Exploitation of low enthalpy geothermal resource: the case study of a coastal area affected by seawater intrusion

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ABSTRACT

The exploitation of geothermal energy suitable for direct uses is still very limited in Italy. However, recently the interest in it is growing, especially for winter heating and summer cooling. Of particular interest, are the open-loop geothermal systems that are specially attractive in the coastal areas, where the aquifers are generally shallow, though often affected by seawater intrusion. In this work, a detailed characterization of a costal karst area near Bari (Southern Italy), is given as knowledge-base for the exploitation of low enthalpy geothermal resource. At the purpose, a specifically defined monitoring network, consisting of 35 wells, is used to monitor groundwater parameters (temperature, water level, electrical conductivity). The influence of an open-loop geothermal systems on the sea water intrusion is also studied by means of a long-term pumping test, although the results of the test will not be discussed in this paper. The poor groundwater quality, its constant and relative high temperature, and the good productivity of aquifer, make the study area suitable for the installation of geothermal systems. Particular attention must be paid to high salinity and hardness of groundwaters that can lead to fouling and corrosions in machines, reducing their performance. Overall, the experimental approach used for this study represents a good effort to define a standard methodology to characterize a coastal area and to evaluate its geothermal potential.

Abbreviation: T, temperature; EC, Electrical Conductivity.

1. INTRODUCTION

Contrary to exploitation of high enthalpy geothermal resources, the development regarding the direct uses of low-temperature geothermal resources is still very limited in Italy, especially compared to many other countries in Europe and in the world (UGI-CNG, 2007). However, the high cost of fossil fuels and the increasing attention to environmental issues in recent years, put more focus on all types of green energy, including geothermal.

As all exploitation of natural resources, also geothermal must consider the aspects regarding the long-term environmental sustainability. Particular attention must be paid to the open-loop geothermal systems that, as known, can also use groundwaters as geothermal fluid. In the coastal areas, these kind of installations are considered economically convenient, mainly because the presence of shallow aquifer. Regrettably, the coastal areas are often affected by seawater intrusion and this fact leads regional governments to enact restrictive laws to protect groundwater quality and quantity. This aspect could hinder the geothermal resources development, particularly in regions having very long coastlines, like Apulia region. In this work, an experimental approach is proposed for a site-specific characterization of a costal karst area in Apulia region affected by sea water intrusion, with the aim to verify the potential exploitation of low enthalpy geothermal resource.

2. STUDY AREA

The study area (Figure 1) extends for about 20 Km^2 and includes the urban and periurban zone of the city of Bari (Southern Italy).

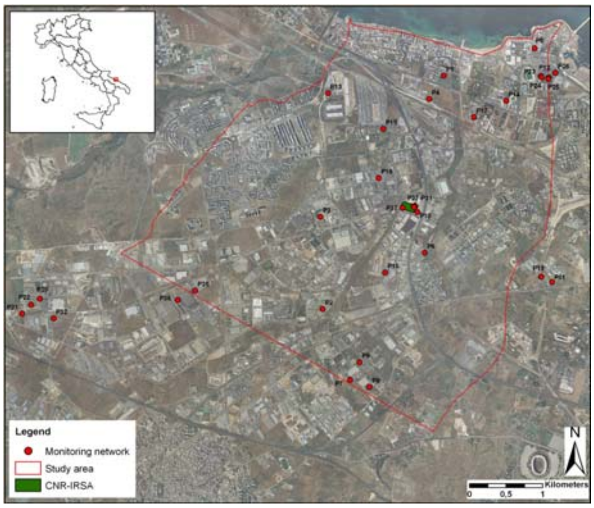

Figure 1: Study area and local monitoring network defined in this study

In this area is also located the building housing the Water Research Institute (CNR-IRSA), where exist different monitoring stations and a test-site used for hydrogeological tests.

