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A decision tool for sustainable agricultural policies: the case of water saving scenarios for Apulia Region (Southern Italy)

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Abstract

The economy of Apulia Region largely depends on agriculture but the scarce water resources are the main factor threatening the sustainable production of this sector. This paper describes a geographical information system (GIS) based water balance tool that integrates maps of crops, climate and soil parameters with various scenarios of cropping pattern and farming practice changes. The aim is to assess the implication of these scenarios on the spatial and volumetric water needs of the region's irrigated agriculture. The total net volumetric irrigation needs, under current land use and full irrigation practices, were estimated on an average year to be 973 million m^3. The deficit irrigation practices currently used in Capitanata water districts can save a volume of 302 million m^3 if they are extrapolated over the entire region. Based on the Common Agricultural Policy (CAP), a replacement of 30% of the actual tomato areas in Foggia Province with sunflowers (energy crop) or durum wheat (rainfed crop) has potential water saving of 9 million m^3 and 67 million m^3, respectively. An additional 103 million m^3 of water saving may be obtained through modernisation of the vineyards' growing practices. Findings of this paper could be used to address the agricultural policies towards a sustainable use of the scarce fresh water.

Keywords: Agricultural policies; Apulia Region; Deficit irrigation; GIS; Irrigation requirement; Water balance; Water scarcity

1. Introduction

Irrigated agriculture in the arid and semi-arid areas of the Mediterranean region provides food and fibre for the local population and the rest of the world and ensures the livelihood of a large number of rural dwellers. A dwindling water supply and a prolonged period of drought are largely attributed to climate change. This combined with the continuous increase in water demand driven by demographic

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and economic development (Hervieu *et al.*, 2006; Al Khabouri *et al.*, 2007; Wolfe, 2009) are the main challenges for irrigated agriculture in the Mediterranean (Benoit & Comeau, 2005; El Chami *et al.*, 2014), especially at the farm level (Berbel *et al.*, 2009). Access to new water sources to cope with the increase in demand in this water-scarce region, is becoming technically, environmentally and economically difficult if not impossible (Daccache *et al.*, 2014).

Under such conditions, the effective planning of water resources should take place for a sustainable strategy (Bazzani *et al.*, 2005; Jacobsen *et al.*, 2012) and should be balanced by programmes mainly on the demand side (Sjömander Magnusson, 2004; Christian-Smith *et al.*, 2012; Aregay *et al.*, 2013).

In actuality, efforts are mainly focused on agriculture which is the largest water consuming sector (70% of the global fresh water resources) and has the largest water saving potential (Molden, 2007). Saving just a small amount of the water used for irrigation and directing it to the urban sector could improve the living conditions of millions of people (Georgoussis *et al.*, 2009).

The quantification of spatial volumetric irrigation needs is essential to both understand and mitigate the impact of water scarcity under different climatic, economic, social and environmental scenarios (Valipour *et al.*, 2015).

In this work, the focus will be on how changes in cropping pattern and on-farm practices affect the water resources of a highly water-stressed agricultural region. A spatialised decision support system tool incorporating these changes will allow stakeholders to develop a planning strategy for managing the Apulian water resources that can ensure and maintain economic and environmental sustainability (Alemu *et al.*, 2011; Ty *et al.*, 2012; Pierleoni *et al.*, 2014).

A geographical information system (GIS) based computational model performing a monthly water balance was developed and used to quantify the potential pressure that might cause changes in agricultural policies and farming techniques on the water resources of the region. The obtained results could be used by local government and stakeholders to address agricultural policies and regulate water abstraction licensing towards an efficient and sustainable water use strategy.

2. The study area

Southern Italy typifies a semi-arid Mediterranean climate characterised by hot and dry summers and wet winters. The annual precipitation in Apulia is on average 600 mm but ranges spatially from less than 500 mm to more than 900 mm.

Water scarcity is the major constraint to the social and economic development of Apulia. At the national level, Apulia is the region with the lowest available water resources per capita (IRSA-CNR, 1999). Other than the Ofanto River, the 20,000 km^2 region is almost completely deprived of surface water. For this reason, one of the largest water conveyance and distribution networks in Europe (Apulia Aqueduct) was built in the 1930s to transfer large water volumes from bordering regions (Campania and Basilicata) to satisfy the urban and irrigation needs of the region (Figure 1). With the region highly dependent on imported water, a complex legislative system for water resources transport and management was enacted to avoid any water disputes with the neighbouring regions.

