Groundwater resources at salinisation risk: effects of climate and utilisation changes in the case of Apulian coastal aquifers (South-eastern Italy)

Abstract: Seawater intrusion is the main cause of groundwater salinisation in Italy. The largest coastal aquifers, highly vulnerable to salinisation, are in Apulia. For these aquifers, main changes in terms of climate change and utilisation are discussed together with piezometric trends, as the latter are relevant triggering factors for upconing and lateral seawater intrusion. For this purpose, time series from 1921 to 2016 concerning climate (rainfall and temperature), from 1965 to 2016 concerning groundwater availability (piezometric values), and recent periodic data on potable utilisation are discussed. Climate and groundwater availability trends at 2016 are compared with trends previously assessed, using the same dataset (1921-2001 for rainfall and temperature). The negative characteristic of rainfall 1921-2001 trend improved in the next years up to disappear in the assessment of rainfall 1921-2016 trend. Notwithstanding the improving of rainfall trend and the reduction of groundwater utilisation, both observed at 2016, the improvement of piezometric trends at 2016 is not enough to remove a prevailing decreasing trend, previously observed. The increases of temperature and effective evapotranspiration should be considered a relevant explanation of groundwater availability reduction. The consequence of these results should be quickly considered in the management of groundwater resources.

Keywords: coastal aquifer, climate change, overexploitation, groundwater management, Apulia, Italy.

Introduction

Apulia region is dominated by karstic features, reason for which scarcity of surface water resources is widespread (Polemio 2016). The historical scarcity of surface water resources deeply conditioned human life, i.e. forcing urbanisation far from the coast in narrow areas where shallow groundwater could be easily exploited. The realisation of very long aqueducts from the beginning of the 20th century gradually satisfied the request of potable water.

Four main hydrogeological structures (HSs), Gargano, Tavoliere, Murgia, and Salento, can be distinguished in Apulia (Fig. 1) (Polemio 2016). Apart from Tavoliere (Fig. 1), which is a shallow porous aquifer, wide coastal karstic aquifers constitute the main water resource for the regional social-economic development.

Tavoliere includes a superficial porous aquifer, few tens of meters thick, with a clayey bottom, hundreds of meters thick. Groundwater flow is phreatic in the innermost portion and confined downward, up to the coast. The groundwater quality does not allow potable use while the significant over-exploitation is so high that the Regional Water Protection Plan provided relevant restriction to permissions for groundwater exploitation (Apulian Region 2009).

High quality groundwater resources can be found in the remaining HSs, Gargano, Murgia and Salento (Apulian Region 2009). These HSs show common characteristics: they consist of Mesozoic calcareous and/or calcareous-dolomitic rocks; they constitute large and deep coastal aquifers; permeability, which is heterogeneous and anisotropic due to the karst and the fracturing, is from medium to high, particularly high in Salento, as discussed by Cotecchia et al. (2005). Groundwater flow is mainly confined unlike what observed near the coasts; Murgia and Salento HSs host an almost continuous water body (Polemio 2016). The three carbonate HSs are affected by the phenomenon of seawater intrusion, with very different effects, generally more severe for Salento (Sanford et al. 2007; Romanazzi et al. 2015; De Filippis et al. 2016; Polemio et al. 2016).

Starting from eighties, several drought periods and a generalised decreasing trend of recharge were observed in the whole Southern Italy, including Apulia, in combination with the increase of groundwater utilisation (Polemio and Casarano 2004; Lionello et al. 2014). These long-lasting conditions caused a significant decreasing piezometric trend up to until the latest decade (Polemio et al. 2009).

Previous experiences concerned the climate change in the period 1921-2001 at scale of Southern Italy and the effects on groundwater availability, focusing on some relevant aquifers, including those of Apulia (Polemio and Casarano 2004; Polemio et al. 2009). This paper zooms into the trends of climate in Apulia. Taking steps from the above-mentioned dataset, this paper aims at detecting the recent effects of the regional groundwater management (Apulia Region 2009), by considering a larger period, improving previous results, upgrading trend assessment. Based on these premises, this paper analyses the most recent climate trends in terms of rainfall, temperature and effective rainfall (calculated using rainfall and temperature data), discussed considering the record over a 96-year period, and the tendency of groundwater resources availability together with main variations of groundwater utilisation, focusing on drinking purposes.

