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Maria Luisa Calvache
Carlos Duque
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Groundwater and Global Change in the Western Mediterranean Area

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Groundwater and Global Change in the Western Mediterranean Area

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Preface

The Western Mediterranean area is a very sensitive area that suffers frequents droughts due to climate conditions, significant anthropogenic impacts on land use (urbanization or increment of cultivated areas) and high seasonality both in precipitation and water resources demands. This effect will be exacerbated in the future due to the global change and specially in the coastal areas with growing urban development and intensive agriculture. In this framework, groundwater plays an important role in the definition of management alternatives of Water Resources systems. An exhaustive knowledge of those systems and their problems is required to identify appropriate sustainable decision, which is one of the most important "challenges of our society".

This book aims to contribute to the dissemination of the knowledge about impacts of global change on water resources systems in the Western Mediterranean area, with special emphasis on groundwater. It is a compilation of works carried out by researchers from Algeria, France, Italy, Morocco, Portugal, Tunisia and Spain. Although most global change investigation is focused on surface water, the number of research papers dealing with global change and groundwater has grown fast in recent years, as shown in recent review papers. This compilation coversa particularly interesting area, the Western Mediterranean countries, from the perspective of the water resources with frequent scarcity periods and societies highly dependent on groundwater. It includes work on this Mediterranean area of both, southern Europe and North Africa, where important impacts are expected on the sustainability, quantity, quality, and management of water resources. This volume is composed by a selection of contributions presented in the Conference "Groundwater and Global Change in the Western Mediterranean" (Granada, November 2017). It covers a wide range of aspects linking global change to groundwater, from monitoring and modeling historical and future impacts to adaption strategies. This provides an overview of methods, study areas and case studies in multiple countries essential for facing future challenges.

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Introduction

The Western Mediterranean areas present a series of specific characteristics due to climate, anthropogenic pressure over natural environments, hydrological conditions and water demands that make it very sensitive to the effects of the global change. This has a direct impact over the quality and quantity of groundwater resources, essential for the water supply of population and the maintenance of agriculture. Valuable ecosystems connected with groundwater are also affected as for example has been shown in wetlands in the South of Spain in Málaga (Nieto-López et al. 2017) and in the sand dune ponds in the Doñana National Park (Fernandez-Ayuso et al. 2017) or in the Biguglia Lagoon in Corsica (Erostate et al. 2017). Agriculture is the base of the economy in multiple regions of the Western Mediterranean and it can be seriously damaged due to the decrease in water resources connected to global change. For example, the cereal in the region of Souss-Massa in Morocco is strongly affected by the precipitation regime (Abahous et al. 2017) and requires a sustainable development as indicated by Mansir et al. (2017). Other potential impacts have been also described for the nitrate occurrence as shown in the Catalonian Inner Basins (Mas Pla 2017a).

Climate change is one of the major concerns when referring to global change. Climate presents a variability that can affect groundwater resources as has been researched in North Algeria (Bouderbala 2017) or in Southern Italy (Ducci et al. 2017). Other case studies describe climatic changes impacting groundwater in areas of Morocco (Ouhamdouch et al. 2017) and in Tunisia (Benabdallah et al. 2017). Successive climate change reports analyzing climate change issues can be summarized as Mas Pla et al. (2017b) did for the Catalonia region in Northwestern Spain.

Potential future hydrological impacts of climatic change can be assessed by propagating future climate scenarios by simulation with hydrological models. This has been done for the groundwater in the Mijas mountains in Spain (Martin-Arias et al. 2017) or for the dynamics of snowpack in Sierra Nevada (Pardo-Iguzquiza et al. 2017). For the correct evaluation of the trends in future scenarios a full understanding of aquifer systems is required. The use of numerical models is a common tool for the assessment of the water budget as shown in Torrevieja aquifer

(Duque et al. 2017a) or for the management of water resources as has been exposed in Dakhla Bay in Southern Morocco (El Kanti et al. 2017).

