

Using the DPSIR framework to identify factors influencing the quality of groundwater in Grecìa Salentina (Puglia, Italy)

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Abstract The Driver-Pressure-State-Impact-Response (DPSIR) framework was applied in a central area of the Salento peninsula to identify environmental and human factors influencing the quality of groundwater and propose strategies for its preservation. In accordance with this approach, a set of indicators providing a simplified description of the various components of a complex environmental system, directly or indirectly related to groundwater quality, was selected to obtain information useful for the management of water resources. A total of 42 indicators were taken into account: 11 for the driving forces, 5 for pressures, 21 for states, 2 for impacts and 3 for responses. The chemical and microbiological characterisation of the deep aquifer in the territory of Grecìa Salentina highlighted a number of cases of contamination attributable to risk factors present in the area. The study enabled the formulation of (a) hypotheses regarding the causes of poor water quality, and (b) management

strategies for resolving the negative aspects of the overall state of health of the aquifer.

Keywords DPSIR · Groundwater · Grecìa Salentina · Pollution · Hydrology

1 Introduction

Groundwaters represent an important source of water supply, especially in those areas in which the shortage or absence of surface waters obliges the resident population to draw from the subsoil to meet the demand for water in the civil and industrial sectors.

Because of its special hygienic characteristics, groundwater is widely used for drinking purposes (Howard et al. 2006). Indeed, it is characterised by a high level of chemical and microbiological purity due to the slow filtering processes that occur in the various layers of the subsoil, by which the contaminants are retained and/or degraded (Chilton and Seiler 2006). However, these compensational mechanisms are sometimes not enough to guarantee the safety of waters, especially when pollutants can easily reach the water table (Kačaroğlu 1999).

The potential contamination risk is specific to the geographical area, depending on the vulnerability of the soil and the amount and type of pollutants released into the environment by human activities (Spizzico et al. 2005).

The geological characteristics of the Salento peninsula (a subarea of the Puglia region) are quite distinct from those of other Italian regions (Giudici et al. 2012). The mainly karstic nature of the terrain results in a lack of superficial watercourses and a highly developed subterranean hydrology. This is characterised by a shallow aquifer occupying only 35 % of the territory and an

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extensive deep aquifer, intensively exploited as a source of drinking water (Masciopinto et al. 2007) and irrigation water (Portoghese et al. 2013). The deep aquifer is supported at its base by sea water from marine invasion and fed by waters from higher layers and rain water, which reaches the deeper layers thanks to the presence of tectonic fractures and sandy horizons in the impermeable calcarenite (Calò et al. 1992). This means the deep aquifer is exposed to a double threat. On one hand, the extraction of water from the aquifer at a faster rate than its natural replenishment might cause sea water to be drawn in from the underlying layers, with a consequent increase in the salinity of the water. On the other hand, the spread of pollutants on the surface might lead to an increase in the risk of chemical and microbiological contamination of the deep aquifer due to the poor degree of filtration provided by the terrain.

The last few decades have seen a deterioration in the available resources which has raised concerns over the potential negative impact on agriculture and public health.

In this context, in addition to the well-known impoverishment and salinisation of the aquifers (Calò et al. 1992), the data available in the literature describe an advancement of saline contamination even in certain inland areas that are subject to intense water extraction (Bagordo et al. 2003) and an increase in parameters associated with both agricultural practices (De Donno et al. 2003) and faecal contamination (Montagna et al. 1997; De Donno et al. 2001; Lugoli et al. 2011).

Identification of all the elements that can positively or negatively affect the quality of the groundwater is now fundamental for the sustainable and responsible management of this resource.

The Water Framework Directive (WFD) 2000/60/EC clearly establishes the basis and principles to be adopted to effectively protect subterranean, inland, transitional and coastal waters. Various approaches have been developed and proposed for analysing environmental issues arising from the impacts caused by human activities and for improving the management of water resources. Among these, the Driver-Pressure-State-Impact-Response (DPSIR) approach (EEA 2007) is currently being extensively applied in the framework of integrated water resource management (Jago-on et al. 2009; Alexakis et al. 2013; Pinto et al. 2013), for various reasons: (a) it is transparent and simple, with five concepts that are readily obvious to both scientists and stakeholders; (b) it enhances communication between scientists and stakeholders by simplifying the complex connections between humans and the environment; (c) it allows particular linkages or interactions to be isolated while retaining conceptual relevance to the larger system; (d) it is appealing to policy makers because it links political objectives to environmental problems and

implies causal relationships among factors (Smeets and Weterings 1999; Giupponi 2007). Moreover, DPSIR elements can be mapped onto other frameworks, including Millennium Ecosystem Assessment (Hassan et al. 2005) and the Long-Term Ecological Research Program (Mirtl and Krauze 2007).

According to the DPSIR model, the systems supporting society's residential, commercial and industrial aspects are the driving forces (D) that exert pressures (P) on the environment, whose state (S) changes as a consequence. An environment so altered may generate negative impacts (I) on human health and limit the use of resources, consequently requiring responses (R)—directed at any element of the system—on the part of society to lighten the impact.

In this study, the DPSIR framework was used to identify environmental and human factors influencing the quality of groundwater and to propose strategies for its preservation in "Grecia Salentina", a central area of the Salento peninsula.

2 Methods

2.1 Study area

The area of study (Fig. 1) is geographically identified with the territory of 13 municipalities in the Province of Lecce (Calimera, Carpignano Salentino, Castrignano de' Greci, Corigliano d'Otranto, Cutrofianno, Galatina, Martano, Martignano, Melpignano, Sogliano Cavour, Soleto, Sternatia and Zollino), which form a consortium (Union of Municipalities of Grecia Salentina) for organising a series of services on a collective basis. The municipalities share culture and traditions, and their inhabitants traditionally speak a dialect of modern Greek known as "Griko".

The area is located in the middle of the Salento Peninsula with no access to the sea and covers a total area of 334.89 square km between 40°16'10" and 40°3'11"N latitude and between 18°24'35" and 18°4'5"E longitude. The mostly flat landscape is traversed longitudinally by a ridge belonging to the "Serre Salentine" hills, giving rise to some hilly elements which do not, however, exceed 200 m above sea level.

