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A risk assessment framework for irrigated agriculture under climate change: the case of Puglia Region (Italy)

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ABSTRACT

In several regions, but especially in semi-arid areas, raising frequency, duration and intensity of drought events, mainly driven by climate change dynamics, are expected to dramatically reduce the current stocks of freshwater resources, limiting crop development and yield especially where agriculture largely depends on irrigation. The achievement of an affordable and sustainable equilibrium between available water resources and irrigation demand is essentially related to the planning and implementation of evidence-based adaptation strategies and actions. The present study proposed a state-of-the art conceptual framework and computational methodology to assess the potential water scarcity risk, due to changes in climate trends and variability, on irrigated croplands. The model has been tested over the irrigated agriculture of Puglia Region, a semi-arid territory with the largest agricultural production in Southern Italy. The methodology, based on the Regional Risk Assessment (RRA) approach, has been applied within a scenario-based hazard framework. Regional climate projections, under alternative greenhouse gas concentration scenarios (RCP4.5 and RCP8.5) and for two different timeframes, 2021-2050 and 2041-2070 compared to the baseline 1976-2005 period, have been used to drive hydrological simulations of river inflow to the most important reservoirs serving irrigation purposes in Puglia. The novelty of the proposed RRA-based approach does not simply rely on the concept of risk as combination of hazard, exposure and vulnerability, but rather elaborates detailed (scientific and conceptual) framing and computational description of these factors, by means of the proposed equations and classification schemes, to produce risk spatial pattern maps and related statistics distinguishing the most critical areas (risk hot spots). The implemented assessment singled out future perspectives of water scarcity risk levels for irrigated agriculture by the administrative extent where individual bodies are in charge of the coordination of public and private irrigation activities (i.e. Reclamation Consortia), identifying the most affected areas (i.e. Capitanata Reclamation Consortia under RCP8.5 2041-2070 scenario); the most affected crops (fruit trees and vineyards); and, finally, the vulnerability pattern of irrigation systems and networks. According to these results, tailored and knowledge-based adaptation strategies and related actions can be developed, to reduce the risk at both agronomic level (i.e. preferring crops with low vulnerability score, as olive groves) and at structural level (i.e. differentiating the water stocks and supplies and reducing losses and inefficiencies).

Keywords: water scarcity, climate change, water resources, irrigated agriculture, reclamation consortium, Puglia

1. INTRODUCTION

Over the past 60 years increasing water demand, population growth, urban expansion, and intensive agricultural practices in many areas have exacerbated the impact of water scarcity and droughts for irrigation purposes (Qadir & Oster, 2004; Dai, 2010; Mishra, 2011; Sheffield, 2012; Flörke et al., 2013; Wada and Bierkens, 2014). Although, approximately, only 17-25% of the world's croplands are irrigated, they produce between one third and one half of the food and fiber harvested throughout the globe (Hillel, 2000; IWMI, 2007; Portmann et al., 2010) and are expected to spread in the future to meet food security (Fuss et al., 2015; Mancosu et al., 2015; Wada et al., 2013a; Wada and Bierkens, 2014).Generally, the progressive increase of irrigation practices causes concern for the long-term sustainability of water resources at multiple scales, with social, environmental and economic implications for the population, and threats for the regular availability of water for other uses, like domestic, industrial and energy (Lionello et al., 2008a; Iglesias et al., 2007; Mancosu et al., 2015; Wada et al., 2013b).Moreover, the increase in frequency, duration and magnitude of droughts with regard to long-term imbalances of water demand and water availability is indisputably due to changes in climatic regimes (McNab &Karl, 1991;EU, 2005; Dai, 2013; Vicente-Serrano et al., 2014) with different spatial and geographical patterns(IPCC, 2013; 2014a; 2014b). Although the Europe is somehow considered as having adequate water resources; long term imbalances where water demand exceed available water stocks are no longer uncommon (Gosling and Arnell, 2013; Van Lanen, 2013). In the last 20 years Europe experienced more than 80% of its driest winters since the last Century (Hoerling et al., 2012), and between 1976 and 2006 the number of areas and people affected by droughts went up by almost 20%, with damages estimated to more than 100 billion Euro, peaking up to 8.7 billion Euro only due to the 2003 drought (Mishra and Singh, 2010). Currently, few river basins can be considered under water stress all year round; although during summer months' water scarcity is markedly pronounced in Southern Europe (Alkama et al., 2013), it is becoming important also in Northern basins (European Commission, 2012;Forzieri et al.,2014; Papadimitriou et al., 2015). The European Commission and the Intergovernmental Panel on Climate Change (IPCC) agree on expecting further deterioration of the water situation in Europe if temperatures keep rising as a result of climate change, where projected (spatial and temporal) trends of drought events (IPCC, 2013; Schneider et al., 2013; Spinoni et al., 2015; Vicente-Serrano et al., 2014) are likely to have significant impacts on both agriculture and other water-dependent sectors over the next few decades (IPCC, 2014b). Such a situation can be further enhanced by socio-economic factors (need of larger crop production and technology development) (Schaldach et al., 2012),while by 2030 half of the European river basins are expected to be affected by water scarcity (European Commission, 2012a).

In the drought-affected regions of Mediterranean basin (i.e. Spain, Malta, Italy, Greece, Turkey), several studies show that the impacts of climate change on water yields are already happening (García-Ruiz et al., 2011; López-Moreno et al., 2010; Ludwig et al., 2011; Estrela and Vargas, 2012; Sen et al., 2012; Koutroulis et al., 2013; Preziosi et al., 2013). For example, in the Iberian Peninsula, the demand for water in different watersheds ranges between 55% and 224% of the corresponding water supply and, at the sub-basin scale, the supply is very often negatively correlated to the water demand (Sabater et al., 2009, Boithias et al., 2014). In Puglia Region, hot and dry climate with increasing variability of the rainfall patterns and intensity (heavy rains during the fall/winter period and severe droughts in summer) pose serious problem sto the (competitive) use of water resources (Lionello et al., 2014; Vanino et al., 2015). In fact, the limitation of the available water stocks for the competitive scenario of users from different sectors (industrial, energy, domestic, agricultural) could trigger severe limitation on productivity (Giglio et al., 2010; Lionello et al., 2014) but also worsen water quality (WHO, 2011).

Currently, many studies have proposed different models that mostly quantify the hazard of water scarcity and drought phenomena caused by climate change (i.e. Barthel et al., 2008; Flörke et al., 2011; García-Ruiz et al., 2011; Falloon & Betts, 2009; Ferrise et al., 2013; Giglio et al., 2010). Despite these efforts, we still remark a need towards more integrated studies where the hazard is combined with exposure patterns and vulnerability assessment to provide a complete risk evaluation, at both quantitative and spatial level on a regional scale, in order to support stakeholders in developing adaptation and mitigation (best) practices to limit losses and damages.

To fulfill the need of such a comprehensive analysis, the Regional Risk Assessment (RRA) paradigm developed by Landis (2005) is useful, as able to provide a quantitative and systematic way to estimate and compare the impacts of environmental problems that affect large geographic areas (Hunsaker et al., 1990), by considering the presence of multiple habitats, and taking into account multiple stressors impacting multiple endpoints (Landis, 2005). The RRA has been successfully tested in a variety of cases across the world, including marine coastal areas, fjords and hydrographic basins' habitats (Landis and Wiegers, 1997). Recently, RRA has been extensively applied to aid complex decision-making processes related to environmental management and climate change adaptation (Pasini et al., 2012; Ronco et al., 2015).This approach supports the identification and ranking of hotspots and targets at risk over wide areas, in order to drive the development of appropriate strategies and actions for mitigation, prevention and adaptation purposes.

With the long-term perspective of supporting the development of regional adaptation measures to mitigate the impacts of a drying climate in already semi-dry areas, the present study proposes a tailored RRA application in Puglia Region in Southern Italy. The case study has been selected in the framework of the ORIENTGATE project (http://www.orientgateproject.org), in order to: assess the risk due to water scarcity induced by climate change on the local irrigation compartment and evaluate if (and what) adaptation strategies (and practices) can be useful to address or minimize the likely reduced water availability and agricultural productivity.

After a description of the case study area (Section 2.1) and of the underlying risk conceptual framework (Section 2.2), the paper introduces the core of the study that stands with the conceptual and computational algorithms and indicators to characterize the risk pattern and its application to the case study area (Section 3), producing maps and synthesis information (statistics, graphs etc.) with the potential of guiding the definition of adaptation strategies (Section 4).

2. BACKGROUND

2.1.1. CASE STUDY AREA: ISSUES AND CONSTRAINTS

The Puglia region, located in the southeast of Italy (between 41°53’N - 39°48’N and 14°49’E - 18°35’E) comprises an area of 19,345 km^2 and has a population of about 4 million people (density of 210 inhabitants/km^2) (ISTAT, 2014).The climate of Puglia Region is purely Mediterranean, with mild wet winters and hot dry summers (the coldest month is January and the warmest is July). Summer season presents semi-desert features where rains may be missing for more than two or three consecutive months. During winter time, rains are limited by the barrier effect of the Southern Apennines with respect to the Atlantic depressions; here rainfalls are shaped by the Mediterranean rising perturbation raids or by the cold air from the north or north-east.

On average, the Region accounts to only 500 mm of rain spread within 60 to 80 days per year (Autorità di Bacino della Puglia, 2004). Snow is rare except in the central Gargano and in some small spots in the Dauno Apennine. For the period 1951-2000, total annual precipitation across Puglia has significantly decreased at a rate of 23.9 mm/decade, which would lead to a one-third reduction of the mean value if this trend would continue for one century. In general, long term observations from meteorological stations in Puglia show trends towards warmer and marginally drier conditions during the second half of the 20th Century (Lionello et al., 2014). Combined trends of increasing evapotranspiration and decreasing precipitation implied a progressively larger water deficit (Hemming et al., 2013). Climate model projections suggest warmer and drier conditions also over the next few decades (Goodess et al. 2013; Santini et al., 2014): a further increase in the water deficit would not be sustainable and would have large negative impacts on the human and agricultural sectors, and on the environment (CMCC et al., 2015).Recently Puglia Region has been alternatively affected by extreme events related to out-of-normal climatic years, i.e. droughts in 2011-2012, floods in 2013-2014 and fast fluctuations of droughts/floods in 2008-2009 (WHO, 2011).

