Università
Ca'Foscari
Venezia

Master's Degree programme – Second Cycle (*D.M. 270/2004*)

in Environmental Sciences

Final Thesis

Impact of hydrological drought to the irrigation compartment in Puglia Region by means of Regional Risk Assessment methods

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2013 / 2014

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Summary

Since the early age, irrigation has played a key role in feeding the expanding world population and it is expected to play a still greater role in the next future. Current stocks of freshwater need to be used much more efficiently since the surpluses of (good-quality) irrigation waters are expected to decrease in several regions due to raising drought events caused by climate change (IPCC, 2014) and to the increase of domestic–industrial–agricultural water demand (Qadir & Oster, 2003). The improvement (of existing) and the development of (new) appropriate and robust tools to assess the impact of drought events on irrigated crops is fundamental in order to assure that the agricultural yields, both at local and global scale, are appropriate to meet to current and future food demand. In this sense, the achievement of sustainable levels of food security requires the identification of effective adaptation strategies (and practices) to address the dual climate constraints of drought that will be further exacerbated by loss of water resources (Vories and Evett, 2010 and Hornbeck and Keskin, 2014).

The present study aims at assessing the impact of hydrological droughts due to climate change on the irrigated agronomic compartment through the development and application of a state-of-the-art risk assessment methodology. Based on theoretical framework of the Regional Risk Assessment (RRA) approach, the methodology is applied to the (extensive) irrigated cultivations that cover a large portion of Puglia Region, in southern Italy, within a scenario-based hazard framework in two different timeframe (2021-2050 and 2041-2070). The ultimate aim of the methodology is to support a knowledge-based decision making process that, in turn, contribute in developing sustainable and climate-proof adaptation measures.

In order to accomplish this overall objective, the thesis pursues the following specific objectives: i) review of current available literature and conceptual frameworks concerning the impact of drought risk and related assessment methodologies; ii) development of an innovative (state-of-the-art) Regional Risk Assessment (RRA) methodology to assess the (climate change induced) risk of drought for irrigated crops; iii) tuning and application of the RRA methodology to the selected case study, by collecting and organizing data, charactering scenarios as well as the related geographical, economic social and environmental features, by implementing the specific risk algorithms, and finally by producing risk maps and related statistics.

The complete ORIENTGATE-RRA methodology, followed four subsequent levels of analysis, namely the hazards, exposure, vulnerability and risk assessments where the latter is functional to the first three steps. Each steps have been characterized by a specific (series of) algorithms that accounts for their spatial and numerical quantification. Two IPCC-RCP's standardized scenarios based on different future emission trends have been selected for the climatic characterization of the hydrological hazard pattern: the RCP4.5, that forecasts the reduction of the current emission rate through the implementation of mitigation actions; and the RCP8.5, that considers the (current) "business as usual" emission trend. Based on these different climatic scenarios, the rainfall pattern feeding the water stocks of the most important (irrigation purposes) Reservoirs in Puglia has been modelled by means of the Arc-SWAT model.

Based on these results, hazard scores have been modelled as the degrees of fulfillment of the Reclamation Consortia irrigation demand when compared to the availability of water from the different Reservoirs.

Exposure assessment consists on the spatial characterization of the most valuable irrigated areas in Puglia Region, according to the specific (cash) crops that are cultivated. Moreover, vulnerability scores have been designed as function of three different factors that accounts for the agronomic and structural pattern of irrigation schemes, namely: i) crops yield variation according to different pattern of water stress; ii) water losses along that particular irrigation network; and iii) diversification of water supplies, other than the Reservoirs' one. Finally, relative risk maps (GIS based) and related statistics have been produced allowing the identification of hot spots and area at risk as well as the spatial characterization of the risk pattern.

The thesis has been developed within the ORIENTGATE-SEE Project (co-funded by South East Europe Transnational Cooperation Programme and coordinated by the Euro-Mediterranean Centre on Climate Change; http://www.orientgateproject.org/), WP5 Thematic Centre 2 - Drought, Water and Coasts, Pilot study 3: Climate change adaptation in the new water regime in Puglia region, Italy. The analysis accomplish the (larger) objectives of the ORIENTGATE project with regards to the development of specific tools, guidelines and adaptation strategies for local and regional decision makers in order to improve water resources management and planning, by taking into account impacts on domestic water supply, agriculture and coastal areas from terrestrial and marine hazards, related to climate change and variability. ORIENTGATE partners have actively contributed to this study, and in particular the Euro-Mediterranean center on Climate Change (CMCC) supported the collection of data, the modeling of climate projections as well as the relationships with relevant stakeholders and end users.

Results from the application of the ORIENTGATE-RRA methodology allow to characterize the spatio-temporal and agronomic pattern of drought risk and, in particular: i) to identify which Reclamation Consortia of Puglia Region are more affected in the different timeframe (e.g. Capitanata Reclamation Consortia in RCP8.5 2041-2070 scenario); ii) to identify the most affected crops ((e.g. fruit trees and vegetables)); iii) to characterize the vulnerability pattern of irrigation systems and networks. According to these results, tailored and knowledge-based adaptation strategies and related actions can be developed, both at local and regional scale, to reduce the risk pattern at both agronomic level (preferring crops with low vulnerability score, as olive groves), at structural level (differentiating the water stocks and supplies and reducing losses and inefficiencies) and at governance level (optimization of demand pattern and networking among different Consortia).

Motivations and Objectives

Drought impacts have been increased over the past 60 years because of increased water demand, population growth, urban expansion, and environmental protection efforts in many areas (Mishra, 2011). Moreover, there was a dramatically increase in frequency and magnitude of droughts especially with regard to long-term imbalances of water demand and water availability, also due to climatic changes. Both droughts and water scarcity can cause huge economic losses in key water-using sectors as well as substantial environmental impacts on biodiversity, water quality, deterioration and loss of wetlands, soil erosion, land degradation and desertification (European Commission, 2012). Water is no longer the problem of a few regions, but concerns over 500 million European citizens (European Commission, 2012). In fact, while Europe is by large considered as having adequate water resources, the long term imbalance resulting from water demand exceeding available water stocks is no longer uncommon. Between 1976 and 2006 the number of areas and people affected by droughts went up by almost 20% and the consequences amounted to more than 100 billion Euro. In particular, the droughts in 2003, one of the most widespread and severe in Europe, affected over 100 million people living in a third of the European territory, with a cost of more than 8 billion Euro. After this dramatic event, the EU Council of Ministers asked the European Commission to address the challenges of Water Scarcity and Droughts (WS&D) within the EU with proper instruments, including legislation (European Commission, 2012). Moreover, in 2011 and 2012 droughts affected large parts of Southern, Western and even Northern Europe. The 2011 drought has been referred to as the worst in the century, with rainfall as low as 40% of normal. Here, water availability was significantly reduced in spring and water use restrictions were put in place in large parts of the European Union. Currently, several river basins can be considered as under water stress all year round; during summer months water scarcity is more pronounced in Southern Europe, but also in Northern basins, including UK and Germany, is becoming important. The European Commission and the Intergovernmental Panel on Climate Change (IPPC) agree on expecting further deterioration of the water situation in Europe if temperatures keep rising as a result of climate change and the projected (spatial and temporal) trend of drought events is likely to have significant impacts on both the agricultural and water sectors over the next few decades (IPCC, 2007). By 2030, a modeled localization of water scarce basins shows that the number of river basins under water scarcity are expected to increase by up to 50% (ClimWatAdapt project, Flörke et al., 2011).

Irrigation has ever been an important factor in agricultural development. The area of land under irrigation in the world has expanded substantially, particularly in the second half of the last century. Between the mid-1960s and the mid-1980s, expansion of irrigation has accounted for more than 50% increase in global food production (El-Ashry & Duda, 1999). Although only approximately 17% of the world's cropland is irrigated, it produces more than a third of the food and fiber harvested throughout the world (Hillel, 2000).

Currently, many specific studies on superficial hydrology have been produced (Barthel et al., 2008; Flörke et al., 2011; García-Ruiz et al., 2011; etc.) in order to define through models drought phenomena caused by climate change and, many sector studies (e.g. studies on agricultural and economic values for single culture/fields) have been provided (Falloon & Betts, 2009; Ferrise et al., 2013; Giglio et al., 2010; etc.). It can be observed, however, a lack in integrated studies where hydrological drought should be combined with vulnerability of the irrigated agricultural sector, in order to give an evaluation, both quantitative and spatial on a regional scale, which can be useful for stakeholders. This thesis aims to fill this scientific gap. With the final target of supporting the development of site-specific adaptation measures to mitigate the impact of climate change, a specific methodology is developed and applied to assess the risk of climate induced drought risk on valuable irrigated crops in a semi-dry environment.

Thesis structure

This thesis is composed by six chapters. First three chapters regard a theoretic description of the background of the analysis. In particular:

- chapter 1 focalizes on climate change background (Sect. 1.1) and on the effects of drought (Sect. 1.2) as hazard for the agricultural compartment (Sect. 1.3).
- Chapter 2, instead, addresses the project framework where the thesis has been developed: the ORIENTGATE-SEE (Sect. 2.1) as well as the climatic scenarios (Sect. 2.2) and the theoretical background of the assessment: the Regional Risk Assessment (RRA) (Sect. 2.3).
- Chapter 3 describes the case study, where the methodology has been tuned and applied through the characterization of its climatic (Sect. 3.2), agronomic (Sect. 3.3) and hydrological (Sect. 3.4) features.

The last three chapters (4-6) specifically address the algorithms and results of the application of the methodology, and in particular:

- chapter 4 presents the mathematical and theoretical procedure characterizing the basis of the methodology.
- Chapter 5 regards its application (with maps, results and statistics) at the Puglia Region case study.
- In chapter 6, conclusions are treated, with a comment on results and methodology efficacy.

1 Climate change and hydrological drought

1.1 Background

In climatology the definition *Climate Change* indicates variations in the global climate of the Earth, or variations at different spatial scales and time-history of one or more environmental and climatic parameters, among temperature (average, maximum and minimum), precipitation, cloud cover, ocean temperatures, distribution and development of plants and animals (change of mean values) (IPCC, 2007).

In particular, *global warming* is the specific physical phenomenon that refers to the increase in average temperatures of the Earth' surface that has been recorded from the middle of the last twentieth century. Intergovernmental Panel on Climate Change (IPCC) declares that most of the increases in temperature should be attributed to the increase in greenhouse gases concentrations, mainly released from human activities, such as combustion of fossil fuels and deforestation. The so called *global dimming*, caused by the increase of the aerosols' concentration in the atmosphere, blocks the Sun's rays, so, in part, could mitigate the effects of global warming.

The *greenhouse effect* is a natural phenomenon that heats the surface of the Hearth to a higher degree than that occurring for pure radiative equilibrium. This concept, calculated according to the Stefan-Boltzmann law, has been proposed for the first time by Joseph Fourier in 1827 (Weart, 2014). The greenhouse effect on Earth's surface rises the temperature of the atmosphere to an average of 33°C, due to the increase of greenhouse gases[1] (considering the average temperature of the Earth in 1850) (IPCC, 2007).