From the hydrogeological point of view, the territory of Grecia Salentina is characterised by calcareous outcrops that are highly permeable to water due to the large quantity of cracks, sinkholes, ponors and dolines, associated with karst phenomena. The high permeability of the terrain means that in most of the territory there is no easy access to the water table. Indeed, the precipitation, more intense in autumn and winter, is rapidly absorbed by the terrain and percolates directly to the deep aquifer, which rests on a base of sea water from marine invasion. Only in the

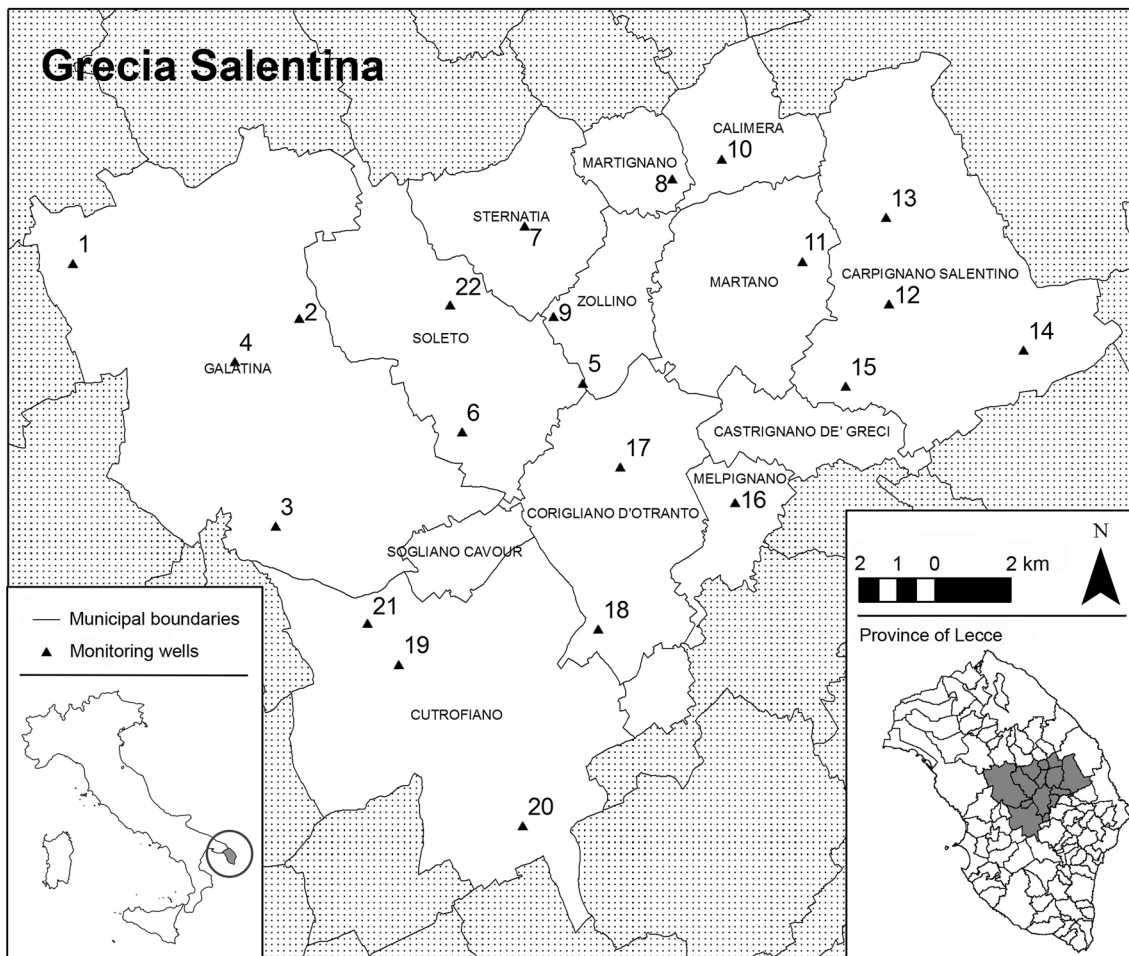


Fig. 1 The study area and the location of monitoring wells

territory of Calimera municipality, in the north-east of the area, is there a significant impermeable layer in the soil, which provides a certain degree of protection for the deep aquifer below it while creating the conditions for the development of a shallower aquifer above it.

The surface hydrography is also highly conditioned by the karstic nature of the terrain, which prevents the formation of water courses almost throughout the area, with the exception of its south-western corner, where the Canale Asso is located. This is an endorheic hydrographical system made up of a series of surface channels in the territory of the municipalities of Cutrofiانو and Galatina which flow into the karstic subsoil through ponors, of which the most important is situated in the territory of the municipality of Nardò, to the west of the Municipality of Galatina.

2.2 DPSIR framework

A preliminary study of the territory of Grecia Salentina was conducted on the basis of scientific publications and official documents regarding the quality and management of

deep water resources, identifying the key natural and anthropic factors and verifying the availability of data to be used. In accordance with the DPSIR framework, a set of indicators that could provide a simplified description of the various components of a complex environmental system was then selected to obtain information useful for the management of water resources in the study area. The indicators were chosen with reference to anthropic activities that might directly or indirectly influence the quality of the deep groundwater. Specifically, this entailed selecting indicators linked to (1) the processing of wastewaters from both human settlements and industrial activities; (2) agriculture; (3) activities liable to increase the intrinsic vulnerability of the aquifers, such as the quarrying of limestone for construction and the pumping of waters from the deep aquifer for irrigation or domestic consumption via private wells. Regarding agriculture, since it was not possible to identify reliable sources of data concerning the pressure exerted by the use of fertilisers, indicators pertaining to the Utilised Agricultural Area (UAA) and the use of chemicals in agriculture (such as ammonium and

nitrates) were considered. Measures taken to mitigate the effects of these substances by means of sustainable farming methods were also taken into account.

2.2.1 Driving forces

The driving forces (D) considered in this study were linked to socio-economic factors that exert direct or indirect pressure on deep water resources. Specifically, population density and density of dwellings were used to describe the degree of urbanisation. The unoccupied dwelling rate was used as an indirect indicator of second homes, which in Grecia Salentina and throughout the province are typically located in rural areas; mainly used in summer, in many cases they are not connected to the sewage network, using on-site sewage facilities instead. The tourist offer in terms of the number of beds per unit area was used to verify any significant increase in the population due to tourist flows. Industrial activity was quantified in terms of the density of manufacturing companies, while agriculture and livestock rearing were measured, respectively, in terms of the Utilised Agricultural Area (UAA) as a percentage of the total, and livestock density. The percentage of the area affected by the extraction of limestone for construction, the density of wells, and the presence of wastewater treatment plants with discharge into the groundwater or without tertiary treatment were also considered.

