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Deliverable 4.4.1

Participatory systems performance

Interreg V- A Greece-Italy Programme 2014 2020

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Large Scale Irrigation Management Tools for Sustainable Water Management in Rural Areas and Protection of Receiving Aquatic Ecosystems

Subsidy Contract No: I1/2.3/27

Project co-funded by
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Partners

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Notes

Deliverable 4.4.1 – Participatory systems performance

Performance of participatory irrigation management and sustainability of irrigated agricultural systems: The case of irrigation district 17, Consorzio di Bonifica of Capitanata

Involved partners:

PB4 CIHEAM - ISTITUTO AGRONOMICO MEDITERRANEO – BARI (IAMB)

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Summary

In some countries of the Mediterranean, the sustainability of irrigation systems is mainly a function of the performance of water user associations (WUAs). However, the physical and financial sustainability of both hydraulic infrastructures and associations are not forthcoming, especially in large-scale irrigation schemes. Efficient irrigation water management has become a fundamental goal in Southern Italy, an area marked by high water scarcity and the impacts of climate change. This is particularly relevant for the Capitanata Irrigation Consortium, one of the greatest and most important in the Mediterranean region. But how is the performance of local WUA in managing the irrigation scheme? Using qualitative and quantitative data this study analyzed the performance and sustainability of participatory irrigation management in Water Users Organization "Consorzio di Bonifica della Capitanata" with a specific focus on irrigation district 17. The analysis covered four sustainability dimensions: environmental integrity, economic resilience and profitability, social well-being, and good governance. The results were useful to understand the current operational practices and overall system performance.

Keywords: monitoring, Evaluation, Performance, irrigation systems, benchmarking, participatory irrigation management

Sommario

In alcuni paesi del Mediterraneo, la sostenibilità dei sistemi di irrigazione è principalmente una funzione delle prestazioni delle Associazioni di utenti dell'acqua (WUAs). Tuttavia, la sostenibilità fisica e finanziaria sia delle infrastrutture idrauliche che delle associazioni non è imminente, specialmente negli schemi di irrigazione su larga scala. Una gestione efficiente dell'acqua per l'irrigazione è diventata un obiettivo fondamentale nel Sud Italia, un'area segnata da un'elevata scarsità d'acqua e dagli impatti dei cambiamenti climatici. Ciò è particolarmente rilevante per il Consorzio per la Bonifica della Capitanata, uno dei più grandi e importanti comprensori irrigui del Mediterraneo. Ma come sono le prestazioni della WUA locale nella gestione dello schema di irrigazione? Utilizzando dati qualitativi e quantitativi, questo studio ha analizzato le prestazioni e la sostenibilità della gestione partecipativa dell'irrigazione nel "Consorzio di Bonifica della Capitanata" con un focus specifico sul distretto irriguo 17. L'analisi di sostenibilità e stato su quatro dimensioni: integrità ambientale, resilienza economica e redditività, benessere sociale e gestione del governance. I risultati sono stati utili per comprendere le pratiche operative correnti e le prestazioni complessive del sistema.

Parole chiave: monitoraggio, valutazione, prestazioni, sistemi di irrigazione, benchmarking, gestione partecipata dell'irrigazione

1. Introduction

Large-scale irrigation systems play a significant role in developing, stabilizing, and diversifying agricultural production in rural areas making productive use of water at the farm level, and keep losses at a minimum level. However, due to technical and operational reasons, irrigation systems often do not meet the design objectives (Dejen 2011). Consequently, irrigation agencies and farmers' associations, especially in the arid and semi-arid regions of southern Europe and the Mediterranean area, are urged to improve the efficiency of their irrigation networks and delivery systems using more rational use of limited water resources in a coordinated, integrated, and participatory manner. Participatory Irrigation Management (PIM) is recognized as one of the key approaches for improving the productivity and sustainability of irrigation. The concept of PIM refers to management by irrigation users at all levels of the system and in all aspects of management. The philosophy of PIM is hinged around developing cooperation with and involvement of farmers in operation, management, and maintenance of the irrigation systems at secondary and tertiary levels through the Water User Associations (WUAs). Accordingly, it is believed that the performance of the irrigation systems is dependent on the performance of the WUAs (Uysal and Atiş 2010). The role of Water User Associations (WUAs) in managing the irrigation resources of agriculture through a "participatory irrigation management" approach is widely recognized in Mediterranean agriculture, especially in Italy and Spain. The tradition of the participatory approach in irrigated agriculture is of long history and great relevance in many parts of Southern Italy. Water is the main issue in the political and administrative agenda of the Apulia region, as it is essential for its agricultural sector, encompassing almost 352.000 farms (IPA-CBC 2016). Sinistra Ofanto is one of the greatest and most important multi-cropped irrigated areas in the Apulia region and Mediterranean region (Lamaddalena et al. 2004). However, the area is facing context-specific challenges associated with a change in cropping pattern respect to the design stage, intensive agricultural activities, increasing droughts, and water scarcity leading to limited surface water resource availability and over-exploitation of groundwater (Giordano et al. 2010; Levidow et al. 2014). In this context, irrigation scheme performance assessment is vital to evaluate the impacts of irrigation practices, identify performance gaps, and improve system performances. This study used a holistic framework with associated indicators for performance evaluation of water users organization Consorzio per la Bonifica della Capitanata (henceforth the CBC) and obtain a holistic picture of sustainability in irrigated agriculture areas. The analyzed study area is irrigation district 17 (Trinitapoli). It is one of the first areas in the Apulia region to activate and implementing the treated wastewater for irrigated agriculture in its sub-districts.

2. Assessment framework

Fig. 1 shows the simplified conceptual research methodology framework with the following steps: i) primary field data collection in the irrigation scheme; ii) Understand current operational practices through the interpretation of data, computation of indicators, and application of complementary tools; iii) Evaluate the current level of the overall system performance.

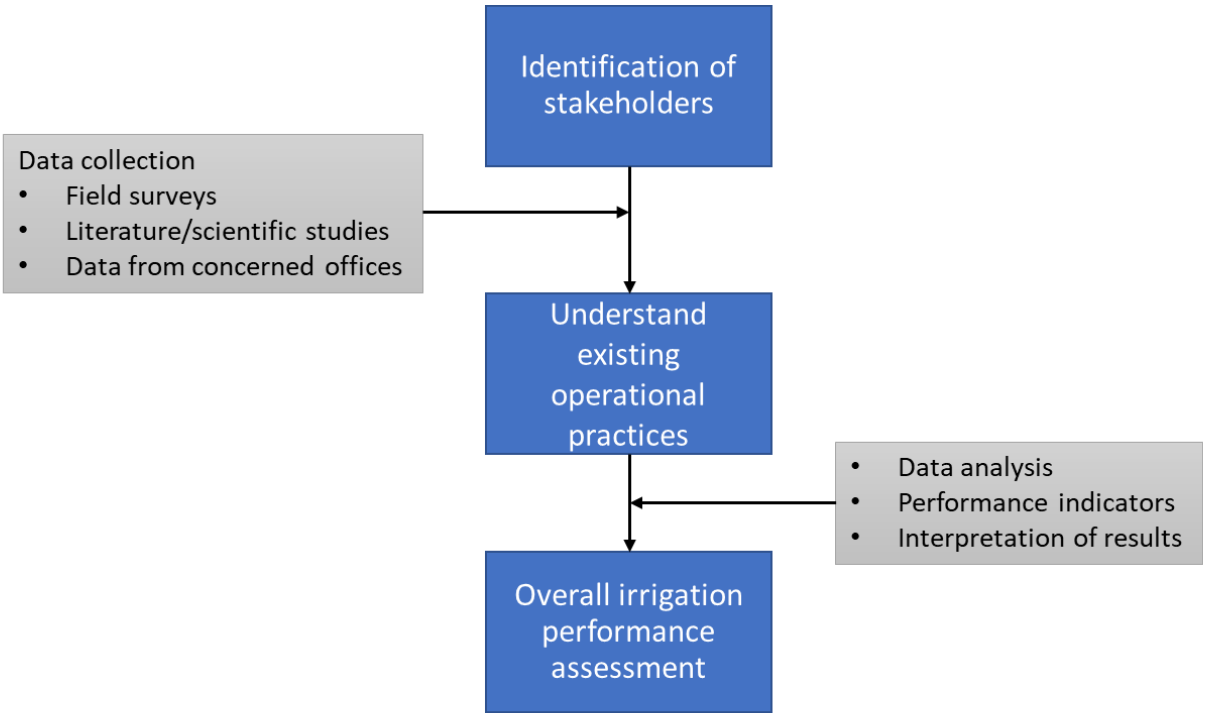
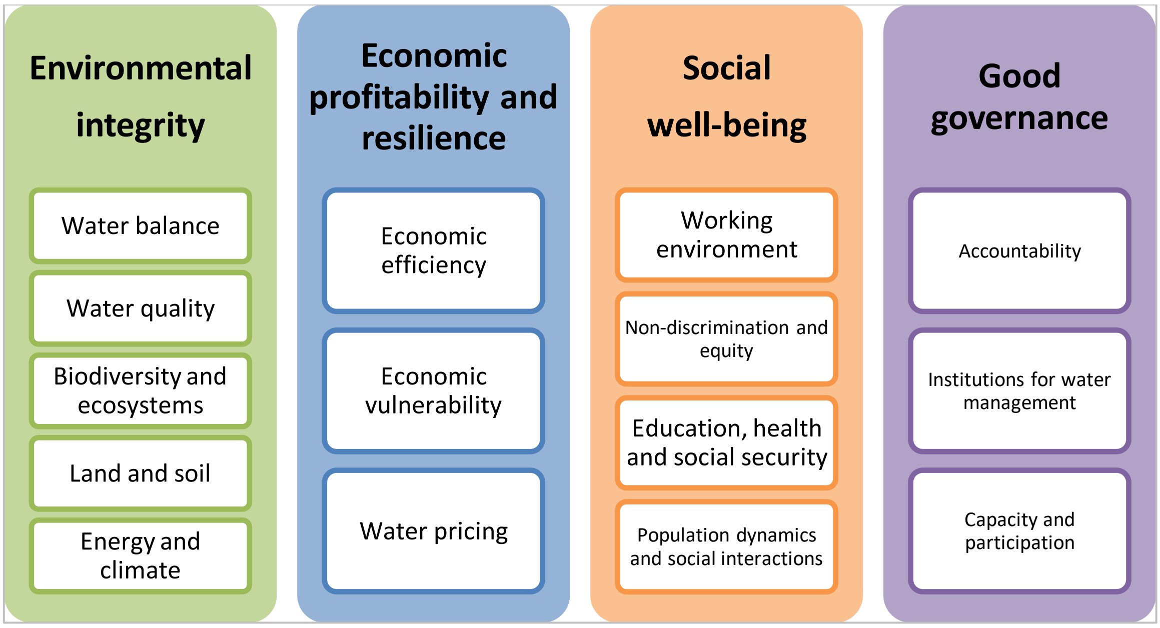


Fig. 1. Simplified conceptual framework of the research.

The assessment was based on the SIRIUS sustainability assessment framework (Antunes et al. 2017) considering 4 basic dimensions (Fig. 2) in the sustainability assessment of irrigation areas: (1) environmental integrity; (2) economic profitability and resilience; (3) social well-being and (4) good governance. For each of the core issues, the aspects to be evaluated, and corresponding indicators were associated. The data for performance assessment was collected from various sources, including field measurements, observation, previous studies, informal meetings, and data from the WUO CBC.



Modified from Antunes et al. (2017)

Fig. 2. Main dimensions and core issues addressed in this assessment.

3. Introduction Capitanata Irrigation Consortium

The “Capitanata area” is a plain area of about 4000 km^2 located in the northern part of the Apulia Region (south-eastern Italy), province of Foggia (Fig. 3). The consortium territory is extended on 39 municipalities for a total of 441,553 hectares, all falling within the province of Foggia. It is one of the greatest and most important Irrigation Consortium in the Mediterranean region (Lamaddalena et al. 2004). The consortium is characterized by a heterogeneous mixing crop mixing with the presence of cereals, olive trees, vineyards, and orchards. The entire area is served by a network of 227 natural watercourses and consortium channels. For efficient management, the territory of Capitanata has been divided into three (3) territorial areas. Two irrigation districts are established to serve about 40,000 delivery points: the Fortore district, in the Northern part, covering a surface area of 1100 km^2, and the Sinistra Ofanto district, in the South, expanding over the surface area of 400 km^2.