Human activities (principally through the burning of fossil fuels), since the industrial revolution, increased the amount of greenhouse gases in the atmosphere by changing the radiative balance and partition energy surface (radiative-convective atmosphere). Since 1750 the concentration of CO_2 and methane increased by 36% and 148%, respectively (EPA, 2007). Recent estimations report that photosynthesis and oceanic algae would be able to absorb less than half of these emissions. Deforestation and subsequent reduction of CO_2-absorbing biomasses play a relevant role in this feature (Climate Change, 2007). This is clearly indicated as key element of current global warming (Anthropogenic Global Warming theory) (IPCC, 2007). During the last three decades of the twentieth century, the growth of population and GDP per capita were the thrust for the increase of greenhouse gas emissions (World Bank, 2010). In light of these studies, knowledge-tools have been developed to predict future scenarios. The Special Report on Emissions Scenarios prepared by

[1] The main greenhouse gases are: water vapor, responsible for the greenhouse in a percentage variable between 36-70%; carbon dioxide (CO_2), which accounts for 9-26%; methane (CH_4), which accounts for 4-9%; ozone (O_3), which affects between 3-7% (EPA, 2007).

the IPCC draws likely scenarios for 2100: the concentration of CO_2 in the atmosphere could vary from 541 to 970 ppm (increase of 90-250% compared to the year 1750) (IPCC, 2013).

Basing on the scientific observation and understanding evaluations, the principal consequences of increasing concentrations of greenhouse gases in the atmosphere are identify, with high degree of certainty[2], on the warmed of atmosphere and ocean, on the diminished amounts of snow and ice, and on the risen of sea level (IPCC, 2013). In particular, regarding global climate and global water cycle are established consequences on actual terrestrial hydrology and over the coming century. It is virtually certain (with a probability of 90%), that by the end of the twenty-first century temperature of atmosphere and oceans will become more high, cold days fewer unusually and, heat waves for frequency, intensity and duration, are generally expected to increase. While the number of frost days is likely to decrease (IPCC, 2013).

Regions of southern Europe, are the most exposed to the impact of Climate Change in Europe (EEA, 2005). In particular, between 2030 and 2060, increases in the average annual temperatures from 1°C to 3°C (Giannakopoulos et al., 2005) and reductions between 30% and 40% in precipitation (Giorgi, 2005) may occur. The last IPCC report (WGI Fifth Assessment Report - AR5, 2013) suggests that, during the twenty-first century, Earth's average temperature will increase to a faster pace than the current one. Changes have been observed in the amount, frequency, intensity and type of precipitation. Widespread increases in heavy precipitation have occurred, even in places where total rain amounts have decreased (Karl et al., 2009).

Impacts of Climate Change regarding, in particular, the variations on precipitation regimes, insist on several sector, such as impacts on health, agriculture, forest, water resource (change in water supply and change in water quality), coastal areas and species & natural lands (IPCC, 2013).

From this background can be deduce that the question of the analysis of vulnerability, impacts and risks of climate change is an important issue especially to address the definition of policies and adaptation measures.

Within the international arena, climate change is addressed by the United Nations Framework Convention for Climate Change (UNFCCC) at the policy level, and by the Intergovernmental Panel on Climate Change (IPCC), at the scientific research level, to provide research assessments to aid policymakers and the wider community in implementing the UNFCCC.

[2] High degree of certainty: high confidence in the validity is based on the type, amount, quality, and consistency of evidence (e.g., data, mechanistic understanding, theory, models, expert judgment) and the degree of agreement. Probabilistic estimates of quantified measures of uncertainty in a finding are based on statistical analysis of observations or model results, or both, and expert judgment (IPCC, 2013).

1.2 Drought

Some evidence suggests that droughts have been occurring more frequently because of global warming and they are expected to become more frequent in southern Europe (Dai, 2011). Between most recent studies, in 2013 Prudhommea et al. analyzed the global pattern drought events, by using an ensemble of 35 simulations from a global multimodel ensemble experiment. Results show a likely increase in the global severity of hydrological droughts at the end of the 21st century, with systematically greater increases for RCPs describing stronger radiative forcings. Under the worst scenario (RCP8.5), droughts exceeding 40% of analyzed land area. This increase in drought severity has a strong signal-to-noise ratio at the global scale, and Southern Europe, the Middle East, the Southeast United States, Chile, and South West Australia are identified as possible hotspots with an increase of frequency of droughts events by more than 20% (Prudhommea et al., 2013).

The definition of drought is subtle and complex: is not purely a physical phenomenon that can be defined by the weather. It is a period of hot, dry weather with scarcity of rain (any or all of those conditions can be present during a drought); rather, at its most essential level, drought is defined by the delicate balance between water supply and water demand. Whenever human demands for water exceed the natural availability of water, the result is drought. Given this definition, drought can be caused by scarcity of precipitation over an extended period, but can also be caused by increased demand for the available supply of usable water, even during periods of average or above average precipitation (National Drought Mitigation Center, 2015).

Both the climate dynamics and the societal impacts of droughts are highly complex, poorly understood, and difficult to generalize. Drought is commonly divided in: meteorological, agricultural and hydrological, which are illustrated in the following:

- Meteorological drought: this type of drought regards all about the weather and occurs when there is a prolonged period of below average precipitation, which creates a natural shortage of available water.
- Agricultural drought: this type of drought occurs when there isn’t enough moisture to support average crop production on farms or average grass production on range land. Although agricultural drought often occurs during dry, hot periods of low precipitation, it can also occur during periods of average precipitation when soil conditions or agricultural techniques require extra water.
- Hydrological drought: this drought occurs when water reserves in aquifers, lakes and reservoirs fall below an established statistical average. Again, hydrological drought can happen even during times of average or above average precipitation, if human demand for water is high and increased usage has lowered the water reserves (National Drought Mitigation Center, 2015).

Figure 1.1 Sequence of drought occurrence and impacts (National Drought Mitigation Center, University of Nebraska-Lincoln, U.S.A.)

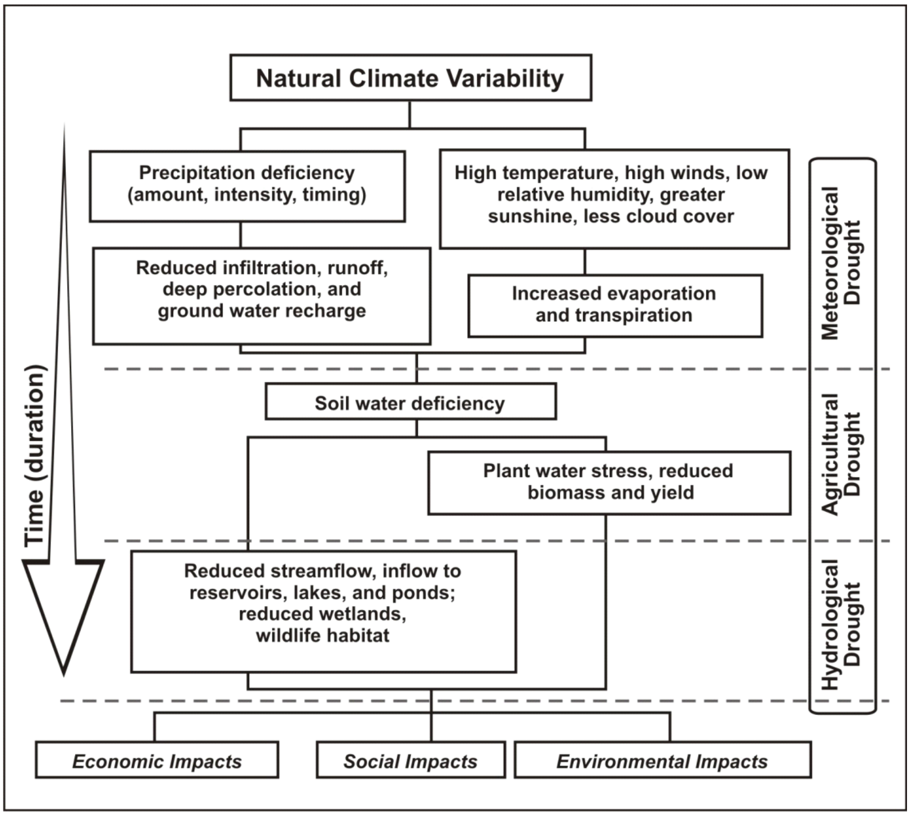

Figure 1.1 schematizes the sequence of drought occurrence and impacts for commonly accepted drought types. All droughts originate from a deficiency of precipitation or meteorological drought but other types of drought and impacts cascade from this deficiency (National Drought Mitigation Center, 2015).

The frequency and severity of hydrological drought is associated with the effects of precipitation shortfalls (including snowfall) on surface or subsurface water availability (e.g. streamflow, reservoir and lake levels, groundwater) and it is defined on a watershed or river basin scale. Although all droughts originate with a deficiency of precipitation, hydrologists are more concerned with how this deficiency plays out through the hydrologic system (National Drought Mitigation Center, 2015).

Hydrological droughts are usually out of phase or in lag with the occurrence of meteorological and agricultural droughts. It takes longer for precipitation deficiencies to show up in components of the hydrological system such as soil moisture, streamflow, and groundwater and reservoir levels. As a result, these impacts are out of phase with impacts in other economic sectors. For example, a precipitation deficiency may result in a rapid depletion of soil moisture that is almost immediately discernible to agriculturalists, but the impact of this deficiency on reservoir levels may not affect hydroelectric power production or recreational uses for many months. Also, water in hydrologic storage systems is often used for multiple and competing purposes (e.g. irrigation, flood control, recreation, hydropower, wildlife habitat), further complicating the sequence and quantification of impacts. Competition for water in these storage systems escalates during drought and conflicts between water users increase significantly (National Drought Mitigation Center, 2015).

1.2. Agricultural water and irrigation system

Climate change in rural areas will take place, with very high confidence, in the context of many important economic, social, and land-use trends (IPCC, 2014). In particular, hydrological drought is decisive about rural areas in the context of climate change impacts, vulnerability, and adaptation. Agriculture and natural resources are greater dependent on hydrological drought, and this correlation makes them highly sensitive to climate variability, extreme climate events, and climate change. Conversely, rural people in many parts of the world have, over long time scales, adapted to climate variability, or at least learned to cope with it through farming practices and use of wild natural resources (often referred to as indigenous knowledge or by similar terms), as well as through diversification of livelihoods and informal institutions for risk-sharing and risk management. Similar adaptations and coping strategies can, given supportive policies and institutions, form the basis for adaptation to climate change, although the effectiveness of such approaches will depend on the severity and speed of climate change impacts (IPCC, 2014).

Irrigation is one of this adaptation strategies. Probably one of the oldest agronomic technique, irrigation is aimed at increasing soil moisture, when natural water supplies and stored reserves are insufficient to cover the needs of the crops (Figure 1.2). In these cases, soil moisture is a limiting factor, therefore, irrigation increases the productivity of agricultural soil offering, as a result, an improvement in the quantitative and qualitative yield. The best yields that can be realized through irrigation are double respect those obtained by rainwater agriculture. Even a limited scale irrigation can get better results than with rainfed agriculture with strong precipitations. However problems of high cost of systems construction, management and maintenance, make that this technique is not predominant worldwide. At global level, irrigated agriculture is spread about 20% of tilled lands, and provides the 40% of world’s food supply (Bellini, 2002).

Figure 1.2 Example of drip irrigation effectiveness (Google images).

Several irrigation systems indicate the mode with which the water should be distributed in the soil. The choice of a method rather than another depends on many factors, such as the availability of water, the morphology and arrangement of the soil, the climate, the source of water supply, the type of crop, the degree of mechanization of the crop, etc. (Bellini, 2002). The main irrigation methods are:

• surface irrigation: in which the crop area is almost or entirely flooded (Figure 1.3 - a.);

• drip irrigation: in which water is dripped onto the soil only over the area of the roots;

• sprinkler irrigation: which imitates rainfall (Figure 1.3 - b.);

• underground irrigation: of the root zone through porous containers or pipes placed in the soil;

• sub-irrigation: in which the saturated level of the aquifer is raised enough to moisten the area of the roots. (Bellini, 2002).

Among irrigation systems the sprinkler irrigation prevailed, followed by the surface system and underground irrigation (INEA, 2013).

a. b.