2.2.2 Pressures

Pressure indicators (P) included factors that could directly modify the quality of groundwater such as the production of pollutants, specifically, the quantity of wastewater as Population Equivalent (PE) produced by all the anthropic components in the area being studied, including the resident population, persons domiciled in the area but officially resident elsewhere, commuters, accommodation structures, second homes, restaurants, bars and manufacturing.

2.2.3 State

For assessment of the state (S) of the groundwater, the physical–chemical and microbiological quality of the deep aquifer was monitored. Eighty-eight water samples were taken from 22 wells situated in the territory of the “Union of Municipalities of Grecia Salentina” (Fig. 1). The samples were collected in four seasonal sampling campaigns conducted in April 2009, July 2009, November 2009 and February 2010. During sampling, physical parameters (conductivity and pH) were determined in situ using a WTW Multiline P4 multiparametric probe. Samples were transported to the laboratory in refrigerated boxes and were analysed for three microbiological (Coliform bacteria,

Escherichia coli, Enterococci) and 17 chemical parameters [Ammonium (NH_4^+), Chlorides (Cl^-), Nitrates (NO_3^-), Sulphates (SO_4^{2-}), Arsenic (As), Cadmium (Cd), Chromium (Cr), Copper (Cu), Iron (Fe), Mercury (Hg), Manganese (Mn), Sodium (Na), Nickel (Ni), Lead (Pb), Vanadium (V), Calcium (Ca) and Magnesium (Mg)]. These parameters were selected from those established by Council Directive 98/83/EC on the quality of water intended for human consumption, subsequently transposed into Italian law by Decree Law 31 of the 2nd of February 2001 (D. Lgs. 31/01). Vanadium is not present in the EU Directive but was included in the Italian law, while calcium and magnesium were used to calculate the Sodium Adsorption Ratio (SAR), defined as $\text{SAR} = \text{Na}/[(\text{Ca} + \text{Mg})/2]^{0.5}$, where concentrations are expressed in mEq/L.

The microbiological indices were determined by the methods indicated in Council Directive 98/83/EC.

Concentrations of NO_3^- , NH_4^+ , SO_4^{2-} and Cl^- were determined by ionic chromatography using a Metrohm 883 Basic IC plus chromatographer. Water samples, unmodified or diluted 1:10, were filtered and injected into the instrument, equipped with a column and pre-column for both anions and cations.

Concentrations of As, Ca, Cd, Cr, Cu, Fe, Hg, Mg, Mn, Na, Ni, Pb, and V were simultaneously determined using an ICP-OES spectrometer (a Thermo iCAP 6000). Undiluted water samples were acidified to facilitate nebulisation and filtered. Concentrations of Ca, Na and Mg were determined in 1:100 diluted samples to bring the concentration values within the range of the calibration curves used with the ICP-OES spectrometer.

Maps of the measured parameters were created to identify spatial gradients using the “Inverse Distance Weighting” method (Legendre and Legendre, 1998). Inverse distance weighting interpolates the unknown value in a non-sampled location by calculating a weighted average of values in a set of known locations. The weighting is established as a power of the inverse of the geographical distance. For generating our maps, the power of the distance was set at two and the interpolation was determined with reference to the ten closest known locations. The interpolation grid was set to a spatial resolution of 250×250 m. The data processing was carried out using ESRI ArcGis Desktop 10.1 (ESRI 2012).

2.2.4 Impact

The impact (I) of human activities on the water resources was measured as the percentage of deep aquifer wells whose waters were unfit for either drinking or irrigation. The suitability for drinking of the waters sampled from the 22 monitored wells was assessed as a function of the values recorded for the parameters included in Part A (*E. coli*,

Enterococci) and Part B (Arsenic, Cadmium, Chromium, Copper, Mercury, Nickel, Lead, Vanadium, and Nitrate) of Annex I of Italian Decree Law 31/01. In the absence of a specific law regarding waters drawn from the subsoil, the waters' fitness for irrigation was assessed with reference to SAR and *Escherichia coli*, in accordance with Italian Ministerial Decree 185 of 12 June 2003, which regulates the recycling of wastewaters.

2.2.5 Response

The final step was to assess the potential ability of selected responses (R) to prevent or reverse negative impacts or to conserve natural resources. These included the percentage of dwellings connected to the sewer system (%), wastewater treatment capacity (%) and the percentage of agricultural land used for organic farming.

2.3 Source of data

The data on Driving forces, Pressures and Responses were acquired on the Municipal and Provincial levels from official sources such as the Province of Lecce Statistics Office (USPL), the Chamber of Commerce of Lecce (CCIAA), the Province of Lecce Technical Office ("Genio Civile", GC), Puglia regional administration's Regional Census of Water Wells (CRAE), the regional water company ("Acquedotto Pugliese", AQP) and Puglia regional administration's Department of Ecology (AERP). Data refer to the situation in 2010. In addition, reference was made to Puglia regional administration's "Water Protection Plan" (PTA) published in 2009. The data on status indicators derive from the monitoring conducted in accordance with the described approaches, while the impact indicators were calculated on the basis of the data drawn from the monitoring activities.

A total of 42 indicators were taken into account: 11 for the Driving forces, five for Pressures, 21 for States, two for Impacts and three for Responses.

Thereafter, the value of each indicator was compared with a reference value to give an environmental quality rating. The reference value corresponds to the value of the indicator calculated on a larger scale (i.e. provincial), or the limit specified in national laws, or is drawn from the scientific literature.

3 Results

3.1 Driving forces

Table 1 shows the values recorded for all the indicators, grouped in accordance with type, together with the unit of measurement and source of data.

The area of study (Table 2) has a total area of 340.00 km² and a total population of 85,433 inhabitants. The population density is 251.27 inhabitants/km². In total, there are 41,708 dwellings (122.7/km²), of which 11,144 (26.7 %) are not occupied by residents and thus constitute a potential index of second homes. The municipalities with the highest rate of empty dwellings are Cutrofiano (46.7 %) and Galatina (29.3 %), where there is a greater intensity of rural urbanisation.

Regarding economic data, the territory of Grecìa Salentina hosts 6188 companies; the most common type of company is involved in commerce, followed by agriculture and construction, while manufacturing accounts for 754 companies (12.2 % of the total), with a density of 2.22/km², greater than the Provincial average (2.12 factories/km²). The municipality with the highest number of manufacturing companies is Galatina (246), and the one with the highest density is Calimera (5.18/km²). The tourist offer is considerably below the provincial average. The municipalities of the area have 1445 tourist beds in 136 accommodation structures, making an average density of 4.25 tourist beds/km². The highest density is seen in Martano (10.3/km²), Sogliano Cavour (5.63/km²) and Corigliano D'Otranto (5.07/km²).

