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THEMATIC ISSUE

# Summary Editorial: Impacts of global change on groundwater in Western Mediterranean countries

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## Abstract

The western Mediterranean is especially sensitive to global change impacts. Climate change, population growth, urbanization and expansion of infrastructures, and land use and land cover changes are affecting the quality and quantity of groundwater resources primarily in this region characterized by frequent and severe meteorological and hydrological droughts, and a high population density. Climatic forecasts anticipate long-term regional precipitation decreases and temperature raises. The direct consequence of this over groundwater is the diminishing in springs discharge and the progressive fall of the piezometric levels. However, the anthropogenic action has also strong impacts over water systems as land use modifications and the change in recharge conditions or the increase of water demand and the variation on water abstracted from aquifers and the consequent water quality changes associated. A variety of tools and monitoring systems emerge as essential needs for society to confront the frequent current problems in the western Mediterranean and the future water challenges that are just starting to be foreseen.

**Keywords** Global change · Western Mediterranean · Groundwater · Recharge · Deterioration

## Introduction

The countries that border the Mediterranean Sea are characterized by a climate with frequent droughts and irregular precipitation which, combined with high demographic pressures, is increasing water demands from society. Major drivers of global change like climate change, population growth and migration, urbanization and expansion of infrastructures, changes in land use and pollution will lead to impacts on the sustainability of water resources in the region. Consequently, countries in both, southern Europe and the northern part of Africa, will have to deal with large and increasing challenges for managing both, the availability of water resources, and their quality (García-Ruiz et al. 2011; Leduc et al. 2017; Kuper et al. 2017).

Future scenarios of climate change in this region forecast the decline in streamflow, more irregular precipitation regimes and a reduction of between 10 and 30% of rainfall during the dry season (Cramer et al. 2018). These changes will increase the length of time where groundwater recharge will not take place (Ehlers et al. 2016; Yagbasan 2016; Zakhem and Kattaa 2016; Moutahir et al. 2017) and will decrease the mean annual recharge in most of the aquifers in the region (Pulido-Velazquez et al. 2018). In this context, groundwater will become an increasingly important and strategic resource to meet water demand from irrigated and urban areas and will help diminish the impacts of extreme events (droughts or floods) on the water for human supply.

The region is experiencing a wide range of land uses that can affect the hydrological cycle very differently. For example, deforestation can lead to significant changes in

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groundwater recharge (Reis and Dutal 2019). Conversion of natural rangeland to agricultural lands impacts the subsurface portion of the hydrological cycle by changing groundwater recharge and flushing salts to the underlying aquifer (Scanlon et al. 2005). In addition, the type of irrigation technique used in agricultural areas also affects to groundwater quantity and quality. On the one hand, ineffective irrigation practices can lead to a fairly significant recharge of underlying aquifers and a dilution in pollution caused by agriculture (Calvache et al. 2009; Duque et al, 2011; Rotiroti et al. 2019). On the other hand, optimal, cost-effective irrigation management strategies can potentially address the water scarcity issues (Escriva-Bou et al. 2017). Urbanization entails the waterproofing of large areas and the reduction of the natural recharge from precipitation in most of the cases, but the total aquifer recharge may increase due to the numerous losses that occur by leakage from water supply and sewage networks (Foster 1990; Lerner 2002). However, multiple sources of pollution in these urbanized areas can cause deterioration of groundwater quality.

Strategies to adapt to the effects of global change such as new agricultural practices, water recycling, saltwater desalinization, demand optimization, artificial recharge are constantly proposed. However, the effectiveness of these solutions requires political support, economic investment (Candela et al. 2012; Hof et al. 2014; Verdier and Viollet 2015) and the development of innovative methodologies.