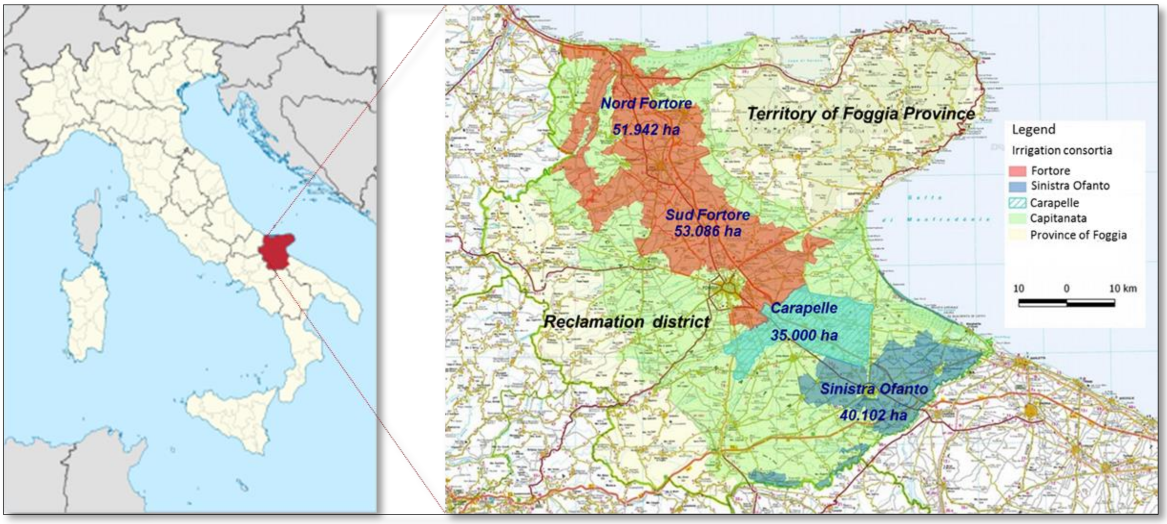


Fig. 3. Location of Capitanata irrigation consortium.

The two irrigation districts (Fortore and Sinistra Ofanto) deliver water to irrigation fields independently through a network of primary adductors (1,200 km) and a secondary water distribution network (8,000 km). The network consists mostly of pipes. The “Consortium per la Bonifica Della Capitanata” (CBC) technical service is responsible for the overall planning and management of the two districts, including the operation of artificial reservoirs. From a hydraulic point of view, the consortium territory can be subdivided into "systems" having characteristics of homogeneity, called "watersheds" are indicated below with names and numbers from 1 to 18 (Fig. 4).

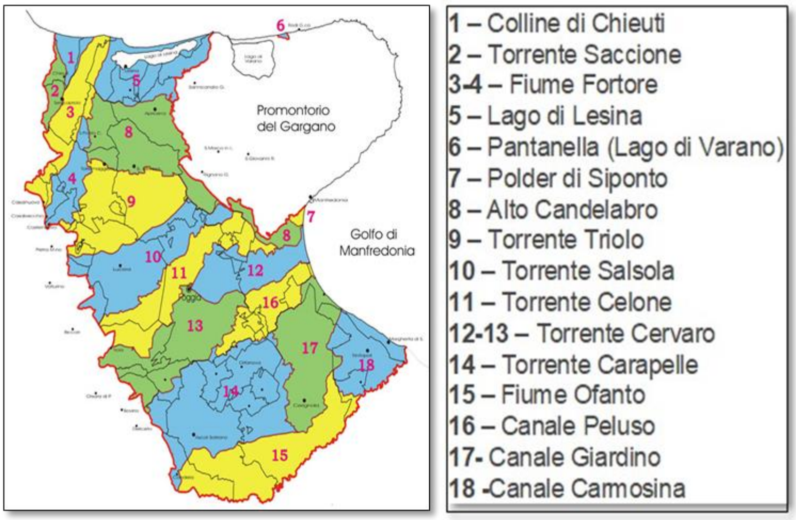


Fig. 4. Capitanata watersheds.

2.1 Sinistra Ofanto irrigation scheme

The Sinistra Ofanto constitutes an important agricultural district and irrigation system located in the province of Foggia (Italy) and managed by the Consortium "Bonifica Della Capitanata" (CBC). The water scheme of Ofanto is intended to meet the drinking and irrigation needs and industrial areas of Basilicata, Puglia, and Campania. The scheme (Fig. 5), covering a surface of about 39,000 ha of which 22,500 ha in the lower area, is approximately triangular-shaped, bounded at south by the Ofanto river and at south-east by the town of Cerignola. The system is divided into seventeen irrigation districts (numbered from 1 to 17) with a size from 300 ha (district 15) to 5450 ha (district 11). The large size of farms, the type of productive systems applied (arboreal, horticultural, etc.) and the need for rational use of water, has led to the coexistence of two company irrigation systems: localized low-pressure and mini sprinklers. The pressurized irrigation network in each district originates from those reservoirs and is designed for an on-demand delivery schedule. The resources available for the Sinister Ofanto District have been estimated at 76 Mm^3, which, with an endowment of 2,000 m^3/ha, allows to supply water to a potential irrigable area of 38,000 hectares.

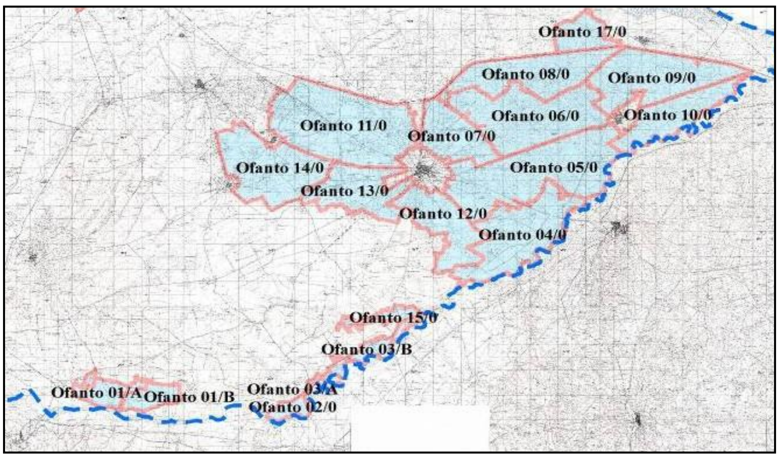


Fig. 5. Location of the Sinistra Ofanto irrigation scheme within the Ofanto River Basin.

Table 1 shows the area of each district and municipality. The districts are subdivided into sectors with a surface ranging from 20 ha to 300 ha. The irrigation districts are served by storage and daily compensation reservoirs supplied by a conveyance conduit which originates from the Marana-Capacciotti dam (the year 1969) with a height of 50 m, crown length of 825 m, and a capacity of about 50 Mm^3. It is located 13.5 km southwest of Cerignola city, in the northern part of the Apulia region. Another source of water is the San Pietro Osento dam (the year 1958) with a height of 49 m, crown length of 450 m with a potential capacity of 14.5 Mm^3 (Di Pasquale et al. 2018). The conveyance network is branched, with a small portion as an open canal and most of it as pressurized pipes feeding the reservoirs that, in turn, supply water to the districts. The system uses 10 accumulation tanks with daily compensation of 20,000-40,000 m^3 capacity. Also, there are three (3) pumping stations with a total output of 1520 kW that pump the water to the upper zone.

Table 1. Distinctions of irrigation districts according to the size and municipality.

District	Area (ha)	Municipality
1a/b	1180	Candela, Ascoli
2	490	Candela, Ascoli
3	1042	Ascoli, Cerignola
4	3256	Cerignola
5	4930	Cerignola, San Ferdinando
6	3960	Cerignola, San Ferdinando, Trinitapoli
7	1741	Cerignola, Trinitapoli
8	2960	Cerignola, Trinitapoli
9	3300	Trinitapoli
10	2070	San Ferdinando, Trinitapoli
11	5450	Cerignola, Stornara
12	2070	Cerignola
13	2020	Cerignola
14	3215	Stornara, Stornarella, Ortanova, Cerignola,
15	300	Cerignola
16	850	Margherita di Savoia, Zapponeta
17	800	Trinitapoli

There are 13,650 hectares served from pumping stations. The remaining surface is exclusively served by gravity. The cropland allocation for each irrigation zone is reported in Table 2.

Table 2. The Main crop distribution [ha] in the sub-schemes of the Sinistra Ofanto scheme.

Crop	Zone 1 (D1-2-3)	Zone 2 (D11-14)	Zone 3 (D4-10)
Artichoke	43	20	506
Asparagus	102	-	5
Olive	60	3656	3619
Orchards	67	13	3147
Sugarbeet	3	-	25
Table Grape	0	41	3233
Tomato	218	63	90
Vegetables	47	215	483
Wheat	2218	2604.6	1943
Winegrape	98	3793	7338

The distribution network consists of approximately 2000 km of fiber cement pipes or P.V.C (only for small sections), with a diameter between 350 and 90 mm. The sectoral distribution network conveys water to all individual delivery points farms falling within the sectors. From the distribution, network water is delivered to farms through automated irrigation hydrants (Fig. 6), which are composite valves usually consisting of an isolation valve, a pressure reducing valve, a flow limiter, and a water meter. At the nozzle, a minimum pressure of 20 meters and a flow of 10 l/s is guaranteed.

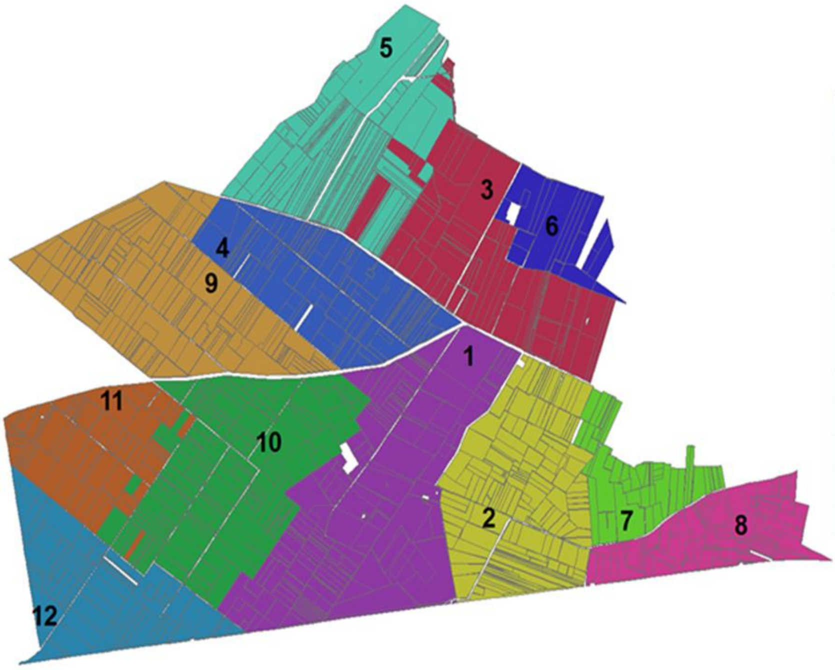
Fig. 6. Electronically fed hydrant, Sinistra Ofanto irrigation scheme.

The distribution network has been designed assuming a 50% partitioning with an endowment of 2,050 m^3/ha, a delivery group for every 7 hectares for a total of over 5,400 points, and a system for delivering water to users of the type to the question. The beginning of the irrigation season has been fixed by the statute and goes from 1 March to November 30th. The prevalent crops are tree crops, vineyards (42%), olive groves (27%), orchards (5%), followed by vegetables (15%, mainly artichoke and asparagus), and industrial crops (6%).

3.Case study area- Irrigation District 17, Sinistra Ofanto

Irrigation district 17 constitutes an important agricultural district and irrigation system within the Sinistra Ofanto irrigation scheme. Hereafter, the agriculture, geographical background, general agro-climatic, and other important features of the irrigation district 17 have been described.

Irrigation district 17 has an area of 880 ha located in the countryside of Trinitapoli (Foggia). The Municipality of Trinitapoli is located in the northern area of the province of Barletta-Andria-Trani, in Puglia at a height of 5 m s.l.m. It borders the Municipalities of Barletta, Cerignola (FG), Margherita di Savoia, San Ferdinando di Puglia, and Zapponeta (FG). The municipal territory extends over one surface of 147.62 square kilometers.



Sector	Area (ha)
S1	129.6
S2	76.9
S3	49.3
S4	58.8
S5	83.7
S6	20.9
S7	23.8
S8	35.6
S9	90.7
S10	104.0
S11	49.0
S12	55.0

Fig. 7. Sinistra Ofanto irrigation district 17 and its sub-sectors with the relative surface.

The irrigation district is divided into 12 sub-sectors (Fig. 7) that represent the territorial units served by the irrigation distribution network and a network of irrigation facilities. The size ranges from 20.9 ha (sector 6) to 129.6 ha (sector 1). The average size of the sector is 75.5 ha. The size of land holdings is less than 2 hectares. Farming is the dominant form of land use and the main source of income for most households.

3.1 Environmental integrity

The primary objective of sustainable water management is to protect the environment and the ecosystem to ensure environmental integrity. Such a dimension encompasses the evaluation of the integrity of the natural capital of irrigated agricultural areas, and its capacity to ensure the fulfillment of the basic ecological functions underpinning the delivery of a sustainable flow of ecosystem services (Antunes et al. 2017). Poor irrigation practices impacted environmental integrity in different ways. Therefore, irrigators must become "environmentally friendly" through a better understanding of water balance, water quality, land, and soil, and energy-climate aspects.

3.1.1 Water balance

Surface water, groundwater, and municipal treated wastewater are potential sources for irrigation water supply in D17. The **main source of irrigation water** is surface water managed by the Consorzio di Bonifica della Capitanata (CBC). As an irrigation service provider, the CBC is composed of irrigation service users, i.e. farmers. The irrigation district 17 is served by 651 automatized hydrants (Fig. 8) with a continuous flow rate of 0.202 l/s (reaching up to 0.303 l/s when operated 16/24) and a minimum running pressure of 2 bars (20 meters). At the farm level, micro-irrigation is currently adopted in most of the irrigated areas. The specific continuous discharge of the system is 0.4 l/s/ha or 34.5 m^3/day/ha.