The Regional Water Protection Master Plan (Regione Puglia, 2009) contains an exhaustive description of the geological, topographic and hydrological settings of the region, which is mostly flat and hilly, with limited mountainous areas (Gargano massif and Dauno Apennine). Due to high permeability of the karstic substrate that favors infiltration of rainwater, there are few surface rivers concentrated in the northern area: Candelaro, Cervaro, Carapelle, Ofanto, while Fortore and Bradano river basins occupy the northern and western boundaries across the Molise and Basilicata regions, respectively. Given the scarcity of superficial water courses, in the past Puglia's aquifers were valuable for quality and quantity and held extremely important for agriculture (Giordano et al., 2013). These resources were increasingly exploited since the early decades of the last century. To date, despite scientific, technical and cultural progresses, management and governance policies have not prevented a gradual degradation of these limited resources (Polemio, 2009a, 2009b).

2.1.2 Agronomic pattern andnetworks of infrastructures for irrigation

Agriculture in Puglia covers a relevant share of Italian agricultural area (~10%), used to be the main occupation in Puglia and currently still implies a very large national portion of farming holdings (18%), mostly characterized by many farms with small agricultural area and thus structurally less disposed to investment for adaptation (ISTAT, 2014).

The land use composition (EEA, 2007; Büttner and Kosztra, 2006) coupled with regional and national statistical datasets, demonstrates that currently, almost 80% of Puglia region is used for agricultural purposes (about 14.700 km^2), while only 10% of the territory is covered by wild vegetation (Aretano et al., 2006).

Despite the larger (agricultural) land's devoted to arable crops (mainly cereals with 43% of the cultivable land), the most important (cash) crops from the economical point of view are olives (32%), vineyards (9%), citrus (3%) and vegetables (2%) productions (ARPA Puglia, 2015; Lionello et al., 2014).

The network of irrigation infrastructures in Puglia reaches a large share of cultivated land (64.4% of the total area, corresponding to almost 244,270 hectares) with an average volume of water supply of 2,792.54 m^3/ha/year. Puglia accounts for9.8% of the total irrigated area of Italy and the 34.6% of southern Italy (ISTAT, 2014). Irrigation requirements vary greatly from crop to crop, and they depends on occurring climatic patterns (as a sake of simplification, seasonal irrigation volumes used by Capitanata Reclamation Consortia have been used for the entire Region: vineyards 1.800/3.000 m^3/ha; olive groves2.000/3.000 m^3/ha; fruit trees (peach) 3.000 m^3/ha and vegetables (tomato 4.000/5.000 m^3/ha and artichoke 2.500/4.000 m^3 /ha) (www.consorzio.fg.it, 2015).

The hydro-morphological features of Puglia Region, which impede the stock of large volume of surface waters, has required the development of large interregional water schemes (system of hydraulic infrastructures like dams/reservoirs and aqueducts), also collecting water flowing from surrounding regions (Basilicata, Campania, Calabria and Molise), in order to meet Puglia water demands(Lopez and Vurro, 2008). The most important (multi-purpose) water schemes are: Fortore (Puglia and Molise), Ofanto

(Campania, Basilicata and Puglia), Jonico-Sinni (Basilicata, Puglia and Calabria) and Bradano (Puglia and Basilicata) (EIPLI, 2014).

Within the case study, we consider three main Reclamation Consortia that manage the distribution of water for (private and public) irrigation purposes: *“Consorzio per la Bonifica della Capitanata”*, *“Consorzio di Bonifica Terre d’Apulia”* and *“Consorzio di Bonifica Stornara e Tara”* (Figure 1). These Consortia have been selected because they are supplied by reservoirsor plants for which projections of changes in water inflow have been made available within the ORIENTGATE project. These reservoirsare: Occhito dam (137 Mm^3) on Fortore scheme; Santa Venere traverse (82.1 Mm^3) and Locone dam (7.7 Mm^3) on Ofanto scheme; San Giuliano dam (30 Mm^3) on Bradano scheme; and, finally, Monte Cotugno dam (300 Mm^3) on Jonico-Sinni scheme.

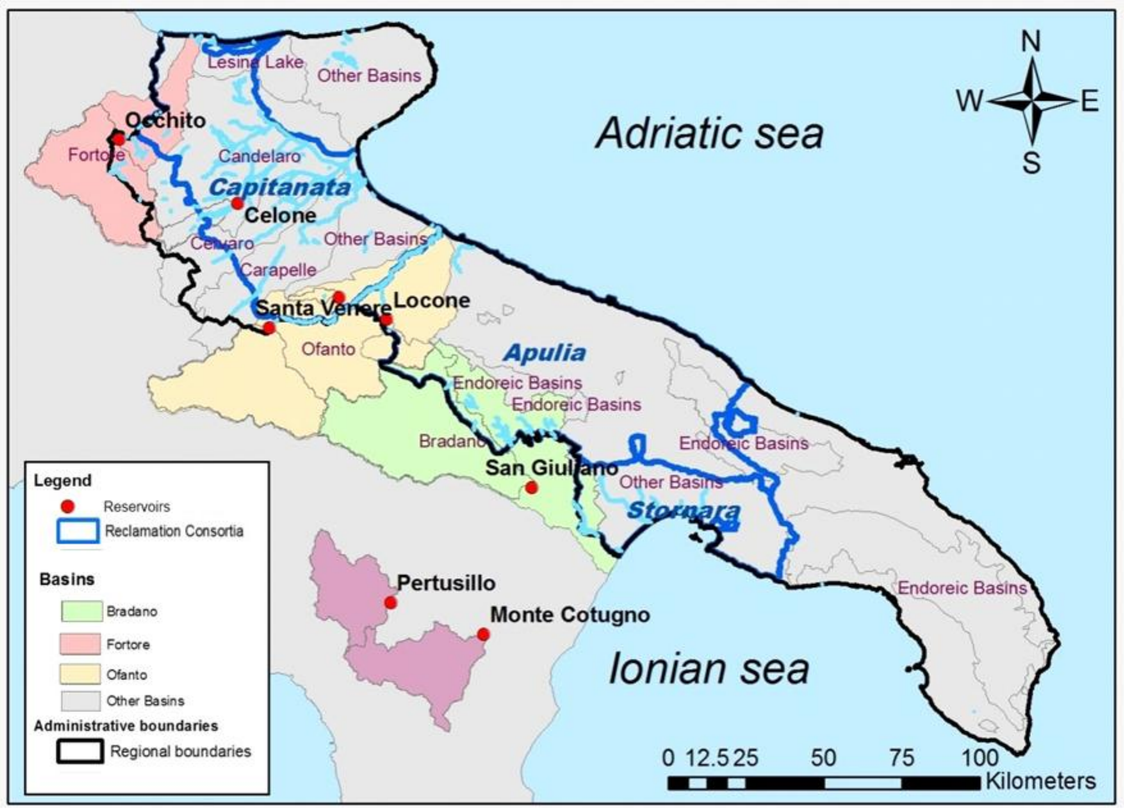


Figure 1 Case study basins, water schemes, reservoirs (also not included into the analysis) and Reclamation Consortia.

2.2 CONCEPTUAL FRAMEWORK FOR RISK ANALYSIS

The overall ORIENTGATE methodology for climate risk assessment and adaptation (CMCC, 2015) has been designed by means of an integrated approach through different components. Data, models, downscaling procedures, spatial analysis techniques, decision support tools and indicators, have been merged into a single theoretical framework that includes hazard assessment (at process level: climate and hydrology) to vulnerability and risk assessment (at resource/sector level: water, agriculture). Analyses are based on the use of indicators, aimed at synthesizing complex scientific information into quantities easily understandable and communicable to stakeholders and policy makers (Martinez et al., 2012). To effectively promote the integration of knowledge into decision making processes, indicators have been grouped into hazard, exposure, vulnerability and risk categories, as per the last IPCC (2014) (Annex I).

The overall integrated approach that characterizes the scientific track of the project was articulated into three modules, as schematized in Figure 2: i) the **climate modeling** simulated the atmospheric dynamics for the Puglia Region within selected future time frames 2021-2050and 2041-2070, using the 1976-2005 scenario as baseline (Module 1: Climate projections); ii) these projections have been used as input for assessing **water scarcity/drought hazards** (hydrological component) (Module 2: Drought scenarios); iii) finally, hazard scenario have been combined with exposure and vulnerability patterns of the selected irrigated crop systems to quantify the consequent **impacts** and **risks** on agriculture (Module 3: Water resources and agriculture risk assessment).

Two IPCC standardized scenarios based on different future greenhouse gas (GHG) concentration trends have been selected for the characterization of the climate regime and of consequent **hydrological hazards and risks** in irrigated agriculture. The RCP4.5 is a stabilization scenario where total radiative forcing is stabilized shortly after 2100 to 4.5 W m−2 (approximately 650 ppm CO2-equivalent) by employing technologies and strategies to reduce GHG emissions. The RCP8.5 is a business as usual scenario and is characterized by increasing GHG emissions and high GHG concentration levels, and represents a rising radiating forcing pathway leading to 8.5 W m−2 in 2100 (approximately 1370 ppm CO2-equivalent).

In Module 1, Regional Climate Model (RCM) simulations with COSMO-CLM (Rockel and Geyer, 2008) were first conducted at project level for the western part of South East Europe domain (Italy and surrounding), to dynamically downscale (at 0.0715°, ca. 8 km horizontal resolution) the atmospheric component of General Circulation Model projections performed with CMCC-CM (Scoccimarro et al., 2011) at 0.75° horizontal resolution in the context of CMIP5 experiment (http://cmip-pcmdi.llnl.gov/cmip5/). Further, statistical downscaling was performed at site level for 31 and 21 meteorological stations measuring precipitation and temperature, respectively, to support basin scale hydrological analyses in Module 2.

Indeed, based on the different scenarios of the expected rainfall pattern under climate change, modifications in annual river inflow to the most important (with irrigation purposes) reservoirs in Puglia have been simulated by means of the ArcSWAT model.

The ArcSWAT model is a GIS implementation of the Soil & Water Assessment Tool (SWAT; http://swat.tamu.edu/software/arcswat/), a semi-distributed hydrological model to simulate the water cycle in large, complex watersheds. The model includes different components of the water balance according to the application needs: weather, surface runoff, return flow, percolation, evapotranspiration, transmission losses, pond and reservoir storage, crop growth and irrigation, groundwater flow, reach routing, nutrient and pesticide loading, and water transfer (SWAT Literature Database, 2012;https://www.card.iastate.edu/swat_articles/).For the purposes of the present analysis, the model was calibrated and validated in the long term annual and intra-annual inflow reconstruction building on literature information (De Girolamo et al., 2014) and using discharge data available in the Hydrological Annals for the rivers of interest.

