Environmental issues and anthropic pressures in coastal aquifers: a case study in Southern Latium Region

Abstract: Saline intrusion is one of the main problems in the drinking water quality management, especially for those coastal areas in which urbanization is seriously increasing. In fact, in some countries with an extensive coastline, such as Italy, the high drinking water demand can lead to an uncontrolled groundwater exploitation of coastal aquifers. During summer 2017, a severe drought event affected the entire Italian territory, including the study area located in the southern part of Latium Region. In order to overcome future water crisis, the water-supply agency (Acqualatina S.p.a.) has planned the realization of a wellfield in the “25 Ponti Area”, belonging to the Municipality of Formia and about 500 m far away from the coastline. From September 2017 to December 2017, Tulliola Well has been completed and used at increasing flow rates to monitoring the effects of groundwater exploitation on this karst coastal aquifer. The aim of this paper is to present the first results of the monitoring activities, carried out by the Department of Civil, Building and Environmental Engineering (DICEA) of Sapienza University of Rome, in order to evaluate the rate of groundwater salinization due to a possible seawater intrusion phenomenon in the study area.

Introduction

Water management is one of the current global challenges due to the role played by freshwater as a resource for sustaining life and human needs. In many parts of the world increasing urbanization and improvement of living conditions have led to a growth of drinking water demand, causing in some cases an uncontrolled groundwater exploitation of coastal aquifers (Capaccioni et al. 2005; Sappa and Luciani 2015; Najaib et al. 2017). Intensive groundwater withdrawals from coastal aquifers may decrease freshwater outflows to the sea, lower the water table, and cause the encroachment of seawater inland, resulting in a worsening of groundwater quality (Alfarrah and Walraevens 2018). Therefore, seawater intrusion is an active process, driven by changes to hydrogeologic system, which trigger substantial groundwater quality changes (Sappa et al. 2015; Barbieri et al. 2017; Bakalowicz 2018). Several water geochemical indicators and diagrams are mainly used in literature to investigate potential seawater intrusion in coastal aquifers (Kelly 2006; Giménez-Forcada 2010; Saïl Kumar 2016; Jorreto et al. 2017). A sustainable groundwater exploitation is an important environmental issue in this context, because the intensity of these events depends on several factors as the pumping rates, the well field location and design, as well as the geometry, and the hydrogeological parameters of the pumped aquifer (Alfarrah and Walraevens 2018). In summer 2017, a severe drought event affected...
the Italian territory (IRSA 2017) with serious impact on population and inconveniences for local water supply agencies. In the municipality of Formia (Latina Province), the local water supply agency, because of the decreasing flow rates supplied by Mazzoccolo and Capodacqua di Spigno springs, planned and built a well field in the “25 Ponti Area” in order to handle future water crisis. Groundwater monitoring activities performed in the “25 ponti” area will support the local water supply agency in its decisions aimed at sustainable water resource management, avoiding groundwater salinization by seawater intrusion.

**Site description**

The study area is located in the western part of the Municipality of Formia, in the south-eastern part of Latium Region (Fig. 1), about 500 m far away from the coastline. Formia is a highly urbanized city with recognized water-shortage challenges and high dependence on groundwater resources. A fractured, heterogeneous aquifer lies below the inhabited area. The geological setting (Baldi et al. 2005) is characterized by Pliocene sea deposits overlapping detrital-organogenic limestone and calcareous-dolomitic rocks (platform deposits).

Permeability characteristics and the extent of the Cretaceous limestone complex and the underlying Jurassic dolomite complex allows the presence of important aquifers. Underground circulation takes place mainly in the limestone, while dolomites act as the bottom boundary of the groundwater flow (Sappa et al. 2018). In the study area, the aquifer is made up of a fractured and karst micritic limestone with interbedded clay levels (about 8 m), a calcareous breccia (about 30 m) and, at the bottom, a micritic limestone with a thickness of several hundred meters (Fig. 2).

The aquifer is characterized by elevated values of transmissivity and infiltration rate due to a well-developed karst (Sappa et al. 2015). Currently only two wells have been completed in the “25 Ponti” area (Tab. 1).

Tab. 1 - The location of well water sampling survey.

| Name          | ID | Latitude       | Longitude       | Elevation (m a.s.l.) | Depth (m) |
|---------------|----|----------------|-----------------|---------------------|-----------|
| Tulliola well | TUL| 41°15'8.21"   | 13°35'2.23"    | 20                  | 55        |
| Terenzia well | TER| 41°15'8.04"   | 13°34'59.06"   | 20                  | 90        |

Fig. 1 - Study area and localization of Tulliola and Terenzia wells.