In some cases, the changes observed in the quality of groundwater can be related to global changes or a natural evolution of the system. The differentiation between both is possible with the application of numerical models but demands a good knowledge of the current and the historical conditions of the aquifers. This principle has been applied for understanding the salinity changes of the Lower Sado aquifer in Portugal in the last 20000 years (Carreira and Marques 2017), or the Motril-Salobreña aquifer in Spain for the last 6000 years (Duque et al. 2017b). In these cases the use of environmental tracers can determine the age of groundwater (Sanchez-Úbeda et al. 2017a) that can be eventually used for the integration into numerical models to answer hydrogeological questions (Sanchez-Úbeda et al. 2017b).

In addition to the models, the prevention of the impact of global change requires the use of other methods for the research of aquifer systems. The application of hydrogeochemical and isotopic tracers is a useful tool as demonstrated in the Plaine of Kasserine (Hassen et al. 2017), the Moroccan High Atlas (N´Da et al. 2017), the Massa catchment (Oumarou Danni et al. 2017) or with a multitracer approach in Corsica (Santoni et al. 2017).

In this global change framework, coastal areas are critical for the groundwater resources as they are exposed to the additional risk of saltwater intrusion. For this reason, it is important to develop methods to summarize impacts as for example an index-based method (Baena Ruiz et al. 2017) or for evaluating the vulnerability as in the Ghiss-Nekor aquifer (Kouz et al. 2017). The Mediterranean coast of Spain has an elevated number of aquifers with variable circumstances and different seawater intrusion processes (Custodio 2017b) but the risk can be extended to almost all the coastal areas in the western Mediterranean as for example is seen in North East Tunisia (Lachaal et al. 2017).

One of the methods to adapt to global change impacts and to optimize water resources is the artificial recharge. This technique requires a good knowledge of the land infiltration capacity. For this purpose, high precision lysimeters in South Spain are being used (Molano-Leno et al. 2017). In Tunisia, Horriche et al. (2017) propose to apply an integrated model as Wetpass and Zammouri et al. (2017) the assessment of the efficiency against groundwater stress.

Since global change is a phenomenon that probably will continue in the future, there are investigations presenting adaptions to future changes. In this sense, Alhama et al. (2017) propose the improvement of the management through numerical models in Calasparra aquifer, Braca and Ducci (2017) evaluate groundwater resources with GIS tools in Italy and Berbel et al. (2017) suggest better regulations measurements in Llanos de la Puebla aquifer. Climate change adaptation requires a special effort for managing aquifer recharge as proposed for the Monchique mountain (Carvalho et al. 2017) and also it is important to use a clear and homogeneous terminology when referring to groundwater resources (Custodio 2017a).

A solid knowledge about the groundwater resources, a variety of tested methods for the research and understanding of aquifers and reliable potential future scenarios as well as science-based adaptations will be essential to confront the challenges that global change will bring to the Western Mediterranean countries.

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Impacts of the Water Resources Variability on Cereal Yields in the Region of Souss-Massa Southern Morocco

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1 Introduction

The demographic growth and the emergent position of Souss Massa region as competitive economic pole in Morocco represent the main pressures to the regional water resources. The climate conditions influences the availability of water in this semi-arid area and at the same time allows a developed agriculture in the region. Since the second half of the last century, an intensive agriculture is practiced. Yet, the region has experienced in the past, periods of prosperous agriculture.

Recent works show a decline of surface water discharge in Souss Massa region since the early 1970s, directly linked to decrease in annual precipitation during 1970–2007 (Brahim et al. 2016). An alarming decrease in groundwater levels is also shown by Bouchaou et al. (2011) due to intensive agriculture. In this context, questions like food security and/or sustainable development are of great importance for local populations.

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The region of Souss Massa knows a continuous improvement of techniques of irrigation for a sustainable management of water resources. To better understand the impacts of inter-annual precipitations variability on rainfed and irrigated crop yields, we analyze the correlations between cereals yields and seasonal precipitations.