2.1 Geological and hydrogeological set up

From geological point of view, the study area lies on the Murge, that is the central part of the Apulian foreland (Ciaranfi et al., 1988; Pieri et al., 2011). In the Murge, the foreland is characterized by a thick Mesozoic sedimentary succession belongs to *Calcare di Bari* formations (Figure 2), made up of limestone with frequent intercalations of dolomitic limestones and grey dolostones. Different fields of tectonic stresses involve the carbonate bedrock that are the base for the developing of numerous karstic cavities, of different shapes and sizes. The Quaternary deposits consist of different sedimentary units overlaying the carbonate bedrock. The oldest is represented by *Calcarenite of Gravina*, of Pleistocene age and made up of litho-bioclastic calcarenites. Upper Pleistocene-Holocene alluvial deposits, made up of carbonate gravels with reddish fine-grained matrix, outcrop in the little canyons, locally named “lame”. The Quaternary sequence is completed by Holocene travertine deposits (crust) which appear at times in a narrow band, parallel to the coast.

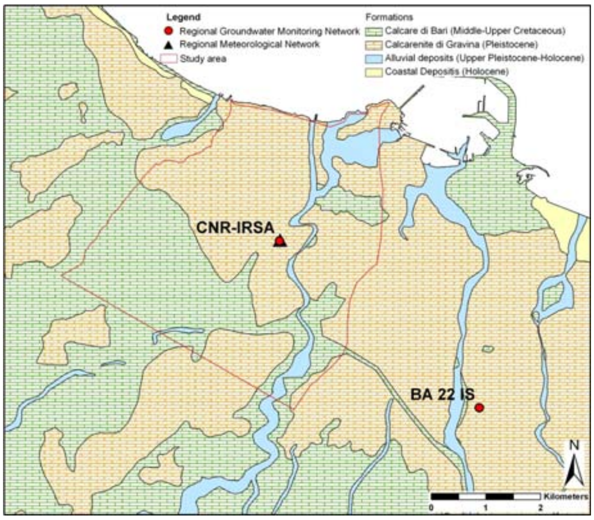

Figure 2: Geological map and location of regional monitoring stations

A wide and thick aquifer resides in the carbonate bedrock. The irregular distribution of fractures and karstic channels cause a large-scale heterogeneity and anisotropy of the aquifer and differences in horizontal and vertical hydraulic conductivity that vary, ranging from 10^{-2} to 10^{-5} cm/s (Maggiore, 1993). More specifically, previous pumping tests performed in the test-site of CNR-IRSA, provided a mean value of hydraulic conductivity in the order of 10^{-3} m/s and transmissivity between 9.8 and 12.1 m^2/s, highlighting a good productivity of aquifer (Di Fazio et al., 1992).

Groundwaters flow toward the sea, mainly under pressure (confined aquifer), as fractionated in distinct levels, separated by intervals of dry rock. Fractures and karstic channels, that involve the carbonate rock also below sea level, cause the intrusion of seawater into aquifer. The effect of this natural phenomenon is worsened with time due to the overexploitation of groundwaters. Aquifer is recharged only through precipitation that mainly infiltrate in the inner part of the Murge and along the natural drainage lines (lame).

2.2 Monitoring network

For a detailed hydrogeological and hydrogeochemical characterization of the investigated area, different kind of data are used coming from the existing regional monitoring networks (Regional Groundwater Monitoring Network, called “Tiziano Network”-Regional Meteorological Network) or produced for the purpose of this study. In fact, a site-specific groundwater monitoring network, consisting of a total of 35 wells (Figure 1), is defined. Water level is measured at each monitoring well, while temperature (T) and electrical conductivity (EC) logs are realized only where possible. All measurements are collected during June-July 2011.

3. LOCAL AQUIFER CHARACTERISTICS

3.1 Water table

A map of piezometric head (Figure 3) is obtained from water levels measured in the 35 wells making up the monitoring network. Starting from 30 m above sea level in the inner part of the study area, the piezometric head declines up to zero towards the coast.