The flat landscape of Apulia is predominantly (72%) agricultural lands with the largest crops being cereals (33%) and olive trees (25%) followed by vineyards, fruit trees and vegetable crops. Cereals and vegetables are mainly grown in the fertile zone of Foggia, where water is made available to the farmers through a large irrigation infrastructure managed by the Consortium of Capitanata. Olive trees and

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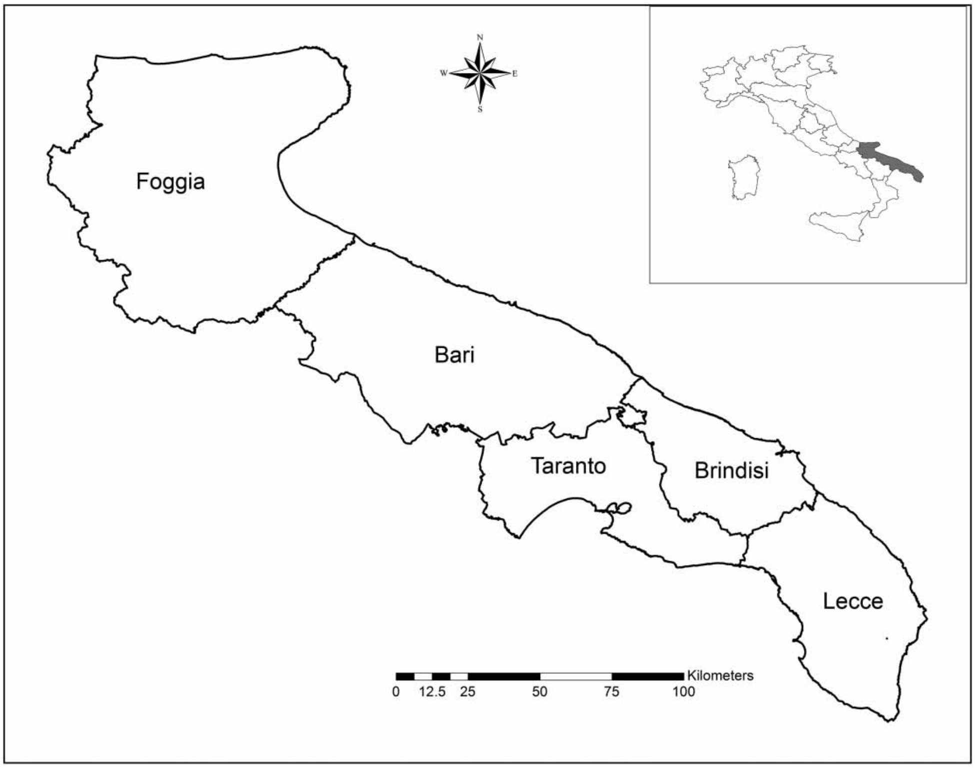

Fig. 1. The five administrative provinces of Apulia.

vineyards dominate the central and southern parts of the region and also where irrigation relies exclusively on groundwater abstraction. Although, the crop water demand in the dry semi-arid climate of the region is relatively high, only 20% of the agricultural fields are irrigated and the main limitation for irrigation expansion is the lack of water resources. This explains the popularity of the drip irrigation system that is more often used by far than all other type of irrigation systems in the region.

The imbalance between demand and availability of water in large parts of the region puts lot of pressure on farmers relying on irrigation for their production and on those looking for irrigation to expand and develop their businesses. Farms served by collective irrigation networks face the prospect of not being able to fully irrigate crops while those relying on groundwater will have to deepen their wells which has serious implications on the environment and on abstraction costs. The groundwater levels of wells monitored by the Irrigation Development and Land Transformation Agency in Apulia and Lucania' have shown a decreasing trend in various parts of the region (De Girolamo *et al.,* 2002) with an increase in sea water intrusion in coastal areas (Polemio & Limoni, 2001).

3. Datasets

The regional water balance model used for this work was implemented in Visual Basic incorporating the GIS component of MapWindow. The model extracts pedoclimatic and land cover data from different

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input layers to generate volumetric maps of crop water needs across the region. The model will then be used to assess potential pressures on water resources that may arise from adopting different agricultural policies or irrigation practices. A summary of the datasets and the model algorithm is presented hereafter.

3.1. Climatic dataset

Monthly gridded (2 × 2 km) rainfall and reference evapotranspiration (ET_0) maps were obtained by interpolating the long term average data (1950–1992) of the 162 weather stations of the Servizio Idrografico Nazionale. The spherical function of the Kriging method was found to best match the semi-variance for most of the weather variables of Apulia (Todorovic & Steduto, 2003).