Data and Methods

The study is part of a long-term research activity of the Hydrogeology Group of CNR-IRPI, based mainly on the application of geostatistical analysis methods of climate, hydrological and geochemical time series studying aquifer characteristics, groundwater-surface water relationships and the estimation of the qualitative-quantitative trends of groundwater (Polemio et al 2009; Chiaudani et al. 2017). Climate and piezometric data, usually monthly data, were considered. The data come from historical research, monitoring networks, as well as sporadic surveys carried out by the Hydrogeology Group.

For the whole region, 27 gauges, currently managed by the Apulia Region, 16 of which include temperature probes, were selected among many tens of gauges, some of which with data from the 19th century (Fig. 2). Between monthly time series that are complete in the latest two decades, the selected time series were selected maximising length and minimising gaps, starting from 1921. Data start from 1921 and 1924 for rainfall and temperature respectively, up to 2016.

Piezometric time series at 26 wells (Fig. 1) were selected from a wide database with data from 1965 to 2016, giving priority to time series with recent data. The very rare rainfall and temperature gaps were filled using interpolation. For each missing data, the nearest and best correlated gauges/time series were used, using all the dataset, including
values of about 700 and 800 mm respectively (Fig. 2). The average annual rainfall over the whole region is about 640 mm. More than 66% of average annual rainfall is observed from autumn to winter; summer rainfall exceeds 100 mm only in the rainiest areas of Gargano. Annual mean temperature at low altitude (less than 200 m a.s.l.) gauges ranges between 16.0 and 17.5 °C. Values of the coldest month, January, are between 7.5 and 10.7 °C; the hottest month (generally July, August in some parts of Salento) reaches temperature from 25.0 to 26.4 °C.

Two decades after 1980 with recurrent droughts were confirmed, as previously highlighted (Polemio and Casarano 2004; Lionello et al. 2014; Doglioni and Simeone 2019). Since 2002, an almost rainy period occurred, contrarily to the previous two decades.

The almost generalised decreasing rainfall trend observed in 1921-2001 showed a low statistical significance (Tab. 1) and was the less evident in Southern Italy in the same period (Polemio and Casarano 2004). Moving to the whole study period (96 years, 1921-2016) this decreasing trend was nullified by rainfall observed in the latest 15 years, from 2002 to 2016 (Tab. 1). This rainfall trend change is coherent with results of Lionello et al (2014) and Doglioni and Simeone (2019).

Except for the station at higher altitude, located in Gargano (annual rainfall between 800 and 1200 mm), annual rainfall ranges between about 450 mm (part of Tavoliere, close to Gargano coast, and close to northern Ionian coast) and 800 mm; inland recharge areas of Murgia and Salento record

### Data discussion and conclusions

Except for the station at higher altitude, located in Gargano (annual rainfall between 800 and 1200 mm), annual rainfall ranges between about 450 mm (part of Tavoliere, close to Gargano coast, and close to northern Ionian coast) and 800 mm; inland recharge areas of Murgia and Salento record
Moving to seasonal trend, it is relevant that the rainfall trend is not univocal (Table 3). The decreasing winter trend of 1921-2001 is still confirmed in 1921-2016 and is generalized on the study area, even if only in few cases it is statistically significant. On the contrary, the analysis for the other seasons over the whole period (1921-2016) indicates an increasing trend, so relevant that the autumn is becoming rainier than winter. The increasing trend of spring and summer rainfall, almost everywhere not statistically significant, shows a low magnitude with respect to the annual rainfall contribution.