A large part of the area is used for agriculture. The Utilised Agricultural Area (UAA) accounts for 61.1 % of the total area and is almost entirely given over to either permanent crops (46.2 %), consisting mainly of olives, and field crops (45.4 %). The municipalities with the highest level of cultivated areas are Sogliano Cavour (91.6 %), Carpignano Salentino (73.3 %) and Sternatia (69.9 %). Livestock rearing is limited, with 378.42 ha used for grazing. The total number of animals reared is 66,306, with a density of 204.68/ha.

Data provided by the Province of Lecce Technical Office show that in the territory of the Union of Municipalities of Grecìa Salentina there are 7181 wells, equivalent to 21.8 wells/km². Authorised wells are used mainly for domestic purposes (48.2 %) and irrigation (46.1 %).

Due to its particular lithostratigraphic characteristics, the subsoil of the Salento is widely exploited for the extraction of limestone for construction. In total (Table 3) in the Province of Lecce, there are 164 quarries, of which 68 are active, occupying a total area of 10.13 km², equal to 0.36 % of the total area of the Salento. Quarrying is particularly intense in Grecìa Salentina, where there are 64 quarries (25 active) occupying a total area of 3.90 km², equal to 1.15 % of the territory. The Municipalities most affected by quarrying are Melpignano (3.41 %), Martano (1.50 %) and Galatina (1.49 %).

For the purposes of removal and disposal of wastewaters, the municipalities of Grecìa Salentina are organised into "urban agglomerations", each of which has a treatment plant. In accordance with article 2 of Council Directive

Table 1 Values recorded for all indicators, grouped in accordance with type, together with the unit of measurement and source of data

Indicator	DPSIR	Source of data	Unit of measurement	Value
Population density	D	USPL	n°/km ²	251.27
Density of dwellings	D	USPL	n°/km ²	122.7
Unoccupied dwelling rate	D	USPL	%	26.7
Intensity of tourism supply	D	CCIAA	beds/km ²	4.25
Density of manufacturing companies	D	CCIAA	n°/km ²	2.22
Area affected by quarrying	D	CRAE	%	1.15
Density of wells	D	GC	n°/km ²	21.8
UAA as percentage of total land	D	USPL	%	61.1
Livestock density	D	USPL	n°/km ²	204.68
Wastewater treatment plants with discharge into groundwater	D	PTA	n°	0
Wastewater treatment plants without tertiary treatment	D	PTA	n°	1
Total load generated	P	PTA	PE/km ²	370.43
Load generated by manufacturing activities	P	PTA	PE/km ²	51.02
Load generated by second homes	P	PTA	PE/km ²	60.22
Load generated by accommodation structures	P	PTA	PE/km ²	5.91
Load generated by restaurants/bars	P	PTA	PE/km ²	17.89
Maximum conductivity	S	Monitoring	μS cm ⁻¹	1127.0
Hydrogen ion concentration (min and max)	S	Monitoring	pH	6.88–8.0
Maximum concentration of NH ₄ ⁺	S	Monitoring	mg/L	0.76
Maximum concentration of Cl ⁻	S	Monitoring	mg/L	209.8
Maximum concentration of NO ₃ ⁻	S	Monitoring	mg/L	64.8
Maximum concentration of SO ₄ ²⁻	S	Monitoring	mg/L	107.0
Maximum concentration of As	S	Monitoring	mg/L	0.004
Maximum concentration of Cd	S	Monitoring	mg/L	<0.001
Maximum concentration of Cr	S	Monitoring	mg/L	0.003
Maximum concentration of Cu	S	Monitoring	mg/L	0.044
Maximum concentration of Fe	S	Monitoring	mg/L	0.23
Maximum concentration of Hg	S	Monitoring	mg/L	0.027
Maximum concentration of Mn	S	Monitoring	mg/L	0.030
Maximum concentration of Na	S	Monitoring	mg/L	110.6
Maximum concentration of Ni	S	Monitoring	mg/L	0.034
Maximum concentration of Pb	S	Monitoring	mg/L	0.016
Maximum concentration of V	S	Monitoring	mg/L	0.144
Maximum value of SAR	S	Monitoring	–	2.8
Maximum concentration of Coliform bacteria	S	Monitoring	CFU/100 ml	1000
Maximum concentration of <i>E. coli</i>	S	Monitoring	CFU/100 ml	1000
Maximum concentration of Enterococci	S	Monitoring	CFU/100 ml	300
Unfit for drinking	I	Processing	%	86.4
Unfit for irrigation	I	Processing	%	18.2
Dwellings connected to the sewer network	R	AQP	%	33.9
Effectiveness of treatment	R	PTA	%	69.8
Organic agriculture	R	USPL	% of UAA	13.2

91/271/EEC concerning urban wastewater treatment, “agglomeration” means an area where the population and/or economic activities are sufficiently concentrated for urban wastewater to be collected and conducted to an urban wastewater treatment plant or to a final discharge point.

Table 4 shows the agglomerations to which the 13 Municipalities of the studied area belong, their wastewater treatment systems, the capacity of each treatment plant and the final point of discharge of the treated waters. The data show that no treatment plant discharges

Table 2 Indicators of urbanisation, tourism supply and manufacturing activity in the municipalities of Grecia Salentina and the Province of Lecce

Municipality	Area (km ²)	Population (inhabitants)	Population density (n°/km ²)	Density of dwellings (n°/km ²)	Unoccupied dwelling rate (%)	Intensity of tourism supply (beds/km ²)	Density of manufacturing companies (n°/km ²)
Calimera	11.18	7281	651.25	292.3	19.3	4.03	5.19
Carpignano Salento	48.99	3853	78.65	32.6	18.5	3.18	0.73
Castrignano de' Greci	9.62	4144	430.77	178.8	20.1	0	3.53
Corigliano d'Otranto	28.41	5889	207.29	95.4	26.1	5.07	2.11
Cutrofiano	56.81	9292	163.56	111.7	46.7	2.76	1.34
Galatina	82.65	27,299	330.30	169.6	29.3	4.55	2.98
Martano	22.25	9485	426.29	166.3	9.00	10.25	2.88
Martignano	6.49	1748	269.34	115.9	16.0	3.85	2.62
Melpignano	11.10	2217	199.73	93.2	23.5	4.77	3.78
Sogliano cavour	5.33	4122	773.36	333.0	20.7	5.63	4.50
Soletto	30.46	5572	182.93	85.4	22.4	3.97	2.04
Sternatia	16.76	2459	146.72	72.9	19.2	3.94	0.60
Zollino	9.95	2072	208.24	96.9	22.9	4.42	2.51
Grecia Salentina	340.00	85,433	251.27	122.7	26.7	4.25	2.22
Province of Lecce	2799.07	815,597	291.38	143.4	19.3	26.00	2.12