Due to a lack of complete weather data, the empirical formula of Hargreaves–Samani (Hargreaves & Samani, 1982) has been used to calculate the reference evapotranspiration (ET_0) from minimum and maximum temperatures. Razzaghi & Sepaskhah (2009) have assessed nine different equations for ET_0 estimation using lysimeter data and found that the FAO-Radiation method (Jensen *et al.,* 1990) and the Hargreaves–Samani method were the most effective for estimating the mean monthly ET_0 in a semi-arid environment.

Similar findings were reported by Valipour (2015) showing that the modified Hargreaves–Samani method provides better estimation of evapotranspiration than any other temperature-based models. A summary of the rainfall and ET_0 maps used to run the model are presented in Figure 2.

3.2. Land cover dataset

The SIGRIA project (INEA, 1999)[1] used satellite images to develop further the CORINE land cover map (EEA, 2000) of the region. The main contribution of SIGRIA is the identification of the geographical location of fields with access to water for irrigation. A summary of SIGRIA outcomes is presented in Table 1.

Most of the land cover units ‘*j*’ (LCU) of SIGRIA are not detailed to single crop level. Some LCUs (i.e. vegetables…/ fruit trees…) encompass a series of individual crops ‘*i*’ (tomato, potato, lettuce…/ apple, peach…) each with different growing seasons and cropped area. Hence, the water requirement under the same pedoclimatic conditions of one LCU might differ depending on the proportion of individual crops within.

To overcome this problem and for better accuracy in the crop water requirement, agricultural census data (ISTAT, 2007) showing the cropped area (A_i) of each individual crop ‘*i*’ by province were extracted and appended to the land cover unit. Accordingly each LCU ‘*j*’ is then represented by a fictive crop with crop coefficient (Kc_j) and root depth (RD_j) weighted by the area of each crop ‘*i*’ within that unit, as follows:

$$\overline{Kc_j} = \frac{\sum_{i=1}^{N} Kc_i \times A_i}{\sum A_i} \quad (1)$$

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[1] SIGRA is an Italian abbreviation for ‘Il sistema informativo territoriale per la gestione delle risorse idriche in agricoltura’ (spatial information system for water management in agriculture).

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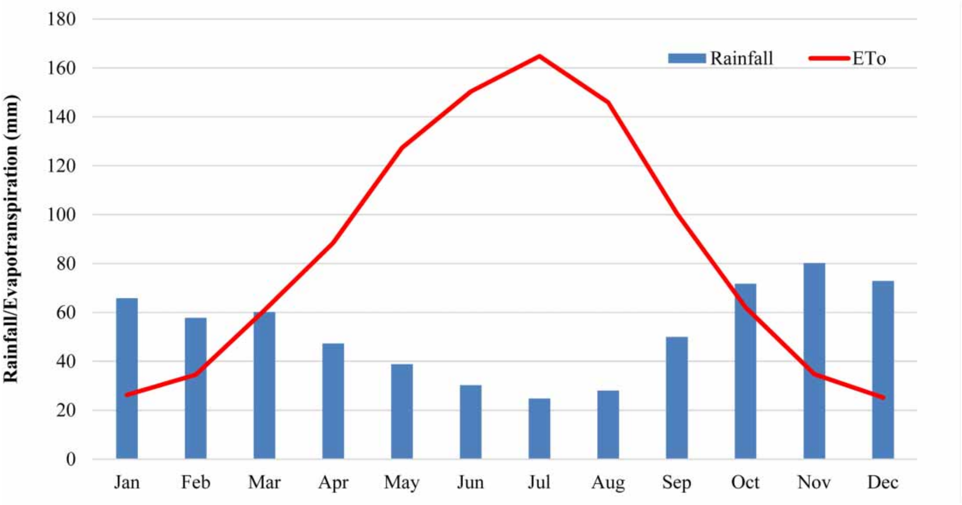

Fig. 2. Monthly average rainfall (mm) and average ET_0 (mm) of the case study.

Table 1. Area occupied by each land cover unit according to SIGRIA's land cover map.

Land cover unit	Irrigated (ha (10 m^4 m^2))	Rainfed (ha (10^4 m^2))	Total (ha (10^4 m^2))
Cereals	58,688	639,131	697,819
Olive trees	110,902	371,257	482,159
Fruit trees	25,532	11,317	36,849
Vineyards	100,176	26,518	126,694
Grass	96,816	137	96,953
Vegetables (spring/summer season)	54,583	–	54,583
Vegetables (summer to autumn/spring season)	34,843	–	34,843
Greenhouses	61	–	61

$$\overline{RD_j} = \frac{\sum_{i=1}^{N} RD_i \times A_i}{\sum A_i} \tag{2}$$

where:

Kc_i Crop coefficient (Allen *et al.*, 1998) of crop '*i*' within land cover unit '*j*';
RD_i Root depth of crop '*i*' within the land cover unit '*j*' (m);
N Number of different crops '*i*' within the land cover unit '*j*'.