Figure 1.3 Example of irrigation methods: a. surface irrigations and b. sprinkler irrigation (Google images).

Worldwide agriculture consumes the largest percentage of water: about 69% of all withdrawals (followed by industry 21% and domestic use 10%). Italy is one of the European countries that mainly use irrigation (Figure 1.4). In detail, in Italy, in the agrarian year 2009-2010, the volume of irrigation water used by agriculture amounted to 11’618 Mm^3 (INEA, 2013). According to the Italian Agricultural Census of 2010, about 400’000 farms use irrigation, with an irrigated area of about 2.4 million hectares[3] (divided into: 1’591’746 in North Italy, 145’102 Center and 682’072 in South and Islands), 19% of Utilized Agricultural Area (UAA).

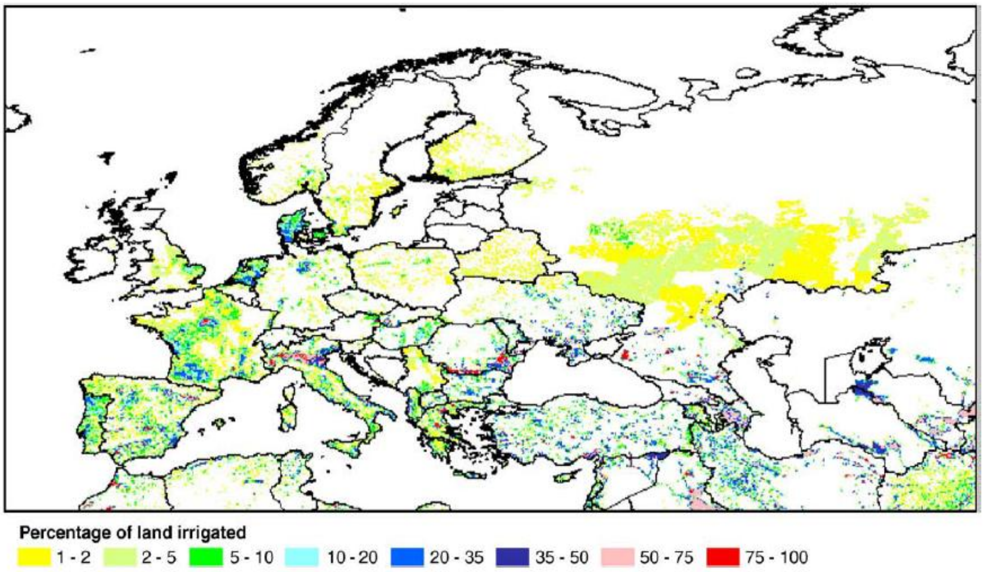

Figure 1.4 Map of present-day irrigated areas in Europe (Siebert et al., 2007)

[3] 2’418’921 hectares of irrigated area in Italy (ISTAT, Census of Agriculture, 2010).

Regarding economic side, intermediate consumption in agriculture in 2011 was, for Italy, 347 million Euros. The main sources of supply were collectively managed aqueducts, followed by groundwater (INEA, 2013).

Worldwide irrigation is used for several culture (e.g. cereals, wheat, fruits, etc.). Regarding Italy, water is used in agriculture for irrigation of rice (41.9% of irrigation volumes), citrus 14.1%, fruit and olive trees consume both the 8.5% of the complex irrigation water, then alternated forage (excluding green maize) with 6.4% and vegetables grown in the open air with 5.7% (Bellini, 2002).

Sources of water supply intended for irrigation are mainly lakes, rivers or water courses (5’071 m^3/ha of irrigated land), natural and artificial basins (4’276 m^3/ha of irrigated land) and groundwater (3’451 m^3/ha of irrigated land) (Bellini, 2002).

An aspect not to be overlooked, is the excessive extraction of water for irrigation (including the illegal extraction). This is, in fact, a serious problem in the EU, especially in many river basins of the Mediterranean, and this prevents the achievement of “good environmental status” established by the Water Framework Directive (see Sect. 1.3). In addition, the situation is even aggravate by wasted water that result by losses in the distribution networks, that could be also at the 50% of the total water introduced in the irrigation system (European Commission, 2011).

1.3. The Water Framework Directive

The Water Framework Directive – WFD (Directive 2000/60/EC establishing a framework for Community action in field of water policy; integrated by the Groundwater Directive (2006/118/EC) and the Directive on Environmental Quality Standards (2008/105/EC)) introduced in the year 2000, posed new and ambitious targets for the protection and recovery of aquatic ecosystems in order to ensure a sustainable use of water for people, businesses and the natural environment. It have an innovative approach in the European legislation on water, by environmental and administrative-management point of view.

The Directive ambitious goals are dedicated i) to prevent the deterioration of water quality and quantity, ii) to improve the status of water and iii) to ensure a sustainable use based on the long-term protection of available water resources by the end of 2015 as the ultimate date by which all European waters should be in good condition. The specific aims of the WFD are achieve the following general objectives:

- expand the protection of water, both surface and underground;
- achieve the state of "good" for all waters by December 31, 2015;
- water management based on river basins regardless of the administrative structures;
- proceed through an action that combines emission limits and quality standards;

- recognize all water services at the right price that takes into account their true economic cost;
- encouraging the active participation of the citizens of the choices made on the subject.

The Directive establishes that Member States should address water conservation at the *river basin* level and the territorial unit of reference for the management of the basin is located in the river basin district, entity formed, where appropriate, by one or more neighboring river basins, large and small, and from the respective groundwater and coastal waters. A river basin covering the territory of several Member are assigned to an international river basin district (DIRETTIVA 2000/60/CE, 2000). The Italian Legislative Decree of April 3, 2006 n°152 has established eight river basin districts in Italian territory. Regarding the case study of this thesis, the basins of Puglia Region belong to “Appennino Meridionale” river basin district (68’200 km^2) (Dlgs. n. 152, 2006).

Member State, through appropriate and operative river basin authorities, should implement: the analysis of the characteristics of the district, reviews of the impact caused by human activities on the status of surface water and groundwater and an economic analysis of water use. The programs of measures are indicated in the Management Plans that Member States must prepare for each river basin and therefore constitutes the programming tool/implementation to achieve the objectives set by the directive (Gazzetta ufficiale delle Comunità Europee, 2000).

Regarding droughts, the major challenge of European Union has been recognized in the Communication *“Addressing the challenge of water scarcity and droughts"* adopted in 2007 by European Commission [COM(2007)414]. The Environmental Council of 30 October 2007 supported the Commission’s 2007 Communication and invited the Commission specifically to review and further develop the Water Scarcity and Drought policy (WS&D). The review of the strategy for WS&D are - together with an analysis of the Implementation of the Water Framework Directive and a review of the vulnerability of environmental resources such as water, biodiversity and soil to climate change impacts and man-made pressures - integrated into a planned "Blueprint to safeguard European waters".

In 2012, based on the periodical *Follow-up Reports*, the Water Scarcity and Droughts Policy Review concludes that the overall objective of the Water Scarcity & Droughts policy - to prevent the WS&D trends - has not been achieved so far, even if progress has taken place in implementing the policy instruments identified in the Commissions Communication from 2007. The WS&D policy has to some extent been considered as self-standing by Member States and a stronger focus on quantity issues in the implementation of the WFD is critical. In the next steps WFD will be ensured along with further integration of water quantity issues into sectoral policies. The characterization includes the analysis of pressures and impacts, economic analysis, the description of water bodies and the definition of the type and reference conditions of surface water bodies, well as the basis of the assessment of the ecological status (European Commission, 2012).

2 Background: ORIENTGATE project and Risk Assessment methods

2.1. ORIENTGATE project: objectives and expected results

The research proposed in this thesis has been implemented in the framework of ORIENTGATE, a project, co-funded by the South East Europe Transnational Cooperation Programme[4] and coordinated by the Euro-Mediterranean Centre on Climate Change[5]. The duration of the project was three years (2012-2014), and the partnership comprises 19 financing partners, 11 associates and 3 observers, covering 13 countries (Appendix 1). The project explored climate risks faced by coastal, rural and urban communities, contributing to better understand the impacts of climate variability and climate change on water regimes, forests and agro-ecosystems. The ultimate objective was to support the development of a knowledge-based decision-making process concerning climate change adaptation strategies with a particular focus in selected case of studies across South Eastern Europe (SEE) countries.

In particular, the project intended to develop and communicate up-to-date climate knowledge for the benefit of policy makers, including urban planners, nature protection authorities, regional and local development agencies, and territorial and public works authorities.

Specific objectives were:

- To develop a comprehensive and consistent methodology for assessing the risks arising as a result of climate variability and change;
- To harmonize risk assessment and communication on the part of hydro-meteorological services;
- To encourage the use of acquired climate adaptation knowledge and experience in territorial planning and development;
- To enhance capacity to reconcile the risks and opportunities inherent in environmental changes, including rising temperatures.

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[4] The **South East Europe Programme** (SEEP) is a unique instrument which, in the framework of the Regional Policy's Territorial Cooperation Objective, aims to improve integration and competitiveness in an area which is as complex as it is diverse. "Jointly for our common future" is the slogan, it is a highly complex programme which presents challenges such as ensuring good mechanisms to contract partners who receive funding from different instruments.
The SEEP is the transnational programme which gathers the biggest number of participating countries: 16. As 8 of these are EU Member States, 6 are candidate and potential candidate countries and 2 are countries participating in the European Neighbourhood Policy (http://www.southeast-europe.net/en/).

[5] The **Euro-Mediterranean Center on Climate Change** (CMCC) is a non-profit research institution established in 2005, with the financial support of the Italian Ministry of Education, University and Research. CMCC manages and promotes scientific and applied activities in the field of international climate change research (http://www.cmcc.it/).

The core output developed by ORIENTGATE project was a set of web tools, designed to provide access to data and metadata from climate observations and simulations that were available through a data platform connected to the European Climate Adaptation Platform (CLIMATE-ADAPT).

The project included six pilot case studies across Europe, characterized by different pattern of climate impacts where specific climate adaptation exercises has been developed by the project's thematic centers: forestry and agriculture, drought water and coasts and, finally, urban adaptation and health.

The implementation of project was organized into seven work packages (WPs), as follow:

- WP1 Transnational Project and Financial Management
- WP2 Communication
- WP3 Mapping, Harmonizing Data and Downscaling
- WP4 Thematic Centre 1 — Forestry and Agriculture
    - Pilot Study 1: Adapted forest management at LTER Zöbelboden (Austria)
    - Pilot Study 2: Climate change adaptation measures in Romanian agriculture
- WP5 Thematic Centre 2 — Drought, Water and Coasts
    - Pilot Study 3: Climate change adaptation in the new water regime in Puglia region, Italy
    - Pilot Study 4: Effects of climate change on wetland ecosystems in Attica region (Greece)
    - Pilot Study 5: Water resources and hydroelectric use in Trento, Italy
- WP6 Thematic Centre 3 — Urban Adaptation and Health
    - Pilot Study 6: Vulnerability assessment in Budapest and Veszprém (Hungary)
- WP7 Regional Planning Cross-Sectoral Study

The Risk Assessment and Adaptation Strategies Division of the Euro-Mediterranean Center on Climate Change (CMCC) (http://www.cmcc.it/), based in the Department of Environmental Sciences, Informatics and Statistics of Ca' Foscari University of Venice (http://www.unive.it/pag/2378/) was involved in the WP5 Thematic Centre 2 - Drought, Water and Coasts, in particular in the Pilot study 3: Climate change adaptation in the new water regime in Puglia region, Italy. This pilot study, supported the development of specific tools and guidelines for local and regional decision makers in order to improve water resources management and planning, by taking into account impacts on domestic water supply, agriculture and coastal areas from terrestrial and marine hazards, related to climate change and variability (ORIENTGATEproject.org, 2015). The overall methodology for Pilot Study 3 has been designed through a comprehensive integrated approach by connecting data, models, downscaling procedures, spatial analysis techniques, decision support tools and indicators, into a chain of activities ranging from hazard quantification (at process level: climate and hydrology) up to vulnerability and risk assessment (at resource/sector level: water, agriculture and coasts). Links among these components are strongly based on the use of indicators, aimed at synthesizing complex scientific information into quantities easy understandable and communicable to stakeholder and policy makers (Martinez et al., 2012). To effectively promote the integration of knowledge into decision making, indicators have been grouped into hazard, exposure, vulnerability and risk categories, sensu IPCC (2014).