As observed in the past, the combined effect of annual and seasonal temperature and rainfall modifications can determine a significant increasing of effective evapotranspiration, so reducing the natural recharge of the aquifers and emphasizing cultivation water deficit, increasing groundwater exploitation (Polemio and Casarano 2004).

A regional decreasing trend of effective rainfall was found on the whole study period 1924-2016 (Tab. 4), although it is significantly less than the 1924-2001 trend. The occurrence of rainy years after 2001, in wide areas, balanced the negative rainfall trend previously determined, but was not enough to nullify the decreasing trend of effective rainfall. This was mainly due to an overall increase of actual evapotranspiration due to the increasing temperature trend and to modifications of the seasonal rainfall distribution: a downward rainfall trend is still observed during winter, when generally net rainfall reaches maximum levels and actual evapotranspiration is at its minimum. The increasing rainfall trends observed in the other seasons are associated to higher and increasing evapotranspiration values. These results confirm a decreasing trend of natural recharge, which is a rate of effective rainfall.

![Fig. 3 - Mean annual temperature of Murgia hydrogeological Structure and trends of 1924-2001 and 1924-2016.](image)

**Tab. 2** - Temperature annual trend assessed in hydrogeological structures (HSs) and in Apulia from 1924 to 2001 and from 1924 to 2016 (in parentheses number of significant trends).

**Tab. 3** - Apulian rainfall seasonal trend from 1921 to 2016 (in parentheses number of significant trends).

**Tab. 4** - Effective rainfall trend from 1924 to 2001 and from 1924 to 2016 (in parentheses number of significant trends) of hydrogeological structures (HSs) and of Apulia.
Starting from 2008, a continuous decrease of potable groundwater utilisation was observed at regional scale (Tab. 5), which was certainly useful to improve the groundwater availability trend together with improvement of effective rainfall trend.

Moving to piezometric trends (Fig. 1), if a generalised decreasing trend was observed in 2008 (Polemio et al. 2008), 18 out of 26 selected time series (69%) show decreasing trends in 2016. Checking the 18 negative trends, 12 are statistically significant (46%); 5 cases of significant increasing trend were observed (20%). This figure defines a relevant improving in terms of Apulian groundwater availability if 2008 is considered as a reference.

Neglecting the unique available time series of Gargano for low data availability, the 3 statistically significant Murgia trends correspond to wells located in the core of Murgia recharge area, where the direct groundwater utilisation by wells is negligible. The unique positive trend of Salento is in an area under the effect of inflow to Salento due to leakage from recharge area of Murgia (Polemio 2016). Both these observations suggest that the lower hydrogeological characteristics of Murgia HS, in terms of permeability and storativity, cause quicker effects of recharge on piezometric levels. The above-mentioned results are coherent with the studies performed on the same areas with different datasets and methodologies by Doglioni and Simeone (2019). They observed that the recent effects of the inversion of the negative recharge trend, were detected where the hydrogeological characteristics are lower, as in the case of Murgia, and were not still detected for Salento.

Piezometric trend can be considered predominantly negative in 2016 at regional scale, although it is lower in absolute value with respect to previous evaluations; using other words, a slight improvement of the global negative trends was detected. Decreasing piezometric trend implies reducing groundwater resources availability and worsening salinisation risks for seawater intrusion. As this worsening scenario is confirmed in 2016, it is suggested an improvement of management criteria of these natural resources.

Tab. 5 - Apulian potable groundwater utilization from 2008 to 2015 (Thousands of cubic meters, ISTAT data available at link https://www.istat.it/it/archivio/127380).

<table>
<thead>
<tr>
<th>Year</th>
<th>Spring</th>
<th>Well</th>
<th>Total</th>
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<td>2008</td>
<td>838</td>
<td>115181</td>
<td>116019</td>
</tr>
<tr>
<td>2012</td>
<td>560</td>
<td>88481</td>
<td>89041</td>
</tr>
<tr>
<td>2015</td>
<td>414</td>
<td>71954</td>
<td>72368</td>
</tr>
</tbody>
</table>

REFERENCES


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