2 Data and Methods

2.1 Rainfall Data

A dataset of monthly precipitations records are provided by the Hydraulic Agency of Souss-Massa-Draa Basin (ABHSMD). The stations were chosen to cover rainfed and irrigated perimeters during the corresponding period of available data of barley, hard and soft wheat yields. Figure 1 represents topography and locations of the stations used in this work.

2.2 Cereals Yields Data

The crop data collected from the Office of ORMVASM are superficies in hectares and annual productions in hundredweight from 1973 to 2014. The main species of crop cultivated in the region are barley, "hard" and "soft" wheat. The spatial distribution of rainfed and irrigated perimeters are shown in Fig. 2.

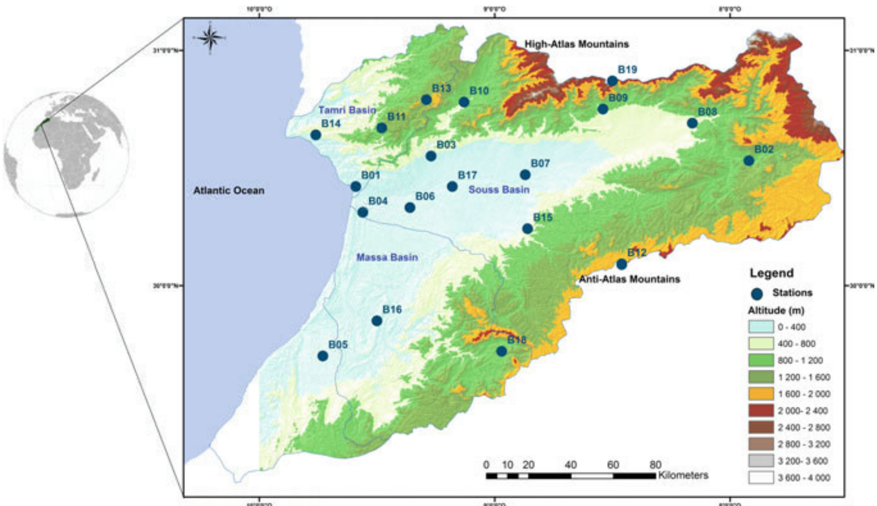

Fig. 1 Distribution of meteorological stations with altitudes in meters

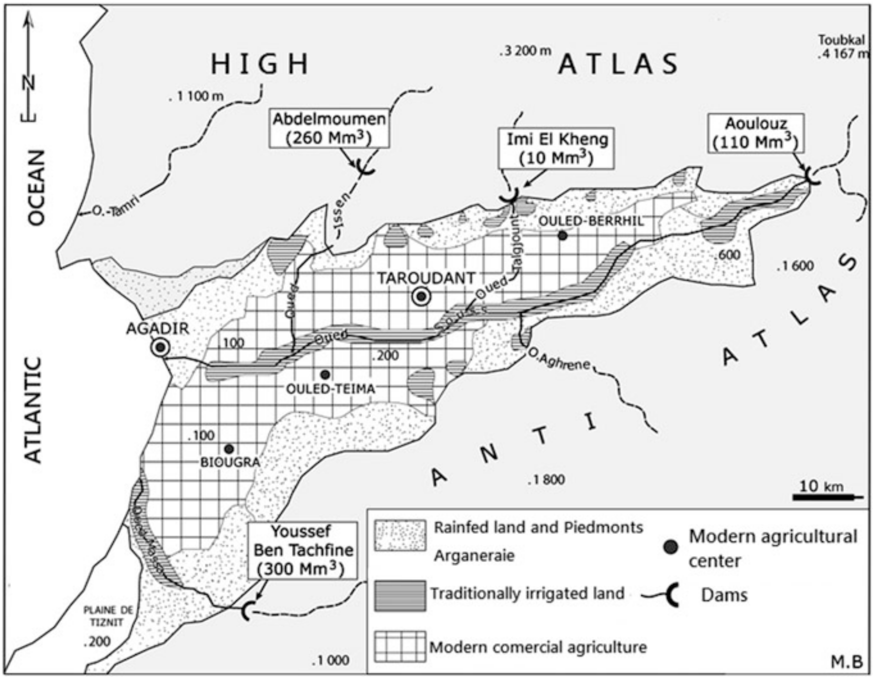

Fig. 2 Location map and agrarian landscapes of the Souss valley [modified from Boujnikh and Humbert (2010)]