The overall integrated approach that characterize the scientific track of the project was articulated into five modules, schematized in Figure 2.1. Starting from the main component represented by climate modeling, providing simulations about future atmosphere and ocean regime for the Puglia Region (Modules 1 and 2), the risk assessment was performed considering drought hazards scenarios (both for the agro-meteorological and hydrological component) (Module 3) and the consequent impacts on rainfed/irrigated agriculture (Module 4), as well as to quantify the potential consequences of rising sea levels on low-lying coastal areas (Module 5).

Withis this study, in particular, the development and application of a Regional Risk Assessment for the climate change impacts on irrigated agriculture (Module 4) has been addressed.

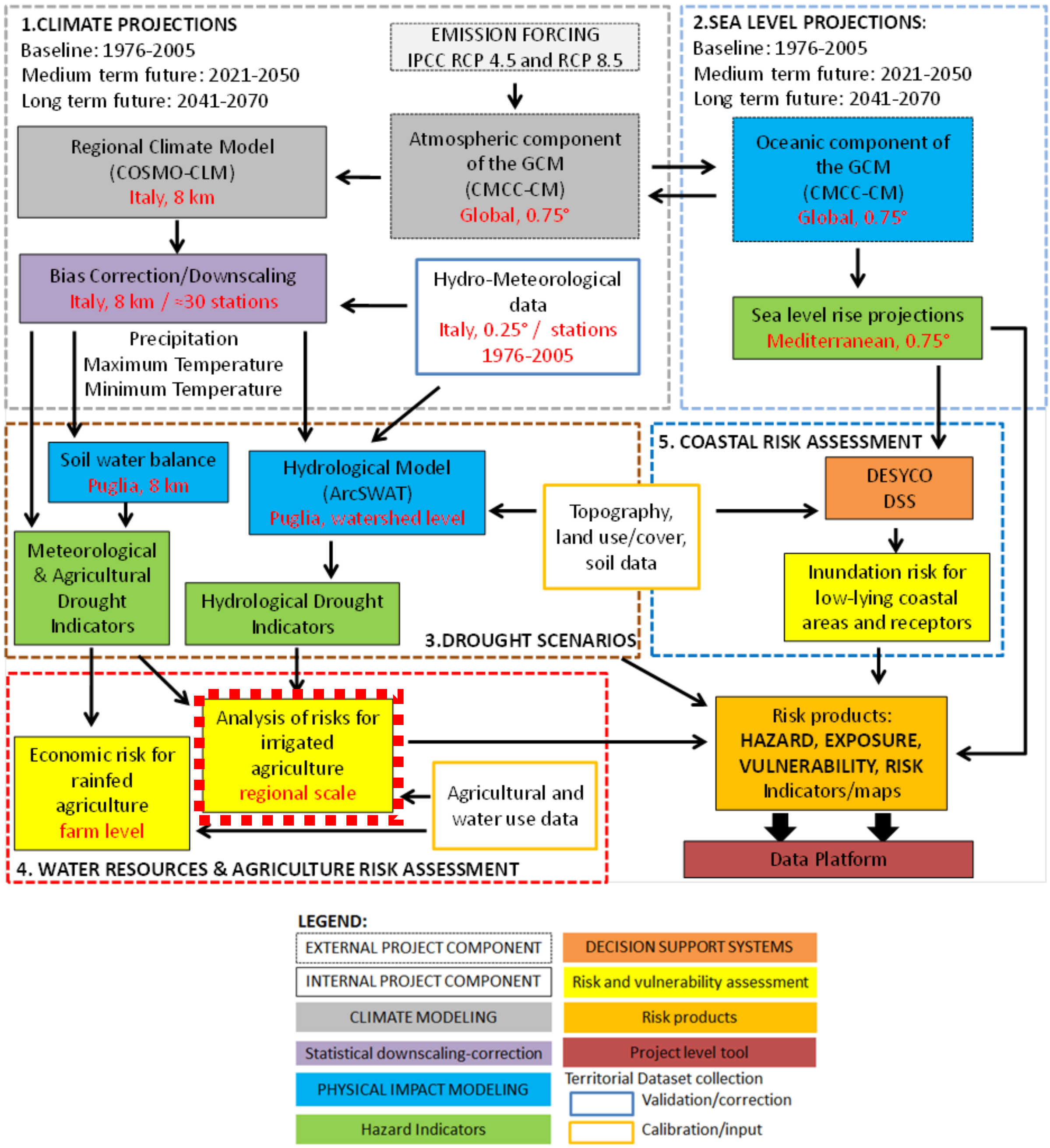


Figure 2.1 Scheme of WP5 task 2, Pilot study 3 modules (CMCC, 2015).

2.2. Climatic scenarios

As far as the temporal characterization of the climatic scenarios is concerned, the ORIENTGATE project considered the period 1976 to 2005 as baseline for comparing future trends, and two different perspectives for the future: the medium term, from 2021 to 2050 and the long term, from 2041 to 2070. In each future scenario the characterization of a likely range of future conditions was performed by considering climate and impacts under different emission scenarios. The basis of the projections were the ones adopted by IPCC for its fifth Assessment Report (IPCC, 2014), known as “Representative Concentration Pathways (RCP)”.

It is worth to notice that levels of future emissions are still largely uncertain, for this reason emission scenarios provide alternative images of how the future might unfold. Scenarios describe future releases into the atmosphere of greenhouse gases, aerosols, and other pollutants and, along with information on land use and land cover, provide inputs to climate models (IPCC, 2013).

RCPs scenarios are expressed in terms of concentrations of greenhouse gases (the result of emissions) rather than in terms of emission levels. Each scenario implies a different magnitude of climate change produced by human activities (e.g. each RCP shows a different amount of additional heat stored in the Earth system as a result of greenhouse gas emissions). The scenarios reflect, in turn, a wide range of possible mitigation actions (World Meteorological Organization, 2015), that are based on assumptions about driving forces such as patterns of economic and population growth, technology development, and other factors. Scenarios convey to the analysis on how driving forces may influence future emission outcomes and to assess the associated uncertainties. They assist in climate change analysis, including climate modelling and the assessment of impacts, adaptation, and mitigation, but, it’s important underline that the possibility that any single emissions path will occur as described in scenarios is highly uncertain (IPCC, 2013).

Conceptually, the process begins with pathways of radiative forcing, not detailed socioeconomic narratives or scenarios. Within ORIENTGATE project two RCPs (RCP4.5 and RCP8.5) were selected and used, according to their total radiative forcing in 2100. The number associated with each RCP indicates the strength of climate change caused by human activity by 2100 compared to pre-industrial period (it’s important underline that the climatic changes will continue after 2100 and temperature remain high for many centuries even after CO_2 emissions have ceased) (Moss et al., 2008).

Each scenario leads to different results on the extent of climate change produced by human activities. Any scenario necessarily includes subjective elements and is open to various interpretations. No judgment is offered by IPCC as preference for any of the scenarios and there isn’t assigned probabilities of occurrence (IPCC, 2014).

In particular **RCP4.5** is a “medium-low” magnitude scenario, that assume that selected initiatives to reduce emissions are undertaken (e.g. cuts on greenhouse gas emissions of anthropogenic origin, through large-scale changes of energy systems and land use: bioenergy, direct solar energy, geothermal energy, hydropower, Ocean energy, wind energy, etc.) (Victor et al., 2014). This is a stabilization scenario that stop radiative forcing at 4.5 W/m² in the year 2100, without ever exceeding that value (Thomson et al., 2011). By 2070, CO_2 emissions fall below current levels and the atmospheric concentration stabilizes by the end of the century at about twice the pre-industrial levels (World Meteorological Organization, 2015).

RCP8.5, instead, assumes an approach "business-as-usual": by the year 2100, atmospheric CO_2 concentrations are tripled or quadrupled compared to the pre-industrial levels. This RCP combines assumptions about high population and relatively slow income growth with modest rates of technological change and energy intensity improvements, leading in the long term to high energy demand and greenhouse gas emissions in absence of climate change policies. Rising radiative forcing pathway leading to 8.5 W/m² in 2100, that, compared to the total set of RCPs, corresponds to the pathway with the highest greenhouse gas emissions (Riahi et al., 2011).

The emission scenarios RCP4.5 and RCP8.5 have been considered for the two different time-horizons selected and allowed to have, in total, four different future scenarios, as follow:

- scenario 1: RCP4.5 years 2021-2050;
- scenario 2: RCP4.5 years 2041-2070;
- scenario 3: RCP8.5 years 2021-2050;
- scenario 4: RCP8.5 years 2041-2070.

In Figure 2.2 is represented the Radiative Forcing of the Representative Concentration Pathways projected in the year 2100 (Van Vuuren et al., 2011).

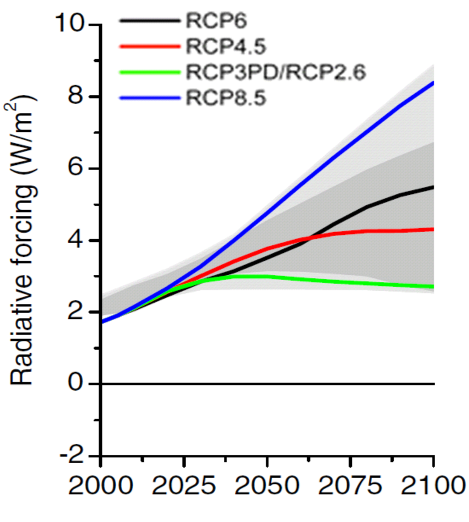


Figure 2.2 RCPs Radiative forcing in relation with years: RCP 4.5 red line and RCP8.5 blue line. (Van Vuuren et al., 2011).

2.3. Integrated assessment of climate change impact on irrigated area

"Drought trends emerges slowly and then intensifies until people can no longer ignore it or simply hope this will stop. When drought ends, people are often happy to forget it and to resume business as usual. But people and decision makers also need to stop and learn from their experiences. Climatology shows that drought will happen again and in the future more frequently. What can people learn from one drought that reduce the impacts and damages of the next? How information on future trend can additionally help on this?" (National Drought Mitigation Center, 2015). The pilot study in Puglia Region focus on identifying tools and guidelines to support local and regional decision makers for a knowledge-based planning, management and protection of the areas, focusing on change impacts of droughts that influence water availability, determining its scarcity, and affect all sectors competing for water resources.

2.3.1. Regional Risk Assessment: introduction and general features

Climate change due to the enhanced greenhouse effect can be defined as an environmental risk in two senses: (1) the environment is directly exposed to risk from climate change, and (2) environmental change resulting from climate change may threaten human activities.

Environmental Regional Risk Assessment (RRA), proposed for the first time in 1997 by Landis and Wiegers, is the process of identifying, evaluating, selecting, and implementing actions to reduce risk to ecosystems and to human health (USPCC RARM, 1997). The increasing importance of environmental quality to the economy, human health and ecosystems has influenced a number of recently formulated environmental risk assessment/risk management frameworks (Power and McCarty, 1998). The focal point of RRA is that this methodology considers the presence of multiple habitats and multiple sources releasing a multiplicity of stressors impacting multiple endpoints (Landis, 2005).

