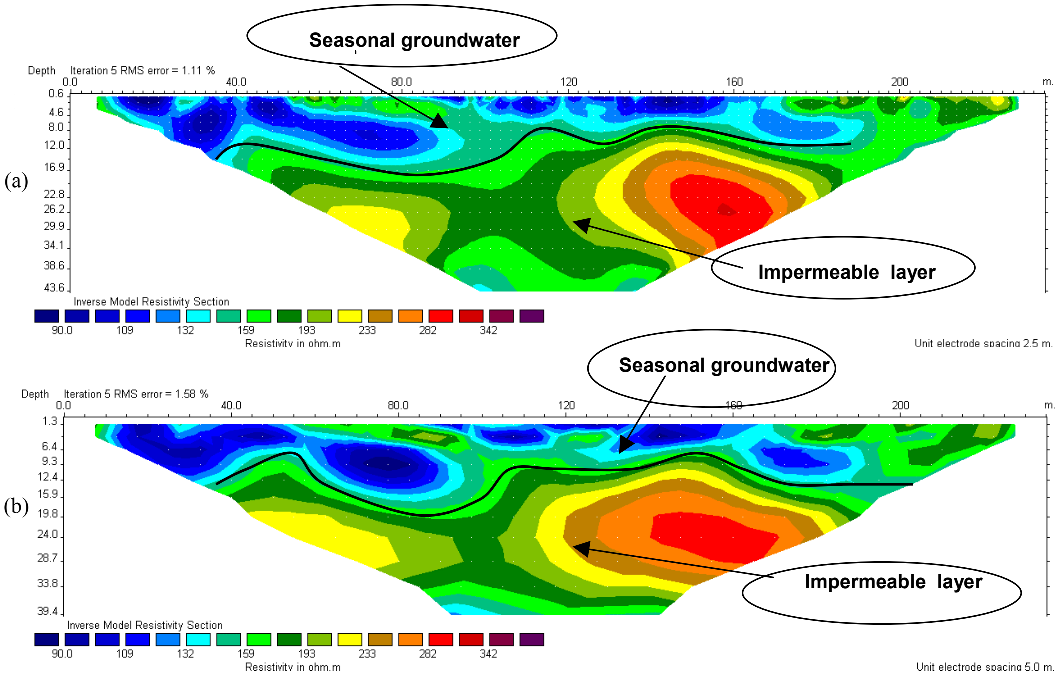

Fig. 7. (a) 2D resistivity model (Wenner array); **(b)** 2D resistivity model (Wenner-Schlumberger array).

In conclusion, the data show that a generalised diminution of the volume of fresh water available in the subsoil of the area under study is in progress. The results of our surveys demonstrate the ongoing process of saline water intrusion into the deep groundwater, highlighting the need to address the issues of protection, conservation and correct management of the groundwater resources. In an area like Salento which is substantially lacking in superficial water resources, the groundwater constitutes the only renewable water resource.

The results obtained support the use of the methods of electrical tomography and induced polarisation to complement and spatially correlate the data from the various surveys and tests, which would otherwise be limited to the individual points where the wells are drilled. Further research, aimed at accurately evaluating the over-exploitation of the underground water resources, would involve an increase in the number of observation points and measurements, and the preparation of a detailed model taking into account the actual permeability of the aquifer, in order to contribute to provide the basis for a correct hydro-geological management of the area. In addition, other studies of a chemical and bacteriological nature are required.

Acknowledgements. We are grateful to Calò, I., Guerrieri, F., Mazzone, F., and Di Paola, M. for their continued support of this research.

Edited by: M. Parise
Reviewed by: M. Delle Rose and another referee

References

Bossio, A., Esu, D., Foresi, L. M., Girotti, O., Iannone, A., Luperto, E., Margiotta, S., Mazzei, R., Monteforti, B., Ricchetti, G., and Salvatorini, G.: Formazione di Galatone, nuovo nome per un'unità litostratigrafia del Salento (Puglia, Italia meridionale), Atti Soc. tosc. Sci. Nat., Mem., Serie A, 105, 151–156, 1998.