2.3 Methods

Standardized Precipitation Index (SPI) was calculated to represent the evolution of interannual precipitation in the Souss-Massa region during the studied period. Mann-Kendall test (Pettitt 1979; Mann 1945) was applied to detect possible trends of the three species yields. While correlation between crop yields and inter-annual precipitations were calculated using the Pearson's coefficient and Bravais-Pearson table to evaluate the significance of computed values. Calculated cereals yields are expressed in quintals per hectare (Qx/ha), where 1 quintal is equal to 100 kg.

3 Results and Discussions

3.1 Rainfall Evolution Since the 1970s

The SPI for meteorological seasons is calculated during the period 1973–2010 from 19 stations covering the region of Souss Massa to be used in correlation analysis. The stations are located in both high and low altitude and the most are located in the plains of Souss and Massa. We also calculated the annual SPI to identify extreme events. The results show that the years 1988, 1996 and 2010 are distinguished as extremely wet years, while 1993 is the driest year during this period. Consecutive droughts are also observed in 1982–1983, 1992–1993, 1999–2001 and 2007–2008. The analysis shows that wet years represent 16% of the total years and dry years represent 35%. The evolution of seasonal SPI indexes is shown in Fig. 3, with DJF (December-January-February), MAM (March-April-May), JJA (June-July-August) and SON (September-October-November).

3.2 Cereals Yield Evolution During 1973–2014

The evolution of both rainfed and irrigated crops during the period 1973–2014 is shown in Fig. 4. The rainfed average yields during 1973–2014 for the barley, soft and hard wheat are respectively 3.93, 4.91 and 3.57 Qx/ha. While irrigated average yields are respectively 14.77, 23.16 and 22.15 Qx/ha. We observe for the three species that the irrigated cereals yields are more important comparing to rainfed. Soft wheat yields are the highest, for both irrigation methods. A statistically significant positive trend during 1973–2014 for irrigated soft and hard wheat is detected using Mann-Kendall test with ($p = 0.05$) (Table 1).

3.3 Relationship Between Crop Yields and Seasonal Standardized Precipitation Index

Before proceeding to correlations analysis, de-trended time series of soft and hard wheat are calculated. Table 2 is representing the coefficients of correlations between seasonal standardized precipitation indexes and yields of barley, soft and hard wheat for both rainfed and irrigated crops. The most significant correlations are positive and are observed between rainfed crops and DJF SPI with ($p = 0.05$). The results show significant positive correlations between MAM SPI and rainfed crops and also between MAM SPI with irrigated barley. This positive correlation implies a strong dependence of cereal crops of precipitation in the region of Souss-Massa.