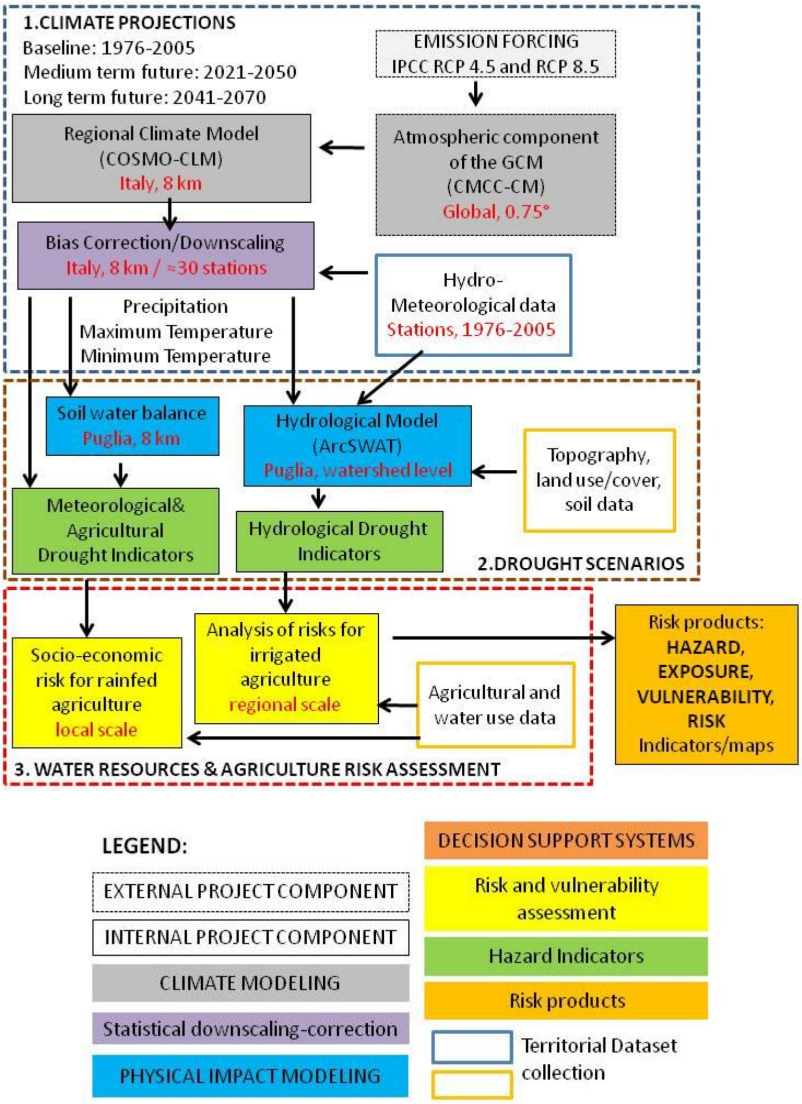


Figure 2: Conceptual framework applied for the integrated assessment of climate change impacts, vulnerability and risks in the ORIENTGATE project (adapted from CMCC, 2015).

Based on IPCC risk's general concepts (Annex I), a comprehensive, multidisciplinary and integrated risk assessment procedure has been developed based on the Regional Risk Assessment (RRA) paradigm developed by Landis (2005), to anticipate climate change effects on water scarcity and to effectively provide early warning to reduce the impact on production for irrigated agriculture. The outputs of the RRA methodology are GIS-based risk maps identifying and ranking areas and hotspots at risk within the studied region. These outcomes result useful to communicate the potential implications of water scarcity and stress to stakeholders and decision makers and can be a basis for the management of related risks. Moreover, statistics can be extrapolated from risk maps and can be used to mainstream adaptation in the development of territorial plans, policies and programs towards the potential threats posed by climate change.

3. METHODOLOGY

There is a vast literature about the different approaches and theories that shape the concept of risk. Several authors proposed different methodologies, theoretical frameworks and specific algorithms to estimate the risk for a wide range of contexts. Here, as stated above, the characterization of the risk pattern is based on the evaluation of its three main components: hazard, exposure and vulnerability (IPCC, 2014). Moreover, it is worth to notice that the risk of water scarcity (long term water scarcity or drought episodes) for the irrigated agriculture compartment is unequivocally related to the (not-linear) trade-off between the availability and the demand of water resources for irrigation purposes. The first aspect is essentially driven by the climatic regime and, therefore, its future variability is projected upon by the coupled climate-hydrological simulations, while the second aspect depends on the users' needs, its hydro-demand and, finally, by the overall management of water resources. In particular, hazard, exposure and vulnerability (spatial) assessments are shaped through the characterization of the complex feedbacks between these two drivers (availability-demand) and embedded by the different management modes.

In the following paragraphs, the specific algorithms to compute the hazards, exposure, vulnerability and risk patterns are analyzed in detail.

3.1 HAZARD

The first step of the RRA methodology is the hazard assessment that is aimed at identifying, quantifying and indexing physical impacts on water scarcity, according to the climate projections under RCP4.5 and RCP8.5 scenarios and for the 2021-2050 and 2041-2070 periods compared to the baseline 1976-2005.

Water scarcity occurs where and when water resources are not enough to meet all the demands and this affects both provisioning to humans and the ecosystem functions.

Reclamation Consortia are the (only) Institutions in charge of the overall management and distribution of private and public irrigation in Puglia (Regione Puglia, 2009). They are supplied by multiple reservoirs through a complex pattern of water distribution systems (Annex II). With this complex network, each reservoir supplies multiple Consortia with different volumes of water according to their (Consortia) specific demand and its (reservoir) availability. In this sense, the hazard score has been calculated as the degree of fulfillment of the Consortia's annual demand (volume of water per year), compared with the (projected) water availability from the different reservoirs (Annex III).

In fact, while current water demands are assumed to be constant over the time, water inflow to the selected reservoirs are simulated through the hydrological modeling for the different (future) climatic conditions. Lower is the degree of fulfillment, expressed as the ratio between the projected water availability and its theoretical (current) water demand for that particular Consortium, higher is the hazard score.

The downstream water demands for irrigation purposes have been estimated from the Regional Water Protection Master Plan (Regione Puglia, 2009) where a detailed spatial database of regional water resources is implemented. The spatial coverage of the Reclamation Consortia has been characterized with available maps (Ministero delle Infrastrutture e dei Trasporti databases, 2003; ISTAT Census 2010) for framing the area.

Hazard is computed in two subsequent phases: (i) at reservoir (<u>res</u>) and (ii) at consortium (<u>con</u>) level.

i) <u>At reservoir level</u>, the future water availability for irrigation purposes, in terms of Mm^3/year, is calculated according to the variation in streamflow simulated with ArcSWAT between different future emission scenarios and timeframes, and the Baseline Scenario (BS) for 1976-2005 (Eq.1).

$$\boldsymbol{futureavailability, res_{(s)}}\left[\boldsymbol{Mm^3}/year\right] = \boldsymbol{availability, res(BS)}\left(\mathbf{1} + \frac{\%\,\boldsymbol{ofvariation, res}}{\mathbf{100}}\right) \tag{1}$$

Where:

- *future availability, res$_{(s)}$* [Mm^3/year] is the water availability of the reservoir (res) in future scenario (s);
- *availability, res (BS)*[Mm^3/year] is the current water stocks of the reservoir (res);
- *% of variation, res* is the annual streamflow percent variation for the reservoir (res), simulated by ArcSWAT (Annex III).

Furthermore, for each scenario, the degree of fulfillment of water demand (Eq. 2) is computed by dividing the volume of water available for irrigation with the reference water demand for that particular reservoir, which is the sum of the withdrawal from the various Consortia for the BS (1976-2005).

$$\boldsymbol{degreeoffulfillment, res_{(s)}}[\%] = \frac{\boldsymbol{futureavailability, res_{(s)}}}{\boldsymbol{waterdemand, totcon}\ (\boldsymbol{BS})} \times 100 \tag{2}$$

Where:

- *degree of fulfillment,* $res_{(s)}$[%]is the balance between supply and demand (S:D percent ratio) in the reservoir (res);
- *water demand, tot con (BS)*[Mm^3] is the sum of Consortia's (tot con) demands (from Annex II).

II) At Reclamation Consortia level, the availability of water for the various scenarios (Eq. 3) is computed according to the degree of fulfillment of the different reservoirs (see Eq. 2) multiplied by the specific Consortium(con) water demand, assumed unchanged with respect to the BS (1976-2005):

$$\boldsymbol{totwateravailable, con_{(s)}}\left[\boldsymbol{Mm^3}/year\right] = \\ = \sum_{\boldsymbol{reservoirs}} \boldsymbol{degreeoffulfillment, res_{(s)}}[\%] * \boldsymbol{waterdemand, con}\ (\boldsymbol{BS}) \tag{3}$$

Where:

- *tot water available,* $con_{(s)}$ [Mm^3/year] is the water quantity that will be available for the Consortium (con), in future scenarios (s).
- *water demand, con (BS)*[Mm^3/year] is the Consortium's (con) demand (from Annex II).

The degree of fulfillment for each Consortium (con) is then calculated as the ratio between the water availability for each scenario and its reference water demand, which correspond to the BS (1976-2005) (Eq. 4).

$$\boldsymbol{degreeoffulfillment, con_{(s)}}\ [\%] = \frac{\boldsymbol{totwateravailable, con_{(s)}}}{\boldsymbol{totwaterdemand, con}\ (\boldsymbol{BS})} \times 100 \tag{4}$$

Where:

- *degree of fulfillment,* $con_{(s)}$ [%] is the percentage of water that a Reclamation Consortium (con) could fulfill in the future scenario (s),as ratio of the supplying reservoirs over the Reclamation Consortium demand;
- *tot water demand, con (BS)*[Mm^3/year] is the Consortium's (con) demand in the BS considering all the supplying reservoirs.

Finally, the hazard score is calculated as in Eq. 5, with 0 representing no hazard and 1 the maximum hazard. Final scores are classified (equal interval) into a numerical scale between 0 and 1 and later used, together with the vulnerability scores, to compute the (relative) risk index.

$$\boldsymbol{Hazard, con_{(s)} = 100 - degreeoffulfillment, con_{(s)}}\ [\%] \tag{5}$$

3.2 EXPOSURE

The second step of the RRA methodology is the exposure assessment, which identifies, selects and classifies receptors that could be adversely affected (cultivated irrigated fields with losses of valuable crops)by long term water scarcity or drought events because of their spatial and physical characterization.

Within this step, the exposure score equal to 1 is assigned to cells where the receptors are located (i.e. irrigated lands) and equal to 0 in case of absence of the receptor (i.e. not irrigated lands). Spatial characterization of valuable irrigated crops is based on the ISTAT sixth agricultural census (ISTAT, 2014) and on the European CORINE Land Cover IV level dataset (EEA, 2007; Büttner and Kosztra, 2006). The latter is operationally available for most areas of Europe (Büttner and Kosztra, 2006). In Italy, the database is implemented by ISPRA (Istituto Superiore per la Protezione e la Ricerca Ambientale) (puglia.con, 2014). According to the available datasets, the exposure assessment has been based on spatial resolution (i.e. grid cells) of 25 m.