This represents the water demand of the optimal cropping pattern. Considering the irrigation season between 180-200 days (1st March – 30th November) the potential water supply is estimated from 4000 to 4500 m^3/ha.

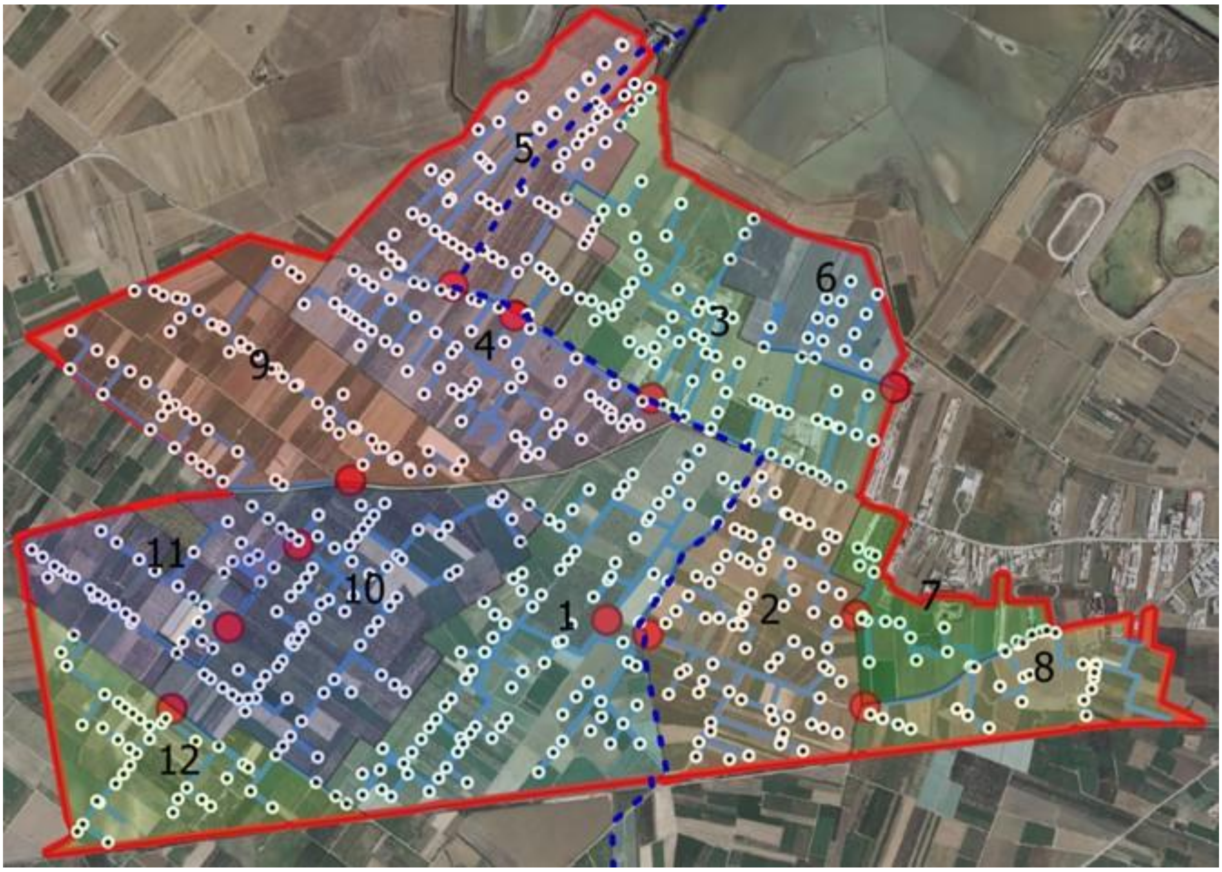


Fig. 8. The layout of hydrants and water distribution networks of irrigation district 17 (CBC).

The model-based annual irrigation demand of district 17 for an average hydrological year estimated with the CROPWAT model using site-specific weather-crop-soil information is about 1.57 Mm^3. The annual irrigation supply is 0.97 Mm^3 or about 70% of district water demand (Table 3). This means that the system cannot satisfy full crop water requirements increasing complexity related to the water management aspect. (equitable distribution of water, reliability, and adequacy in water distribution, reduction in the frequency of disputes). During peak periods, sometimes, a restriction of deliveries is imposed. Consequently, irrigation distribution networks are shifted from on-demand operation to a fixed rotation delivery schedule where operating time is divided into periods or turns. Merely shifting scheme operation from on-demand to restricted delivery, does not radically improve the efficiency and the equity of water distribution. The restricted-flow demand delivery schedule prevents the quick completion of irrigation cycles in medium-large farms (Levidow et al. 2014). Likewise, uncertainty in supply is likely to generate more water-related conflicts that also impact the efficiency of the system. Operation under restricted demand does not necessarily induce water saving but rather an increase in water demand (Lamaddalena et al. 2004). Faced with uncertain supply farmers and fear that water might not be forthcoming in the next irrigation rotation farmers tend to over-irrigate their lands (Ghazouani et al. 2012). In some cropped areas through groundwater salinity is quite high, groundwater pumping is conducted by farmers to avoid the limitations of the demand or arrangeddemand delivery schedule from CBC. Apulian aquifers have suffered both in terms of water quality and quantity (Polemio 2016). All over the Apulia region, it has been estimated that farmers have drilled about 140,000 wells (Giungato 2010).

Table 3. Total irrigation water requirements within the irrigation district 17.

Crop	Average		
	NIR (m^3/ha)	GIR (m^3/ha)	Total scheme GIR (m^3)
Olive	1961	2389.561	256,479.59
Wine grape	2316	2642.164	456,204.80
Autumn-winter cereals	2154	2881.792	-
Artichoke	3708	4484.671	223,785.09
Early Peach	4213	4878.743	310,125.41
Table grape	950	1097.778	46,337.20
Apricot	3875	4476.082	89,969.25
Tomato	4639	5232.865	91,400.72
Almond	3711	4300.175	28,811.18
Late Peach	3846	4458.567	-
Melon	3483	4245.592	28,303.95
Mixed Orchard	3932	4549.971	8,326.45
Autumn vegetables	133	142.1528	-
Spring vegetables	4024	4896.966	-
Total			1,539,743
Water delivered from CBC 2016			833,531
Water delivered from CBC 2017			1,118,269

In the last decade, the regional policy on integrated water resources management is supporting the use of treated wastewater reuse in agriculture to achieve the following objectives: i) reduce the consumption of conventional water resources in agriculture, ii) increase environmental and agronomic security, iii) reduce environmental impacts from salinization and counteract desertification. In Apulia for 258 municipalities, 185 wastewater treatment plants are aiming to provide extra water for irrigation. Nevertheless, in 2019 only 9 plants (Acquaviva Delle Fonti, Casarano, Corsano, Gallipoli, Ostuni, Fasano, Noci, San Pancrazio Salentino, and Trinitapoli) matched the level quality suitable for reuse. In the district of the Capitanata reclamation consortium, one of the treatment plants and associated reuse schemes is in the municipality of Trinitapoli. The project aims for the recovery of about 1 Mm^3 per year and a potential irrigated area of about 500 hectares in irrigation district 17. Yet, the share of water reused is zero because works are still ongoing. Reuse of treated wastewater can help to preserve the extraction of water from aquifers (at least 1500 m^3/ha) and reduce fertilizer requirement to about 45 kg ha^{-1} of nitrogen and 90 kg ha^{-1} of phosphorus. Farmers are not committed to contribute to the cost of water reclamation of 0.3 €/m^3 but pay the only delivery cost of 0.12 €/m^3. This an offsetting element for adoption irrigation reuse since in many cases cost recovery from the farmers is unlikely to be feasible.

The irrigation requirements of a crop are affected by weather variability. The amount of rainfall in the study area is important but often not enough to cover the water needs of the crops because the rains are scarce from June to August, i.e. irrigation period. Mean annual precipitation ranges from 400-600 mm with precipitation concentrated mostly during the autumn (October and November), while quite scarce during spring and summer (Fig. 9). Consequently, there is also a direct impact on groundwater recharge. The recharge of aquifers is irregular and occurs only in periods of heavy rainfall in the winter months. This Thermo-Pluviometric Bagnauls-Gaussen diagram in Fig. 9 shows that the dry period goes from May to September which could correspond to the period of the year where irrigation is needed to sustain agricultural production. The inter-annual variability of precipitation is much accentuated. In Southern Italy, the net rainfall trend ranges from −0.23 to −3.52 mm/year (Polemio 2016). This anomalous sequence of negative values is evident since 1980. The study area is characterized by a maritime Mediterranean climate, with an average annual temperature of about 15.7 °C. The average annual minimum and maximum temperatures are 7.6 °C and 25.3 °C, respectively. December represents the coldest month whereas the hottest months are July and August.

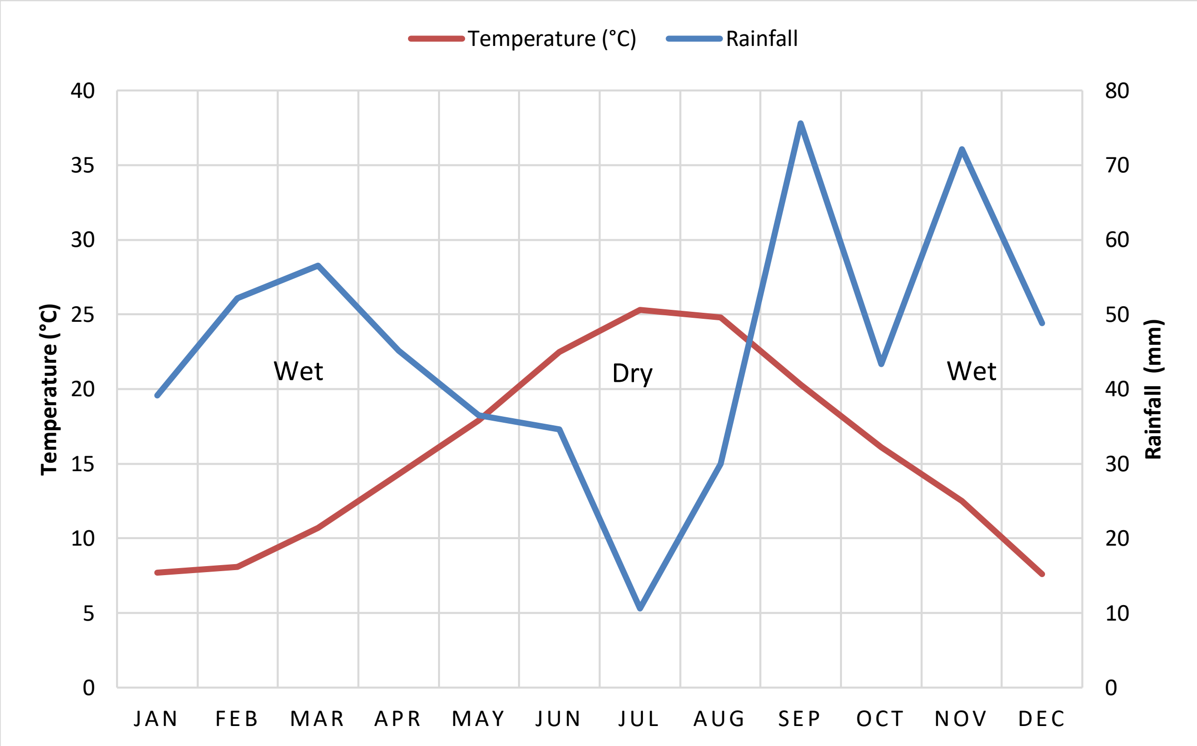


Fig. 9. Thermo-pluviometric Bagnouls-Gaussen diagram for the irrigation district 17.

In southern Italy, climate change-induced water scarcity has become increasingly problematic. Among the Reclamation Consortia in Southern Italy, Capitanata is the most affected by projected water scarcity hazards (Ronco et al. 2017). Fig. 10 shows the local water scarcity indicator (AWARE characterization factors for water scarcity footprint). They can be used to calculate water scarcity footprints as defined in the ISO Standard multiplying ta volume of water consumed. AWARE characterization factors represent the **potential water scarcity impact** between 0.1 (minimum water scarcity) and 100 (maximum water scarcity), expressed in m^3 world eq. m^{-3} (dimensionless). Irrigation in Trinitapoli and Capitanata consortium from May to September would result in a marked increase in blue water footprint due to crop water consumption which is concentrated over the summer month (Fig. 11). Tomato, artichoke, and orchard growing systems are highly intensive in this area, with a massive application of irrigation water. The *annual AWARE Agri* factor per Trinitapoli watershed is 96.33 m^3 world eq. m^{-3} while the Apulia region is 90.89 m^3 world eq/ m^3 consumed. The AWARE CFs close to 100 means that has no or very little remaining freshwater in an area and consequently this area is facing water scarcity (Kaewmai et al. 2019). Apulia is the second Italian region most affected by agricultural water scarcity (Table 4). The scarcity has wide regional disparities. The *annual AWARE*

Agri factor (Boulay and Lenoir 2020) for Northern regions is significantly lower, e.g. 2.89 m^3 world eq./m^3 for Lombardy or 2.91 m^3 world eq./m^3 for Piemonte.

