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

Risorse idriche sotterranee a rischio di salinizzazione: effetti dei cambiamenti del clima e di utilizzo nel caso degli acquiferi costieri pugliesi (Italia sudorientale)

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Riassunto: L'intrusione marina è la causa principale della salinizzazione delle acque sotterranee in Italia, i cui più estesi acquiferi costieri, molto vulnerabili alla salinizzazione, si trovano in Puglia. Per questi acquiferi, visto il legame tra calo della disponibilità e intrusione marina, sia laterale che per risalita, si discute il trend piezometrico unitamente a quelli delle variabili che principalmente lo determinano, focalizzando su cambiamenti climatici e utilizzo delle acque sotterranee. A tale scopo, si discutono le serie temporali dal 1921 al 2016 relative al clima (precipitazioni e temperature), dal 1965 al 2016 relative alla disponibilità di acque sotterranee (serie piezometriche) e recenti dati periodici sull'utilizzo potabile. Le tendenze relative al clima e alla disponibilità delle acque sotterranee al 2016 sono confrontate con le tendenze precedenti, utilizzando lo stesso set di dati (1921-2001 per le precipitazioni e la temperatura). La tendenza negativa della piovosità registrata dal 1921 al 2001 è migliorata negli anni successivi al 2001, fino a scomparire nel trend delle piogge del 1921-2016. Nonostante il miglioramento dell'andamento delle precipitazioni e la riduzione dell'utilizzo delle falde acquifere, entrambe osservate al 2016, il miglioramento dei trend piezometrici al 2016 non è sufficiente a rimuovere una prevalente tendenza decrescente, precedentemente osservata. L'aumento della temperatura e dell'evapotraspirazione reale può giustificare la riduzione della disponibilità delle acque sotterranee. Tali risultati dovrebbero essere presi rapidamente in considerazione per migliorare la gestione delle risorse idriche sotterranee.

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

Parole chiave: acquiferi costieri, cambiamento climatico, sovrasfruttamento, gestione delle acque sotterranee, Puglia, Italia.

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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.*

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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.

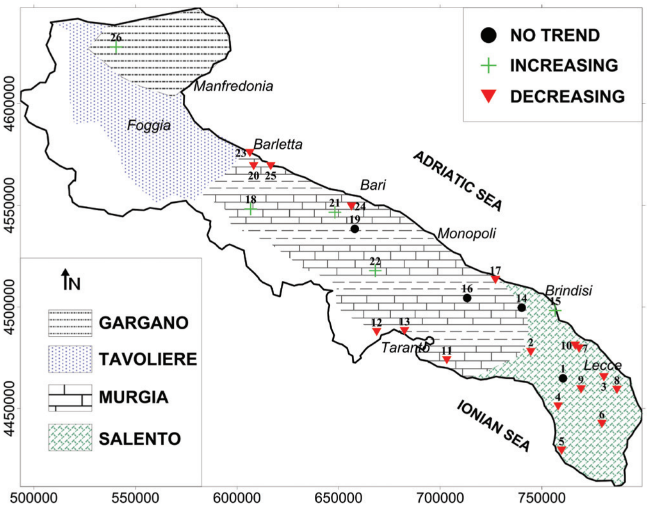

Fig. 1 - Main Apulian hydrogeological structures, selected monitoring wells and statistically significant piezometric trend of 1965-2016 (the axes show UTM33 WGS84 coordinates).

Fig. 1 - Principali strutture idrogeologiche pugliesi, pozzi di monitoraggio selezionati e trend piezometrico statisticamente significativo del 1965-2016 (gli assi rappresentano le coordinate show UTM33 WGS84).

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

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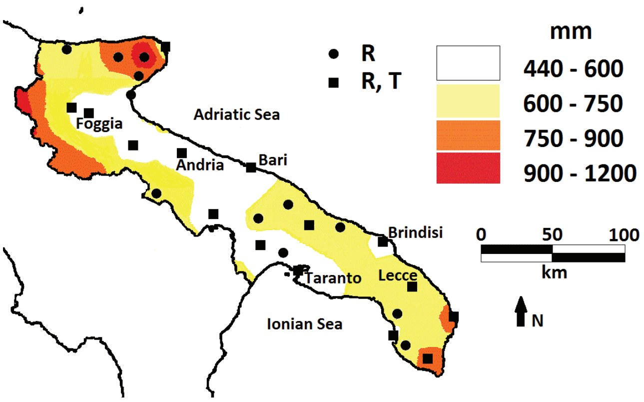

Fig. 2 - Rainfall (R) and temperature (T) gauges and mean annual rainfall map (mm, period 1921-2016).

Fig. 2 - Ubicazione delle stazioni pluviometriche (P) e termometriche (T) selezionate e mappa della piovosità media annua (mm, periodo 1921-2016).

each available time series. Interpolation used annual and monthly values of neighbouring gauges with the same facing, selecting those with higher correlation coefficient, generally with r>0.7 (Polemio and Casarano 2004). The low or negligible correlation between contemporaneous piezometric measurements of available piezometric time series prevents gap filling. The statistical significance of observed trends was evaluated with the Mann-Kendall test (Mann 1945; Kendall 1975), and correlation coefficient probability, assuming significance for probability lower than 5% and uncorrelated datasets as null hypothesis. Trends were quantified as angular coefficient (AC) of least-square line (Polemio et al. 2004). Data were discussed considering monthly, seasonal and annual durations. The meteorological seasons September-November, December-February, March-May, and June-August were considered. Using monthly data of rainfall and temperature, annual actual evapotranspiration and effective rainfall were assessed using the modified formula of Turc (Cotecchia et al. 1990). The effective rainfall was then calculated subtracting the actual evapotranspiration from (actual) rainfall.