Table 3 Extraction of limestone for construction (number of quarries and area covered) in Grecia Salentina and the Province of Lecce

Municipality	Number of quarries		Area	
	Total	Active	km ²	%
Calimera	0	0	0.00	0.00
Carpignano Salentino	2	2	0.25	0.51
Castrignano de' Greci	0	0	0.00	0.00
Corigliano d'Otranto	8	5	0.30	1.06
Cutrofiano	9	5	0.83	1.46
Galatina	8	3	1.23	1.49
Martano	5	2	0.33	1.50
Martignano	1	1	0.06	0.91
Melpignano	22	17	0.38	3.41
Sogliano cavour	0	0	0.00	0.00
Soletto	4	0	0.29	0.96
Sternatia	2	1	0.18	1.06
Zollino	3	3	0.05	0.46
Grecia Salentina	64	39	3.90	1.15
Province of Lecce	164	68	10.13	0.36

directly into the deep aquifer while the Maglie treatment plant, which discharges into the Canale Asso, has no tertiary treatment.

3.2 Pressures

Table 5 shows the anthropic load generated in the territory of Grecia Salentina in terms of wastewater produced per

unit area (PE/km²), subdivided by agglomeration and type. Overall, the agglomerations encompassing the 13 Municipalities of Grecia Salentina produce a load of 225,334 PE, which is 370.4 PE/km², less than the provincial average (465.2 PE/km²). The data on the economic sectors also show lower values than the average for the Province of Lecce but individual agglomerations show contrasting situations. For example, the Galatina agglomeration produces a higher load from its resident population (290.1 PE/km²) and catering services (31.4 PE/km²) than the Provincial average, while the Melendugno agglomeration has a particularly high load from accommodation structures (24.7 PE/km²) and second homes (144.8 PE/km²). In contrast, manufacturing seems to be more intense in the Maglie agglomeration, which produces a wastewater load of 64.3 PE/km².

3.3 State

Table 6 shows the results of the physical, chemical and microbiological analyses conducted on the 88 water samples from the deep aquifer monitoring wells in Grecia Salentina.

The data from the microbiological analyses highlight widespread contamination of faecal origin, as seen in the concentrations of Coliform bacteria, *E. coli* and Enterococci.

Coliform bacteria were found in 73 % of samples analysed, with an average concentration of 100.4 CFU/100 ml and maximum values of 1000 CFU/100 ml. It is

Table 4 Agglomerations of municipalities sharing wastewater treatment facilities (municipalities lying within Grecia Salentina shown in uppercase, other municipalities in lower case), the rate of connection to the sewer network (referring only to municipalities in Grecia

Salentina), the capacity of each treatment plant (as the percentage of the load generated in the agglomeration), the level of treatment and the final point of discharge of the treated waters

Agglomeration	Municipalities	Dwellings connected to the sewer network (%)	Capacity of treatment plant (% of loads generated)	Level of treatment	Final point of discharge
Carpignano Salentino	CARPIGNANO SALENTINO, MARTANO	5.5	70.8	Tertiary	Soil
Galatina	GALATINA, SOLETO	41.4	70.3	Tertiary	Soil
Maglie	Maglie, Bagnolo del Salento, Botrugno, Cannole, CASTRIGNANO DE' GRECI, CORIGLIANO D'OTRANTO, Cursi, CUTROFIANO, Giuggianello, MELPIGNANO, Muro Leccese, Nociglia, Palmariggi, S.Cassiano, Sanarica, Scorrano, SOGLIANO CAVOUR, Surano	42.4	54.3	Secondary	Surface water (Canale Asso)
Melendugno	Melendugno, CALIMERA, MARTIGNANO	23.8	106.5	Tertiary	Soil
Zollino	STERNATIA, ZOLLINO	24.9	100.4	Tertiary	Soil

Table 5 Loads (PE/km²) generated in the territory of Grecia Salentina subdivided by agglomeration and source of production

Agglomeration	Resident population	Population not officially resident	Commuters	Accommodation structures	Second homes	Restaurants/bars	Manufacturing companies	Total
Carpignano Salentino	191.20	2.00	-3.16	0.76	20.30	9.66	51.75	272.51
Galatina	290.13	6.00	3.51	2.26	56.47	31.37	44.88	434.62
Maglie	248.91	5.10	-1.74	1.72	40.57	20.47	64.33	379.35
Melendugno	164.44	3.43	-6.16	24.71	144.79	6.38	26.77	364.35
Zollino	175.61	3.07	-7.39	1.71	35.72	0.00	23.30	232.01
Grecia Salentina	232.86	4.55	-2.00	5.91	60.22	17.89	51.02	370.43
Province of Lecce	273.94	6.42	-0.23	18.71	79.65	22.87	63.81	465.17

important to stress that in all wells the test for Coliform bacteria was positive in at least one sample in four.

Of the 88 samples tested for *E. coli*, 33 (38 %) were positive, with an average concentration of 28.9 CFU/100 ml and a maximum value of 1000 CFU/100 ml. During the monitoring period, 22.7 % of the wells were always negative for *E. coli*.

The average concentration of enterococci was 6.5 CFU/100 ml, with a maximum of 300 CFU/100 ml. Tests for enterococci were negative in 81 % of cases and no well had values above 100 CFU/100 ml. In addition, no wells were found to be constantly positive for Enterococci.

The temporal analysis of the indicators of faecal contamination highlights a seasonal pattern for Coliform bacteria, *E. coli* and Enterococci, with higher average loads in summer and lower ones in the rest of the year.

The spatial analysis (Fig. 2) highlights a north-to-south contamination gradient, passing from a generally healthy situation to one of severe pollution.

On the whole, the microbiological characterisation highlighted a heterogeneous but non-optimal state of hygiene and health, attributable to discontinuous contamination of cloacal origin as shown by the indicators of faecalisation.