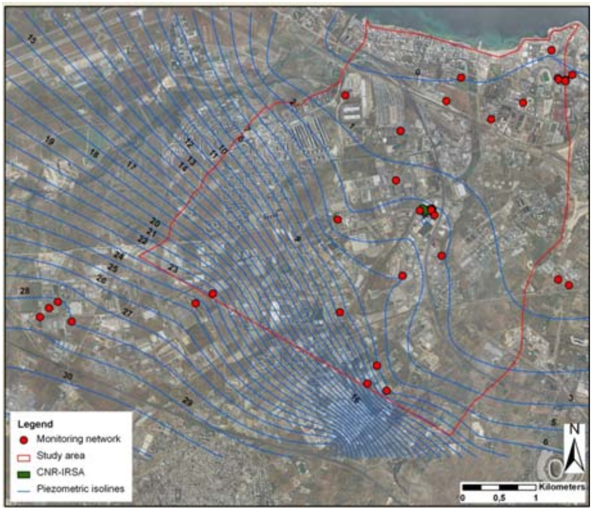

Figure 3: Piezometric contour map (June-July 2011) - contour interval 1 m

More dense contour lines, that is higher hydraulic gradients (0.9%), are visualized in the inner part of the investigated area, while less dense contour lines, meaning lower hydraulic gradients (0.1%), appear proceeding towards the coast. This behaviour is due to the influence of different fracture and karstification degree of the bedrock. The groundwaters flow under slight confining pressure in the direction SW-NE, that is roughly perpendicular to the coast.

Informations about the water table dynamic come from the daily groundwater levels, recorded at the CNR-IRSA groundwater monitoring station. Water table levels versus time are plotted in the graph of Figure 4, together with rainfall data recorded at CNR-IRSA meteorological station. The variations in time of groundwater levels reflect the pluviometric regime. In fact, the minimum of water table is recorded in October at the end of the dry season, instead the maximum occurs in the period of November-April when the groundwater resources are recovered by the winter recharge. In addition, the graph highlights a rapid changes of water level after rainfall events, that is a high rate of aquifer recharge. The maximum excursion of water table during the observation period, is about 2.0 m.

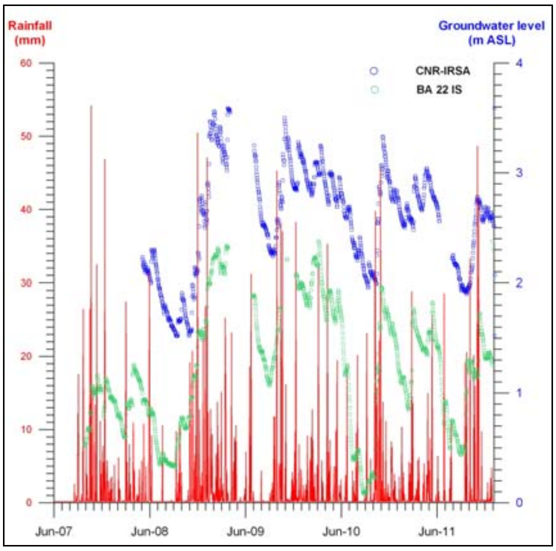

Figure 4: Groundwater levels and rainfall vs time

3.2 Water quality

Groundwater quality refers to the data, collected during May 2010, in two wells, CNR-IRSA and BA 22 IS, belonging to Tiziano network (see Figure 2 for locations). Chemical compositions of groundwater samples are shown in Table 1.

Concentrations of dominant cations and anions are found in the following order: Na+K>Ca>Mg> and Cl>HCO3>SO4, revealing a sodium-chloride facies for the investigated water samples. This means that two main processes contribute to determine the chemical composition of groundwaters: the interaction with the carbonatic rock through which groundwaters move and the well-known phenomenon of seawater intrusion affecting the coastal aquifers in Apulia region. The high values of EC confirm this last assertion. Particular attention must be paid to high hardness degree of the groundwaters that is more than 46°F, which corresponds to hard water. Hard water is not a health risk, but since it can lead to fouling and corrosions in machines, it requires some precautions such as the use of water softeners or carbon dioxide and other gases to keep calcium and magnesium in solution in the water. Moreover, the high values of total organic carbon, nitrate, iron, and bromide, reflect the presence of urban and industrial pollution. Ultimately, groundwaters in study area are not chemically suitable for drinking purposes and they must be used with caution also for irrigation, due to its high salt concentration. This means there are no strong competitions in use of groundwater resources in this area.