3.3 VULNERABILITY

As far as the vulnerability assessment is concerned, relative scores are calculated as function of three different factors that contribute to characterize the (intrinsic) “propensity or predisposition” of irrigation systems to be adversely affected by water scarcity, according to Eq. 6.

$$\boldsymbol{Vulnerability_{(crop,cons)} = V1_{(crop)} * V2_{(con)} * V3_{(con)}} \tag{6}$$

Where:

- V_1 is vulnerability related to reference water demand rates, for different crops;
- V_2 is vulnerability related to Degree of efficiency - system losses, at the consortium (con) level;
- V_3 is vulnerability related to Degree of diversification of water sources, at the consortium (con) level.

These three (vulnerability) factors have been chosen in compliance with the state of art (Renault et al., 2013; IPCC, 2014; FAO, 2015).Factors “Efficiency of the distribution networks” and “Diversification of water sources”, jointly with data on irrigation useful for the hazard assessment, were provided by each Reclamation Consortia: “Consorzio per la Bonifica della Capitanata” (www.consorzio.fg.it), “Consorzio di Bonifica Stornara e Tara” (www.bonificastornaratara.it) and “Consorzio di Bonifica Terre d’Apulia” (www.terreapulia.it). Finally, for the vulnerability correlated with crops (V_1), CORINE Land Cover IV level dataset was used to define the spatial distribution of main relevant crops for exposure assessment.

The factors, explained in detail in the following paragraphs, are classified, ranked and then normalized in the range 0-1, in order to aggregate all the vulnerability factors in the total vulnerability index with a common numerical scale (i.e. normalized between 0 and 1) (Zabeo et al., 2011).

V_1. Hydro-demand presents crops.

The vulnerability factor V_1 captures the likelihood that crops located in a considered area could potentially be harmed (namely: significantly reduce their productivity) by water scarcity due to their water use efficiency.

The vulnerability score is related to the Yield-Response factor (Ky), indicator that captures the essence of the complex linkages between production and water used by a crop, where many biological, physical and chemical processes are involved (Doorenbos & Kassam, 1979; FAO, 2002; Gastélum et al., 2008; Xiaojuan et al., 2011; Steduto et al., 2012).

The Ky values are crop specific and vary according to the following trend:

- Ky > 1: the crop response is very sensitive to water deficit, with a yield reduction much larger than the water reduction, in relative terms.
- Ky = 1: the yield reduction is directly proportional to the reduction of water for the crop.
- Ky < 1: the cultivation is more tolerant to water stress, showing a yield reduction less to the reduction of water available in the soil.

For each crop, the vulnerability normalized score V_1 is calculated according to the following (Eq. 7):

$$\boldsymbol{V_1} = \frac{\boldsymbol{K_y mean}}{\boldsymbol{K_y max}} \quad (7)$$

Where **$K_y$mean** indicates the mean K_y for each crop (see table 3) among different K_y values reported in literature (FAO, 2002; Steduto et al., 2012), while **$K_y$max** indicates the maximum K_y reported value among the considered crops (i.e. 1.2 for vegetables). In Table 1a V_1 scores are indicated according to their relative classes of vulnerability. Each score is divided into five classes, from 0 to 1, where 0 represents the minimum and 1 the maximum.

V_2. Degree of efficiency - system losses.

Unequivocally, water losses decrease the efficiency of the distribution systems and increase their vulnerability to climate change impact because of their (reduced) capacity to compensate for water stresses. Larger system losses increase the vulnerability of irrigated crops under projected reduction in water availability. On average, near to 30% of the total water introduced in the irrigation system network is lost (European Commission, 2011).Water losses of irrigation systems depends on different factors, such as the efficiency of water transport in canals, open water evaporation, the type of crops, the technique of irrigation (i.e. sprinkler, drip irrigation, surface irrigation, etc.), the level of maintenance and the level of farmer discipline (Brouwer et al., 1989; European Commission, 2011).

Within the proposed methodology, the rate of water losses of each Consortia has been divided into five classes of increasing vulnerability scores (Table 1b). The maximum vulnerability score is 1 that corresponds to 50% of losses, chosen because normally irrigation networks losses estimates in literature don’t exceed 50%.

V_3. Degree of diversification of water sources.

Diversifying (water) supplies tends to mitigate risks. Overall, the general strategy of adaptation to climate change is to develop integrated programs to improve the efficiency of irrigation, drinking water and industrial exploitation to minimize consumptions and reduce unsustainable levies on natural water bodies (Cotecchia and Polemio, 1995; Ministero dell’Ambiente e della Tutela del Territorio e del Mare, 2015). As a consequence, lower vulnerability scores are associated with Reclamation Consortia that rely on different sources to fulfill their demand, in addition to reservoirs. A possible, plausible, alternative is presented by groundwater despite the fact that under heavier water exploitation and drought, this source would probably decline in the future. However, the magnitude of such decrease would likely be much less severe of the one affecting the surface water supplies. The scores are divided into four classes as the inverse of the rate supplied by ground waters (Table 1c).

Table 1: Vulnerability factors (V_1, V_2 and V_3).

a) Vulnerability classes of crops efficiency (V_1)		
Ky value	V_1. Normalized Score	Vulnerability class
0.00 - 0.24	0.2	Very low (0-0.2)
0.24 – 0.48	0.4	Low (0.2-0.4)
0.48 – 0.72	0.6	Medium (0.4-0-6)
0.72 – 0.96	0.8	High (0-6-0.8)
0.96 – 1.2	1	Very high (0.8-1)
b) Vulnerability of degree of efficiency (V_2)		
Percentage of losses	V2. Score	Vulnerability class
0 - 10 %	0.2	Very low (0 – 0.2)
10 – 20 %	0.4	Low (0.2 – 0.4)
20 - 30 %	0.6	Medium (0.4 – 0.6)
30 – 40 %	0.8	High (0.6 – 0.8)
40 - 50 %	1	Very high (0.8 – 1)
c) Vulnerability of degree of diversification of sources (V_3)		
Water drawn from underground water	V_3. Score	Vulnerability class
0 - 25 %	1	Very high (0.75 – 1)
25 - 50 %	0.75	High (0.50 – 0.75)
50 - 75%	0.50	Medium (0.25 – 0.50)
75 - 100 %	0.25	Low (0 – 0.25)

3.3 RISK

The risk assessment integrates hazards for water scarcity, for each climate change scenario, with spatialized assessments of exposure and vulnerability to identify and prioritize receptors and areas at risk in the region. In literature there is not a binding and unique method of risk calculation and different solutions are suggested, provided that the 3 pillars are well considered within (Giupponi et al., 2014). Here, the simplest algorithm has been implemented, by multiplying the three standardized factors, equally weighted, to compute the Risk index:

$$\boldsymbol{Risk(R) = \; Hazard_{(s)}(H) * Exposure(E) * Vulnerability_{(,con)}(V)}. \qquad (8)$$

Where:

- Hazard$_{(s)}$ is the degree of fulfillment of each Consortia, for any proposed Scenario (s);

- Exposure is the localization of receptors within each consortia;
- Vulnerability$_{(con)}$ is the specific vulnerability determined by crop types, system losses and diversification of sources.

The combination of these three factors, for the different climate scenarios, produces risk maps related to water scarcity for the irrigation compartment in Puglia. Risk index can theoretically range between 0 (relative low risk) and 1(very high risk).

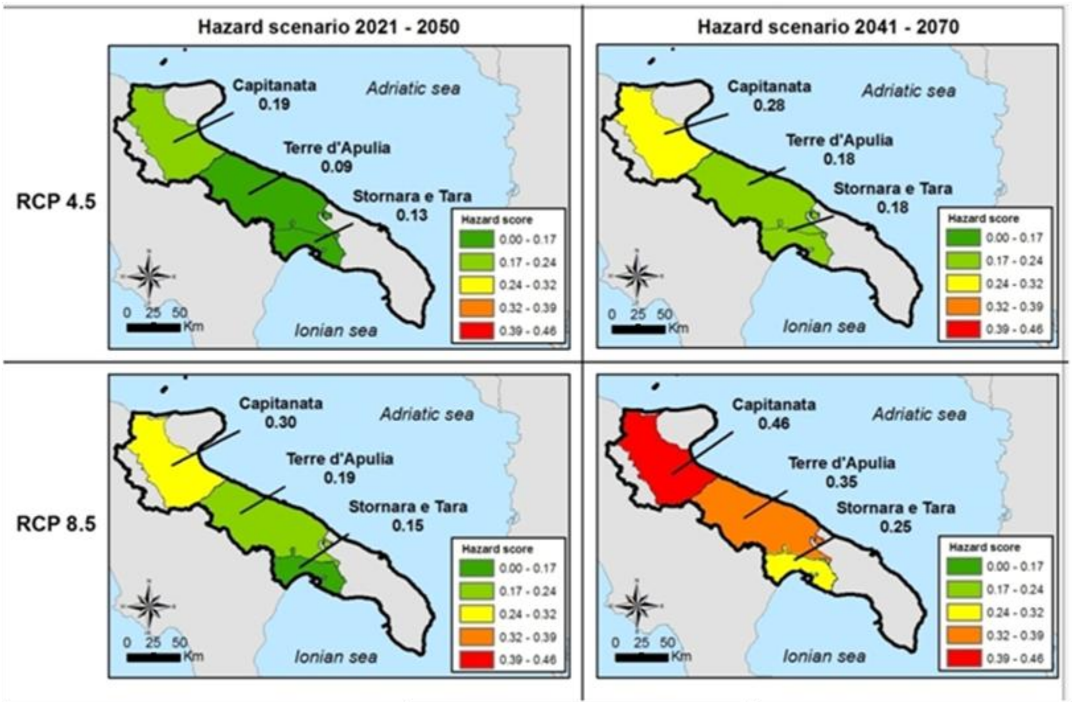
4. RESULTS AND DISCUSSION

The RRA methodology described and presented in Section 3 was applied to assess the impact of water scarcity due to climate change on a large irrigated agricultural area in Puglia Region, Italy. Results are presented and discussed in the following paragraphs.

4.1 Hazard scores and maps

Hazard maps represent the spatial pattern of physical impact to water scarcity for the different Reclamation Consortia (Figure 3).In relative terms, hazard scores, normalized with equal interval method, vary between 0 (low water scarcity hazards) and 0.46 (higher probability of water scarcity).