Fig. 2 - Seawater-freshwater interface in the study area.

Fig. 2 - Interfaccia acqua dolce - acqua salata nell’area di studio.
Materials and Methods

Groundwater monitoring activities were carried out from August 2017 to July 2018. Eighteen (18) groundwater samples were collected from Tulliola and Terenzia wells (Table 2): sixteen water samples were collected from August to November 2017 from Tulliola well, during a long-term exploitation period, whereas two samples were collected in June 2018 from Terenzia well, during the first pumping tests. The chemical composition was determined using standard analytical methods (APHA 1995). Analyses of major cations and anions were carried out by the laboratory of the local water-supply agency, using a Dionex ICS 1000 Ion Chromatograph (Tab. 2).

Results and discussion

The geochemical data analysis show an increasing trend of electrical conductivity (EC) due to the rise of some ions concentrations, such as chloride. For Tulliola well, EC values range from 607 μS/cm to 858 μS/cm, respectively at the beginning and at the end of the long-term exploitation period. Cl− content also increases from 44.7 to 136.7 mg/l from August 2017 to November 2017, proportionally to the EC increasing trend (Tab. 2).

This EC trend seems to be related to the flow rates exploited from Tulliola well, which have been increased from 17 l/s (September 2017) to 37 l/s (October-December 2017). Therefore, pumping rates would play a key role in the observed changes in groundwater salinity (Fig. 3).

Terenzia well samples show EC values above 1100 μS/cm and higher chloride concentrations (up to 218 mg/l) compared to Tulliola outcomes (Tab. 2), probably due to the greater depth of the well (Tab. 1). The potential groundwater salinization has been investigated by the analysis of the Na+/Cl− ionic ratio. All groundwater samples, except TUL_01, show Na+/Cl− molar ratios lower than the seawater value (0.88). The decreasing trend over time, as the groundwater exploitation increases, may suggest a possible seawater encroachment (Fig. 4). The lowest values of this ratio may be attributed to depletion of Na+, probably caused by cation

| ID   | Date  | EC    | Na+ | K+ | Ca2+ | Mg2+ | Cl− | SO42− | NO3− | HCO3− |
|------|-------|-------|-----|----|------|------|-----|-------|------|-------|
| TUL_01 | 01/08/2017 | 607  | 27.3 | 12.4 | 62.9  | 11.3  | 44.7 | 30.6  | 16.3  | 244.0 |
| TUL_02 | 08/08/2017 | 661  | 19.6 | 3.1 | 86.3  | 12.9  | 42.8 | 27.8  | 17.6  | 475.8 |
| TUL_03 | 25/08/2017 | 661  | 29.9 | 1.8 | 88.6  | 15.7  | 56.8 | 27.2  | 14.8  | 535.8 |
| TUL_04 | 30/08/2017 | 644  | 20.5 | 1.0 | 83.3  | 12.5  | 43.3 | 32.3  | 17.4  | 317.2 |
| TUL_05 | 31/08/2017 | 664  | 16.7 | 2.1 | 72.9  | 9.8   | 44.2 | 30.1  | 18.6  | 268.4 |
| TUL_06 | 01/09/2017 | 662  | 18.1 | 0.4 | 75.4  | 10.2  | 45.4 | 30.4  | 18.0  | 280.6 |
| TUL_07 | 14/09/2017 | 665  | 20.5 | 1.0 | 88.1  | 12.9  | 48.1 | 31.5  | 18.6  | 329.4 |
| TUL_08 | 18/09/2017 | 683  | 23.2 | 1.0 | 95.0  | 14.1  | 55.0 | 29.6  | 16.3  | 366.0 |
| TUL_09 | 18/09/2017 | 684  | 22.6 | 1.0 | 95.5  | 13.9  | 55.8 | 29.9  | 16.5  | 366.0 |
| TUL_10 | 02/10/2017 | 740  | 23.9 | 1.0 | 92.9  | 13.4  | 80.9 | 30.2  | 15.0  | 355.8 |
| TUL_11 | 10/10/2017 | 764  | 30.3 | 2.4 | 120.6 | 17.8  | 91.2 | 29.6  | 14.3  | 451.4 |
| TUL_12 | 02/11/2017 | 835  | 33.3 | 1.9 | 111.2 | 15.3  | 123.2| 29.8  | 13.4  | 414.8 |
| TUL_13 | 08/11/2017 | 843  | 32.4 | 1.5 | 112.5 | 16.4  | 122.2| 30.2  | 13.3  | 427.0 |
| TUL_14 | 13/11/2017 | 835  | 32.4 | 1.4 | 113.1 | 16.0  | 122.6| 29.9  | 13.1  | 427.0 |
| TUL_15 | 20/11/2017 | 846  | 36.7 | 1.0 | 116.4 | 16.3  | 136.7| 29.8  | 12.9  | 439.2 |
| TUL_16 | 27/11/2017 | 858  | 35.6 | 0.3 | 114.4 | 14.6  | 137.3| 30.8  | 13.3  | 427.0 |
| TER_01 | 09/07/2018 | 1102 | 55.0 | 1.4 | 133.3 | 32.9  | 196.0| 69.2  | 28.5  | 573.4 |
| TER_02 | 11/07/2018 | 1146 | 58.0 | 2.0 | 140.1 | 34.1  | 218.3| 69.6  | 27.6  | 597.8 |