Risk is defined by the US Presidential/Congressional Commission on Risk Assessment and Risk Management (USPCC RARM)[6] as "the probability that a substance or situation will produce harm under specified conditions". Risk analysis is the process of assessing these two factors:

i. The probability that an adverse event will occur.
ii. The consequences of the adverse event (USPCC RARM, 1997).

[6] **Commission on Risk Assessment and Risk Management** (also known as Presidential/Congressional Commission on Risk Assessment and Risk Management) is a commission authorized as part of the Clean Air Act Amendments of 1990 to develop recommendations for how the United States Environmental Protection Agency would perform risk assessment as a part of developing air quality regulations.

Risk Assessment can be related with climate change impacts, in order to try to achieve important objectives:

i. identification and prioritization of areas and targets at risk from climate change in a considered region;
ii. identification of homogeneous areas (e.g. homogeneous geographic sites for the definition of adaptation and management strategies) resulting from the aggregation of multiple climate change stressors and vulnerable exposure units;
iii. definition of the consequences / impacts of future climate on vulnerable or climate-sensitive exposure units and receptors;
iv. helping decision-makers in examining the possible risks and damages associated with uncertain future climate and in identifying where adaptation to climate change may be required.

IPCC describes the role of the risk assessment as to assess on a comprehensive, objective, open and transparent basis the scientific, technical, and socio-economic information relevant to understanding the risk of human-induced climate change, its potential impacts, and options for adaptation and mitigation (IPCC, 2013).

Specifically, with the aim to rank potential impacts, targets and areas at risk from climate change at the regional scale, the RRA methodology integrates the three main pillars of risk defined by UNISDR (2009) and IPCC (2012): hazard, exposure, and vulnerability. In fact, the severity of the impacts of extreme and non-extreme weather and climate events depends strongly on the level of hazard, vulnerability and exposure to these events. Trends in vulnerability and exposure are major drivers of changes in risk impacts. Understanding the multi-faceted nature of this three factors is a prerequisite for determining how weather and climate events contribute to the occurrence of environmental, social and economic issues, and for designing and implementing effective adaptation and management strategies (Cardona et al., 2012).

Risk is often represented as probability of occurrence of hazardous events or trends multiplied by the impacts if these events or trends occur (IPCC, 2014). In the last IPCC WG2 AR5 (2014), the risk is defined as "The potential for consequences where something of human value (including humans themselves) is at stake and where the outcome is uncertain". Risk results from the interaction of vulnerability, exposure and hazard, very often expressed by the equation:

$$\boldsymbol{Risk}\ (\boldsymbol{R}) = \boldsymbol{Hazard}\ (\boldsymbol{H}) * \boldsymbol{Exposure}\ (\boldsymbol{E}) * \boldsymbol{Vulnerability}\ (\boldsymbol{V}) \qquad (2.1)$$

In which:

- **Hazard (H)** 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 (IPCC, 2014). The United Nations International Strategy for Disaster Reduction (UN/ISDR, 2009) defined a natural hazard as: "Any natural process or phenomenon that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption or environmental damage". Between major categories of environmental hazard there is the hydrological hazard that include river floods, coastal floods and drought (Smith, 2013). Drought ranks as the natural hazard with the greatest negative impact on human livelihood (Arnold et al., 2006).

- **Exposure (E)** is defined as 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 (IPCC, 2014). Exposure analysis is the science that describes how an individual or population or an environmental asset comes in contact with an hazard, including quantification of the amount of contact across space and time. To characterize exposure, the processes take place at the interface between the environment containing the hazard (or contaminants) of interest and the receptors being considered (US EPA, 2015).
- Finally, **vulnerability (V)** is the propensity or predisposition of an expose element 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 (IPCC, 2014). Vulnerability was also defined by UN/ISDR as: "The characteristics of a community, system or asset that make it susceptible to the damaging effect of hazard" (UN/ISDR, 2009).

Several specific contexts and systems can be dealt with a risk assessment. A growing number of studies have presented themselves as Regional Risk Assessments of climate change impacts. Such studies include for example global sea-level rise (Shepar et al., 2011), forest disease (Kliejunas, 2011), impact on groundwater (Pasini et al., 2012), loss of biodiversity (Bellard et al., 2012), flood risk assessment (Zhou et al., 2012, Ronco et al., 2014), etc. Most of these studies, explicitly or implicitly, measure risk in terms of thresholds and use as inputs two or more climate scenarios or a projected range of uncertainty bound by low and high extremes.

2.3.2 Development of an innovative methodological approach for drought Regional Risk Assessment

Even though there are many uncertainties in the prediction of future climate change, is widely accepted that global warming could accelerate the global hydrological cycle, and therefore change the frequency of drought and flood disasters (Mu et al., 2009). Literature shows that risk of hydrological drought due to climate change, due to many factors, cannot accurately be predict by human beings. In the future of hydrological scheme always exists uncertainty, and therefore, risk is inevitable (Karimi and Hüllermeier, 2007): *"…The first rainless day in a spell of fine weather contributes as much to the drought as the last, but no one knows how serious it will be until the last dry day is gone and the rains have come again."* (Tannehill, 1947).

Regional Risk Assessment support the identification and ranking of hotspots and areas at risk in order to support the development of appropriate mitigation, prevention and adaptation strategies and actions. In fact, a comprehensive, multidisciplinary and integrated approach is essential to monitor drought effectively in a dry region as is Puglia, Italy. It is important realizes early warning to reduce the impact on agricultural production making the best possible use of available datasets. By using up-to-date vulnerability indicators and by developing new (tailored) ones along with an innovative characterization and computation of the hazard score pattern, the proposed RRA method allow to identify the spatial pattern of drought risk for the irrigation-fed agricultural compartment in Puglia Region.

In recent years, an increasing number of studies focus on natural disaster risk analysis and assessment of droughts among others (Liu et al., 2010). Regional Risk Assessment methods have been applied in several studies in order to assess drought risk. In Bangladesh for instance, drought is a recurrent phenomenon where many tens droughts of major magnitude have been experienced (Ramamasy and Baas, 2007). In 2008, Shahid and Behrawan investigate the extent and impact of droughts in the western part of Bangladesh. They developed a method for spatial assessment of drought risk, that combine hazard and vulnerability, by means of a standardized precipitation index method in GIS environment to map the spatial extents of drought hazard in different time horizons. The assessment identified the key social and physical factors that define vulnerability to drought in agricultural lands, in that particular context and corresponding drought vulnerability map were produced. Finally, the risk is computed as the product of the hazard and vulnerability (Shahid and Behrawan, 2008).

A methodology for risk analysis and assessment of drought disaster to agricultural production has been presented by Jiquan Zhang in 2003. In his study, Zhang combined the model of risk assessment of drought disasters with the occurrence frequency, duration and intensity of drought applied to the maize production. By using the quantitative risk analysis approach, the authors developed a crop yield-climate and a regression analysis to evaluate the consequences of drought disaster based on historical climate, crop yield, crop sown area, crop damaged area and crop loss data from 41 maize-producing districts of Songliao Plain in China (1949-1990). The results shown that drought was the greatest agro-meteorological disaster since it occurred with the highest frequency, covers the largest area, and causes the greatest loss to agricultural production and economy in the region (Zhang, 2003).

Recent drought events in the United States and the (high) magnitude of losses confirmed the continuing vulnerability of this country to drought events. So far, drought management strategies in many states of the USA has been largely response-oriented with little or no attention to mitigation and preparedness measures. One of the main aspects of drought mitigation and planning is the assessment of who and what is vulnerable and why. In 1998, Nebraska began to revise its drought plan in order to place more emphasis on mitigation. Wilhelmi and Wilhite in 2002, presented a method for spatial, GIS-based assessment of agricultural drought vulnerability in Nebraska. They hypothesized that the key biophysical and social factors that characterize agricultural drought vulnerability were climate, soils, land use, and access to irrigation. By means of a innovative (numerical) weighting scheme to evaluate the drought potential for these factors, an agricultural drought vulnerability map was produced for that region. The results indicate that the most vulnerable areas to agricultural drought were non-irrigated cropland and rangeland on sandy soils, located in areas with a very high probability of seasonal crop moisture deficiency (Wilhelmi and Wilhite, 2002).

As these studies confirmed, the assessment of drought risk could give a relevant support to stakeholders in an awareness-based decision making process as well as in communicating the (complex) concepts of hazard-vulnerability-risks to agricultural producers, natural resource managers, and others stakeholders (Wilhelmi and Wiljite, 2002). The purpose of assessing risk is to identify appropriate actions that can be taken to reduce vulnerability before the potential for damage is realized. Despite limitations, available information on regional drought risk could aid decision makers in identifying appropriate mitigation actions before the next drought event and lessen impacts of that event. Accordingly with this argumentations, this thesis developed a method for assess the risk that hydrological drought involves on an irrigation compartment, by using geographic processing techniques. The developed methodological approach for drought Regional Risk Assessment is innovative, and it was designed (and applied) for Puglia Region case study (see Chap. 3), but, at the same time, it is ensue by theoretical definitions of RRA (see Sect. 2.3.1).

3. Case study: Puglia Region

The Regional Risk Assessment (RRA) methodology developed in the framework of the ORIENTGATE project has been successfully applied in Puglia Region to assess the risk due to climate change that induce droughts for the local irrigation compartment. Puglia is located in the southeast of Italy (between 41°53’N - 39°48’N and 14°49’E - 18°35’E) bordering the Adriatic Sea to the east, the Ionian Sea to the southeast, and the Strait of Otranto and the Gulf of Taranto to the south. Its southern part, known as Salento, forms a peninsula: the heel of the well-known “Italian boot”. The region comprises an area of 19’345 km^2 and has a population of about 4 million people (density of 210 inhabitants/km^2); the capital of the Region is the city of Bari surrounded by six provinces (Bari, Foggia, Barletta-Andria-Trani, Taranto, Brindisi and Lecce) and 258 municipalities (ISTAT, 2011).

The economy is concentrated in tourism and agriculture, with a share of Gross Domestic Product (GDP) above the national average (5.24% in Puglia vs. 2.65% in Italy). A smaller and declining role is played by the industry, except the food industry, and this emphasizes the strong role of agriculture, complemented by fishing. Farming used to be the main occupation (driven principally by the forefront in the production of olive oil (32%), wine and wheat (9%) (Lionello, 2008)), while fishing is very active in the Adriatic sea and in the Gulf of Taranto (OECD, 2011).

As far as the geomorphologic setting is concerned, the Region is mostly flat and hilly. Gargano and Appennnino Dauno are the only mountainous areas of Puglia. The substrate is constituted almost 80% from limestone and dolomite rocks of large extensions and arranged in vast horizontal or sub-horizontal strata; the structure of the underlying rock confers smoothness to the landscape. Due to high substrate permeability and infiltration of rainwater, there are few rivers: Candelaro, Cervaro, Carapelle, Ofanto and Fortore are the most important ones. The prevailing karst nature of the area limits the availability of surface water resources and gives particular value to groundwaters.

In the past Puglia’s groundwater aquifers were valuable for quality and very important, given the scarcity of alternative resources. This resources were exploited increasingly since the early decades of the last century. To date, despite the scientific knowledge, management policies applied have not prevented a gradual degradation of this resources (Polemio, 2011).

Regarding vegetation, the protagonist of the Puglia’s landscape is the olive tree. Along the coast the expanses of olive trees leave space to the Mediterranean scrub, a set of shrubs able to resist naturally also to the torrid summer climates. In the past, most of Puglia’s territory was probably covered with Mediterranean scrub composed of evergreen bushes and trees, but today only 67’000 hectares remain wooded, the 5% of the entire territory of the Region (Fiore et al., 2010).