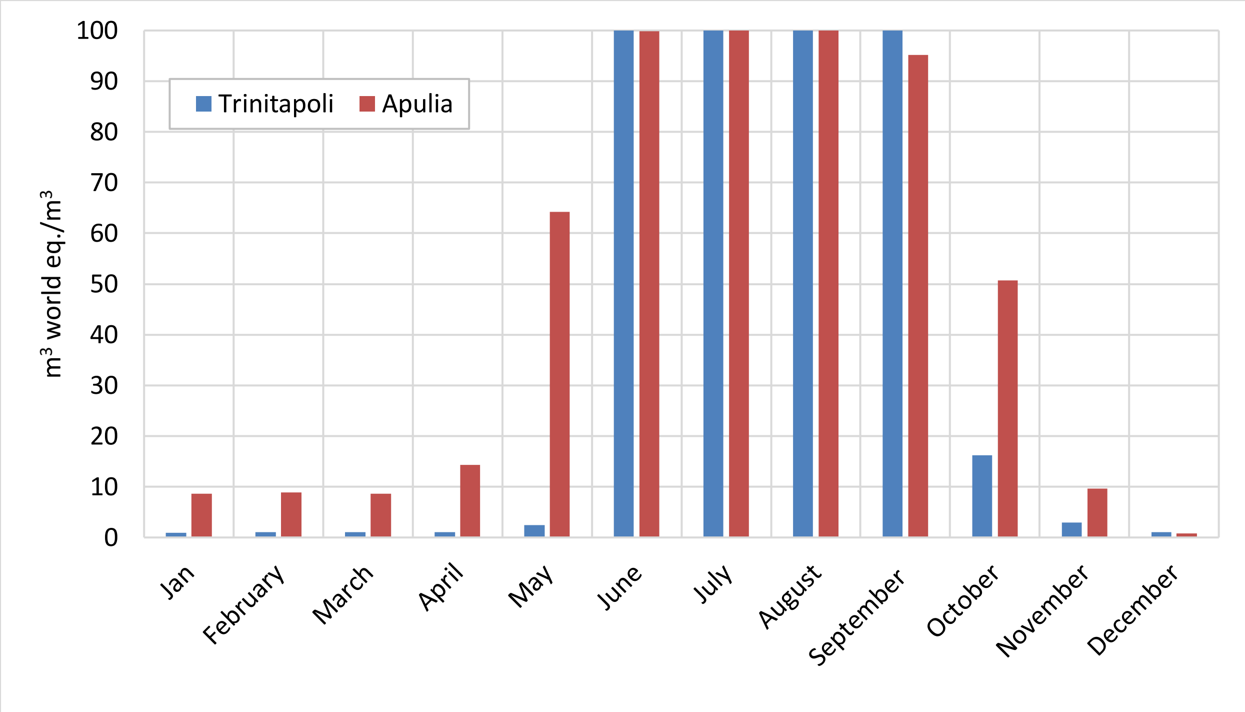


Fig. 10. The indicator AWARE, which denotes local impacts of the water consumption in district 17, Trinitapoli, and the Apulia region (0 – minium scarcity, 100 maximum scarcity).

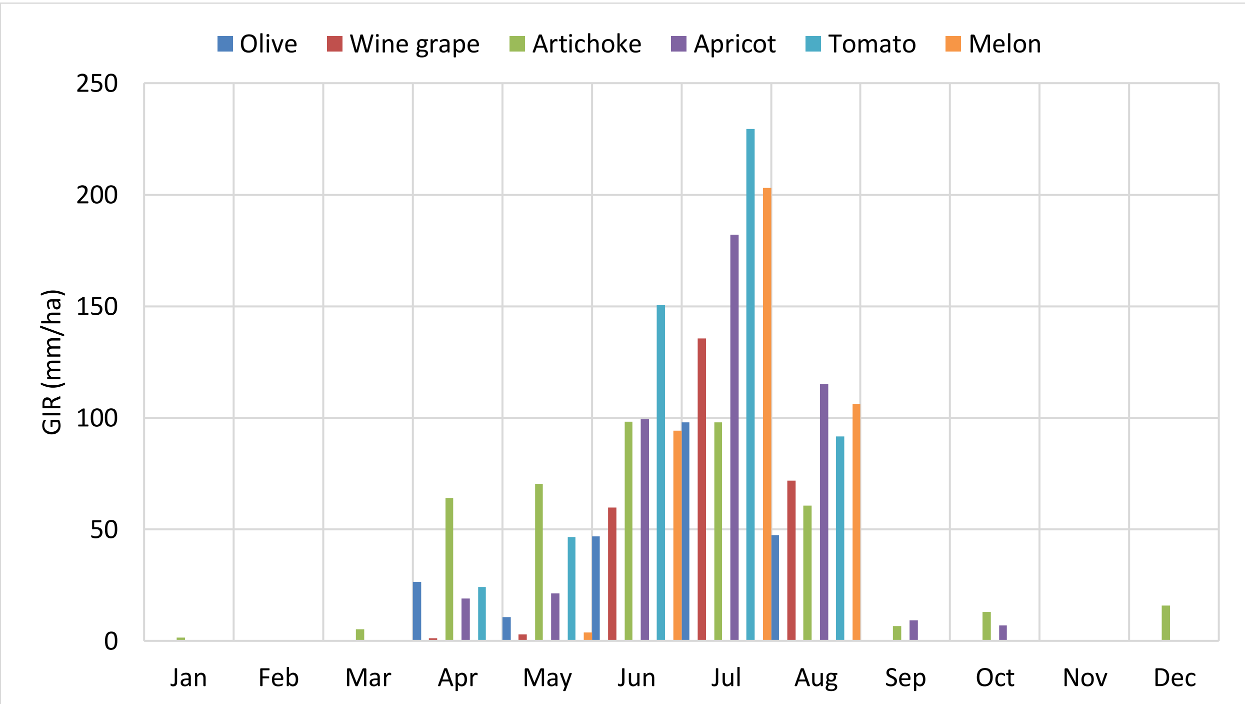


Fig. 11. Monthly gross irrigation requirement (GIR) of major crops in district 17, Trinitapoli.

Table 4. Sub-national regional AWARE indicator for water scarcity footprint (0 – minium scarcity, 100 maximum scarcity).

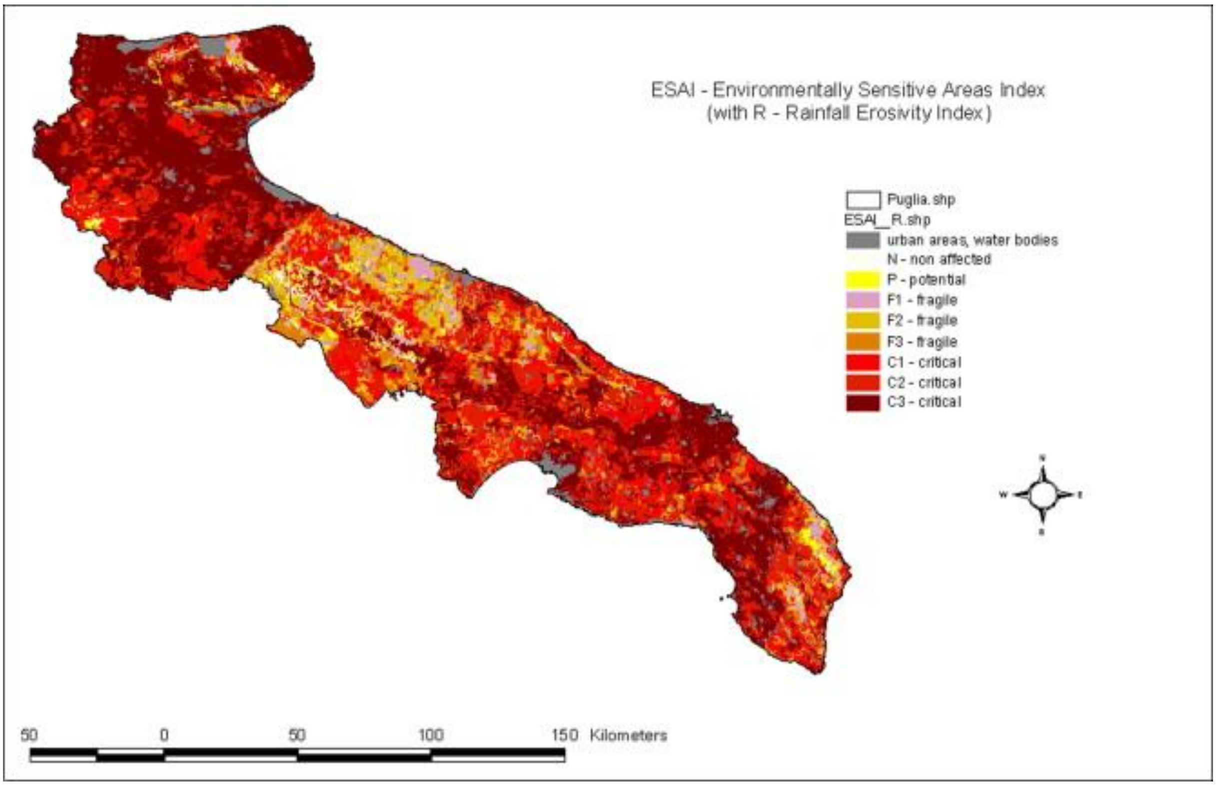
Region	WSF
Sicily	92.10
Apulia	90.89
Molise	84.90
Sardegna	82.78
Basilicata	82.77
Calabria	78.68
Campania	64.86
Abruzzo	54.02
Lazio	53.37
Toscana	41.04
Marche	23.65
Liguria	18.85
Umbria	18.57
Emilia-Romagna	8.73
Piemonte	2.91
Lombardia	2.89
Valle d'Aosta	2.89
Veneto	2.03
Friuli-Venezia Giulia	1.00
Trentino-Alto Adige	0.90

3.1.2 Water quality

The corresponding analysis presented in D3.4.1 demonstrated that surface water quality from the distribution network matches the limits defined and recommended by the Italian legislation (DM 185/2003). This shows that surface water is the subject area that is suitable for agricultural uses and its good water as emphasized also by Portoghese et al (2021). For GW, both good quality and contaminated water are reported. In most cases, the GW tends to have high values of salinity, especially along with the coastal areas of the Apulian region. Salt contamination of the Apulian groundwater which flows within hydrogeological units and overlies intruded seawater - is a well-known and thoroughly investigated phenomenon (Polemio, 2016). The use of saline groundwater for irrigation could become a serious threat to the sustainability of the cropping systems (Libutti et al. 2018). The results for treated wastewater showed that quality is generally acceptable; some parameters are recommended to be adjusted. Previous experimental analysis in the study area demonstrated that the tertiary effluent has better characteristics than underground waters with no presence of any dangerous pollutant, like pesticides, solvents, and heavy metals, thus, causing no pollution or degradation neither of the soil nor groundwater (D'Arcangelo 2005). In similar cases, the microbial quality of treated effluents has been than that of local well-water used for irrigation (Lopez and Vurro 2008). All the water sources of the area are generally alkaline/basic (pH>7). The normal range for pH in surface water systems is 6.5 to 8.5 and for groundwater systems 6 to 8.5.

3.1.3 Land and soil

Soil vulnerability to salinization in Southern Italy is getting higher due to progressive aquifer depletion and seawater intrusion along the coastline (Libutti et al. 2018). The soil analysis performed in the study area in Deliverable 3.4.1 demonstrated no particular problems with soil salinization or contamination of the upper layers. This indicates that farmers apply good quality water and have relatively effective salinity control. Salinization was more likely to endanger irrigation water quality of groundwater and surface stored water. Since considerable variation occurs from one cropping season to the next; therefore, monitoring should stress long-term trends and changes in soil salinity. About 57% of the study area in the Apulia region is classified in the high-risk desertification class (Fig. 12). This is due to various degradation factors: erosion and disaggregation, salinization, decrease in organic matter, loss of biodiversity, land consumption, increase in drought events. Concerning combating drought and desertification the regional strategy 2007-2013 and 2014-2020 includes a series of agronomic interventions such as - reduced tillage or no-tillage and direct sowing, crop rotations, correct management of crop residues, fertility management, and fertilization, hydraulic-agricultural arrangements, and bioengineering works, and balanced control of pesticides and plant diseases.



Retrieved from Ladisa et al. (2010)

Fig. 12. Map Environmental Sensitive Areas to Desertification index in Puglia.

3.1.4 Energy and climate

Energy is becoming one of the main inputs for irrigators and a major challenge in the irrigation supply (Khadra et al. 2016). Large quantities of energy required to pump irrigation water in large-scale pressurized irrigation systems are significant considerations both from the standpoint of energy and water resource management, but also in terms of environmental burdens, an issue of increasing importance to European agriculture. Regarding energy consumption and intensity, the CBC has a low-energy process because the irrigation water supply in D17 relies mainly on gravity. The embodied carbon dioxide equivalent in the surface water supply is 0.00041 $kgCO_{2-eq}/m^3$. The energy intensity of groundwater supply with diesel-powered pumps varies from 0.39 to 0.78 kWh/m^3-water pumped for a range of a total pumping head of 40-80 m. When electrically powered pumps are used varies from 0.2 to 0.41 kWh/m^3-water pumped. The intensity for TWW is about 0.6 kWh/m^3 including reclamation and pumping in the field. Knowing the carbon footprint of Italian electricity generation (0.59 $kgCO_2/kWh$) the carbon footprint of the unit of water range from 0.12 to 0.46 $kgCO_2/m^3$. The average CO_2 emissions per alternative water source per cubic meter of pumped water are 0.29 $kgCO_{2-eq}/m^3$. Indirect energy and environmental impacts are associated with water storage and distribution infrastructures; however, large-scale systems are negligible because they manage large amounts of water over the useful life and are multi-purpose (Moretti et al. 2019).