3.3. Soil dataset

The soil database of Apulia was obtained by analysing circa 4,000 soil samples collected from the entire region (Steduto *et al.*, 1999; Steduto & Todorovic, 2001). Each sample contains general information on the site, such as slope, stoniness, morphology, texture, parent material, soil colour, layer

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depth and permeability. This information was necessary to develop a US Department of Agriculture (USDA) and Food and Agriculture Organization of the United Nations (FAO) soil classification map at a scale of 1:1,000,000.

Using part of these samples, Cainarca (1998) validated different pedotransfer functions with laboratory tested soil hydraulic parameters (Gupta & Larson, 1979; De Jong, 1982; Rawls *et al.,* 1982, 1991; Saxton *et al.,* 1986; Vereecken *et al.,* 1989). Accordingly he recommended the use, for each soil type, of the appropriate pedotransfer function. This work was used to estimate the water holding capacity of the 4,000+ soil samples from texture, bulk density and organic matter content. The spatial distribution of soil hydraulic characteristics was then obtained by taking the average value of the total soil samples within each soil classification unit (Figure 3).

4. Water balance model

The previously described climate, land cover and soil datasets are used as input for a one dimensional, monthly, soil water balance in which the soil system is divided into two connected subsystems. The upper subsystem represents the water dynamics at the root depth, while the second represents the natural groundwater recharge. This simplistic water balance approach was used since the aim of this work is not to accurately model the physical process but to present a decision support tool based on crop water needs for sustainable agricultural policies.

The monthly soil moisture content variation is summarised hereafter:

$$\delta w_i = P_i - ET_{c_i} - RO_i + I_i \tag{3}$$

where:

P_i Precipitation (mm) in month '*i*';
ET_{c_i} Crop evapotranspiration (mm) in month '*i*';

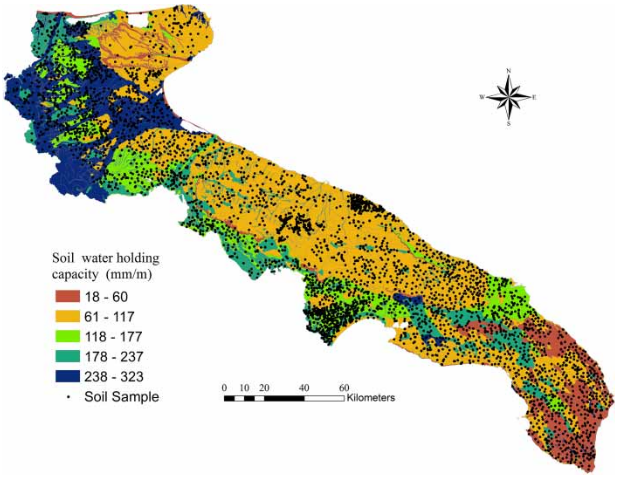

Fig. 3. Water holding capacity per 1 meter soil depth and location of soil samples collected by ACLA 2 project.

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RO_i Surface runoff (mm) in month '*i*';
I_i Irrigation applied (mm) in month '*i*'.

According to the methodology described by Dean (1970) the effective rainfall for month ($Peff_i$) that will contribute to the natural water supply of the crop is obtained through:

$$Peff_i = \left(\frac{P_i}{125}\right) \times (125 - 0.2P_i) \qquad \text{for} \quad P_i < 250\,\text{mm} \tag{4}$$

$$Peff_i = 125 + 0.1P_i \qquad \text{for} \quad P_i > 250\,\text{mm}. \tag{5}$$

The difference between the monthly rainfall (P_i) and the net water infiltration ($Peff_i$) is the surface runoff (RO_i) for month '*i*'. Due to the flat landscape of Apulia, the hydrological fluxes through the soil surface were considered vertical and the water table interaction with the unsaturated zones is ignored due to the deep aquifers of the region.