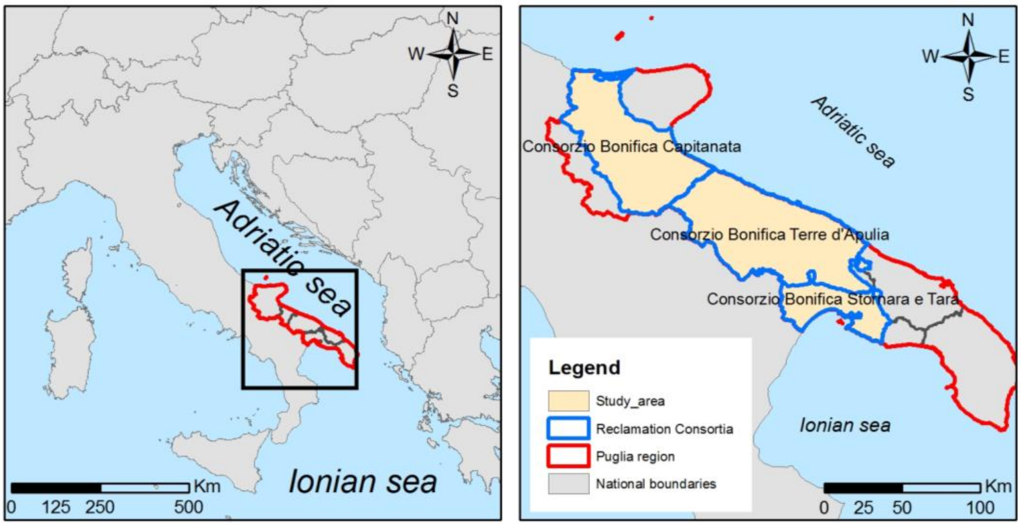


Figure 3.1 Puglia Region and study area.

3.1. Climatic pattern

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 (this condition can lead to snowfall even at low altitudes).

On average, the Region accounts to only 500 mm of rain spread within 60 to 80 days per year; with the maximum in November - December and a minimum normally in July. Instead, the interannual variability of precipitations is not negligible: in Bari, for example, in 1913 the total rainfall amounted to only 371 mm while the following year it was almost three times more (1’095 mm) (Autorità di Bacino della Puglia, 2004). The spatial pattern of (total annual) precipitations ranges from 1000 mm in Gargano area (intercepting robust and humid easterly winds), to a minimum of 400 mm close to the plains of the Gulf of Taranto, where prolonged periods without rains can happen quite frequently. Values about 600-700 mm are observed in Murgia and close to the Apennine hills at the border with Campania and Molise (Reale et al., 2011). For the period 1951-2000, total annual precipitation across Puglia has significantly decreased at a rate of 23.9 mm/decade, which would approximately imply a one third reduction of the mean value if this trend would continue for one century (Lionello et al., 2010). Finally, snow is rare except in the central Gargano and in some small spots in the Sub Appennino Dauno.

The differences in temperatures between summer and winter times are pronounced: in inland plains the maximum reaches more than 40°C in summer while the minimum is -2°C / 3°C in the winter mornings. Moreover, data from CIRCE project suggests a narrowing of the daily temperature range for the period 1951-2000; in fact, the (mean) annual minimum temperature (T_{min}) has warmed at a rate of about 0.11°C/decade while the (mean) annual maximum temperature (T_{max}) has not changed significantly (Lionello et al., 2010).

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. Combined trends of increasing evapotranspiration and decreasing precipitation implied a progressively larger water deficit (Hemming et al., 2013), as the Figure 3.2 clearly shows with respect to the Thornthwaite Climatic Index (I)[7]. It combines evapotranspiration (Ep) and precipitation (P), Equation 3.1:

$$\boldsymbol{I} = \frac{\overline{\boldsymbol{P}} - \overline{\boldsymbol{Ep}}}{\overline{\boldsymbol{Ep}}} \qquad (3.1)$$

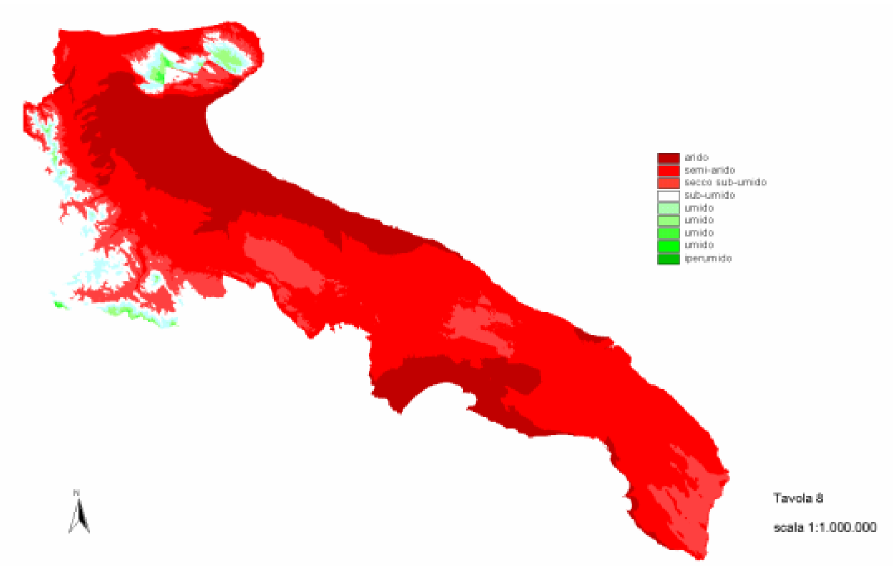


Figure 3.2 Representation of Thornthwaite Climatic Index in Puglia region (CMCC, 2015)

Actually, recently Puglia Region has been alternatively affected by extreme events related to out-of-normal climatic years, e.g. droughts in 2011-2012, floods in 2013-2014 and fast fluctuations of droughts/floods in 2008-2009, that caused pollution in the Occhito reservoir (WHO, 2011). This (climatic) severe pattern of variability under opposite extremes can lead to dramatic consequences, since it endangers: i) the

[7]**Thornthwaite Climatic Index (I)** combines evapotranspiration (Ep) and precipitation (P) to classify climates (arid to humid); P is expressed in mm of annual precipitation and Ep is the potential average annual evapotranspiration in mm and is determined by the sum of all the monthly mean values of the same parameter.

availability of (sub)surface water and soil moisture to offset the evapotranspiration demand from crops, not fully satisfied by rain; ii) the temporal reliability of water yield from existing infrastructures for water accumulation/diversion (single and multipurpose dams); iii) the quality of water to be provided for agricultural production and domestic uses; iv) the standards required (e.g. minimum environmental flow) to maintain the ecological function of water in rivers and/or lakes. Population growth and tourism (EUROIDEES, 2014) worsen this situation by increasing the region overall vulnerability because of decreasing water availability and increasing water demand particularly during summer (CMCC, 2015).
Climate model projections suggest warmer and drier conditions also over the next few decades (Goodess et al. 2013): a further increase in the water deficit would not be sustainable and would have a large negative impact on the human and agricultural sectors, and on the environment (CMCC, 2015).

3.2. Hydrological pattern

The landscape of the Puglia Region is dominated almost everywhere by limestone covered by rock formations or by layers of agricultural soil, more or less thin. It is within this particular geological pattern that lies the roots of droughts, an authentic concern for this Region. In fact, the predominantly karst territory, except for the Tavoliere, makes the Region poor of surface waters, such as lakes (Lesina and Varano lakes). For centuries, the people of the Region relied only to the few spring waters and those underground karst (Autorità di Bacino della Puglia, 2004).

Among the rivers the most important is Ofanto that borns in Irpinia and, after a path along 165 km (85 km of which interest the Puglia territory), flows into the Adriatic to the North of Barletta. Among the streams that run through the Tableland we can remember: Candelaro (70 km), Salsola (60 km), Cervaro (80 km), Carapelle (85 km), Celone (59 km) and other of minor interest. These rivers are mainly seasonal, and their average flow is very small. In general, the regime is highly irregular and torrential, characterized by lean summer and autumn-winter floods. Other rivers of regional interest are Fortore (86 km, including 25 km in Puglia), Lato and Galasso in the province of Taranto and the Canale Reale at Brindisi. Negligible is the contribution of Bradano river that flows almost entirely in Basilicata. In correspondence of the limestone outcrops, the superficial hydrography is absent: on the Murge, for example, there is a series of erosive gullies generally characterized by a flat bottom, called "lame" (Engl.: blades). These “blades” are the remains of an ancient superficial hydrography now disappeared. Only in the case of very abundant precipitations, they can convey, for short periods, limited discharges (flash floods).

3.3. Agronomic pattern

In order to mitigate the severe impact of its challenging climate and vegetation features on the agricultural production and productivity, the (spatial) agronomic pattern of the Puglia Region has been deeply modified (and improved) by the intense and widespread intervention of the local stakeholders (including the government) through prolonged land-recovery practices. The land use composition derived from the Corine Land Cover (CORINE, 2006) coupled with regional and national statistical datasets, demonstrates that agriculture is the most important economic compartment for Puglia and its production is one of the most relevant in Italy (Reale et al. 2011). Currently, about 80% of its area is used for agricultural purposes (about 14’700 km^2) (Table 3.1), while only 10% of the territory is occupied by natural vegetation (Aretano et al., 2006).

Puglia’s climatic conditions limit the conduction of agricultural activity of crops that do not require very fertile land (43% of the total cultures) (Lionello et al, 2008). 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, 2014).

Table 3.1 Coverage of the most relevant crops for the Puglia Region. Corine land cover dataset (CORINE, 2006).

Crops	Coverage [ha]
Non irrigated land	716’391
Rice	0
Vineyards	127’242
Fruit trees	10’627
Olive groves	401’179
Pastures	52’946
Annual crops associated with permanent crops	73’537
Complex cultivation patterns	225’165
Land principally occupied by agriculture, with significant areas of natural vegetation	11’007

As described along with the 6° General Agricultural Census of ISTAT (2010), the network of irrigation infrastructures in Puglia, allows to reach a large share of cultivated land (64.4% of the total area) that corresponds to almost 244'270 hectares) with a volume of water of 2’792.54 m^3/ha/year. The use of water resources for irrigation purposes is mainly intended for the cultivation of olive groves, vineyards, fruit trees and vegetable crops (Regione Puglia FEASR, 2010; CORINE, 2006). Puglia holds the 9.8% of the irrigated area of Italy and the 34.6% of southern Italy (ISTAT, 2014).

Irrigation requirements vary greatly from crop to crop. They are, moreover, as function of climatic trend, but, in general, they can be identified in the seasonal irrigation volumes used by Capitanata Reclamation Consortia (and they can be generalized for the entire Puglia Region). This volumes are: vineyards 1800/3000 m^3; olive groves 2000/3000 m^3; fruit trees (peach tree) 3000 m^3 and vegetables (tomato 4000/5000 m^3 and artichoke 2500/4000 m^3) (www.consorzio.fg.it, 2015).

In the drought-affected regions of Mediterranean basin (e.g. Spain, Greece, Turkey), several studies show that it is already facing the impacts of climate change on water yields (García-Ruiz et al., 2011; López-Moreno et al., 2010; Ludwig et al., 2011). For example in the Iberian Peninsula, the demand for water in different watersheds ranges between 55% and 224% of water supply (Sabater et al., 2009).