Agriculture uses energy directly (foreground) as fuel or electricity to operate machinery and equipment, to heat or cool buildings, and for lighting on the farm, and indirectly (background) in the inputs produced off the farm. Table 5 summarizes the input of specific crops in D17 of Sinistra Ofanto. Total fertilizer nutrient ($N+P_2O_5+K_2O$) consumption estimated is about 4.25 t/ha where 40% is in the form of nitrogen, 29% form of phosphorus, and the rest in the form of potash. The total fuel requirement of the D17 is estimated at 600 kg/ha while the cumulative amount of machinery 70 kg/ha.

Table 5. Crop input in terms of mechanization and agro-chemicals.

Crop	Fuel (liter/ha)	Working hours (h/ha)	N fertilizers [kg N/ha]	P fertilizers [kg P_2O5/ha]	K fertilizers [kg K_2O/ha]	Pesticides [kg/ha]
Apricot	40	17	120	80	100	8
Artichoke	100	15	200	120	100	5
Wheat	30	6	120	60	100	0.5
Almond Tree	40	10	120	80	100	6
Melon	62,5	10	120	100	100	3
Olive	37,5	7	100	80	120	2
Early Potatoes	50	10	150	120	150	2
Peaches	37,5	7	150	120	120	3
Tomatoes	50	10	150	100	150	5
Plums	15	12	120	70	100	15
Table Grapes	75	15	150	150	150	6
Wine Grapes	62,5	12	100	100	100	4
Fennel	50	10	200	100	100	2
Broccoli /Squash / Pumpkin	37,5	7	200	150	80	2

Fig.13 shows a streamlined carbon footprint (CF analysis) of the irrigation scheme considering the average values from the cropping pattern and considering some inputs used for crop production e.g. fertilizers, pesticides, water, and tractors (fossil fuel energy and machinery). The data for analysis were retrieved from the Ecoinvent database.

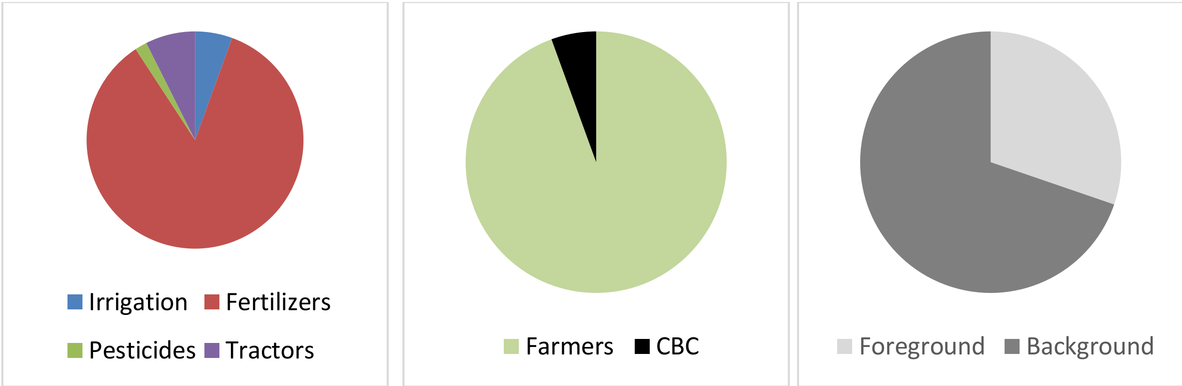


Fig. 13. Average carbon footprint analysis of district 17 with surface water supply.

The GWP of the irrigation scheme is dominated by fertilizers that have direct consequences on the environment. The carbon footprint of irrigation managed by CBC is quite low considering gravitational surface water supply. When TWW will be used electricity, CO_2 emissions and resource consumption will increase, although this effect will be partially offset by avoided groundwater withdrawals and the application of mineral fertilizers and related effects.

In the study area, agriculture is seriously threatened by increases in the occurrence of drought and high-temperature events associated with climate change (del Pozo et al. 2019; Vitale et al. 2010), an inevitable phenomenon in recent years and is expected to gain momentum with the coming time (Singh and Tiwari 2019). The analysis by Ronco et al (2017) demonstrated that agricultural (irrigated) areas of Capitanata are at high risk of water scarcity induced by climate change, especially in a long-term perspective, with considerable economic losses associated. Table 6 shows the indicator of the crop vulnerability to water stress retrieved from Ronco et al (2017). Vegetables, together with fruit trees, are identified as the most affected crops. Olives are very much resilient to severe water stress while vegetables (tomato, onion, peppers, peas, etc.) are very sensitive to water stress.

Table 6. The vulnerability of crops to water stress is related to the crop's water requirement (0 represents the minimum and 1 the maximum).

Class risk	Crop	Score
Very low	-	-
Low	Olives, Vineyards	2 – Low (0.2-0.4)
Medium	-	-
High	Vineyards	4 – High (0.6-0.8)
Very High	Fruit trees, Vegetable crops	4 – Very High (0.8-1)

Adverse impacts of climate change are a reality in most Mediterranean countries influencing crop yield and productivity, water resources but will also generate substantial physical and socio-economic impacts critically shaping the patterns of future crop production. The impact of climate change will vary for different crops and areas of the Mediterranean region with likely more negative impacts in the Southern Mediterranean countries where water scarcity is already a limiting factor of agricultural production (Saadi et al. 2015).

3.2 Economic resilience and profitability

3.2.1 Economic efficiency

Table 7 present the main type, cultivated area, and the average yields of the main agricultural products for each crop during 2015, 2016, and 2017. Fig. 14 depicts the percentage of area concerning total land use for major crops included in the cropping pattern. The main crop groups grown in the study area for three years are vineyards, olives, and cereals totaling 32%, 28%, and 18% of the total land, respectively. Grapes are one of the most important and cultivated crops throughout the sub-sectors. Grapes are one of the most important and cultivated crops throughout the sub-sectors.

Table 7. Crops cultivated and relative area in the district 17, Sinistra Ofanto.

Cultivated crop	Cropped area (ha)				Yield (t/ha)
Name	2015	2016	2017	Average	Range
Apricot	13.9	21.0	25.4	20.1	30
Artichoke	53.2	35.8	60.7	49.9	20-25
Autumn-winter cereals	167.1	143.6	99.6	136.8	6.5
Almond Tree	1.6	2.8	15.7	6.7	15
Melon	7.6	6.9	5.5	6.7	50-65
Olive	213.1	213.2	217.7	214.7	5-7
Early Potatoes	0.2	0.6	0.6	0.5	25
Peaches	61.5	59.0	70.2	63.6	45
Tomatoes	12.7	22.9	16.8	17.5	90-110
Plums	0.3	2.9	2.9	2.0	40
Table grapes	48.2	45.7	46.8	46.9	20-30
Wine grapes	193.2	205.1	211.1	203.1	22-27
Fennel/Broccoli	0.7	-	3.3	2	20-30

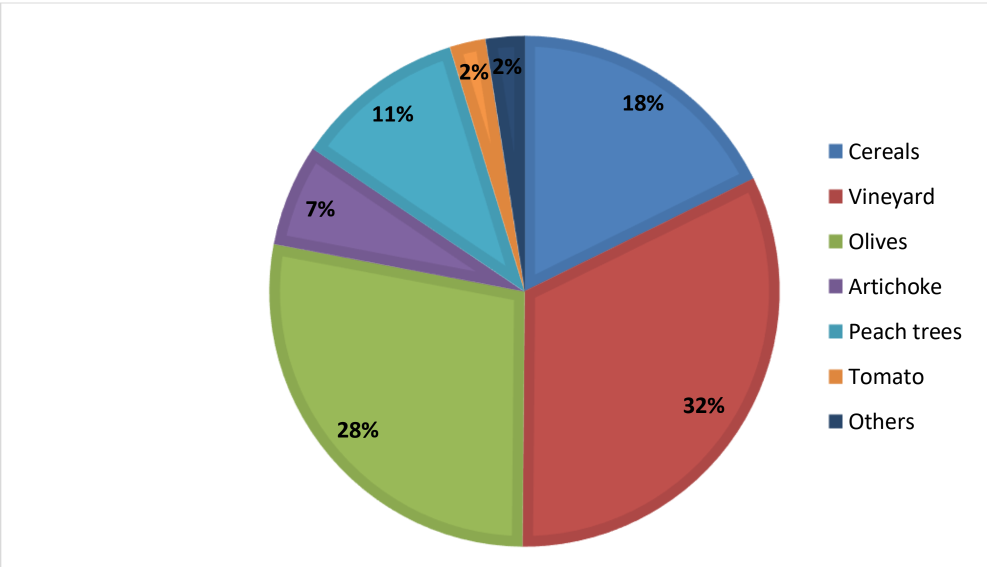
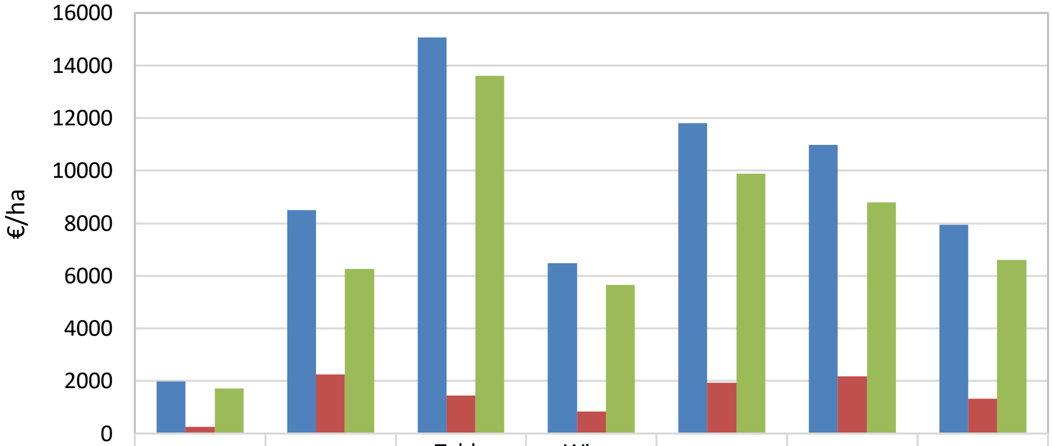


Fig. 14. The share of crop cultivated area to the total cropped area during three cropping seasons.

The average economic performance of the main crops grown in the study area is presented in Fig. 15. Regarding the economic performance of farming activities, data retrieved from the Farm Accountancy

Data Network for 2007 show an average turnover of nearly about 6,600 € and 3,300 € per cropped hectare, respectively (FADN, 2007). Grape and orchard cultivation or farming is one of the most lucrative and profitable farming in the study area and Capitanata in general.



	Olives	Tomato	Table grapes	Wine grapes	Orchards	Potato	Artichoke
Turnover (€/ha)	1979.4	8507.8	15059	6491.4	11817	10976.4	7947.5
Costs (€/ha)	261.4	2254.3	1448.7	829.6	1929.9	2184.5	1332.2
Gross income (€/ha)	1718	6253.4	13610.8	5661.7	9887.1	8791.9	6615.3

Fig. 15. Economic performance of the main crops in the Sinistra Ofanto area.

For surface water, the WUO CBC bears the cost of 0.03 €/m^3 for conveyance and storage; the cost for water distribution is 0.075 €/m^3. The water price to consumers takes into account the cost related to energy, personnel involved in technical management, costs related to ordinary and extraordinary maintenance of distribution system, costs of the vehicle, and water supply. The cost of energy is 10 cent€/kWh in the consortium of Capitanata (Khadra et al. 2016). The total cost of the treated wastewater supply told from CBC is 0.42 €/m^3 (treatment 0.3 €/m^3 and delivery 0.12 €/m^3). The treatment costs are comparable with the cost of groundwater withdrawals being up 20-25 €/hour or 0.37 to 0.465 €/m^3 (Fatone 2017). Irrigation with groundwater include also additional costs for the metering and control of groundwater withdrawals, which can be very costly with up 59 €/delivery points (Ursitti et al. 2018).

3.2.2 Water pricing

The CBC defines a tariff plan for surface water every year, at the beginning of each irrigation season. A binomial pricing policy (with a fixed part and a component varying with the volume consumed) is used in the study area. The fixed tariff is 30 €/ha and depends only on irrigable land without taking into consideration water consumption. The fixed cost cover fixed personnel cost, transport, the surveillance and organization of distribution, energy consumption, and part of the costs of technical assistance for irrigation not covered by regional funding. The variable tariff varies according to the quantity of water consumed according to the following water tariffs:

- 0.12 €/m^3 for water up to 2.050 m^3/ha (the duty);

- 0.18 €/m^3 for water from 2.051 m^3/ha to 4.000 m^3/ha;
- 0,24 €/m^3 for the quantity of water above 4,000 m^3/ha;

The user contributions are determined on a provisional basis and subject to an adjustment. A flat rate of 25% is added to the aforementioned expenses, except for variations to be determined year by year, to cover the general operating expenses of the Organization. The following items are charged to the maintenance costs: government water concession fees, ordinary and extraordinary maintenance costs of infrastructure and equipment, part of the expenses related to permanent irrigation personnel, and depreciation of mechanical equipment.