The infiltration below the root zone (Inf_i) is then separated into groundwater recharge (GW_i) and sub-surface runoff (RO_{sub_i}) using the coefficient of potential infiltration ($\propto$) of the geological layers of the region (Celico, 1986), which depends on the composition and the morphology of the parent material. Consequently:

$$GW_i = \propto \times Inf_i \tag{6}$$

$$RO_{sub_i} = (1 - \propto) \times Inf_i. \tag{7}$$

Within a drainage basin, sub-surface runoff will spill away and will not contribute to the groundwater recharge, while within an endorheic basin, RO_{sub_i} will be forced to re-infiltrate in the soil rather than being lost to the sea.

Crop evapotranspiration (ET_c) is defined as the water flux to the atmosphere through soil evaporation and plant transpiration. In this work, crop evapotranspiration (ET_c) was estimated using the Allen *et al.* (1998) methodology where reference evapotranspiration (ET_0) is adjusted by a correction factor known as crop coefficient (K_c):

$$ET_c = K_c \times ET_0 \tag{8}$$

K_c depends mainly on the crop type, variety and growth stages. For each individual crop, K_c values were obtained from a long series of field experiments conducted at the Mediterranean Agronomic Institute of Bari (Caliandro *et al.,* 1990) and, where experimental data were not available, from the literature (Allen *et al.,* 1998).

Evaporation from bare soil was calculated by adjusting the reference evapotranspiration (ET_0) with a correction coefficient that depends on soil texture, quantity of infiltrated water and on the number of days between consecutive rainfall events (Allen *et al.,* 1998). The latter were obtained from the analysis of daily weather data and the average number of consecutive rainy days then the rainfall events were spatially distributed using Thiessen polygons techniques.

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The water balance model starts in January assuming the soil water content is at field capacity. To reduce any error that might occur from such assumption, the model iterates three times with the same climatic data and the results of the third iteration are used in this paper. The outcomes of the model based on the climatic, land cover and farming practices scenarios consist of monthly irrigation need, runoff and groundwater recharge.

5. Water saving scenarios

5.1. Restricted irrigation practices

The crop evapotranspiration (ET_c) used in the model corresponds to the maximum evapotranspiration that a given crop can reach when planted and grown under optimal conditions without any water shortage, nutrient, pest or diseases stresses (Allen *et al.,* 1998). In the field, these conditions are rarely achieved technically and sometimes economically and so the difference between the actual (ET_a) and potential crop evapotranspiration (ET_c) is proportional to the level of stress exerted on the plant. Ciollaro *et al.* (1993), Lamaddalena *et al.* (1995) and Khadra & Lamaddalena (2006) all compared the actual water consumed by the farmers in an irrigation district managed by the Consortium of the Capitanata (Foggia) with that estimated using the standard crop evapotranspiration methods. They found that farmers use less water than that needed to maintain the maximum evapotranspiration rate. Hence, they identified a series of irrigation reduction factors (K_r) for different plant stages in order to reflect the actual irrigation practices conducted by local farmers (Table 2).

The irrigation season for olive trees in the Mediterranean extends from May to September. Olive is a drought tolerant crop and this explains the dominance of rainfed production in Apulia. However, numerous studies have shown that high quality fruits and minimisation of the alternate bearing phenomenon require supplemental irrigation (Goldhamer *et al.,* 1994; Çiçek *et al.,* 2014). Oil content in rainfed trees was similar or even greater than in irrigated trees (Goldhamer *et al.,* 1994). Therefore, the best management practices for olive irrigation consist of maintaining mild to moderate levels of water stress at different growing stages (Ben-Gal *et al.,* 2009). According to Capitanata farmers' practices, a deficit irrigation of 60% during the post-flowering and pre-maturity period (June–July) is well accepted by olive trees growers (Table 2). In May and August, which correspond to the flowering and filling stages, the plant is more sensitive to water stress and this is consistent with the findings of Çiçek *et al.* (2014) and Goldhamer *et al.* (1994).

Fruit trees and vegetables are much more water sensitive when compared to olive crops. Also, these are considered as cash crops and hence the money value obtained from each unit of water applied (m^3) is potentially much higher than that applied on olive trees (D'Agostino *et al.,* 2014; Scardigno *et al.,*

Table 2. Reduction coefficients (Kr) used to reflect Capitanta farmers' practices (Khadra & Lamaddalena, 2006).

Crop	April	May	June	July	August	September
Vegetables	0.8	0.85	0.9	0.9	0.7	0
Fruit trees	0.6	1	1	1	0.75	0
Olive trees	0	0.6	0.4	0.4	0.6	0.4
Vineyards	0	0	0.7	0.75	0.5	0.15

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2014). This further explains Captinata farmers' behaviour where almost-full irrigation is practised during May, June and July in an attempt to boost the yield and quality of these high value crops (Table 2).