Figure 3 represents the spatial pattern of hazard scores of the four analyzed scenarios. In line with RCPs definitions, RCP8.5 causes higher hazard values respect to RCP4.5. Moreover, the longer term projections include more severe hazard likelihood. Among the Reclamation Consortia, Capitanata is the most affected by projected water scarcity hazards, because it is supplied by Occhito and Santa Venere reservoirs which have, on average, the highest rate of water reduction. The other two Consortia present a relatively better outlook, with low to very low scores, with the exception for RCP8.5 2041-2070, where hazard scores, for all three Consortia are within the worst classes (medium, high and very high hazard).



Legend	
Classes	H scores
1 – very low	0.00 - 0.17
2 – low	0.18 - 0.24
3 - medium	0.25 - 0.32
4 - high	0.33 - 0.39
5 - very high	0.40 - 0.46

Figure 3: Hazard map for emission scenarios RCP4.5 and RCP8.5 and the two considered timeframes: 2021-2050 and 2041-2070 for the main consortia of Puglia (Capitanata, Terre d'Apulia, Stornara e Tara).

4.2 Exposure map

The Exposure assessment defines the spatial pattern of irrigated crops which could be adversely affected by water scarcity. Specifically, four main crops together represent the majority of irrigated areas in Puglia (Table 2).

Table 2: Coverage and Corine Land Cover classes of mainly irrigated crops of Puglia Region (EEA, 2007).

Crops typology	Coverage [km^2]	Share [%]	CORINE Land Cover classes
Olive groves	2045.54	57.8	2.2.3
Vineyards	1050.60	29.7	2.2.1
Fruit trees	437.64	12.4	2.2.2
Vegetable crops	2.85	0.1	2.1.1.2
Total	3536.63	100	

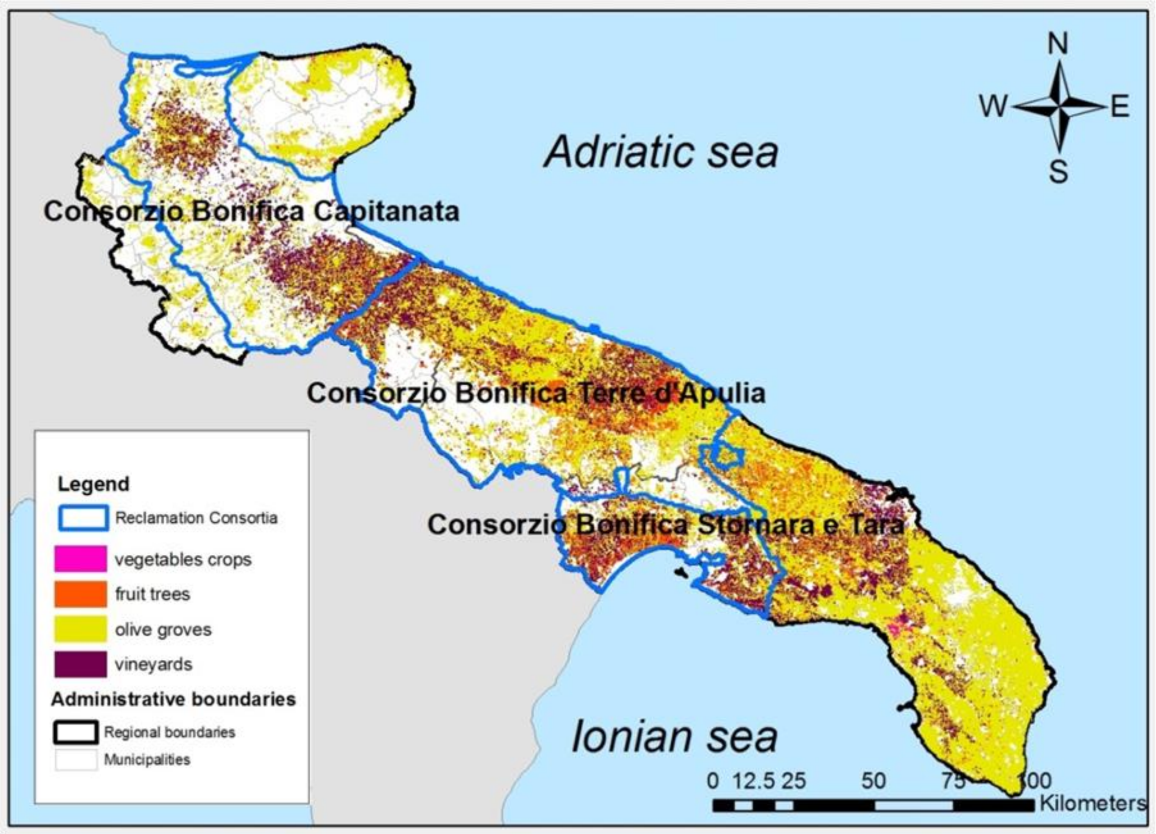


Figure 4: Exposure map: spatial representation of the four major crops, which are mostly irrigated in Puglia Region.

Boundaries of the considered Reclamation Consortia are also presented in Figure 4. The map emphasizes the prevalence of olive groves and vineyards (87.5%), while vegetable crops and fruit trees are less widespread (about 12.5%).Exposure was considered maximum (1) in case of irrigated crops and null (0) for other land uses.

4.3. Vulnerability scores and maps

Vulnerability maps are produced as a combination of three selected vulnerability factors (Section 3.3), reflecting the degree to which the crop systems could be affected by the waters scarcity hazard based on their physical, agronomic and structural (site-specific) characteristics, as follows:

Hydro-demand of crops: V_1

Hydro-demand score V_1 has been assigned according to Eq.7 to each exposed crops according to the Yield-Response factor (Ky) indicator, normalized by the max value attainable (1.2 for vegetable crops), and classified as per Table 3:

Table 3: Vulnerability factor V_1: hydro-demand of crops

Crops and CLC class	Ky value	Ky mean	V_1 Score normalized	Vulnerability class
Olive groves CLC 2.2.3	0.2 – 0.6	0.4	0.33	2 - Low (0.2-0.4)
Vineyards CLC 2.2.1	0.85	0.85	0.71	4 - High (0.6-0.8)
Fruit trees CLC 2.2.2	1	1	0.83	5 - Very high (0.8-1.0)
Vegetable crops CLC 2.1.1.2	1.1- 1.2	1.15	0.96	5 - Very high (0.8-1.0)

Vegetables (tomato, onion, peppers, peas, etc.) hold an high Ky (1.1- 1.2), therefore they are very sensitive to water stress, with a notable yield reduction. For fruit trees (Ky = 1), water deficit brings an equivalent reduction in productivity. Vineyards (Ky = 0.85) are more tolerant to water stress, showing a reduction in productivity that is less pronounced with respect to water gap. Finally, Olive groves (Ky = 0.2 – 0.6) are very much resilient to severe water stress, and any excess irrigation does not benefit significantly their yield.

In Table 5, V_1 scores and its relative classes of vulnerability are indicated; they are also spatially represented in a GIS-based map (Figure 5a). Normalized scores are divided into five classes ranging from 0 to 1(equal interval method), where 0 represents the class with no vulnerability and 1 represents the most vulnerable class.

As evident from Figure 5a, only few areas are characterized by very high vulnerability score V_1 (red zones), since the coverage of crops with higher vulnerability (fruit trees and vegetables) is limited. Predominance of olive groves or vineyards denotes low or high V_1, respectively.

Degree of efficiency - system losses: V_2

Rates of water losses, provided by Reclamation Consortia, have been divided into five classes with increasing vulnerability, to a maximum fixed to system losses equal to 50%.

In Figure 5b data distribution of system losses are represented. Capitanata and Terre d'Apulia Consortia have a percentage of losses between 15% and 20%, (class 2, low vulnerability), while Stornara e Tara Consortia suffer larger water losses, around30% (medium-high vulnerability).

Degree of diversification of water sources: V_3

This (vulnerability) factor reflects the degree to which the different Reclamation Consortia rely on different sources (either than Reservoirs) to fulfill their water demand (see Sect. 3.3). Among the selected Consortia, only Terra d'Apulia is supplied by groundwater. This limitation is mainly due to the excessive drilling of deep wells done in the past decades in Puglia Region that leads to the drying up of millennial wells and springs (Autorità di Bacino della Puglia, 2004).Water withdrawal data have been used to assess this vulnerability score (for larger sustainable shares of groundwater use, there is a lower vulnerability for the Consortia) (Figure 5c).

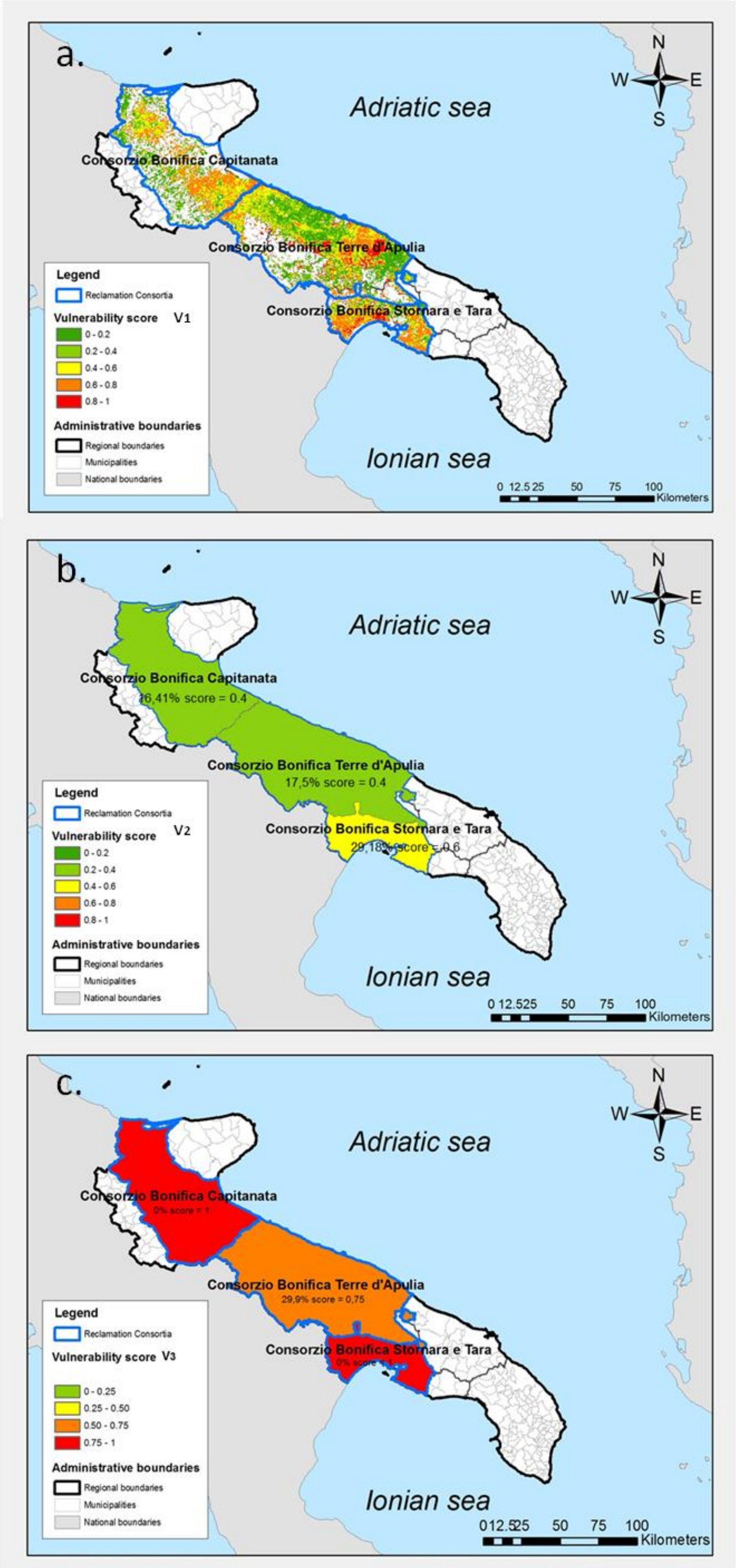


Figure 5: Maps of Vulnerabilities due to: a. *Hydro-demand of crops:V_1*; b. *Degree of efficiency - system losses:V_2*; *Degree of diversification of water sources: V_3*.