According to the last census, 24% of CBC revenue comes from the fixed component related to the farm irrigated area while the remaining 76% comes from the applied volumetric block tariff with an average price of 14 €/m^3(Portoghese et al. 2021). It is recognized that encouraging volumetric pricing leads to fulfilling cost recovery and a perceptible change in the farmer's attitude towards conservation. However, the price of water itself can also have a positive as well as a negative impact on water use behavior. High water prices sometimes lead to a shift in crop production to higher-value crops or the increased illegal use of water. Therefore an optimum price of surface water is needed, to decrease the incentive to extract and use water illegally. On other hand, WUA cannot be interested in water-saving as fees collected for maintenance cost, in essence, depending on the quantity of supplied water: the smaller amount of water is supplied, the lower will be the irrigation service fees. Nevertheless, the adoption of volume-based payment for irrigation services provided by WUA encourages better water records keeping inside WUA. This is facilitated by automatized hydrants (Fig. 6).

3.3 Social-well being

The objective of irrigation is to increase agricultural production and consequently to improve economic and social well-being. The latter is related to means of living, health, and safety, working conditions, as well as the means to satisfy aspirations for a better life, such as education and non-discrimination (Antunes et al. 2017). Due to the difficulty to obtain site-specific data the analysis of social well-being is mainly explored on the provincial or regional level.

3.3.1 Working environment, non-discrimination, and equity

Agriculture is still the most important sector in the Apulian economy, both in terms of employment and production. In economic terms, such a sector is much more important in Puglia than in the rest of the country. Employment in agriculture is above the national average (8.5% vs. 3.6% in 2017). Family is the major source of labor on farms where most of the time the agricultural land is farmed by the owner.

The average wage for an agricultural worker in the Apulia region is around 10.47 €/hour slightly lower than the regional average of 11.21 €/hour. The monthly minimum wage for agriculture works depending on the worker category range from 682,03 to 1.186,23 €/month. The disparity in earnings between men and women is about 7% in Puglia and 5% in the province of Foggia (Fig. 16).

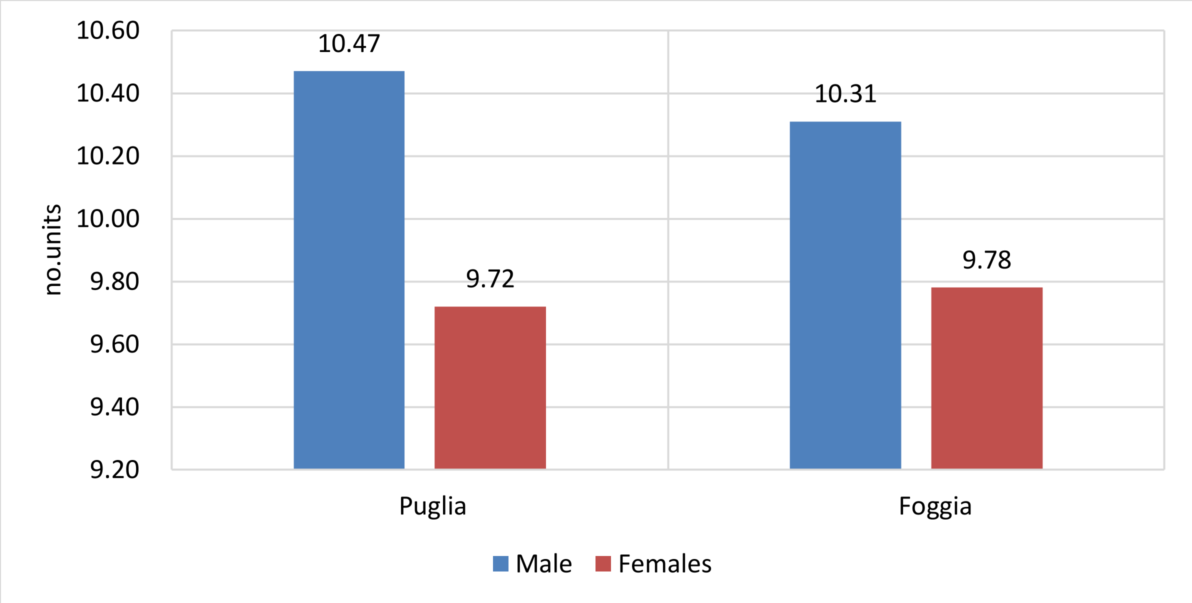


Fig. 16. The average salary for men and women employed in agriculture.

According to different journalistic reports, Southern Italian agriculture is characterized by much lower wages because migrants are the main workforce in agriculture. The relevance of the phenomenon is due to the seasonal nature of the agricultural activity and the strong use of day labor. Regarding working time, the provisions on working hours and overtime are included in Act no. 66/2003, as amended by Act no. 213/2004. In principle, employees are supposed to work 40 hours per week. In any case, the duration of the weekly working time cannot exceed 48 hours per week, including any overtime hours. In some rural parts, working conditions tend to be difficult, precarious, and hazardous because jobs provided are mostly informal, with no written contracts, repeated violation of the relative legislation working hours, and the rules on safety and hygiene. However, a series of legislative measures (especially law 199, October 29th, 2016) is carried out to combat this phenomenon.

The sense of inequity remains more intense in the South of the country when comparing with the North of the Country (Fig. 17). Within the country, the regions of the South are mainly those in which the highest values of intense frustration are recorded while in the North, intense frustration is more contained. In terms of accidents, agriculture is one of the least hazardous sectors with only a 6% share in terms of work-related fatalities, non-fatal accidents, and occupational diseases (Fig. 18).

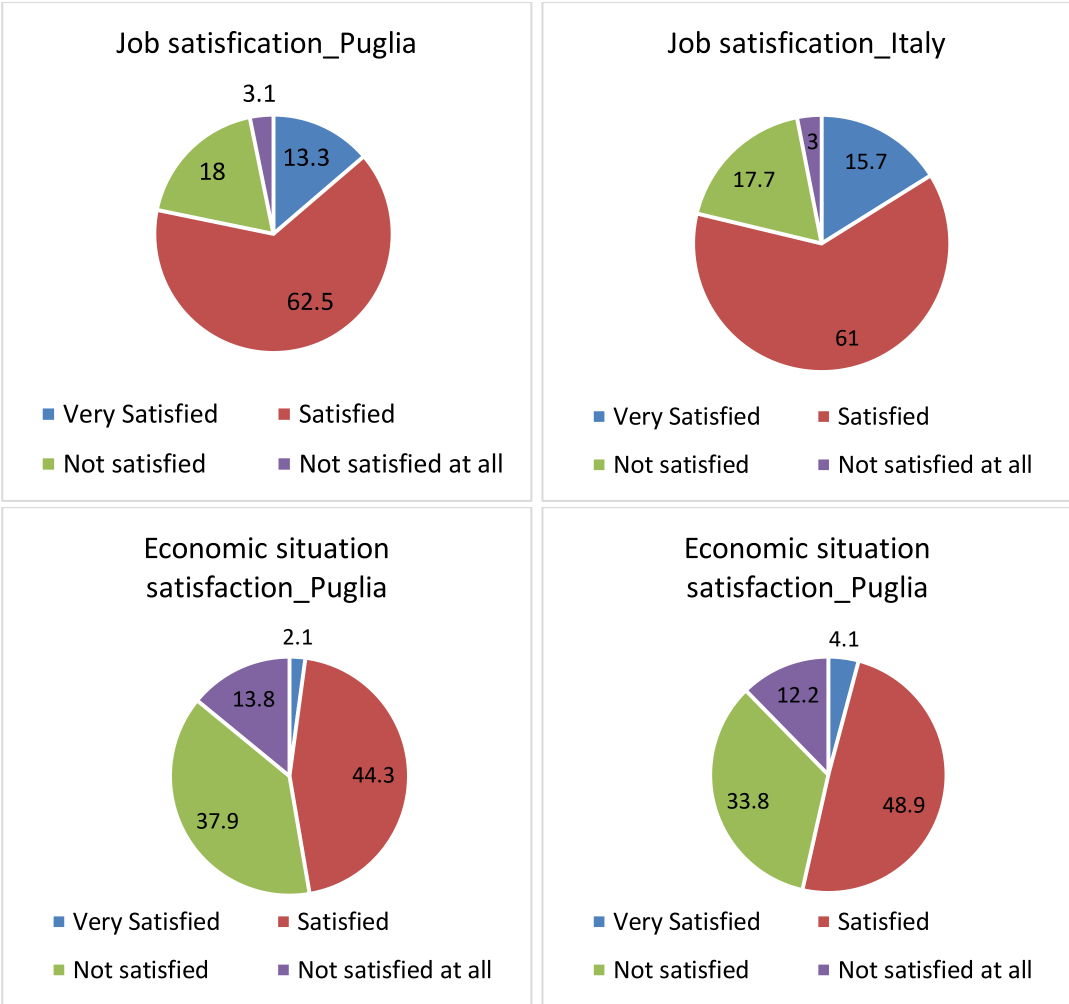


Fig. 17. Indicators of job and economic situation satisfaction, Apulia region, and Italy.

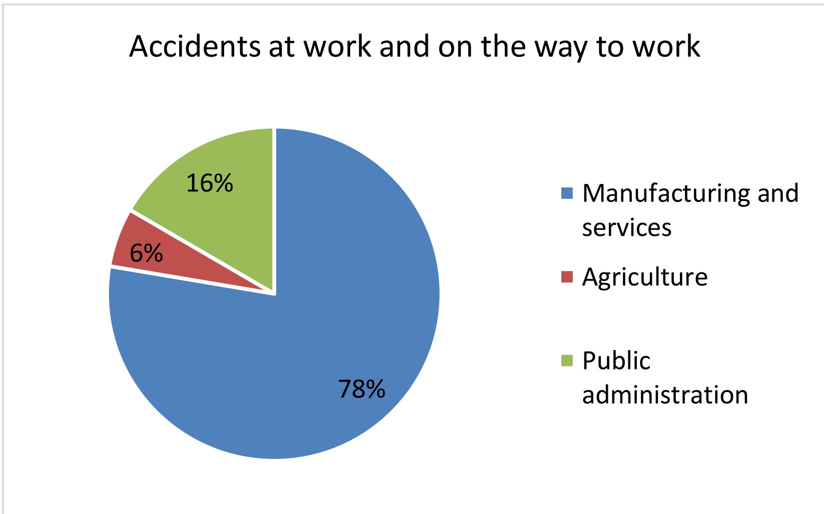
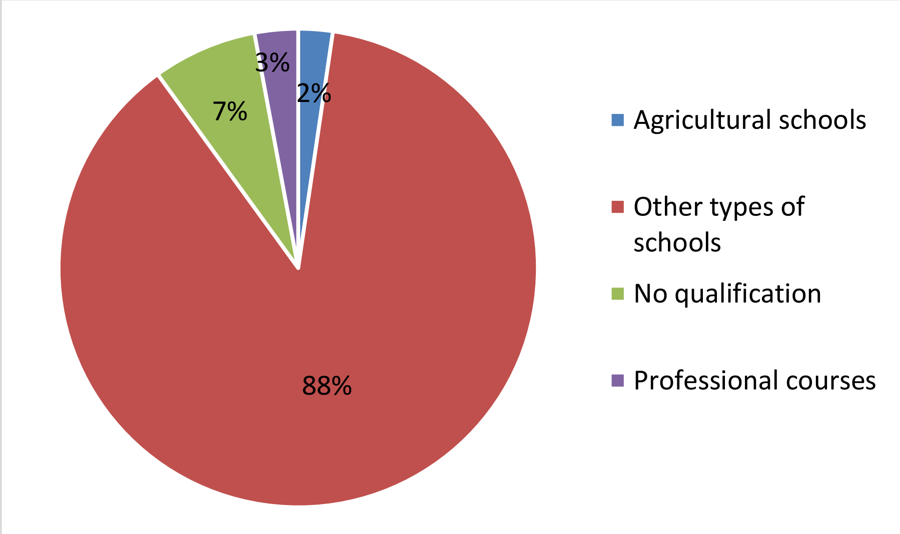


Fig. 18. Accident at work and on the way to work, Apulia region.