Fig. 3 - Comparison between Cl− concentrations and water cumulative volume from Tulliola well.

Fig. 3 - Confronto tra le concentrazioni di Cl− e i volumi cumulati prelevati dal pozzo Tulliola.
exchange occurring in the clay levels interbedded in limestone
(Alfarrah and Walraevens 2018). These results are supported
by the identification of the groundwater hydrochemical facies
obtained by plotting the water samples in a Piper tri-linear
diagram modified for salinization processes (Kelly 2006). All
water samples fall in the freshwater field, but a trend toward
seawater is evident (Fig. 5).

The effect of groundwater withdrawals on salinization
is also pointed out by the Hydrochemical Facies Evolution
diagram (HFE-D), proposed by Giménez-Forcada (Giménez-
Forcada and Sánchez San Román 2015). This diagram has
been created to highlight the main processes occurring in
coastal aquifers, as seawater intrusion evolution. In figure 6
all groundwater samples are plotted on the right and below
the seawater-freshwater mixing line, falling in the field of
Mg-Ca-HCO₃ facies.

In order to investigate the freshwater-seawater mixing in
the study area, a groundwater sample, collected from the
main karst spring near the study area, Mazzoccolo Spring,
(Sappa et al. 2015), was plotted in the HFE-D diagram, as
freshwater end-member. The Mazzoccolo Spring sample and
TUL_01 sample collected in 01/08/2017, fall in the same
position. Therefore Tulliola well water, collected before the
exploitation, have the same characteristics of freshwater.
Tulliola water samples collected in August 2017 fall along
the mixing line, while the other samples show a trend
towards Ca-MixHCO₃ composition (Fig. 6), highlighting a
development of reverse exchange reactions, triggered by the
increase in salinity due to the up-coning phenomenon. Water
samples collected from Terenzia well are closer than Tulliola
ones to the mixing line, suggesting the presence of a more
mineralized water facies.

Fig. 4 - Cl⁻ vs. Na⁺/Cl⁻ ratio bivariate plot.
Fig. 4 - Diagramma binario Cl⁻ vs. rapporto Na⁺/Cl⁻.

Fig. 5 - Piper Diagram of groundwater samples (modified by D. Kelly for saline intrusion evaluation, 2006).
Fig. 5 - Diagramma di Piper relativo ai campioni prelevati (modificato da D. Kelly per la valutazione dell'_intrusione salina, 2006).

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Conclusions

First results of the coastal aquifer groundwater monitoring in the “25 Ponti area” (Municipality of Formia - Latina Province) have been discussed, based on groundwater analysis of several samples withdrawn from two wells (Tulliola and Térenza wells).

Geochemical characterization has been used to evaluate seawater intrusion issues. The enrichment in some chemicals constituents highlights the potential triggering of groundwater salinization, due to water well withdrawals.

For Tulliola well water samples, Na+/Cl- ratios range from 0.39 to 0.94, pointing out an ongoing seawater intrusion process. Moreover, a cation exchange is quite evident, considering the deficit of Na+ and the surplus of Ca²⁺ with respect to the trend indicated by the freshwater-saline water mixing line.

The applied modified Piper diagram (Kelly 2005) shows a slight intrusion process in progress. The Hydrochemical Facies Evolution diagram (HFE-D), (Giménez-Forcada 2010), highlights a trend toward Ca-MixHCO₃ composition, due to observed salinity increasing, which drives the development of reverse exchange reactions. This result is quite remarkable, since groundwater samples, collected before the beginning of well pumping, are very similar to the Mazzoccolo Spring water sample, which represents the freshwater-end member of the mixing line.

Future developments of the study could be the predisposition of:

• an early warning monitoring system;
• more detailed monitoring activities such as isotopic characterization (²H, ¹⁸O, ⁸⁷Sr/⁸⁶Sr) in the same sampling points;
• a groundwater hydrodynamic model extending the water level measurements to other wells present nearby the study area.

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