At the sub-basin scale the supply is, very often negatively correlated to the demand. In Puglia Region, in general, the hot and dry climate with the consequent alteration of the rainfall pattern and intensity (more rains during the fall/winter period) endangers some serious concerns as far as the (competitive) use of water resources is concerned. In fact, the limitation of the available water stocks for the competitive scenario of users from different (industrial, domestic, agricultural) sectors could trigger severe consequences for the productivity of the same but also for the quality of the scarce waters (Giglio et al., 2010). A reduction in water quantity implies a higher cost for agricultural production, because soil is more dry and intense irrigation is required during most of the growing season. This could lead to reduce market competitiveness of local (cash) valuable crops products some, such as vegetables and fruit trees (Lionello at al., 2010). In addition, agricultural water demand is likely to increase if the warming trend observed for the period 1976-2000 continues in the (forecasted) future.

Moreover, as far as the impact of climate change on the agronomic compartment is concerned, future projections and results from CIRCE project (Reale et al., 2011) suggest that regarding crops-specific yields, vineyards and olive crops could be negatively affected by the drier and hotter climate forecasted in Puglia for the first half of 21st Century. Conversely, other results (Mereu et al. 2008; Ponti et al. 2014) suggest that olive production could be favored by new climate regimes, as high temperatures are optimal for growth and development of this crop, giving a higher yield and therefore greater profit. However, new climate regime could also change the suitability of lands (Ferrise et al. 2013; Moriondo et al. 2013) and the crop exposed to (new) invasive pests (Ponti et al. 2014).

Generally, the progressive increase of irrigation practices causes concern for the long-term sustainability of water resources, with economic implications for the population, effects on the working force characterization at regional scale and regular availability of water for domestic uses (Lionello et al., 2008).

Figure 3. Puglia’s typical landscape: olive groves coverage. (Google Maps image)

3.4. Networks of infrastructures for irrigation

The demand for ecosystem services cannot be fulfilled at the local scale, but it can be fulfilled at larger scales (regional, continental): large networks of infrastructures are required, in fact there are spatial differences in the supply and demand of ecosystem services such as water provisioning (Boithias et al., 2013). Networks of infrastructures for irrigation are recognized as one of the urgent vulnerabilities of Puglia under future climate change scenarios, the use of water resources shares is about 54% for agriculture, 36% for domestic use, and 10% for industry (Figure 4.1). Currently, Puglia needs to import waters stocks from nearby regions (up to half of the resource is traded in, reaching 75% for domestic use as well as to extract water from deep aquifers in order to fulfill its demand for irrigation purposes (SOGESID, 2009). Overexploitation of groundwater from private wells is already an issue at a regional scale, since a regulation plan for groundwater exploitation is missing, leading to depletion of underground water bodies in quantity but even in quality especially favoring sea water intrusion (Polemio et al. 2007; Piccinni et al. 2008).

Water scheme is the set of large hydraulic infrastructures that connect sources (of supply) and end-users of water for different purposes (domestic, irrigation and industrial). The hydro-morphological characteristics of Puglia Region, which impede the stock of large volume of surface waters, able to fulfill anthropic needs as stated above, has required the development of large interregional water schemes, in order to meet the water demands of Puglia and the surrounding Regions (Basilicata, Campania, Calabria and Molise). The most important (multi-purpose) water schemes are: Fortore scheme (Puglia and Molise), Ofanto scheme

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

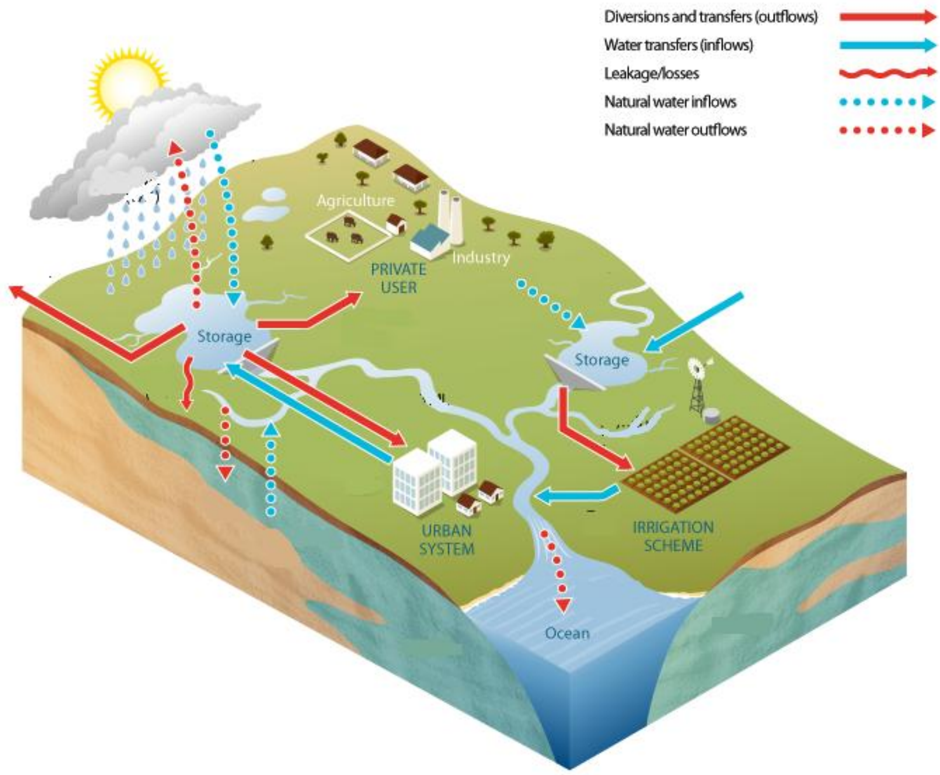


Figure 4.1 Schematization of the system of water transfer for anthropic purposes.

The most important water schemes of Puglia Region analyzed in this thesis are briefly explained below:

- **Fortore scheme:**

The Fortore scheme is shared by two Reclamation Consoria: the Capitanata Reclamation Consortia (for Puglia Region) and the Consortium Larinese (in Molise Region). The sources are constituted by the Occhito Reservoir that is supplied by the Fortore river, and by the Celone reservoir on the homonymous stream.

Fortore scheme supplies the irrigation requirements of Puglia and Molise Regions with 86 and 1 Mm^3 of water respectively, derived exclusively from the Occhito Reservoir.

The scheme, for orographic diversity of the territory which underpins, is divided into two districts: North Fortore and South Fortore.

The Occhito Reservoir, with a total (theoretical) capacity of 250 Mm^3, drains catchment area of about 1'000 km^2; the dam is made of natural materials. Actually, the real capacity amounts to 137 Mm^3, as average of the last 10 years.

The Reservoir of Celone was realized on the homonymous river with a useful capacity of 17 Mm^3. The management of the Reservoir is currently entrusted to the Consorzio per la Bonifica della Capitanata. Currently, the reservoir is not in use but still in an experimental phase.

Waters derive from the Occhito reservoir to the distribution network through a gallery of adduction of 16 km long with a flow rate of about 30 m^3/s. In Finocchito, a splitter derives the flow in four different directions: North Fortore, Ente Autonomo Acquedotto Pugliese implants, Staina district and South Fortore (EIPLI, 2014).

- **Ofanto scheme:**

The Ofanto scheme relies on five different reservoirs: Conza and Osento in Campania, Rendina in Basilicata, Marana Capaciotti and Locone in Puglia. Water distributed by the scheme, are enough to fulfill the irrigation and industrial requirements of Lucania and Puglia territories of the middle and lower Ofanto.

- **Bradano Scheme**

The Bradano river basin has a catchment area of about 3000 km^2. The most important water resources are represented by the inflow of the Basento river and its tributary Camastra torrent. The Reservoirs are: San Giuliano dam (30 Mm^3), Fontanelle on Torrente Camastra, the trasverse of Trivigno on Basento River and the reservoirs of Acerenza-Genzano belonging to the basin of the Bradano river. Overall, the scheme can rely on 175 Mm^3 of water to fulfill the requirements of three different sectors: civil 25 Mm^3, irrigation 130 Mm^3 and industrial 20 Mm^3.

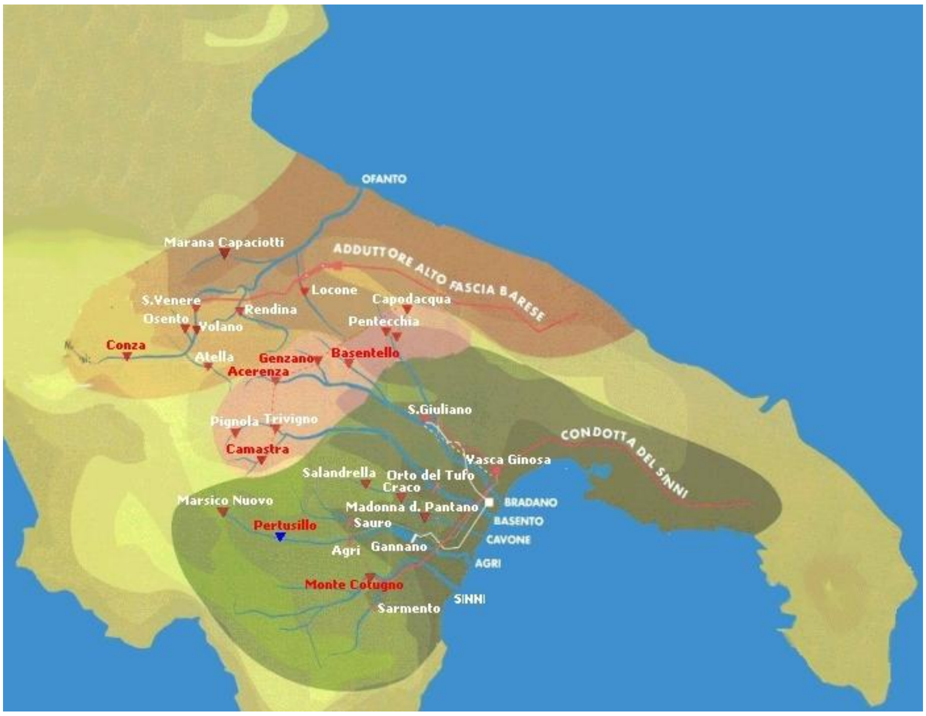
- **Jonico-Sinni scheme:**

The Jonico-Sinni scheme supply water to a large territory covering the provinces of Potenza, Matera, Taranto, Brindisi and Lecce as well as part of the province of Cosenza. The main sources are represented by Monte Cotugno Reservoir over the Sinni river, with the useful capacity of 430 Mm^3, and the Pertusillo Reservoir on Agri river, with an useful capacity of 145 Mm^3. The Reservoir of Monte Cotugno can also receive waters of Sarmento stream, of Sauro river and differential basin of Agri river. The distribution of water is regulated through a complex network of pipelines, in particular the one of Sinni with which extends until the Salento peninsula. Total volumes involved are over 1000 Mm^3. The resource is used for the three sectors: civil 250 Mm^3, irrigation 720 Mm^3 and industrial 30 Mm^3 (EIPLI, 2014).

Table 3.1 Case of study Reclamation Consortia and related Reservoirs.