3.3.2 Education, health, and social security

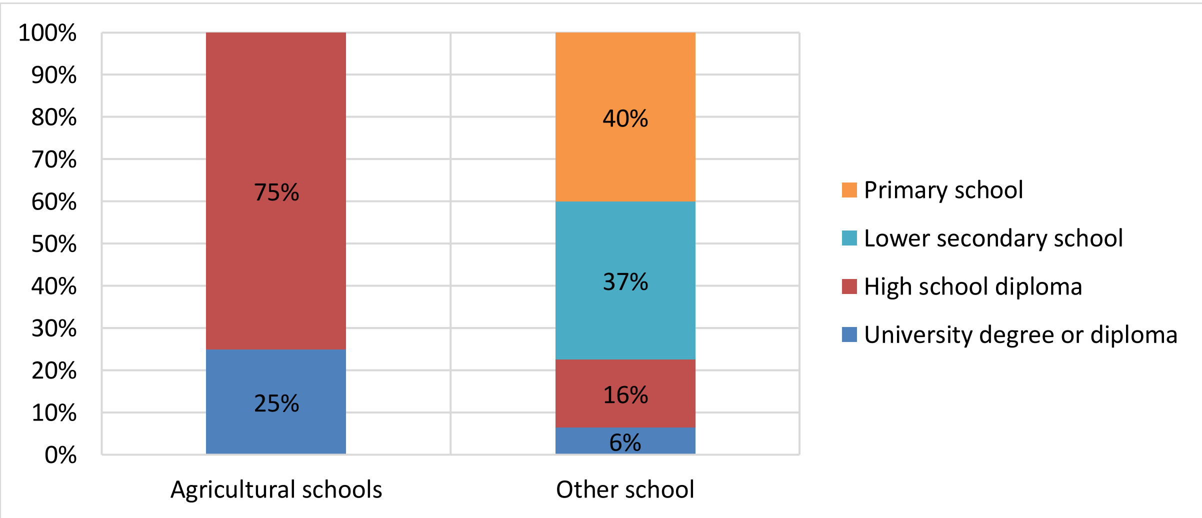
One of the factors of particular importance in terms of the effectiveness of farm activities is the education level of farmers and in particular the level of their agricultural education. The basic level of education predominates in all typologies (Fig. 19). About 7.1% of agricultural company managers lack any qualifications while 40% have achieved a maximum of elementary school.



Source: (Istat 2018)

Fig. 19. The level of education and professional training on farms in Puglia.

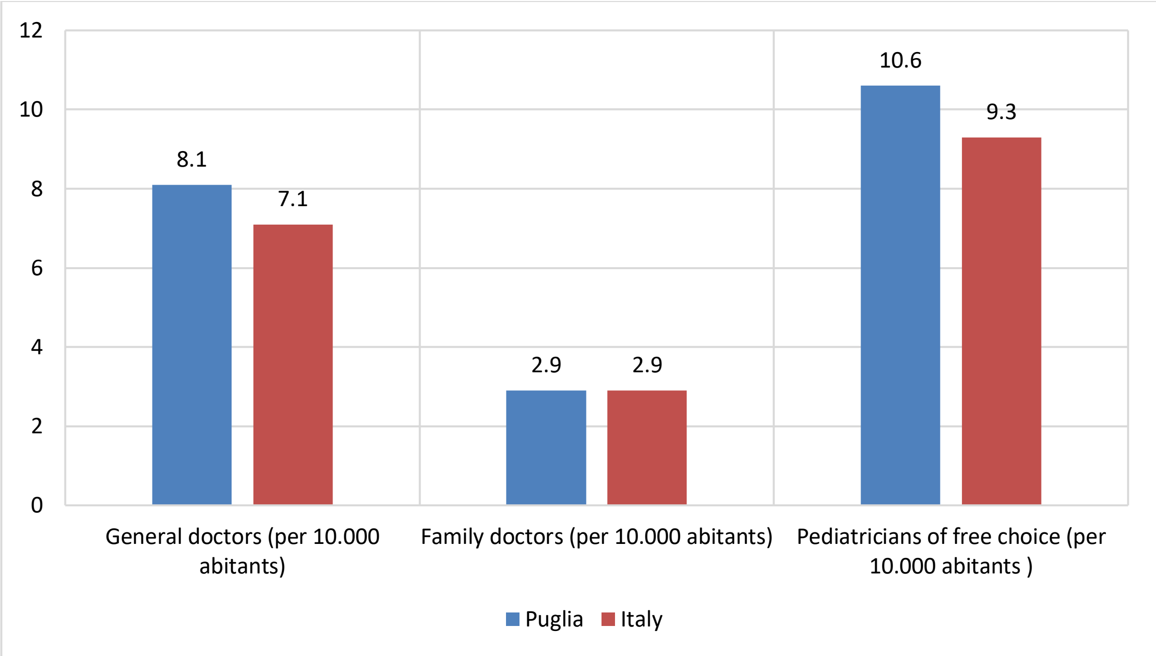
About 16% had a high school diploma or a higher degree (Fig. 20). The high proportion of farmers with basic education may reduce farmers' capacity to embrace new agricultural techniques to increase the productivity of labor and/or land.



Source: (Istat 2018)

Fig. 20. The level of educational qualification on farms per type of school in Puglia.

Regarding access to medical care, compared to the resident population in the region, the NHS employees are almost 85.4 for every 10,000 residents, a value of 14.3 points lower than the national average. As regards the provision of medical personnel assigned to primary care (Fig. 21), in 2018, Puglia has 8.1 general practitioners (against 7.1 in Italy) and 2.9 continuity welfare doctors every 10.000 residents in analogy with the value of Italy. To these are added 10.6 Pediatricians of free choice (PLS) for every 10 thousand inhabitants under the age of 15, a more significant structure than the national average (equal to 9.3 every 10 thousand residents).

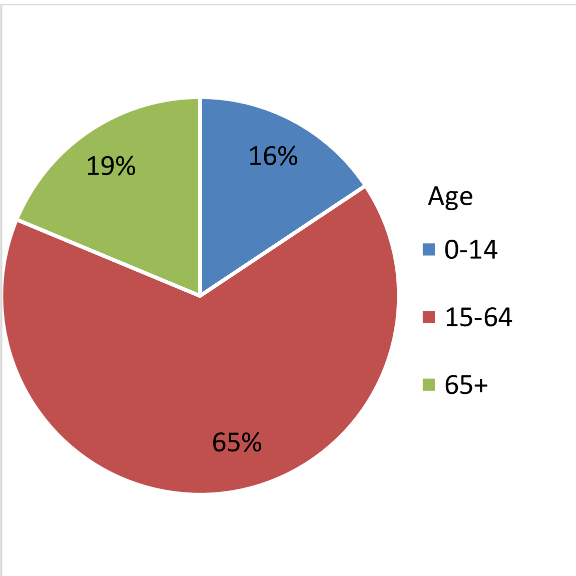


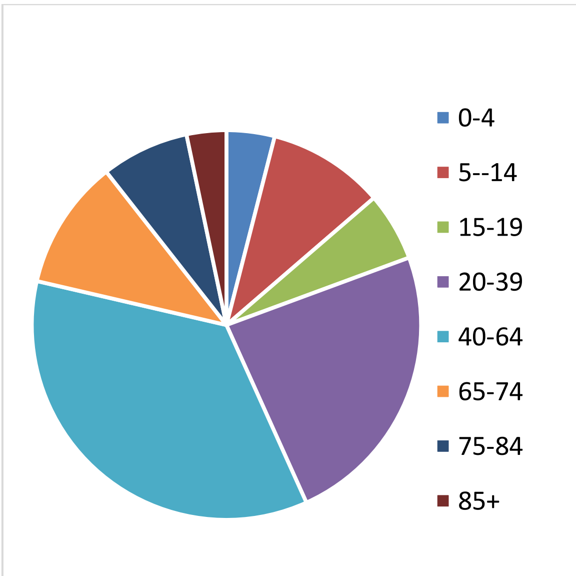
Source: (Regione Puglia 2013)

Fig. 21. Doctors per habitants in Puglia and Italy.

3.3.3 Population dynamics and social interactions

The population dynamics of 2011-2019 in the province of Foggia show a negative natural balance of 32,727 units (649.037 vs 616.310 persons). The social balance (migratory balances), although positive and supported by the arrival of foreigners, overall fails to neutralize the effect of natural balances. Residents are mostly displaced to other urban metropolises (87.3%) and smaller numbers emigrating abroad (12.6%). About 65% of residents are in the 15-64 age group, 16% are 0-14 years old and 19% are over 64 years of age (Fig. 22).

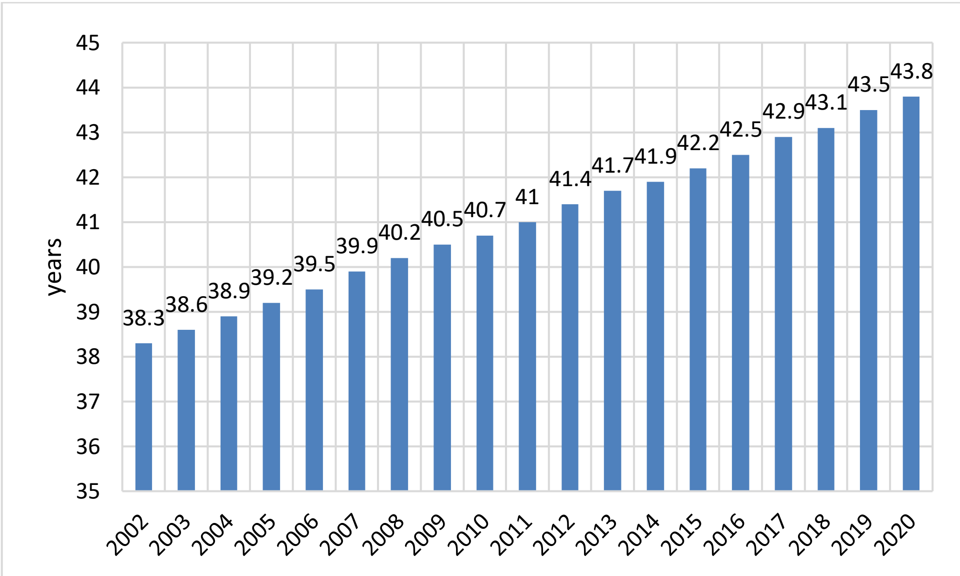




Source: [Tuttitalia]

Fig. 22. Age structure in the province of Foggia.

The average age of the resident population in 2019 is 43.5 years (Fig. 23). An increase of 11% compared with 2001 (38.3 years) is observed. Like other southern regions and especially less populous ones, Puglia enjoys a very strong sense of community with a desire to share the culture and traditions with visitors and the younger generation.



Source: Tuttitalia

Fig. 23. The trend of average age in the Province of Foggia.

3.4 Good governance

Governance is measured considering four main aspects: accountability, institutions for water management, capacity, and participation. The quality of WUA management is linked to the capacity and professionalism of the staff and the degree of commitment of the WUAs‟ members to their organization. Experience from other countries shows that WUAs need to have clear functioning rules which are based on their statutes and transfer agreement that are indispensable legal instruments for their management. Poor leadership may jeopardize WUAs‟ performance. The WUO CBC has clear functioning rules and governance. The manual of WUA organization and functions is available. All the tasks of different Consortium bodies have been defined and regulated by the by-laws of the Consortium. Without a clear legal status, the WUAs cannot operate properly because they do not know the extent of their responsibilities (Lamaddalena and Khadra, 2012). The structure of the association (Fig. 24) is composed of the General Assembly (GA), Administrative Council (ACL), and the Chairman of the Association and Audit Committee (AC). In the GA are included the members of the consortium who enjoy civil rights and are in compliance with the payment of the reclamation contributions indicated in regional law (art. 17, law 4 of 13.3.2012). The ACL is made up of 9 members: 7 directors elected by the Consortium Assembly, 1 director appointed by the President of the Province of Foggia, and 1 director elected by the assembly of mayors of the 39 municipalities falling within the consortium area. These governance bodies of the WUA such as GA and ACL meet at least once per year, but particular circumstances may require more. WUA's activities are audited internally by the auditor.

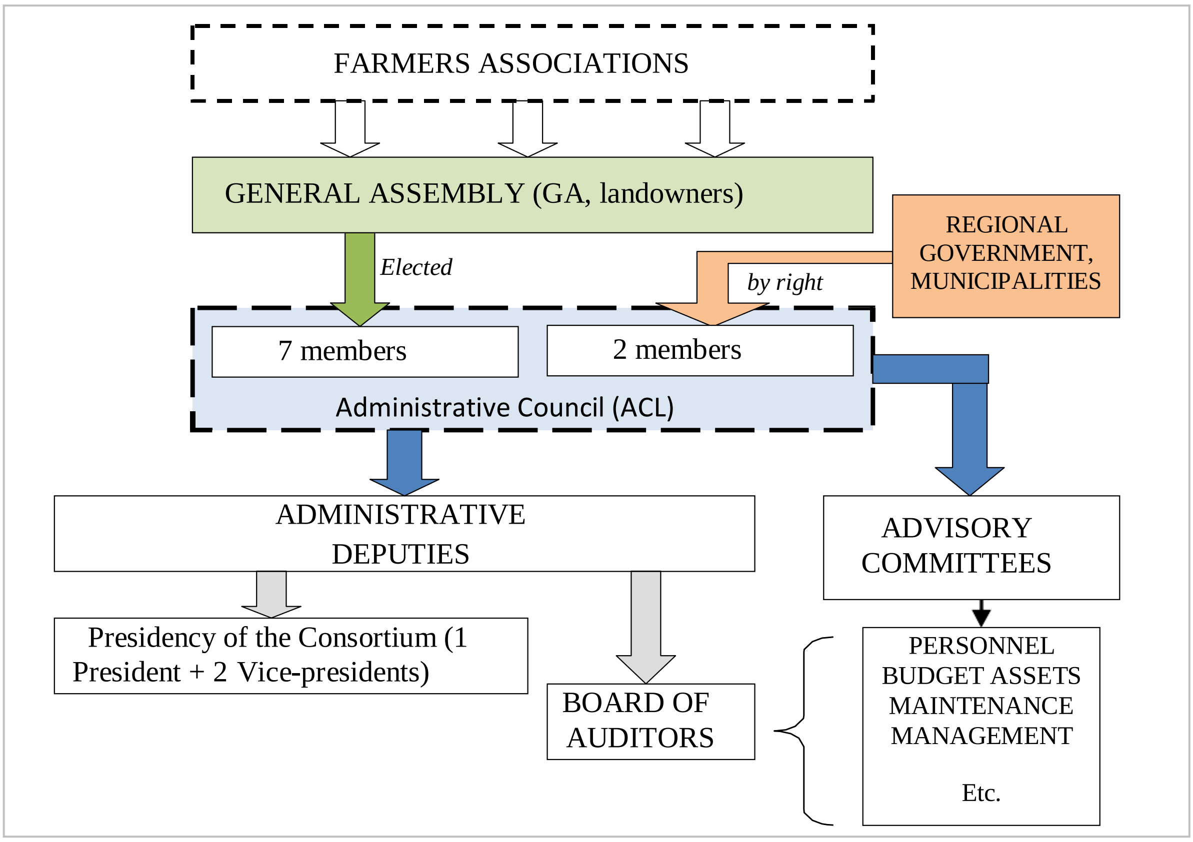


Fig. 24. Administrative organization of Consortium and flowchart of administrative staff.