Table 1: Chemical composition of groundwaters sampled in some wells belonging to Tiziano Network.

Date	10/05/2010	10/05/2010
Well	**CNR-IRSA**	**BA 22 IS**
Sampling depth (m)	18	53
Sampling mode	Static	Static
Temperature (°C)	19,92	17,74
pH	7,97	8,25
EC (mS/cm)	1,92	3,33
Water hardness (°F)	56,9	46,4
Bicarbonates (mg/l)	534	379
Calcium (mg/l)	115	72
Chloride (mg/l)	666	689
Magnesium (mg/l)	68,4	68,9
Potassium (mg/l)	25,3	31,7
Sodium (mg/l)	408	392
Sulfate (mg/l)	132	73,6
Ammonium (mg/l)	0,12	<0.030
Nitrite (μg/l)	<50.00	<50.00
Nitrate (mg/l)	19,2	18,1
TOC (mg/l)	2,49	1,48
SAR index	7,44	7,92
Lithium (μg/l)	16,7	13,5
Bromide (μg/l)	2170	2330
Fluoride (mg/l)	0,37	0,22
Iron (μg/l)	373,4	2200
Manganese (μg/l)	38,5	93,7

3.3 Groundwater temperature and electrical conductivity

More detailed characterization of groundwaters in terms of T and EC, is obtained from the continuous monitoring data acquired in the wells CNR-IRSA and BA 22 IS. Furthermore, vertical thermal-conductivity logs, performed in some wells of the monitoring network specifically defined for this study, is analyzed.

The graphs in Figure 5, show T and EC data recorded over three years in the two well above mentioned. Nearly no variation of T is displayed throughout the monitoring period while difference in T, of about 2°C, is observed from one well to another. In fact the well BA 22 IS exhibits an average value of 17.7°C against the well CNR-IRSA having an average value of 19.6°C. A more consistent variation is observed among two wells regarding EC parameter. It strongly varies in time in the well BA 22 IS, passing from 2 mS/cm up to 3.5 mS/cm, while it fluctuates around value of 2 mS/cm in the well CNR-IRSA. This different spatial and temporal behaviour can be ascribed to the different depth to which the probe for monitoring is placed (see Table 1). In fact, the probe in the well BA 22 IS, placed at greater depth than the other well, intercepts the transition zone within which freshwater and saltwater are mixed, and it's known that its extension and position can vary over time.

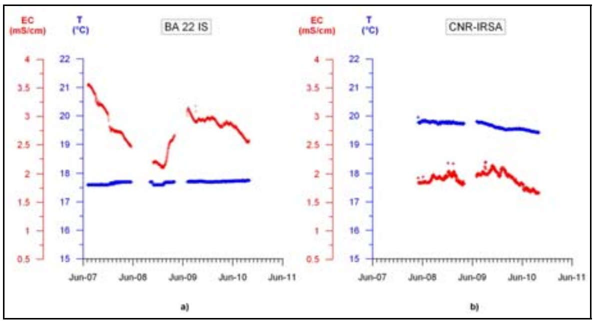

Figure 5: T and EC recorded in two wells belonging to Tiziano Network

The analysis of thermal-conductivity logs provide further details about the vertical distribution of these parameters within aquifer. Figure 6 shows the location of the monitoring points where temperature and electrical conductivity logs are made. The more significant logs are also reported. Log T in well P21, located in the westernmost sector of the area, shows an almost constant value of about 17°C, throughout hole length.

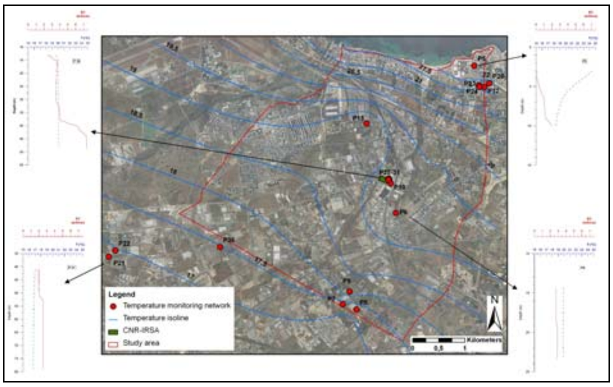

Figure 6: Map of groundwater temperature distribution at a depth of 1 m. The more significant temperature (broken line) and electrical conductivity logs (solid line) are also reported.