Total Vulnerability map and statistics

Final vulnerability score is obtained by multiplying the three vulnerability factors, according to Eq. (6). Resulting scores have been aggregated into five classes (equal interval).

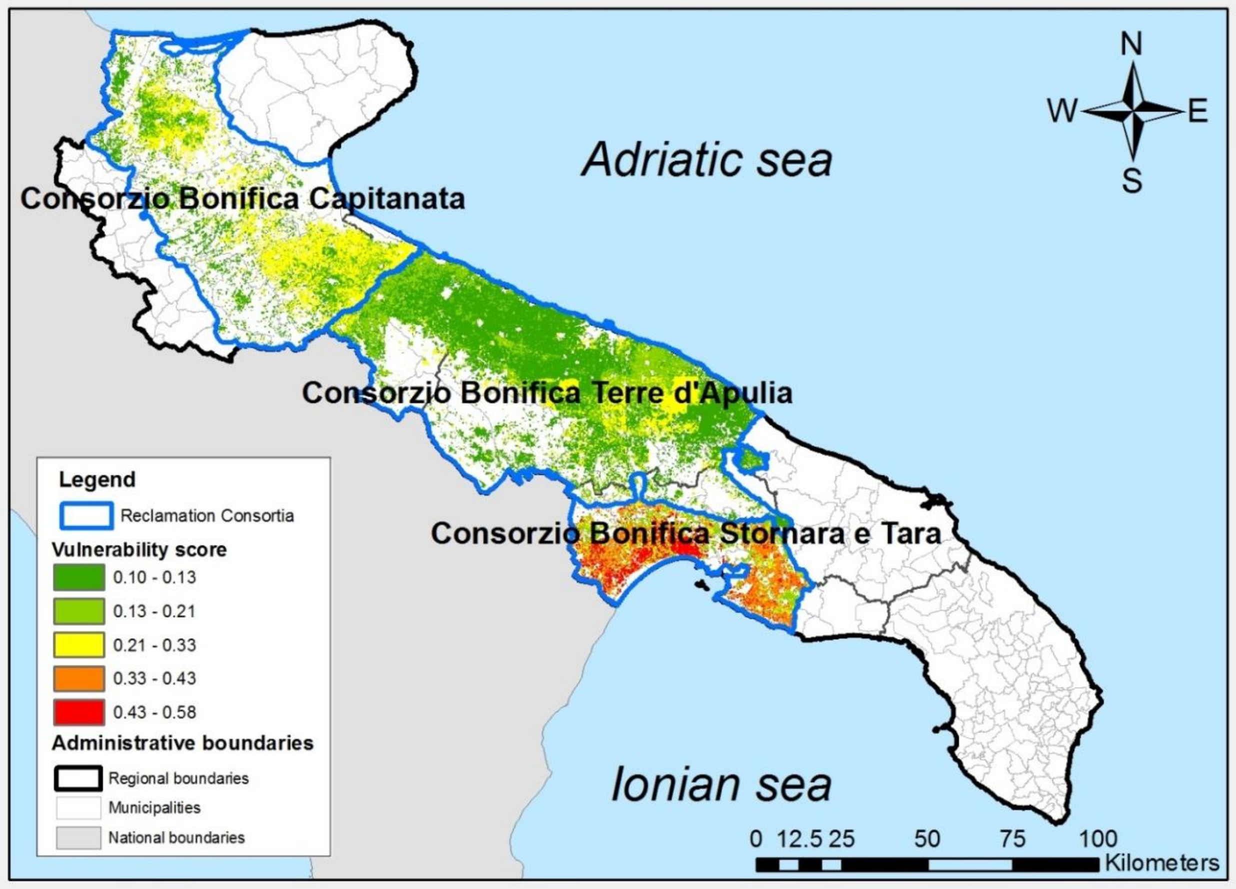


Figure 6: Map of Total vulnerability.

Figure 6 shows that the most vulnerable areas are located in the Stornara e Tara Consortium, in middle-southern Puglia. In fact, this Consortium presents a high percentage of vegetables and fruit trees (the most vulnerable crops), with a relatively high rate of system losses and no water sources diversification. Capitanata and Terre d'Apulia Consortia are characterized by a lower vulnerability score (low to medium) mainly because of the greater presence of vineyards and olive groves and, moreover, Terre d'Apulia Consortium relies on diversification of water sources.

Statistical analyses over the delineated spatial data are described in Figure 7 and reveal the following considerations:

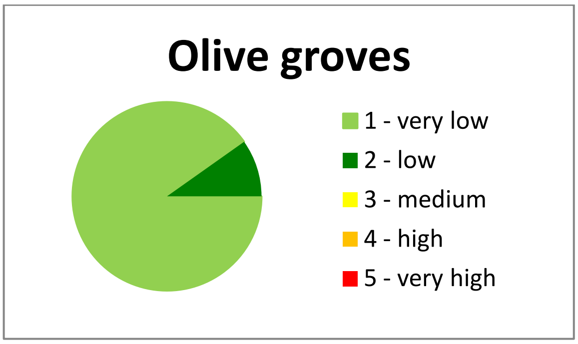
- Approximately, half of the area (52.8%) devoted to irrigated agriculture in Puglia is associated to the very-low class of vulnerability, while a further 37.2% is characterized by the low vulnerability class, and the remaining 10% is included into the higher classes (medium, high and very high).

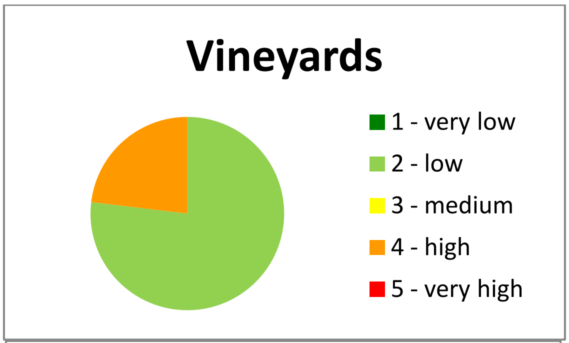
- Olive groves are consistently characterized by the lowest classes of vulnerability, since they are quite effectively preserved by efficient water use mechanisms, rather than the factors V_2 and V_3.

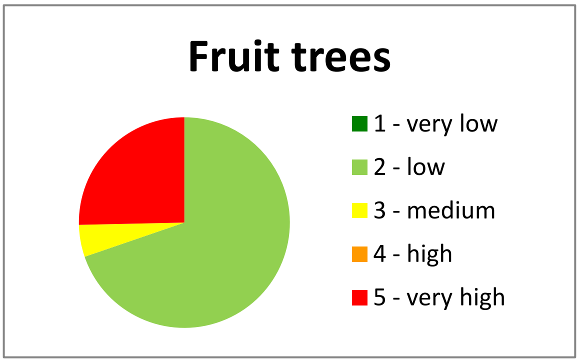
- About one fourth of the vineyards coverage is characterized by the vulnerability class “high”, mainly because they are placed in Reclamation Consortia that are strongly affected by water losses with no diversification of water sources.

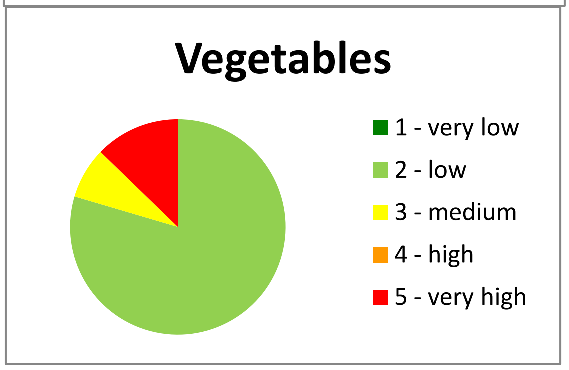
- A not negligible coverage of fruit trees (about one third) is characterized by the highest vulnerability score, both because of the agronomic performances (V_1 factor) and the association to more vulnerable Reclamation Consortia (V_2 and V_3 factors).

- The overall coverage of vegetable crops is very limited but, as one cannot expect, most of it belongs to the vulnerability class “low” mainly because their respective Consortia are sufficiently equipped to reduce losses and rely on other water sources than reservoirs.