Farmers in the Consortium of Capitanata (Foggia) are grouped into water users associations to manage a large infrastructure of pressurised water distribution systems. Because they share the same water source, these farmers are well trained to efficiently control their water consumption. Knowledge sharing, training, water pricing and electronic devices for water abstraction monitoring and control have played an important role in making these farmers efficient irrigators. Comparatively, farmers with private water sources (almost all farmers outside Foggia region), without any restrictions on water access or any water pricing regulations in place, have a tendency to over-irrigate. In this 'efficient irrigators' scenario, it is assumed that all of the irrigators in the region will adopt the same water restriction practices as those used by Capitanata farmers. It is notable that water restriction is also practised for quality purposes especially on high quality crops such as olives for oil production and vineyards.

5.2. Land use change scenarios

The proposed land use change scenarios are based on the Common Agricultural Policy (CAP) that aims to safeguard the environmental and socio-economic aspects of European rural areas. In particular, the EC regulation n. 1782/2003 introduced direct support for different crops including durum wheat and energy crops. Under this regulation, sunflower and oilseed rape (suitable for biofuel production) are identified as the most likely to expand in Italy (Faini *et al.,* 2004) and rainfed wheat is promoted as a replacement for irrigated agriculture in an attempt to reduce the pressure on the water resources especially in water stressed regions.

In this context, land use change scenarios will focus on the large tomato production area in Foggia that is most likely to be affected by the CAP. In the other provinces, perennial crops (mainly vineyards and olive trees) dominate the landscape, and are less likely to be replaced for technical, economic and traditional reasons. Therefore, the two cropping pattern change scenarios proposed and applied are the following:

1. Scenario tomato–sunflower. This scenario assumes a replacement of 30% of the tomato growing area with sunflower, a representative energy crop.
2. Scenario tomato–durum wheat. In this scenario, 30% of the tomato area will be replaced by rainfed durum wheat, an important rainfed crop in the region grown largely for pasta production.

5.3. Modernisation technique scenarios

In Apulia, vineyards for table grapes are traditionally grown on overhead trellises characterised by lush foliage completely shading the ground. Vertical trellises are modern training systems where the vineyard canopy can be better managed to eliminate the excessive shading that impedes grape ripening, encourages disease development but has no effect on photosynthesis. As crops predominately lose their water through their leaves' stomata, restricted canopy development will have a direct impact on crop transpiration and hence on water demands.

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With drip irrigation prevalent on vineyard irrigation, evapotranspiration (ET_r) under vertical trellis was adjusted using the ground cover (GC) percentage from the fully ground covered crop evapotranspiration (ET_c) as follows (Sharples *et al.,* 1985):

$$ET_r = ET_c \times (0.1 \times (GC)^{0.5}). \tag{9}$$

The proposed scenario requires switching all of the table grape vineyards in the region from the dominant, traditional overhead trellis to modern and potentially less water demanding vertical trellis systems.

6. Results and discussion

More than 80% of the Apulian territory is used for crop production. However, while hot and dry summers characterise the Apulian climate, on average, only 20% of agricultural fields are irrigated, Brindisi having the lowest percentage of irrigated land and Foggia the highest (Table 3). Water scarcity in the region is the main factor limiting the development and intensification of crop production, especially in the central and southern provinces that rely almost exclusively on groundwater.

The total volumetric irrigation need of the entire region, under current cropping patterns and climatic conditions, was estimated to be 973 million m^3 a year, 41% of which is concentrated in Foggia Province alone, followed by Bari (19%) and Lecce (17%) (Table 3). On average and based on land use and the pedoclimatic conditions of the region, 2,480 m^3 is needed yearly for each irrigated hectare (10^4 m^2).

Most of the irrigated farms in Foggia are within the administrative boundaries of the Consortium of Capitanata; a water user association that operates and manages a complex infrastructure of water distribution systems designed for on-demand access to pressurised water. The maximum water storage capacity of the collective systems is 140 million m^3 per year which is only 37% of the total irrigation demand of the province (Table 3). Hence, to satisfy the remaining 63% of irrigation need in the province, farmers must depend on groundwater abstraction from private wells (Table 3).

A consortium (water users association) that manages a similar collective water distribution system in the Province of Taranto is Storna e Tara. Its maximum storage capacity per year is 53 million m^3 or 41% of the total irrigation demand, so the remaining 59% of the total volume can only be abstracted from the private groundwater wells (Table 3). Therefore, even if the storage capacity of the system is greatly increased, groundwater will remain the primary source of water because the collective water distribution systems are only capable of supplying the few privileged irrigators that are located in the geographical area of the consortium.