This value of temperature can be taken as typical for groundwaters. EC, instead, shows a slight jump at about 52 m depth from the ground, where it reaches value of 2.5 mS/cm, that remains constant up to the bottom of the hole. Despite the more internal position of the well P21 from the coast, a slight effect of sea water contamination is verified. No significant changes in T and EC logs are reported for P6, located in the central part of the investigated area. However, the values of these parameters are higher than the previous case, that is about 20°C for T and about 3 mS/cm for EC. T log in well P30, reflects the same profile of well P6, being constant at about 20°C. Different behaviour is displayed for EC log, both because the well P30 is closer to the coast and because it is deeper than well P6. In fact, EC values increase downward as a step profile: the first step is between 8 and 19 m below ground, where EC values increase from 2.5 to 4 mS/cm; the second step is between 37 to 43 m below ground, where more marked increase in EC is recorded, reaching values in excess of 7 mS/cm, at the beginning of the transition zone. Maximum T variations are found in the well P5, which is the closest to the sea. Water T rapidly decreases from 25°C to 18°C along the profile. The little depth at which groundwaters occur in this area (1-2.5 meters below ground) make this monitoring point strongly affected by external variations. Overall, the differences in thermal regime and salinity characteristics of groundwaters can be ascribed to the state of fracturing and/or karstification of carbonate bedrock, that is the main factor controlling the groundwater flow in this area.

A map of isotherm curves (Figure 6) was drawn using the T measured at a depth of 1 m below water table. As shown in the map, the T increases from 17-18°C, in the inner part, up to values of more than 21°C near the coast. A general trend of isotherms is observed, being almost parallel to the coast. However an anomalous shape of the isotherm corresponding to 19.5°C is shown. Starting from this isotherm and proceeding towards the coast, a more marked T rise is detected. This is due to the effect, known as Urban Heat Island (UHI) effect (Zhu et al, 2010), that in this area is more effective mainly because the urban fabric becomes more dense.

3. CONCLUSIONS AND FUTURE WORK

A detailed characterization of a costal karst area, affected by seawater intrusion, is achieved in this work. For the purpose, hydrogeological and geochemical existing data, coming from regional monitoring network, and new data, coming from a specifically defined monitoring network, are collected.

High hydraulic conductivity and short time of recharge characterize the investigated portion of aquifer, highlighting its good productivity. A poor groundwater quality is detected due to both the presence of urban and industrial pollution and the well-known phenomenon of seawater intrusion. This evidence implies the absence of a strong use competition of groundwater resource in this area. Therefore, the geothermal use of groundwaters is possible, even though particular attention must be paid to the high degree of hardness in water that can cause a reduce of machines performance. The T of groundwaters, reaching over 20°C near the coast, is particularly useful for direct use, especially for the space heating and cooling.

The experimental approach utilized for this study represents a good effort to define a standard methodology to characterize a coastal area. The acquired informations form a solid base of knowledge to support the geothermal potential evaluation of the area and any type of feasibility study for the installation of a geothermal system.

Nevertheless, the results of this work point to several interesting directions for future work. In fact, especially in a coastal area affected by seawater intrusion, it cannot be overlooked the long-term environmental sustainability of the groundwater use for geothermal purpose. Particularly, the open-loop geothermal system can affect groundwater quality, both due to an additional incoming of sea water induced by pumping, as well as the increase or decrease in temperature of the water returned to the environment, that could result in an alteration of physical, chemical and biological equilibrium of aquifer. For further understanding this important issue, additional work will be done by means of the analysis of data coming from the long-term pumping test, lasting 16 days, performed in the study area. Moreover, the site characteristics will be also explored by the development of the numerical model to simulate both heat transfer and groundwater flow associated with long-term exploitation of a heat exchanger and hence to investigate its environmental impact. A solid process validation of numerical simulations will also rely on experimental data collected during the long-term pumping test.

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