The impact of global events is amplified in coastal areas, where the effects of high population density and landscape and oceanic changes act in combination (Michael et al. 2017). Original coastal landscapes have become unrecognizable in merely a few decades due to the rise of coastal cities, and the effects of mass tourism, fisheries, harbours, land drainage, coastline protection and agriculture (Post and Werner 2017). Coastal areas are particularly threatened by the increasing stress during summer and drought periods causing groundwater depletion and saline water intrusion that can be exacerbated by global changes (Recinos et al. 2015, Pulido-Velázquez et al. 2018) and variations of the recharge process (Petelet-Giraud et al. 2016; Santoni et al. 2018; De Giglio et al. 2018). Sea-level rise is not only affecting areas that are directly exposed to sea flooding but also it will have an impact on the freshwater-saltwater interface position (Wassef and Schüttrumpf 2016). Another problem is the retreat of the shoreline due to the imbalance of coastal sedimentary processes caused by the rainfall decrease combined with the increase in the urban population (Amrouni et al. 2019).

This special issue will integrate studies in this critical geographical environment linking water resources and global change assessment, including impacts and adaptation strategies. It compiles research work that analyse water resource issues at different spatial scale, in specific environments in the region (e.g., coastal areas, mountain regions), climatic (e.g. semi-arid, Mediterranean) and hydrological processes (e.g., inversion of precipitation gradient, groundwater recharge, flow and discharge, seawater intrusion, nitrate concentration increase, snow processes) and management particularities.

## Overview of the research in this thematic issue

The combined effects of population increases, land-use changes, and climate change are having adverse impacts on the availability and quality of water resources in the western part of the Mediterranean region. In this thematic issue, the consequences of future potential climatic conditions are analyzed in four parts of the region. Pardo-Igúzquiza et al. (2019) study the potential impacts of climate change on Sierra de las Nieves karstic aquifer recharge (S Spain), based on local temperature and precipitation scenarios generated from regional climate models projections. This aquifer is located in a protected area, the UNESCO Biosphere Reserve, and has a great interest from multiple viewpoints (geology, geomorphology, hydrogeology and ecology). Moutahir et al. (2019) used the HYDROBAL ecohydrological model to simulate the recharge of the Sierra de las Águilas aquifer (SE Spain) in the historical period 1971–2000 and over two future horizons (2039–2068 and 2069–2098) using 18 downscaled climate projections. This karstic aquifer is located in the driest area of Spain (Alicante) with significant water stress due to the intensive tourist and agricultural activity. Baena-Ruiz et al. (2020) propose a method to assess and analyze the impacts of future global change scenarios on saltwater intrusion in the coastal Plana de Oropesa-Torreblanca aquifer (E Spain). This methodology summarizes saltwater intrusion vulnerability at aquifer scale through snapshots in time (maps and conceptual 2D sections for specific dates or statistics of a period) and though a time series assessment for lumped indices. Additionally, Ouhamdouch et al (2019) found a downward trend of 12% in precipitation and an upward trend of 0.9–1.5 °C in temperature for the period 1950–2015 in the Essaouira Basin (Morocco). They also point out that this has caused a downward trend of water availability due to the shortening of recharge periods and recurrent droughts, and a deterioration of groundwater quality with an increase in salinity.

Agriculture can also cause severe impacts on groundwater availability and its quality in the region and it is another of the topics discussed in this thematic issue. Alhama et al. (2020) show an example of this in the case of the Sinclinal de Calasparra aquifer (SE Spain), located in the driest region of Spain and where droughts are frequent. This is an example of how the conjunctive use of groundwater and surface waters of the Segura River during drought periods may help to define sustainable management strategies to face global change and maintain agriculture. The authors use numerical modeling to estimate the impacts of the abstractions approved by the authorities for the period 2015–2021 on the Segura River flow and Gorgoton spring. Ducci et al. (2020) point out the upward trend in nitrate concentration in areas with high population density and intensive agriculture in the Campania region (Southern Italy). The authors used the Mann–Kendall test to assess the statistical significance of the upward trend of time series and, successively, the Sen method for estimating the value of the trend.