Bossio, A., Foresi, L., Margiotta, S., Mazzei, R., Monteforti, B., and Salvatorini, G.: Carta geologica del settore nord orientale della Provincia di Lecce; 1:25 000 scale, Siena University, 1999.

Cotecchia, V.: Studi e ricerche sulle acque sotterranee e sulla intrusione marina in Puglia (Penisola Salenitina), IRSA, 20, 1–462, 1977.

Cotecchia, V., Tadolini, P., and Tulipano, L.: Sea water intrusion in the planning of groundwater resources protection and utilization in the Apulian region (southern Italy), Geol. Appl. e Idrogeol., 18, 367–382, 1983.

Cotecchia, V., Dauru, M., and Limoni, P. P.: Osservazioni sull'evoluzione dell'intrusione marina degli acquiferi carbonatici costieri della Puglia, Workshop "Il degrado qualitativo delle acque sotterranee in Puglia", 2001.

Cotecchia, V., Dauru, M., Limoni, P. P., Polemio, M., Spizzico, M., and Tadolini, T.: Il controllo idro-chimico fisico della falda idrica carbonatica Murgiano-Salentina (Puglia), Atti della giornata mondiale dell'acqua "Acque sotterranee: risorsa invisibile", 1998.

Fidelibus, M. D. and Tulipano, L.: Inquinamento salino ed antropico degli acquiferi costieri della Murgia e del Salento, Conv. Uso e tutela dei corpi idrici sotterranei pugliesi, Bari, 95–104, 2002.

Glenn, E., Smith Stafford, M., and Squires, V.: On our failure to control desertification: implications for global change issues, and a research agenda for the future, Environmental Science and Policy 1, 71–78, 1998.

Loke, M. H.: Electrical imaging surveys for environmental and engineering studies, Users manual for Res2dinv, Electronic version available from http://www.geometrics.com, 1999.

Loke, M. H. and Baker, R. D.: Rapid least-squares inversion of apparent resitivity pseudosection by a quasi-Newton method, Geophysical Prospecting, 44, 131–152, 1996.

Maggiore, M. and Pagliarulo, P.: Circolazione idrica ed equilibri idrogeologici negli acquiferi della Puglia, Workshop "Uso e tutela dei corpi idrici sotterranei pugliesi", Bari, 13–36, 2002.

Maggiore, M. and Pagliarulo, P.: Siccità e disponibilità idriche sotterranee del tavoliere di Puglia, Geologia dell'ambiente, SIGEA, 11, 35–40, 2003.

Margiotta, B. and Tadolini, T.: Nuovi elementi geoidrologici scaturiti da perforazioni recenti nell'area posta a sud di Lecce, Quad. Ric. Centro Studi Geot. Ing., 11, 287–302, 1987.

Margiotta, S.: Il contatto Formazione di Galatone – Formazione di Lecce: evidenze stratigrafico – sedimentologiche, Atti Soc. tosc. Sci. Nat., Mem., Serie A, 106, 73–77, 1999.

Margiotta, S. and Ricchetti, G.: Stratigrafia dei depositi oligomiocenici del Salento (Puglia), Boll. Soc. Geol. It., 121, 243–252, 2002.

Margiotta, S., and Varola, A.: Nuovi dati geologici e paleontologici su alcuni affioramenti del territorio di Lecce, Atti Soc. tosc. Sci. Nat., Mem., Serie A, 109, 1–12, 2004.

Polemio, M. and Limoni, P. P.: L'evoluzione dell'inquinamento salino delle acque sotterranee della Murgia e del Salento, VI Conv., Geologia Applicata, 1995.

Tulipano, L. and Fidelibus, M. D.: Evaluation of over – exploitation effects for the Salento coastal karstic aquifer through the interpretation of thermo – conductivity logs in observation wells, 2 Symp. On "Protection of groundwater from pollution and seawater intrusion", Bari, 1999.

Tulipano, L. and Fidelibus, M. D.: Mechanism of groundwater salinisation in a coastal karstic aquifer subyect to over – exploitation, Proc. 17 SWIM, Delft, The Netherlands, 2002.

Zito, G.: La desertificazione: passato, presente e futuro, SIGEA, XI, 2, 7–10, 2003.