The Terre d'Apulia consortium has the capacity to store 16 million m^3 of Ofanto River water or 7% of Bari's irrigation need, but this volume is for the urban water supply as well. So in times of scarcity, domestic use is always the priority for the stored water. Further, the irrigation needs of Lecce and Brindisi, where surface water (lakes, rivers, etc.) is completely absent, were estimated to be 165 million m^3 and 95 million m^3 per year, respectively.

As the data indicate (Table 3), groundwater is the main source of water for irrigation (77%) in Apulia Region. Therefore appropriate management of groundwater resources is crucial, especially in coastal areas where over-abstraction will lead to sea water intrusion.

Olive orchards and vineyards dominate the landscape of the Apulia Region. These are relatively drought tolerant crops and are widely grown as rainfed crops across the region. Hence, a large

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Table 3. Annual irrigation water requirements (IWR) and estimated annual groundwater abstraction (GWA) for each province of Apulia under full and controlled irrigation management.

	Irrigated area		Available surface water		IWR				GWA				GWA/IWR	
					Full		Controlled		Full		Controlled		Full	Controlled
Province	Ha (10 m^4 m^2)	%	Million m^3	%	Million m^3	%	Million m^3	%	Million m^3	%	Million m^3	%	%	%
Bari	90,073	23	13	6	184	19	123	18	172	23	110	24	93	90
Brindisi	41,489	11	0	0	95	10	66	10	95	12	66	15	100	100
Foggia	139,585	36	150	69	401	41	291	43	251	33	142	31	63	49
Lecce	75,199	19	0	0	165	17	102	15	165	22	102	22	100	100
Taranto	45,672	12	53	25	129	13	89	13	76	10	35	8	59	40
Total	392,018	100	216	100	973	100	671	100	758	100	455	100	78	60

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margin of water saving can be obtained with deficit irrigation without significant compromise on yield and quality.

This explains a 302 million m^3 difference in the volumetric irrigation need of the region between adopting full and partial crop water need practices that are based on the irrigation practices of Capitanata's farmers as previously described in Table 2. Such deficit practices could be the result of limited access to water and/or measures for boosting crop quality. The implications of irrigation deficit on yield and quality were not assessed in this work but we recommend full investigation on these aspects in any future work.

The results of the scenarios in Foggia that replace 30% of the irrigated tomato cropped land with sunflower (energy crop) or durum wheat (rainfed crop) are presented in Table 4. Annually, 9 million m^3 and 67 million m^3 of water respectively could be saved under the hypothesis of a full irrigation regime. If deficit irrigation is considered, water saving is fairly lower but remains highly substantial. The values show the large amount of water consumed by tomato and the large potential water saving at regional scale if new cropping pattern changes are adopted.

Based on the cropping pattern and climatic demand, the potential water saving varies from 0 to 300 mm spatially across the region (Figure 4). The most remarkable change was observed in Lecce region with the highest percentage change in water saving (38% saving compared to full irrigation water requirements (IWR)) (Table 5). Foggia, the province with the largest concentration of irrigated crops in Apulia (69%), can achieve a water saving of 110 million m^3 yearly but this, in terms of percentage of water saving, is the lowest among the provinces (Table 5) that can be explained by the dominance of relatively water stress sensitive vegetables.

In summary, results in Table 6 show that a switch from horizontal to vertical trellis vineyards across the region is estimated to save 103 million m^3 yearly, with Foggia Province, alone, accounting for almost half of the savings (46 million m^3 per year). From Table 6, the modernisation of Apulia's vineyards will have a significant positive impact not only on yield quality but also on water consumption.

7. Conclusions

The region of Apulia is under severe water stress conditions as are many semi-arid Mediterranean regions. However, the cropping pattern of the region, dominated by water stress tolerant olive trees, vineyards and cereals, gives Apulia great water saving potentiality and high adaptability to deficit irrigation practices. The deficit irrigation practices already adopted by farmers in the northern part of the region showed annual water saving of around 300 million m^3 when compared to full irrigation. The modernisation of the vineyards growing techniques would also save up to 103 million m^3 annually of

Table 4. Annual irrigation water requirement in the province of Foggia under actual and different land use change scenarios.