The study of water resources in coastal areas has been also included in this thematic issue with the assessment of changes in the coastline, the age of groundwater in coastal aquifers and the effect of overpumping and dry periods. Duque et al. (2019) conducted through numerical modeling with SEAWAT a study of the evolution of the coastline and the groundwater salinity of the Motril–Salobreña aquifer (S Spain) for the last 500 years by classifying the global change vulnerability in different areas. Calvache et al. (2020) use environmental tracers to characterize the origin and determine the age of the groundwater in the Motril–Salobreña aquifer to establish the velocity of flow paths in groundwater that is also linked to saltwater intrusion processes. Bouderbala (2019) study the case of the Mitidja plain (N Algeria) where the decrease of the water table (more than 20 m) for the last 50 years is explained by a long drought period and the increase of pumping.

Finally, this thematic issue refers to management strategies such as desalinization for increasing water availability as an adaptation to global change. An overview of the different strategies designed in the southeastern part of Spain show the multiple technical possibilities that can be applied for the establishment of desalinization plants (Pulido-Bosch et al. 2019).

## Conclusions

The main quantitative consequences of global change in the regions studied by this thematic issue contribute to a better understanding of the water resources in the Western Mediterranean and highlight the challenges that will have to be addressed in the next decades. In Sierra de las Nieves, potential future scenarios for the horizon 2071–2100 under the most pessimistic emission scenario (RCP 8.5) would produce on average a 27% reduction in precipitation and a 19% increase in temperature (Pardo-Igúzquiza et al. 2019). These climatic conditions will dramatically decrease recharge and will require new local adaptation measures, in addition to global mitigation measures, to prevent the area's resources, biodiversity, and geodiversity from being drastically diminished. In the Sierra de las Águilas aquifer, Moutahir et al. (2019) estimate that the percentage of rainfall aquifer recharge would decrease significantly (− 0.6% $year^{-1}$) considering the same RCP8.5 scenario. In Morocco (Essaouira Basin) the same trend is also observed for precipitation. Ouhamdouch et al (2019) find a downward trend of 12% in precipitation and an upward trend of 0.9–1.5 °C in temperature for the period 1950–2015. In the Plana de Oropesa-Torreblanca aquifer, the impacts of global climate change are likely to have a larger impact on groundwater availability and quality in the aquifer than the effects of land use and land cover change scenarios (Baena-Ruiz et al. 2020). The lumped indices reveal that global change would involve more variability in saltwater intrusion dynamic and in the aquifer vulnerability. This study of potential scenarios also shows that a greater area would be affected by saltwater intrusion in the future.

In the Sinclinal de Calasparra aquifer, using the pumping recommendations for the 2017–2020 period (34 $hm^3\ year^{-1}$), the Gorgotón spring will dry out and will require one year and a half after the cessation of the pumping to restore the spring. Up to 4 years would be required to recover the current discharge (68000 $m^3\ day^{-1}$) (Alhama et al. 2020). Ducci et al. (2020) point out the upward trend in nitrate concentration in areas with high population density and intensive agriculture in the Campania region (Southern Italy).

In the Motril–Salobreña system, the aquifer flushing time for saltwater ranges from 50 years in the western sector to up to more than 200 years in the central sector for the shallower parts of the aquifer based on numerical modelling. In the deeper layers, the time can be highly increased but the uncertainties in the hydraulic properties generate multiple potential scenarios both in flushing time and water circulation in the aquifer. The sectors in the aquifer where changes took place at a faster rate are also the most sensitive to the effect of global changes, especially those associated to human activity as they occur at shorter time periods (Duque et al. 2019). Calvache et al. (2020) also support these results by groundwater age dating by locating faster groundwater flow paths in the shallower parts of the aquifer that are also the most vulnerable sectors to the pollution.

Bouderbala (2019) show a marked decrease of annual precipitation in the Mitidja plain, with a reduction of about 20%. This has caused a drop of 20 m in the piezomectric level and the encroachment of seawater intrusion 2 km inland.

In areas with water scarcity but intensive agriculture and tourism, saltwater desalination is a useful alternative for the maintenance of the economy (Pulido-Bosch et al. 2019). Based on the experience in the South East of Spain, the most suitable system for taking saltwater in desalination plants consists of a series of vertical wells next to the coastal edge.

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