The spatial and temporal analyses made it possible to establish that the summer is the period of greatest risk to the health of the aquifer and that some areas, such as the south-eastern, are more heavily affected by microbiological contamination.

The chemical–physical analyses of waters circulating in the subsoil of Grecia Salentina highlight a number of problems, particularly concerning the concentrations of V and NH₄⁺.

V concentrations were in excess of the limit of 0.05 mg/L envisaged by Italian Decree Law 31/01 in 25 of the 88 deep aquifer samples analysed in total, with a greater frequency in the south-western part of the studied area (Fig. 3).

Table 6 Indicators of State detected in samples collected from 22 wells situated in the territory of the “Union of Municipalities of Grecìa Salentina”

Parameter	Limits	Min	Max	Mean	Standard deviation	Non-compliance	
						Samples	Wells
Conductivity ($\mu\text{S cm}^{-1}$)	2500	395.5	1127.0	737.7	170.9	0/88	0/22
Hydrogen ion concentration (pH)	≥ 6.5 and ≤ 9.5	6.88	8.0	7.5	0.2	0/88	0/22
As (mg/L)	0.01	0.001	0.004	0.0028	0.0008	0/88	0/22
Cd (mg/L)	0.005	<0.001	<0.001	<0.001	–	0/88	0/22
Cr (mg/L)	0.05	0.002	0.003	0.0023	0.0004	0/88	0/22
Cu (mg/L)	1	<0.001	0.044	0.0028	0.0052	0/88	0/22
Fe (mg/L)	0.2	0.018	0.23	0.030	0.022	1/88	1/22
Hg (mg/L)	0.001	<0.001	0.027	0.0013	0.0028	2/88	2/22
Mn (mg/L)	0.05	<0.001	0.030	0.0017	0.0032	0/88	0/22
Na (mg/L)	200	5.1	110.6	34.0	20.2	0/88	0/22
Ni (mg/L)	0.02	<0.001	0.034	0.0014	0.0035	1/88	1/22
Pb (mg/L)	0.01	<0.001	0.016	0.0014	0.0019	2/88	1/22
V (mg/L)	0.05**	0.005	0.144	0.040	0.019	24/88	10/22
NH_4^+ (mg/L)	0.5	<0.01	0.76	0.28	0.22	13/88	10/22
Cl^- (mg/L)	250	17.5	209.8	71.8	43.1	0/88	0/22
NO_3^- (mg/L)	50	1.4	64.8	14.0	12.0	2/88	2/22
SO_4^{2-} (mg/L)	250	1.0	107.0	32.4	23.8	0/88	0/22
SAR	3	0.1	2.8	0.8	0.5	0/88	0/22
Coliform bacteria (CFU/100 ml)	0	0.0	1000	74.8	191.4	64/88	22/22
<i>E. coli</i> (CFU/100 ml)	0	0.0	1000	40.2	182.1	32/88	16/22
Enterococci (CFU/100 ml)	0	0.0	300	6.6	37.3	17/88	9/22

Limits specified by Council Directive 98/83/EC except ** (specified by D. Lgs. 31/01)

As for the other metals, the permitted limits were exceeded in a few cases for Fe, Ni, Hg and Pb, mainly in the same area.

The other parameter for which the permitted limits were frequently exceeded is NH_4^+ . In 14.8 % of cases, and particularly in the northern and central part of the studied area (Fig. 3), the measured values exceeded 0.50 mg/L. However, the data for NH_4^+ concentrations are characterised by very high temporal variability. Of the other parameters, only NO_3^- exceeded the permitted limits, in just two isolated cases.

3.4 Impacts

The state of quality of the deep groundwater of Grecìa Salentina affects its usability for domestic use and irrigation.

In 19 of the 22 monitored wells (86.4 %), the waters were unfit for drinking under the terms of Italian Decree Law 31/01, with at least one value above the stipulated limits for the Microbiological and Chemical Parameters (Parts A and B of the law, respectively) recorded in the course of the four samplings. Specifically, 31.8 % of the monitored wells were found to have exceeded only the

microbiological parameters, 13.6 % only the chemical parameters and 40.9 % both groups of parameters.

Regarding use for irrigation, the SAR index calculated for water samples from the 22 monitored wells was always below 10 (maximum 2.8). Therefore, considering this parameter alone, under the terms of Italian Ministerial Decree 185/03, water from the deep aquifer in Grecìa Salentina could be used for this purpose with no restrictions. In contrast, the legal limit for the *E. coli* parameter, i.e. 100 CFU/100 ml, was exceeded in 18.2 % of the monitored wells.

3.5 Responses

Analysis of the data on wastewater treatment plants in the municipalities in question shows that the overall capacity is 157.545 PE, below the generated load (225.334 PE), corresponding to an overall treatment effectiveness of 69.8 %. Specifically, the agglomerations with a treatment effectiveness of below 100 % were Carpignano (70.8 %) and the major agglomerations of Galatina (70.3 %) and Maglie (54.3 %). In the studied area, only 33.9 % of the total dwellings are connected to the sewer network for the dynamic removal of wastewaters, falling to 5.5 % in the