Results of trend analysis concerning climate and piezometric variables were compared to previous results, available up to 2001 for the climate of whole southern Italy (Polemio and Casarano 2004) and up to 2008 for piezometric trend (Polemio et al. 2009), based on identical monitoring networks.

Using data of the National Statistical Institute ISTAT (https://www.istat.it/it/archivio/127380), an insight view on potable groundwater exploitation offered a preliminary assessment of groundwater exploitation modifications.

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 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).

Tab. 1 - Apulian rainfall annual trend (all 27 gauges considered) from 1921 to 2001 and from 1921 to 2016 (in parentheses number of significant trends).

Tab. 1 - Tendenza delle precipitazioni in Puglia su base annuale (tutte le 27 stazioni considerate) nei periodi di riferimento 1921–2001 e 1921–2016 (in parentesi il numero di serie con trend significativo).

Period	Average Trend	Number of time series	
	(AC, mm/year)	Increasing trends (of which, significant)	Decreasing trends (of which, significant)
1921 - 2001	-0,658	7 (0)	20 (3)
1921 - 2016	0,192	17 (4)	10 (1)

Frequent warm (temperature higher than the mean value) years occurred after 1990 up to 2001 also if these data were not able to determine a generalized and significant increasing trend in Apulia (Tab. 2). The latest 15 years strengthen this trend showing a generalised and significant warming trend, with increase of about 1.5 °C in the 93-year study period. This result is evident and statistically significant, both on the whole area and on single HS or time series. In figure 3, considering yearly temperatures (average of 6 gauges) of Murgia HS, correlation for the period 1924-2001 is not significant. On the contrary, the occurrence, after 1998, of temperatures constantly higher than the average changed the correlation coefficient for the whole period 1924-2016 to be significant. The null hypothesis (no temperature trend) is less than 0.0001% probable, as confirmed by Mann-Kendall test.

Regarding its spatial distribution, warming trend is lower in the southern part of Apulia (Salento HS).

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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. 2 - Tendenza delle temperature su base annuale in Puglia e nelle principali strutture idrogeologiche nei periodi di riferimento 1924–2001 e 1924–2016 (in parentesi il numero di serie con trend significativo).

HS – Region	Trend (AC, °C/tear) and number of series with increasing and deceasing trend (in parentheses number of significant trends)					
	1924-2016			1924-2001		
	AC	Increasing	Decreasing	AC	Increasing	Decreasing
Gargano	0.0119	2 (2)	-	0.0043	2 (0)	-
Tavoliere	0.0174	3 (3)	-	0.0084	3 (1)	-
Murgia	0.0119	6 (6)	-	0.0043	5 (2)	1 (0)
Salento	0.0047	5 (2)	-	-0.0041	1 (0)	4 (1)
Apulia	0.0107	16 (13)	-	0.0024	11 (3)	5 (1)

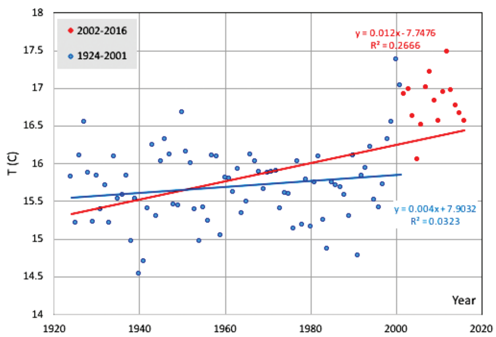

Fig. 3 - Mean annual temperature of Murgia hydrogeological Structure and trends of 1924-2001 and 1924-2016.

Fig. 3 - Andamento della temperatura media annua nella struttura idrogeologica della Murgia e confronto della tendenza 1924-2001 e 1924-2016.

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

Tab. 3 - Tendenza stagionale della piovosità in Puglia (in parentesi il numero di serie con trend significativo).

Season	Trend (AC, mm/year) 1921 - 2016	Increasing trends (significant)	Decreasing trends (significant)
Spring	0.218	25 (4)	2 (0)
Summer	0.190	24 (4)	3 (0)
Autumn	0.209	19 (4)	8 (0)
Winter	-0.416	3 (0)	24 (7)

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.

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.

Tab. 4 - Tendenza della piovosità efficace in Puglia e nelle principali strutture idrogeologiche (in parentesi il numero di serie con trend significativo).

HS – Region	Trend (AC, °C/tear) and number of series with increasing and deceasing trend (in parentheses number of significant trends)					
	1924-2016			1924-2001		
	AC	Increasing	Decreasing	AC	Increasing	Decreasing
Gargano	-1.139	1(0)	1(1)	-2.117	0(0)	2(1)
Tavoliere	-0.231	0(0)	3(0)	-0.368	0(0)	3(0)
Murgia	-0.090	1(0)	5(0)	-0.451	1(0)	5(2)
Salento	-0.337	3 (0)	2(1)	-0.619	1 (0)	4 (1)
Apulia	-0.325	5 (0)	11(2)	-0.696	2 (0)	14 (4)

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.

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).

Tab. 5 - Utilizzazione potabile di acque sotterranee in Puglia dal 2008 al 2015 (Migliaia di metri cubi, dati di ISTAT, https://www.istat.it/it/archivio/127380).

Year	Spring	Well	Total
2008	838	115181	116019
2012	560	88481	89041
2015	414	71954	72368

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.

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