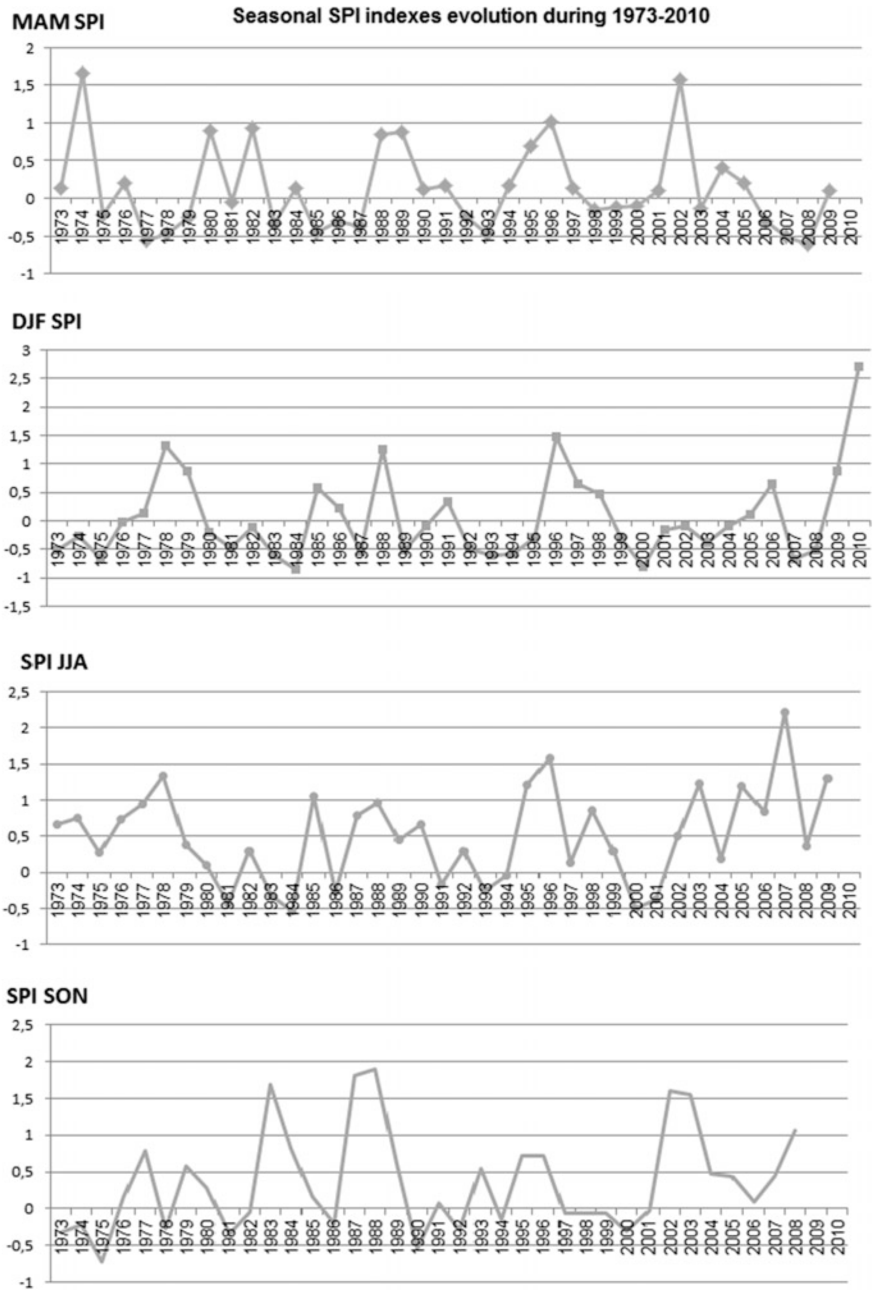

Fig. 3 Evolution of cereals yields during 1973–2014 of rainfed and irrigated crops