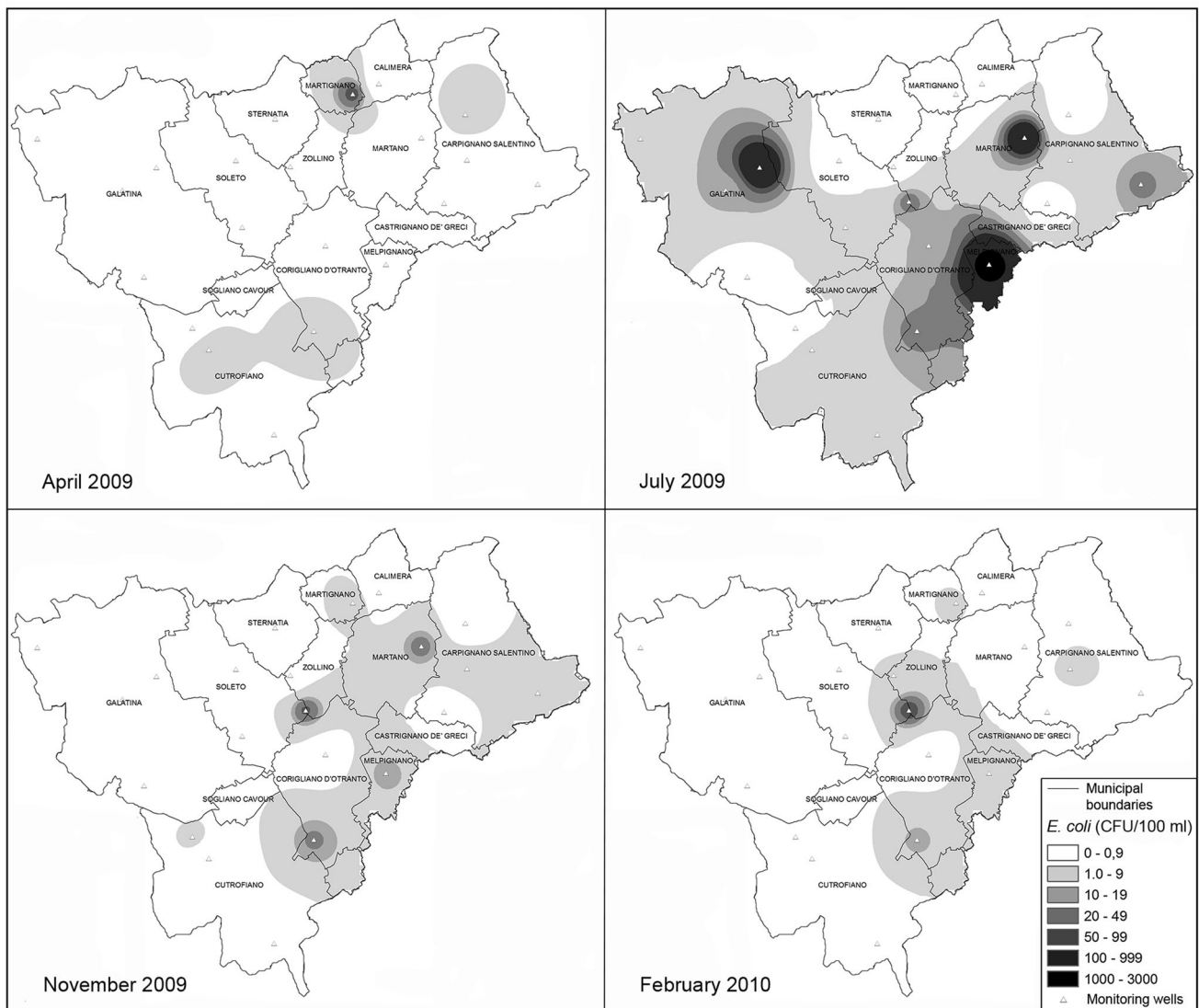


Fig. 2 Maps of the interpolated concentration levels of *E. coli* in the deep water table of Grecia Salentina for each of the surveyed periods. The interpolation used the inverse distance weighting method (Legendre and Legendre 1998)

agglomeration of Carpignano. Non-connected houses are believed to use some form of on-site sewage facility (usually a septic tank or a closed sewage tank that needs to be emptied regularly).

Regarding the adoption of specific measures for limiting the impact of agricultural activities, the 108 farms (1.34 %) in the area of reference that apply eco-compatible production criteria account for a total area of 2733.81 ha, corresponding to 13.2 % of UAA (Table 7).

4 Discussion and conclusion

The study highlighted issues linked to the state of quality of the aquifer in the Union of Municipalities of Grecia Salentina, enabling the formulation of hypotheses regarding the

causes of poor water quality, and of management strategies for resolving the negative aspects of the overall state of health of the aquifer.

The microbiological characterisation of the deep aquifer in the territory of Grecia Salentina highlighted a non-optimal, albeit heterogeneous, state of hygiene and health, due to discontinuous contamination of faecal origin.

Analysis of the data showed the distribution of the problem on spatial and temporal scales and identified certain badly affected contexts associated with risk factors present in the area.

The pattern that emerges is characterised by high contamination values across much of the area during summer, tending to lower and more spatially restricted values in the other seasons.

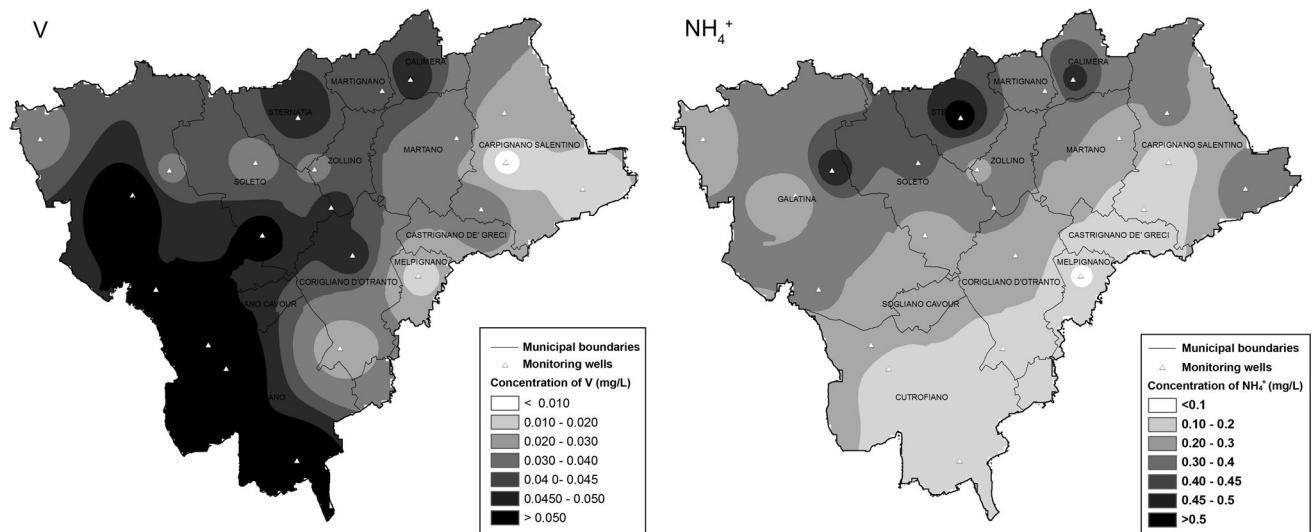


Fig. 3 Map of the interpolated concentrations of Vanadium (V) and Ammonium (NH_4^+) in the deep water table of Grecìa Salentina. Interpolation used the inverse distance weighting method (Legendre and Legendre 1998)

The south-eastern part of the area appeared to be the most affected by microbiological pollution of the aquifer. Other sites, in the central and north-western parts of the area, appeared to be contaminated only occasionally, while in the northern and western parts of the studied area, including the territory of Calimera and Sternatia and part of the Municipalities of Galatina, Soletto, Zollino and Carpignano Salentino, the quality of the waters in the deep aquifer was suitable for the envisaged uses.