WUAs are intended to meet two conditions considered important for improved irrigation performance. The first is the collection of fees to cover the costs while the second is increased farmer participation in decisions. The Consortium is administrated by the farmers who own the land within the Consortium. Irrigation Service Fees are collected by WUAs to finance their tasks. The farmers are called to operate the land, the resources, and the environment in a form of self-management. They are responsible for the preservation, conservation, and custody of the delivery units and all related accessories. They are required to cooperate to prevent or report any damage to public facilities, with the obligation to immediately notify the Consortium offices for appropriate interventions. The main activities carried out by CBC are maintenance of the surface hydraulic network and ordinary and extraordinary maintenance. Metering and control are carried out on-desk by the technical manager of each operating center and his/her assistant, assisted by three employees from the data-processing center. Overall, 90 employees are involved in the metering and control operations using 65 cars and 14 offices (Ursitti et al. 2018). Rules for water management are perceived as clear and fair. By law, the Consortia are private boards of public law and they are non-profit organizations. The associated members have to contribute only to the expenses borne for the management of the activities performed (see water pricing). Sources of income of the WUA are annual maintenance fees, the irrigation service fee; donations or grants; and other funding sources. The rate of fee collection reached and exceeded 90%. The suspension of water distribution is applied, without formalities, in the case when the user fails to pay consortium contributions. When events of an exceptional nature or causes of force majeure or needs for the functioning of the works irrigation or availability of water resources make it necessary, the Consortium can reduce or suspend temporarily the distribution of water or establish a shift program in the distribution itself, as well as establishing those measures that in any case, it deems most suitable for the purpose, without anyone have the right to indemnity or compensation for any reason.

For technical water governance capacity, the CBC uses web-based DSS for weather data, a new generation of flow-meters called ACQUACARD system for volumetric measurement, real-time and historical data on water availability, and is part of the national "IRRIFRAME" program for real-time irrigation scheduling service following the soil-plant-atmosphere water balance. The records of each user are checked against the theoretical irrigation requirement of each crop. If the comparison between the theoretical consumption and the consumption detected during the ordinary inspections produces a deviation greater than 5%, another inspection is carried out to discover the reason for the deviation (Ursitti et al. 2018). For water abstraction, the CBC negotiates with the "Consorzio di Bonifica Terre D'Apulia" where water allocations are agreed among the Ente Irrigazione (Irrigation Authority) under the overall supervision and approval by the River Basin Authority of the Apulia Region. Downstream of the farm delivery points of the distribution networks operated by the CBC, farmers have full control of the management and use of irrigation water in their fields (Fig. 25). All these water bodies are under the responsibility of the River Basin Authority for the aspects related to water use in quantitative terms, and of the Regional Agency for Environmental Protection (ARPA) for the aspects related to water quality and its monitoring.

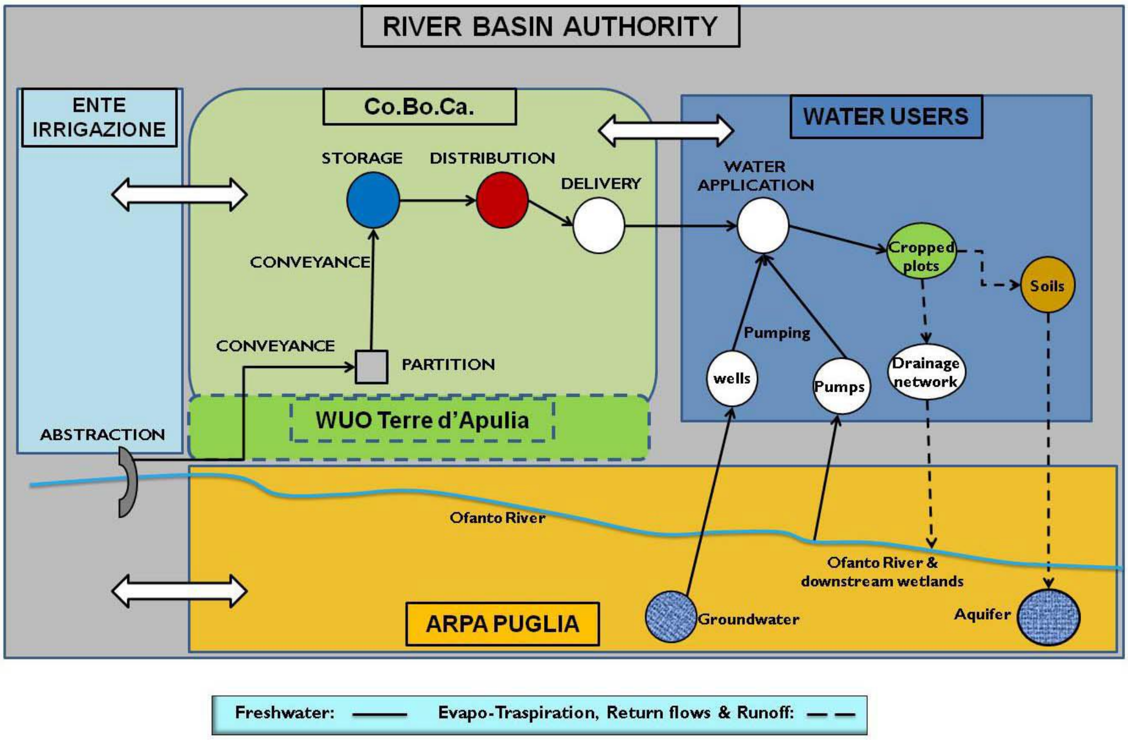


Fig. 25. Interactions among actors in the Sinistra Ofanto irrigation scheme.

4. Conclusions and summary of results

Farmers of Apulia and more generally, of the Mediterranean territories are undoubtedly living water scarcity and the negative impacts of climate change as a daily challenge. As a direct consequence, sustainable agricultural water management, and the potential, to increase agricultural productivity depends substantially on the achievement of an affordable and sustainable equilibrium between available water resources and irrigation demand. In large-scale irrigation schemes water user associations operates as a means of advancing farmer participation in irrigation management. Adopting an integrated indicator approach, this study comprehensively addressed the participatory system performance in Trinitapoli, one of the most intensive agricultural districts of the Apulia region, Southern Italy. The district and overall irrigation scheme is managed by the Reclamation and Irrigation Board of Capitanata (CBC).

The assessment considered environmental, economic, social, and governance dimensions. Table 8 synthesizes the main results obtained for the study area.

Table 8. Summary of results of sustainability assessment in the study area.

Study area	Environmental integrity	Economic resilience and profitability	Social well-being	Good governance
Irrigation district 17, Trinitapoli, Sinistra Ofanto, Southern Italy	Sustainable agricultural water management and farming are becoming increasingly complex because of the inequitable distribution of water and inefficient irrigation delivery. This problem may become even more serious due to the high vulnerability to climate change (abnormal rainfall patterns). Water scarcity and degradation of aquifers are the main environmental challenges. The study area is under stress due to sea (saline) water interference (study area near of sea) and aquifer refreshing, and over-exploitation. Farmers would have a reliable water supply upon completion of the wastewater reuse scheme but energy intensity will increase. Surface and treated wastewater quality is not a problem.	Agriculture is an important regional economic activity. Water and energy costs are not very relevant, since the irrigation system is gravitational. Volumetric Irrigation Water Pricing encourages saving water. Economically efficient groundwater management plans could improve economic performance.	Social well-being remains overall good. Access to medical care and social security is still good. Water scarcity might lead to the abandonment of agricultural activities, emigration, and a shrinking population. The qualification of agricultural workers might be improved.	Stakeholder participation in water management is well established in the area, although mainly through representative processes. They might be conflicts regarding water allocation, especially during the high-demand season. Institutions are committed to ensuring efficient water management and improving governance.

With great confidence, it could be confirmed that the overall performance of the WUA in the region is — satisfactory but improvements are needed. Poor performance is associated with one or more aspects of environmental integrity. Water availability (especially in peak periods) and high vulnerability to climate change are the main environmental integrity and sustainability challenges for the study area. Until now, on the supply side, the reclamation and reuse of wastewater have been a priority but have not yet been implemented due to an incomplete water distribution network. Wastewater must no longer be seen as a problem but as a solution to generate “new” freshwater” by preserving the balance of ecosystems and natural resources (without increasing local water scarcity) triggering net economic, environmental, and health-related benefits. On the demand side, it is important to develop and implement adaptation plans to ensure the resilience of irrigated agriculture areas under climate change scenarios. Future water savings can probably be realized more effectively through a change in the cropping pattern, rather than investing in new water-saving technologies. The vulnerability of basic resources (water, soil, landscape) is moderate. The impacts of future water scarcity will increase the risk of conflicts among water uses and users, poverty, economic losses, social disruption, and migrations. Progress in terms of water-related governance and strengthening of knowledge and capacity is hence required.

A "sustainability profile" was prepared (Fig. 26). This profile depicts the score on a 0–5 scale (0 - very poor to 5 - very good) that was attributed to each of the core issues of the framework, based on the values obtained for the different indicators. The interpretation of the results obtained should be performed with caution since many of the indicators reflect the author's perceptions regarding each issue. Moreover, the analysis is based on the opinions of authors; therefore some deviation may also occur in both validity and reliability.

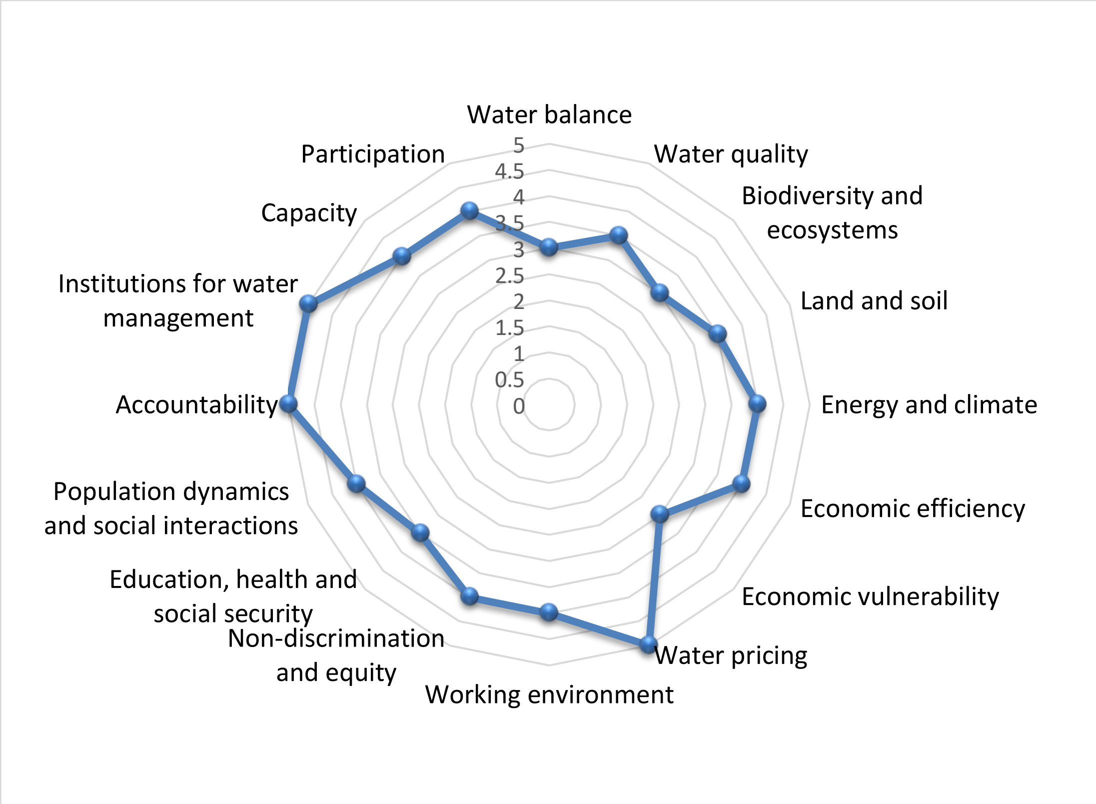


Fig. 26. Sustainability profiles for the study area (0 - very poor to 5 - very good).

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