	Olive groves		Vineyards		Fruit trees		Vegetables	
Class	[km^2]	[%]	[km^2]	[%]	[km^2]	[%]	[km^2]	[%]
1 - very low	1844,9	52,8	0,0	0,0	0,0	0,0	0,0	0,0
2 - low	200,6	5,7	807,8	22,8	305,2	8,6	2,3	0,1
3 - medium	0,0	0,0	0,0	0,0	21,5	0,6	0,2	0,0
4 - high	0,0	0,0	242,8	6,9	0,0	0,00	0,0	0,0
5 - very high	0,0	0,0	0,0	0,0	110,9	3,1	0,4	0,0

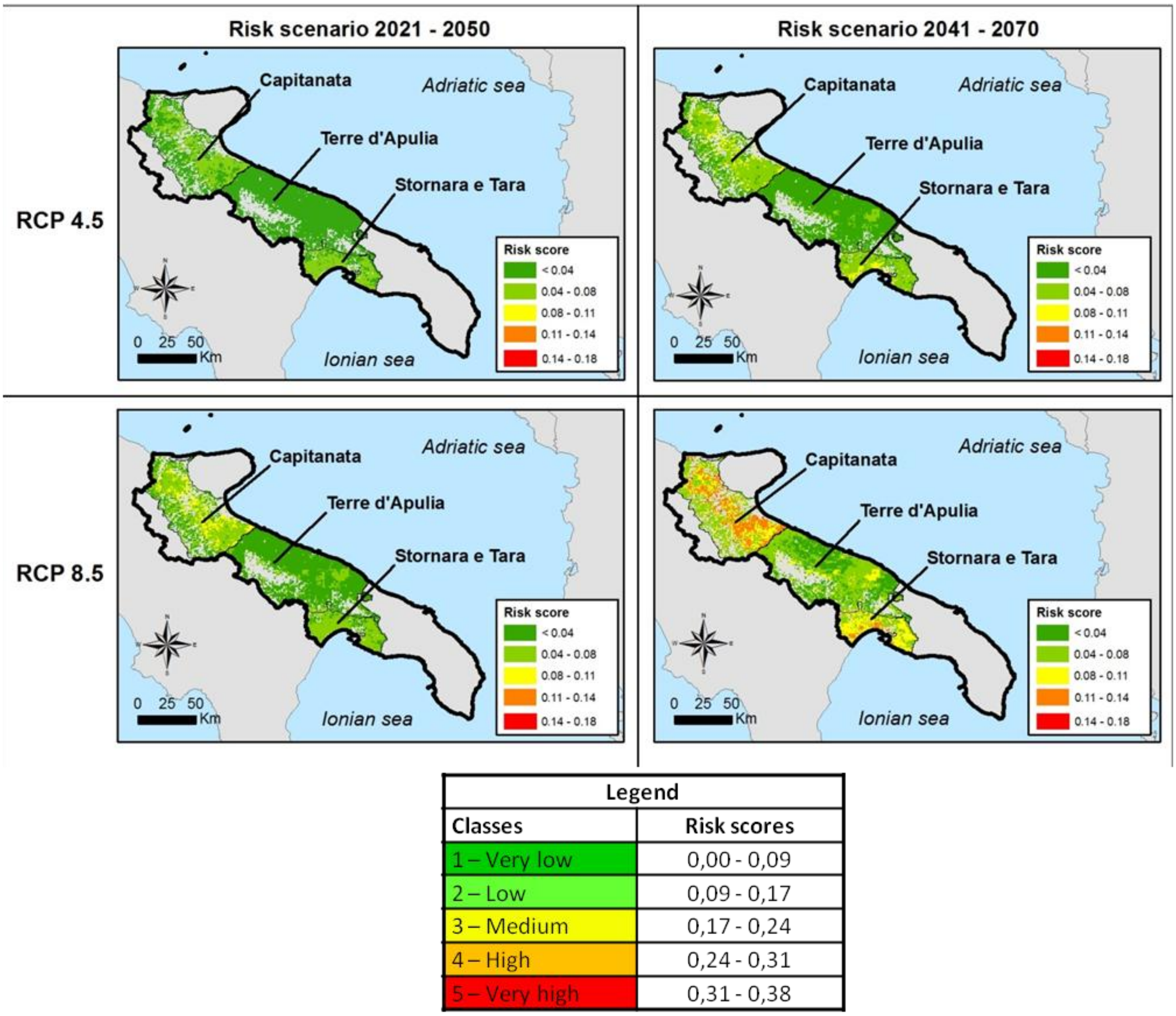
Figure 7: Total vulnerability visualized for each crop. In the table: Extension [km^2] and percentage [%] of vulnerability classes for the different crops.

4.5 Risk scores and maps

Final outputs of the ORIENTGATE-RRA methodology are GIS based risk maps at 25 m resolution and related statistics that allow to identify and rank areas more at risk (hot spots) (namely: elements potentially most affected by water scarcity) within the case study area.

The final risk index ranges between 0 and 0.38. As for the hazard and vulnerability scores, relative risk scores have been divided into five classes, dividing the range of attribute values into equal-sized sub-ranges (Figure 8). This classification method allows for comparison of areas more affected by water scarcity risk under the different scenarios.

The Risk maps, presented in Figure 8, show the relative spatial distribution of water scarcity risk in the study area. Risk hotspots are mostly located in Capitanata and Stornara e Tara Consortia, for RCP8.5 2041-2070 scenario. For the others scenarios, areas with low/very low risk prevail, with a scattered presence of zones characterized by a medium risk.



Legend	
Classes	Risk scores
1 – Very low	0,00 - 0,09
2 – Low	0,09 - 0,17
3 – Medium	0,17 - 0,24
4 – High	0,24 - 0,31
5 – Very high	0,31 - 0,38

Figure 8: Risk maps of water scarcity on irrigated agriculture for the two considered time frame: 2021-2050 and 2041-2070 and the emission scenarios RCP4.5 and RCP8.5.

As for Table 4, results for the RCP4.5 scenario demonstrate that, overall, the risk magnitude is moderate. Within the timeframe 2021-2050 the risk score is limited to the “very low“ and “low” classes for almost all the area. Within the timeframe 2041-2070 there is also not negligible area where the relative risk score is medium (about 22%).

Table 4: Coverage and percentage of relative risk classes for the study area.

RelativeRisk classes	**RCP 4.5 2021-2050**		**RCP 4.5 2041-2070**		**RCP 8.5 2021-2050**		**RCP 8.5 2041-2070**	
Class	**Km^2**	**%**	**Km^2**	**%**	**Km^2**	**%**	**Km^2**	**%**
1 - very low	2760,5	78,1	2453,0	69,4	2453,0	69,4	1487,6	42,1
2 - low	776,2	21,9	307,5	8,7	661,2	18,7	965,4	27,3
3 - medium	0,0	0,0	776,2	21,9	422,2	11,9	550,3	15,6
4 - high	0,0	0,0	0,0	0,0	0,2	0,0	511,3	14,5
5 - very high	0,0	0,0	0,0	0,0	0,0	0,0	22,1	0,6
Tot	3536,6	100,0	3536,6	100,0	3536,6	100,0	3536,6	100,0

Risk maps obtained within the RCP8.5 scenario, which considers the business as usual emission's setting, reveals the most heterogeneous trend. In fact, projections worsen compared to the RCP4.5 scenario, in particular for the long-term timeframe (2041-2070), where almost 31% (1084 km^2) of the irrigated area is characterized by a (relative) risk score in the range "medium"-"high"-"very high". Moreover, within the shorter timeframe (2021-2050), relative risk scores are "very low" for most of the irrigated area, with only 12% (422.40 km^2) characterized by a risk score from "medium" to "high".

Spatial statistical analyses (see Figure 9) of these results show that:

- **Olive groves** are mostly associated to the "very low" risk class, and in part to some limited area (27.3% of the total coverage) "low risk" class under the RCP 8.5 2041-2070 scenario. Therefore, the overall impact of (future) water scarcity to this crop can be considered negligible. However, recent studies expect that over the Mediterranean olive growing coverage could increase by 25% in the next 50 years, with the consequent aggravation of evapotranspiration phenomena as well as irrigation requirements (on average by 8% and by 18.5% respectively) (Tanasijevic et al., 2014).

- **Vineyards**, in RCP4.5scenario within the 2021-2050 timeframe, are principally included in the "low" risk class (61.2%), and partially to the class with "very low" risk. Within the2041-2070 timeframe the percentage of risk risesto61.2% at "medium" risk and remaining 38.8% at "low" risk. For timeframe 2021-2050 and RCP8.5, nearly 38.1% of vineyards is at "medium" risk, 23.1% at "low" risk and the rest nearly 38.8% at "very low" risk. Furthermore, within the 2041-2070 timeframe, nearly 38.8% is at "high" risk, 23.1% at "medium" risk and nearly 38.8% at "low" risk.

In general, vineyards are less resilient if compared to the olive groves but, overall, their vulnerability (and, therefore, their risk) is much more dependent on the structural vulnerability of the Consortia they belong to.

- **Fruit trees,** face “very low” (69.7%) and “low” (30.3%) classes of risk for 2021-2050 timeframe and RCP4.5. The same trend applies for2041-2070, when 69.7% of fruit crops may settle on “low” risk and 30.3% on “medium” risk. Under RCP8.5 scenario and for the 2021-2050 timeframe, the prevalence of fruit trees at “medium” risk is 4.9% and the rest belong to the “low” risk class. In the long term (2041-2070), about 69.7% of fruit tree fields reach “medium” class of risk, 25.3% are at “high” risk and the remaining 4.9% are within the highest class of risk.

- **Vegetables**, along with fruit trees, are the most affected crops. For RCP4.5 scenario, in the medium term79.6% and 20.4% of vegetable crops encounter “very low” and “low” classes of risk respectively, while in the long term similar rates apply but for the “low” and for the “medium” classes of risk, respectively. For the RCP8.5 scenario, broader differences are reported for the two timeframes: in the medium term almost 79.6% of crops belong to the “low” class of risk, while the remaining to the “medium” risk (12.7%) and the “high” (7.7%) classes of risk. For the long term, most of the vegetables are reported to be from “medium” (79.6%) to “very high” risk of water scarcity (20.4%).

Figure 9: Extent (y-axis; km^2) and percentage (labels; %) of risk class per crop under RCP4.5 (a) and RCP8.5 (b) and 2021-2050 (left) and 2041-2070 (right) time periods.

It is worth to notice that within a long-term perspective, the “business as usual” emission pattern can lead to considerable impacts on the agronomic performances of the irrigated agriculture of Puglia Region, especially as far as the most important (cash) crops are concerned. In fact, a considerable decrease on the productivity of fruit trees, vegetables and, to lower magnitude, vineyards is expected, since these cultivations are expected to suffer from a “medium” to “very high” risk of waters scarcity. By contrast, olive groves are projected to be less vulnerable, and therefore more resilient, to the scarcity of water. In a long-term perspective, is very likely that this crop will increase its coverage. Besides being more resilient, olive groves seem recently affected by biotic disturbances (pest such as *xylella fastidiosa*) on which the influence of abiotic (climate) disturbance, although more indirect, has not to be excluded as complementary threat from climate change (Ponti et al., 2014).

The economic consequences of water scarcity on analyzed crops can be easily argued from a simple comparison of the average monetary value per crop per hectare estimated for Puglia. Latest data on production area from ISTAT for the year 2011 were combined with data from INEA (2014) as average 2010-2012 about the gross revenue (gross production value minus costs) for the most representative crops in each macro-category. The results confirm that vineyards, fruit trees and vegetable crops, the crops more at risk, are the most valuable crops in terms of revenue per hectare, more than the olive trees (Table 5). This suggests that, in addition to the environmental and landscape impact, the climatic trend will also have important economic consequences.