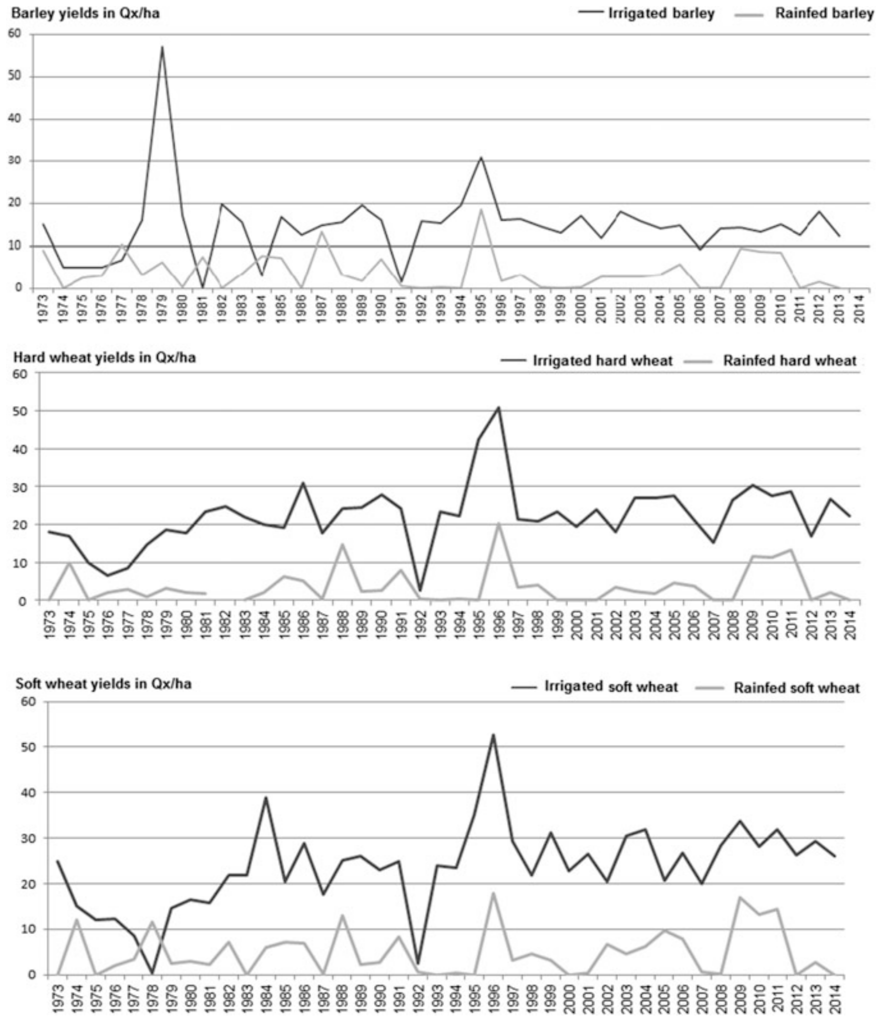

Fig. 4 Evolution of cereals yields during 1973–2014 of rainfed and irrigated crops

Table 1 Computed values of Mann-Kendall test results for crop yields during 1973–2010. Where S is the Mann-Kendall's statistic and Z is the standard test statistic (Gilbert 1987)

	Soft wheat	Hard wheat	Barley
Irrigated			
S	344	272	12
Z	3.7174	2.9371	0.11924
p-value	0.00020125**	0.0033129**	0.90509
Rainfed			
S	51	18	−57
Z	0.54396	0.19173	0.60924
p-value	0.58647	0.84795	0.54237

**Statistically significant with $p = 0.05$

Table 2 Coefficients of correlation between irrigated and rainfed cereals yields and SPI indexes for the seasons DJF, JJA, MAM and SON

	Irrigated barley	Rainfed barley	Irrigated hard wheat	Rainfed hard wheat	Irrigated soft wheat	Rainfed soft wheat
DJF SPI	0.06	0.79**	0.26	0.68**	0.06	0.74**
JJA SPI	−0.15	0.35	0.11	0.31	−0.03	0.37
MAM SPI	0.4**	0.4**	0.29	0.5**	0.26	0.4**
SON SPI	0.12	0.11	0.20	0.18	0.25	0.11

**Statistically significant with $p = 0.05$

4 Conclusions

To analyse impacts of inter-annual precipitations variability on rainfed and irrigated cereals, we first analyse annual and seasonal standardized precipitations indexes. The results show that wet years represent 16% of the total years and dry years represent 35% during the studied period.

We observe for the three species that the irrigated cereals yields are more important comparing to rainfed. Soft wheat yields are the highest, for both irrigation methods. And a statistically significant positive trend is detected during 1973–2014 for irrigated soft and hard wheat using Mann-Kendall test with ($p = 0.05$).

This work highlights the relationship between cereals yields and both winter and spring precipitations in the region of Souss Massa region. A strong positive correlation is revealed between winter precipitations and traditionally irrigated crops, particularly barley yields. A significant correlation is also observed for spring precipitations and rainfed crops, but also with irrigated barley yields.

The obvious significance of positive correlation between winter and spring precipitations and rainfed crops, raises the question of the sustainability of the cereals in the region due to the spatial and temporal irregularity of water resources. While the importance of irrigated crops yields refers to an intensive agriculture