Province of Foggia	Irrigation water requirement (million m^3)		
Scenario	Full	Controlled	% of change
Actual situation	401	291	27
Tomato → Sunflower	392	284	27
Tomato → Durum wheat	333	237	29

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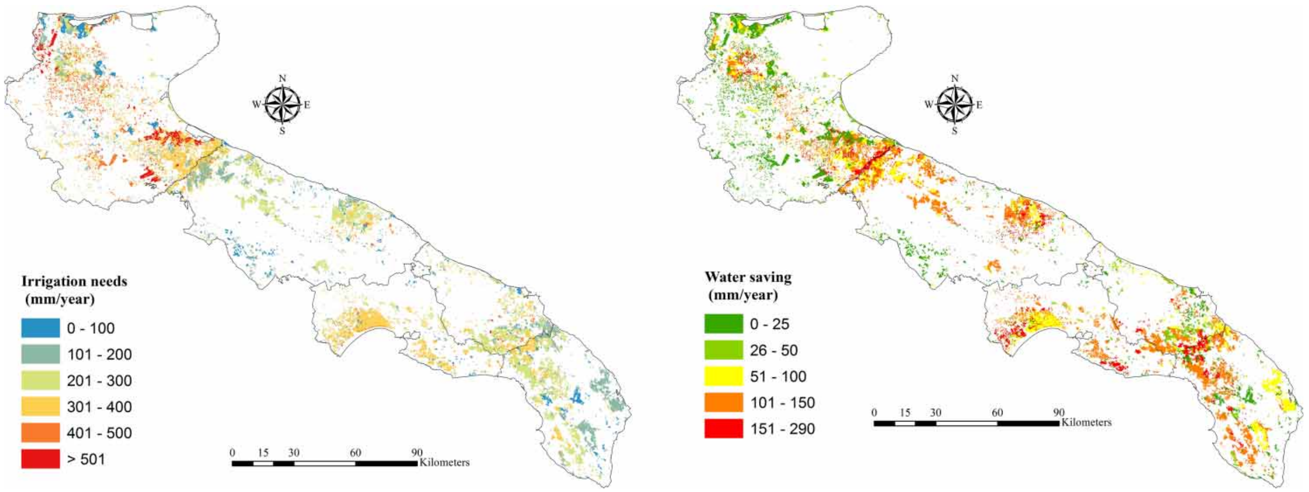

Fig. 4. Spatial volumetric irrigation needs (left) and potential water saving (right) using controlled irrigation scenario.

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Table 5. Annual water saving resulted from the modernisation of the vineyards growing techniques.

	Actual situation of vineyards			Scenario vineyard		
	Irrigation water requirement (Million m^3)			Irrigation water requirement (Million m^3)		
Province	Full	Controlled	% change	Full	Controlled	% change
Bari	184	123	33	165	112	32
Brindisi	95	66	30	87	62	29
Foggia	401	291	27	355	267	25
Lecce	165	102	38	149	93	38
Taranto	129	89	31	114	81	29
Total	973	671	31	870	615	29

Table 6. Water savings per scenario.

		Water savings scenarios (Million m^3)			
Province	Current (Million m^3)	Controlled	Vineyard	Sunflower	Durum wheat
Bari	184	62	19	–	–
Brindisi	95	29	8	–	–
Foggia	401	109	46	–	68
Lecce	165	63	15	–	–
Taranto	129	40	15	–	–
Total	973	303	104	9.2	68

valuable fresh water. The CAP could also play an important role in water saving if tomato growing in Foggia Province is replaced by energy or rainfed crops.

Groundwater remains the major source of water for agriculture in most of the region due to the absence of surface water. This means that major control of coastal abstractions is needed in order to avoid major environmental problems. Pressurised water distribution systems have played an important role in agricultural intensification with positive impacts on the socio-economic aspects of the rural areas of Foggia and Taranto.

Still, the methodology described in this study has some limitations. The use of monthly water balance hides the effect of the temporal distribution of rainfall on surface runoff calculation and consequently on effective rainfall estimation. The same observation applies to temperature, where daily variation may affect the cumulative plant evapotranspiration rates and, consequently, the irrigation water requirement.

Nonetheless, as the aim of this work is to assess the agricultural water consumption and groundwater exploitation of the entire region in terms of quantity, spatial and temporal distribution in an average climatic year, the estimations may be considered adequate and the simplifications adopted in this paper can be justified (Prajamwong *et al.*, 1997).

The results of this work may be used as a decision support system for water managers and policy-makers to improve the sustainable management of the territory, to cope with the continuous increase in water demand by the different user sectors and to manage drought and water quality deterioration. Given the important role that climate changes play in exacerbating water demand, drought conditions

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and water quality deterioration, further studies have to be focused on the assessment of the impact of climate changes in Apulia.

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