From the physical and chemical point of view, the biggest problems regarding the quality of the aquifer underlying the area of the Union of Municipalities of Grecìa Salentina are basically the presence of certain metals, particularly Vanadium, and the concentration of NH_4^+ .

The V levels seem to be particularly high in water samples from the south-western area of Grecìa Salentina, which lies between the industrial areas of Maglie and Galatina and is crossed by the Canale Asso. The high Vanadium concentrations may thus be associated with anthropic pressures on the aquifer (industrial activities) (WHO 1988), but the issue requires further study.

NH_4^+ derives mainly from human or animal excrement or from ammonium salts used in agriculture (Gangbazo et al. 1995; De Simone and Howes 1998). Its presence in waters, especially groundwater, is due in some cases to geological causes such as the decay of material undergoing fossilisation (remains of plants, peat deposits, etc.) (Schilling 2002). In contrast, when associated with harmful microbiological data, its presence constitutes a reliable indicator of pollution from sewers and/or livestock farms (Cabral and Marques 2006).

Under the terms of Italian Decree Law 31/01, the waters of the monitored wells are, in most cases, unfit for use as

drinking water, which justifies the adoption of measures for limiting their use due to the risk to public health. Such measures would have a large impact, given the widespread use of the aquifer in the territory of Grecìa Salentina for domestic purposes (Masciopinto et al. 2007).

Cases of unsuitability were also seen regarding use of the wells for irrigation, arising mainly from the risk of spreading water-borne infections, linked above all to the consumption of raw fruit and vegetables. In contrast, the saline content of the waters drawn from the subsoil of Grecìa Salentina is not so high as to exclude their use in agriculture.

The problems highlighted in the course of the study should be seen in relation to certain anthropic factors, which, in association with the intrinsic characteristics of the territory, result in risk conditions that could compromise the quality of the water resources.

It should be pointed out that from the hydrogeological point of view, the lithological features of the studied area mean that infiltration is generally rapid and the subsoil is highly vulnerable. The only areas where impermeable layers provide a certain degree of protection are those in the northern part of the territory (Calimera). Here, the deep aquifer showed consistently healthy conditions throughout the period of observation. In addition, the intrinsic vulnerability of the deep aquifer is heightened even further by the quarrying of limestone, particularly intense in municipalities with the most serious contamination. In the south-western part of the studied area, the Canale Asso channel provides another potential contamination route for the deep aquifer due to the distinctive karstic conformation of the terrain. Uniquely for the Salento, the surface hydrographical system of this area does not terminate in the sea but in a series of ponors, which represent gateways to the

Table 7 Utilised Agricultural Area (UAA), as a percentage of the total area, and percentage of UAA cultivated by organic methods in the municipalities of Grecia Salentina and the Province of Lecce

Municipality	UAA (% of total land)	Organic agriculture (% of UAA)
Calimera	68.6	16.5
Carpignano Salentino	73.3	25.1
Castrignano de' Greci	58.9	19.7
Corigliano d'Otranto	63.7	5.9
Cutrofiano	57.3	4.7
Galatina	58.6	9.2
Martano	64.0	22.2
Martignano	61.9	5.4
Melpignano	45.2	–
Sogliano Cavour	91.6	44.1
Soledo	46.1	6.2
Sternatia	69.0	16.8
Zollino	57.8	10.0
Grecia Salentina	61.1	13.2
Province of Lecce	57.6	8.5

subsoil through which rainwater reaches and replenishes the deep aquifer, carrying any pollutants that might be in the soil (Giaccari and Vitale 2005; Delle Rose et al. 2009).

This study also made it possible to identify some of the main anthropic factors associated with the chemical and microbiological contaminants identified, for example, the low rate of connection to the sewer network. This situation suggests that numerous dwellings use static systems (septic tanks) for wastewater disposal, consequently increasing the risk of contamination of the aquifer by percolation.

On the whole, the water treatment plants were found to be insufficient to deal with the load generated. The central water treatment plant of Maglie, which collects wastewater from 18 municipalities (five of which lie within the territory of Grecia Salentina), does not perform tertiary treatment (the only treatment plant, of those considered, for which this is the case). Since it discharges the treated waters into the superficial system of the Canale Asso, this could represent a chemical risk for the deep aquifer in the studied area due to the ponors present along the course of the channels. In addition, the load generated by manufacturing activities in this agglomeration is particularly significant.

Another important industrial area is the one lying between the municipalities of Galatina and Soledo. Here, cement production and waste incineration could result in the emission of heavy metals such as Vanadium (Hindy et al. 1990; Juichang et al. 1995).

In the light of what is reported here, it is clear that due to specific local geological and morphological conditions and

the presence of pressure factors (both point and diffuse), the deep aquifer of the area of the Union of Municipalities of Grecia Salentina is affected by chemical and microbiological contamination.

It is also clear that the responses implemented so far have not been sufficient to adequately protect the quality of the waters circulating in the subsoil. Specifically, a high proportion of dwellings are not connected to the public sewers, and the capacity of the treatment plants is not yet sufficient for the load being generated.

These circumstances require the immediate adoption of measures to reduce pollutant loads derived from anthropic activities in the area. It is necessary to reverse the contamination by adopting minimum standards of environmental quality and implementing policies to maintain the objectives achieved.

Specifically, the main safeguard measures should seek to:

- improve the systems of disposal and treatment of wastewaters;
- monitor more closely the construction, location, size and use of septic tanks to prevent pollution caused by the dispersal of the wastewaters they contain;
- raise awareness concerning the application of the Code of Best Agricultural Practice, including manuring, and facilitate the conversion of existing farms to organic farming;
- assess the environmental impacts of industrial activities.

In conclusion, the methodological approach used in this study yielded indications useful for the management of the Grecia Salentina sub-region so as to prevent and/or mitigate the problems affecting the groundwaters that were highlighted by chemical–microbiological monitoring. Indeed, the application of the DPSIR framework made it possible to analyse the relationship between natural and anthropic components, identifying the activities involved in the alteration of the quality of the deep waters. It also succeeded in highlighting causal links that laboratory activities alone—however complex and far-reaching—would not have detected. The use of an integrated system of indicators such as the one proposed here thus makes it possible to respond to the need for sustainable development policies characterised by a balanced integration of environmental, social and economic factors.

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