Table 5: Average economic value per hectare of products from macro-categories of crops (and representative crops according to INEA, 2014) in Puglia Region [€/ha].

Macro-categories of crops	Vegetables (artichoke, egg-plant, industrial tomato, red pepper)	Fruit trees (oranges, peach, cherry, almonds)	Vineyards (table grape, wine grape)	Olive groves
Economic value per hectare [€/ha]	4.946	4.725	5.724	936

Combining the crops' economic value with data in Figure 9 and with the areal extent of crops in Table2, assuming both production value and surfaces unchanging in the future, we obtained some scenarios of economic damages due to the production losses under the most impacting long term RCP8.5. Assuming for example that crop production from areas under "high" to "very high" risk will be completely lost, direct economic damages could reach almost 229M€ for vineyards, around 62.5M€ for fruit trees and less than 300k€ for vegetables, summing up to around 292 M€/year. Under a more optimistic assumption that only areas at "very high" risk will effectively lose production, economic damages restrict to 10.5M€ and mainly related to fruit trees. Instead, being more pessimistic and considering that also areas under "medium" risk will no longer produce, monetary losses reach 576 M€. However, even in the ideal situation of being able to substitute part of lost crops with olive groves appearing less suffering from water scarcity, other issues need attention: recent phyto-pathological problems on olive groves in Mediterranean area (Ponti et al., 2014) and especially in Puglia (Strona et al., 2017) do not support robust choices in expanding olive cultivation. Because of such additional threats, the research can take advantage of considering biotic hazards besides abiotic (climate-related) ones.

5. CONCLUSIONS

The present study assessed the impact of water scarcity due to climate change on the irrigated agronomic compartment. A state-of-the-art methodology, RRA based, has been developed upon a consolidated conceptual framework shaped by four pillars namely hazard, vulnerability, exposure, and risk, where the outcome of the first three affects the latter. Each tier of analysis has been designed to represent the physical characteristics of the natural phenomena (rainfall-runoff driven by climatic change with ArcSWAT model), the spatial pattern of water demand, the agronomic and the structural features of the irrigation compartment. The climatic driver is based on COSMO-CLM downscaled simulations driven by the global model CMCC-CM, under RCP 4.5 and RCP8.5 scenarios, and with two different timeframes (2021-2050 and 2041-2070). It is important to underline that risk scores are not absolute predictions about the risks for crops; rather they support the ranking of the areas and hotspots at risk that are more vulnerable and possibly more affected by water scarcity within the investigated region.

Spatial results of risk assessment support the development of optimal adaptation actions, over the benefits of different risk prevention measures (i.e. baseline and alternative), as well as to communicate to decision makers and stakeholders the potential implications of water deficit in non-monetary terms. On this basis, investments on prevention by Public Administrations can be better evaluated and shared with citizens, also in order to support the rising of a culture of prevention within the (whole) society (Ronco et al., 2014).

It is worth to notice that the novelty of the approach does not simply rely on the “standard” definition of risk as combination of hazard, exposure and vulnerability of course, but rather the detailed (scientific) shaping and computational description of these factors, by means of the proposed equations and classification patterns. This practical methodology is flexible as it can be and has been adapted to several case studies. The methodology has been applied for the irrigated areas in Puglia Region, including three Reclamation Consortia, where valuable crops are mainly olive groves, vineyards, fruit trees and vegetables.

As expected from the RCP’s emission pattern and relative assumptions, the results of the assessment have showed that for the RCP8.5 scenario a not negligible portion of agricultural (irrigated) areas are at high risk of water scarcity induced by climate change, especially in a long-term perspective, with considerable economic losses associated.

Some mitigation and adaptation strategies can be thus designed and implemented. Increasing drought resilience is the ultimate aim of sustainable adaptation actions within the irrigation compartment. As for IPCC (2008), relevant science-based adaptation strategies could address two different levels: (i) supply and (ii) demand side. More specifically, actions can be under taken on both hazard and vulnerability levels. Apart from mitigation strategies to be implemented at global level to reduce GHG emissions, adaptation policies include, instead, measures to be implemented locally where vulnerability factors may be more specifically involved, at both supply- and demand-side, as follow:

i. supply side: increasing (water) storage capacity by building new reservoirs and by restoring the active volume of the existing ones; sustainable use of groundwater, where not in conflict with other uses; desalination of sea water; removal of invasive non-native vegetation from riparian areas and water transfer.
ii. demand side: improvement of water-use efficiency by recycling water and wastewater re-use; promotion of local practices for sustainable water use; household and industrial water conservation; reduction in water demand for irrigation purposes by adapting the cropping calendar,

crop mix, efficient irrigation method and area planted; reduction in water demand for irrigation by importing agricultural products, i.e., virtual water; expanded use of water markets to reallocate water to highly valued uses; expanded use of economic incentives including metering and pricing to encourage water conservation; reducing leaky municipal and irrigation water systems (IPCC, 2014).

Some Consortia are planning the construction of new reservoirs in order to increase the current available water stock and, therefore, to reduce the (water scarcity) hazard pattern (i.e. Capitanata Reclamation Consortia is planning to use the Palazzo d'Ascoli Reservoir to serve the irrigation area of Carapelle). The enormous potential benefits that can be obtained from the use of wastewater for irrigation are well known from local stakeholders and authorities and, in fact, some of the most important Puglia’s municipalities (i.e. provinces Bari and Barletta-Andria-Trani) are considering this option. Wastewater reuse for crop irrigation is worldwide applied, but this practice is largely debated in particular as far as its possible impact on human health is concerned, through the uptake of active pharmaceutical active compounds (PhACs) and organic compounds by plants and consequent contamination of food web (Anastasis et al., 2017; Gao et al., 2017; Gatta et al., 2016). Some Consortia, instead, are currently planning new structural investments to reduce losses, and reduce their vulnerability, through a more efficient maintenance of irrigation systems. Common threads that binds these adaptation strategies, are the related high monetary costs.

Another aspect that cannot be overlooked is the changes in consumption patterns and competition for water among domestic, industrial and agricultural uses, which might ultimately alter the availability of freshwater for irrigation and other agricultural uses (Betts, 2005).In fact, pressing competition among several sectors for available freshwater is a recurrent issue for many drought prone Mediterranean areas. The consequence has often brought in a decreased allocation of freshwater to agriculture (Tilman et al., 2002). As Bogataj and Susnik (2007) suggest, adaptation strategies should not be seen as individual remedies because of inter-sectoral competition for water resource allocation (Barthel et al., 2008), rather they can be considered on small scale, looking at the specific vulnerability of local crops and trying to better manage alternatives of agricultural coverage. Finally, the ultimate purpose of a sustainable agriculture should be to develop and implement site-specific practices that meet current and future societal needs for food and fiber, for ecosystem services, and for healthy lives, and that do so by maximizing the agricultural methods that benefit society (Falloon & Betts, 2009).

The uncertainly related to this study, is mainly related to the GHG emission pattern and consequent climatic variation, and in particular the rainfall regime. The characterizations of hazard, exposure and vulnerability formula and classification are based on literature review, but of course there is a margin of uncertainty embedded into these assumptions. This is mainly due to the novelty of the proposed approach:

to date, no other methods where hazard, exposure and vulnerability factors concur to the assessment of risk levels for the irrigated agriculture have been developed. As such, despite being deeply scientifically argued and justified, the proposed algorithms unavoidably suffer from lack of literature comparison. In any case the level of uncertainly can be lowered by considering further vulnerability factors, regarding both the vulnerability of crops and soil, as well as the vulnerability of Reclamation Consortia. Further limitation of the proposed approach consists in the fact that climate change affects only hazard component, while exposure and vulnerability are only subject to factors that are, in principle, independent from climate variability. While acknowledging that this approach could (hopefully) be improved in next future, the authors believe that the characterization of the exposure and, in particular, the vulnerability patterns deeply reflects the structural efficiency of the water supply and distribution systems and crop productivity. In particular, proposed vulnerability factors accounts for the structural capacity of the irrigation network (V_2 and V_3) and the (crop) productive capacity (V_1) to cope with water scarcities. In this sense, far from being exhaustive, proposed factors really address the vulnerability of the irrigated agriculture to cope with climate induced water scarcity.

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Annex I: IPCC risk's general concepts (IPCC, 2014).

Hazard	Hazard is the potential occurrence of a natural or human-induced physical event or trend or physical impact that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems, and environmental resources. In the IPCC Fifth Assessment report, the term hazard refers to climate-related physical events or trends or their physical impacts.
Exposure	Exposure is the presence of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected.
Vulnerability	Vulnerability is the propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt.
Risk	Risk is the potential for consequences where something of value is at stake and where the outcome is uncertain, recognizing the diversity of values. Risk is often represented as probability of occurrence of hazardous events or trends multiplied by the impacts if these events or trends occur.Risk results from the interaction of vulnerability, exposure, and hazard. In this report, the term risk is used primarily to refer to the risks of climate-change impacts.

Annex II: Water demand for the different Reclamation Consortia, divided per reservoir and for the different uses (from: Relazione Bilancio Idrico Potabile, 2010; Apulia Piano Tutela delle Acque, 2009).

			Water demand for different uses [Mm^3]/year			
Reclamation Consortia	**Basin**	**Reservoir**	**Agricultural**	**Agricultural private**	**Industrial**	**TOTAL**
Capitanata	Fortore	Occhito	72.6	1.2	4.7	78.4
	Ofanto	Santa Venere	40.1			40.1
		Total Capitanata				**118.5**
Terre d'Apulia	Ofanto	Locone	7.3			**7.3**
		Santa Venere	7.1		8.8	**15.8**
		Total Terre d'Apulia				**23.1**
Stornara e Tara	Bradano	San Giuliano	16.4			16.4
	Sinni	Monte Cotugno	22.5			22.5
		Total Stornara e Tara				**38.9**

Annex III: Reduction of water stocks (in percentage) for the different Reservoirs, calculated with the ArcSWAT model.

		Average reduction per year [%]			
Basin	**Reservoir**	**RCP4.5 2021-2050**	**RCP4.5 2041-2070**	**RCP8.5 2021-2050**	**RCP8.5 2041-2070**
Fortore	Occhito	-27.93	-35.54	-36.5	-51.87
Fortore & Ofanto	Santa Venere	-29.32	-37.48	-40.44	-53.43
Ofanto	Locone	-19.92	-24.02	-19.23	-30.96
Agri - Sinni	San Giuliano	-18.59	-27.95	-22.25	-40.32
	Monte Cotugno	-27.17	-35.25	-30.41	-45.97

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