Reclamation Consortia	Reservoirs	Reservoirs water availability [Mm^3]
Capitanata	Occhito dam	137
	Santa Venere trasverse	82.1
Terre d'Apulia	Santa Venere trasverse	82.1
	Locone dam	7.7
Stornara e Tara	San Giuliano dam	30
	Monte Cotugno dam	300

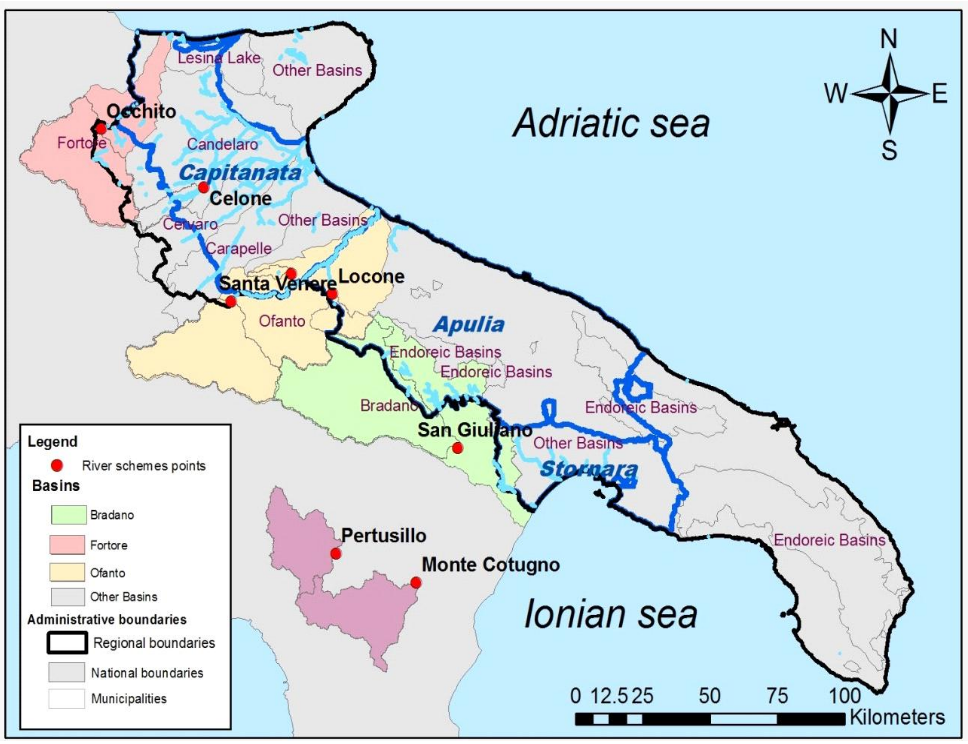
Figure 3.1 Puglia Water schemes. Source: EIPLI, 2014



3.5.1 Case study Reclamation Consortia

Within the case study analysed in this thesis, we consider three Reclamation Consortia that manage the distribution of water for irrigation purposes: *"Consorzio per la Bonifica della Capitanata"*, *"Consorzio di Bonifica Terre d'Apulia"* and *"Consorzio di Bonifica Stornara e Tara"* (Table 3.2). These Consortia have been chosen because they are supplied by Reservoirs where (climatic) projections of changes in water regimes has been made available by the the project ORIENTGATE. These Rerervoirs are: Occhito dam, Santa Venere traverse and Locone dam on Ofanto scheme; San Giuliano dam on Bradano scheme; and, finally, Monte Cotugno dam on Jonico-Sinni scheme (Table 3.1).

Figure 3.2 Case study basins and Reclamation Consortia



- **Capitanata Reclamation Consortia**

Capitanata Reclamation Consortia has a total area of 441'545 ha, and falls in the flat area of the province of Foggia. 140'500 hectares are equipped for irrigation (102'500 ha Fortore, and 38'000 ha left-Ofanto) of these approximately 100'000 (28'000 Ofanto) are actually irrigated.

This Consortia draws water from the river Fortore through the Occhito dam and, from the river Ofanto through the Reservoirs Osento and Marana Capacciotti (this two Reservoirs are upstream of Santa Venere dam). There is also a lower contribution from the water resources of the river Celone, but are not quantitatively relevant.

In addition to the area served by the network Consortia distribution, there is an irrigation extra-consortia carried out by private companies that run autonomously wells. Areas irrigated with private wells have been estimated at about 26’000 ha.

Traditionally, durum wheat was cultivated in this area, and was the main crop. Today, horticultural and industrial crops are grown in rotation. Both herbaceous and arboreal crops are irrigated in the question area. (www.consorzio.fg.it, 2015).

- **Terre d’Apulia Reclamation Consortia**

Terre d’Apulia is the largest Reclamation Consortia of Puglia Region, it includes the province of Bari and six municipalities in the province of Taranto, for a total area of 570’000 ha of which 22’659 ha are equipped for irrigation and 16’225 hectares are actually irrigated. In the vast territory of the Consortia are delineated three homogeneous areas, depending on the presence of irrigation and susceptibility to irrigation transformation: the Coast of Bari and the irrigation Minervino-Loconia District, where irrigation is practiced extensively (irrigated area); (High and Low) Murgia where the susceptibility to irrigation transformation is low or zero (area not susceptible to irrigation); two bands adjacent to the backbone of the Alta Murgia, which is the eastern end of the sea and the western end (Fossa Bradanica) near the border of Basilicata (area susceptible to irrigation).

At present, the Consortia draws water by the Ofanto river, from the Locone dam and accumulation of the reservoirs located downstream of the Santa Venere dam.

- **Stornara e Tara Reclamation Consortia**

This consortia interest the provinces of Taranto (Puglia) and Matera (Basilicata) for a total of 142’949 hectares of surface. Stornara e Tara takes water resources from the Reservoir of San Giuliano, and from the Reservoir of Monte Cotugno on Bradano and Sinni rivers, respectively. Un important amount of water (19%) is taken also from wells.

Throughout the territory of the Consortia, 35’528 ha are irrigated, of which: 17’877 ha are irrigated using waters managed by the Reclamation Consortia. Above all there was a remarkable expansion of private wells within the area equipped with the Consortia’s network. In these areas, the private irrigation is very significant because a large part of surface equipped with Consortia’s irrigation network is not in operation, or because is disused for degradation, or because the network was built and never went into operation.

Table 3.2 Reclamation Consortia irrigation data (INEA , 2011; INEA, 2009; www.consorzio.fg.it, 2015)

Reclamation Consortium	Total area (Ha)	Area equipped for irrigation (Ha)	Irrigated area (Ha)
Capitanata	441’545	140'500	~ 100’000
Terre d’Apulia	570’000	22’659	16’225
Stornara e Tara	142’949	-	35’528

4. Methodological development

4.1 Conceptual framework

Regional Risk Assessment (RRA) support the identification and ranking of hotspots and areas at risk in order to drive the development of appropriate strategies and actions for mitigation, prevention and adaptation purposes. In fact, a comprehensive, multidisciplinary and integrated approach is essential to monitor drought effectively and provide early warning to reduce the impact on agricultural production. By making the best (possible) use of available datasets, by using up-to-date (vulnerability) indicators and, eventually, by developing new (tailored) ones along with an innovative characterization and computation of the hazard score pattern, the present study proposed a specific RRA methodology to characterize the spatial pattern of drought risk for the irrigation-fed agricultural compartment in the Puglia Region.

Risk is often represented as probability of occurrence of hazardous events or trends multiplied by the impacts if these events or trends occur (IPCC, 2014). In the last IPCC WG2 AR5 (2014), the risk is defined as "The potential for consequences where something of human value (including humans themselves) is at stake and where the outcome is uncertain". Risk results from the interaction of vulnerability, exposure and hazard (see Sect. 2.3.1), where:

- Hazard (H) 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 (IPCC, 2014).
- Exposure (E) is defined by IPCC as 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 (IPCC, 2014).
- Finally, vulnerability (V) is the propensity or predisposition of an expose element 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 (IPCC, 2014).

The definition of risk scenarios requires the identification of those stressors that can contribute to determine problems to irrigated crops. These are individuated in the alteration of the precipitation pattern with forecasted reduction in the total volume of rainfall available for irrigation purposes. The receptors considered are the agricultural areas irrigated by the Reclamation Consortia that draw the water from Reservoirs according to their requirements.

Based on these general concepts, the present study has developed a specific methodology to quantify the impact of drought risk on irrigated crops of the Puglia Region, in Southern Italy. The characterization of the risk pattern is based on the specific computation of its three main components, as explained above. Moreover, it is worth to notice that the risk of drought for the irrigation 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 pattern and, therefore, its future variability is simulated and forecasted by the considered climatic scenarios (see Sect. 2.2.), while the second aspect depends on the users' needs, its hydro-characterization and, finally, by the overall management of the (water) resources. In particular, hazard and vulnerability (spatial) assessments are shaped through the characterization of the complex pattern of feedbacks between these two drivers (availability-demand) and embedded by the different management modes.

The (very) final result of the RRA methodology is a GIS-based Risk Map which allows to identify and rank areas and hotspots at risk within the studied area. Moreover, the methodology has been developed with the aim to be applicable in different problem contexts, case studies and spatial scales. GIS-based maps and outcomes result useful to communicate the potential implications of hydrological drought to stakeholders and administrations and can be a basis for the management of drought risks. Moreover, statistics can be extrapolated from risk maps and can be used to mainstream climate change adaptation in the development of territorial plans, policies and programs considering the potential threats posed by climate change. Furthermore, they can provide suitable information for setting priority for prevention measures and for land use planning and land management (Ronco et al., 2014).

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

4.2. Hazard assessment

The first step of the RRA methodology is the hazard assessment that is aimed at identify, rank and prioritize areas that will be affected by droughts events, according to the climatic scenarios RCP4.5 and RCP8.5 for the 2021-2050 and 2041-2070 periods.

Water scarcity occurs where and when water resources are not enough to meet all the demands, and this affects equally the service of water provisioning and the ecosystem needs. According to the conceptual framework explained above, the hazard index has been calculated as the degree of fulfillment of the Consortia's demand, in terms of volume of water per year, if compared with the (forecasted) total water availability stored in the different Reservoirs.

In fact, Reclamation Consortia are the (only) management bodies in charge for the overall management and distribution of agricultural waters in Puglia (Piano Tutela delle Acque, 2009); they are normally supplied by multiple (more or less) large Reservoirs through a complex pattern of distribution systems: water demand cannot be fulfilled at local scale, but it can only be at larger scale through interregional water schemes (see cap. 3.5.) (Boithias et al., 2013). With this complex network, each Reservoir supply different Consortia with different volume 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), if compared with the (projected) water availability stored in different reservoirs.

In fact, current water demands are assumed to be constant over the time, while availability in the various reservoirs are simulated with the ArcSWAT[8] hydrological model for the different (future) climatic scenarios. Less is the degree of fulfillment, expressed as the ratio between the forecasted water availability with its theoretical (current) water demand for that particular Consortium, higher is the hazard score.

Hazard is computed in two subsequent phases: (I) at reservoir (res) level and (II) at consortium (con) level, as follow.

I) At reservoir level, the water availability for irrigation purposes, in terms of Mm^3/year, is computed according to the variation (reduction) in runoff simulated with the ArcSWAT model for the different emission scenario, when compared with the current one, corresponding to the Baseline Scenario (BS) for 1976-2005 (Eq. 4.1).

$$\boldsymbol{future\ availability, res_{(s)}}\ [\boldsymbol{Mm^3}] = \boldsymbol{availability, res\ (BS)}\left(\boldsymbol{1} + \frac{\%\ \boldsymbol{of\ variation}}{\boldsymbol{100}}\right) \tag{4.1}$$

[8] **ArcSWAT model** is an application of SWAT model: Soil & Water Assessment Tool, a river basin scale model developed to quantify the impact of land management practices in large, complex watersheds. It is a hydrology model with the following components: 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). This model is for public domain and actively supported by the Agricultural Research Service (USDA), USA (SWAT: Soil & Water Assessment Tool, 2012).

Where: “future availability, $res_{(s)}$ [Mm^3]” is the water availability in each Reservoirs in futures scenarios, considering runoff variations deducted by ArcSWAT model. The subscript (s) means that the variable is function of different scenarios.

“availability, res (BS)” is the actual availability (annual mean in Mm^3) of each Reservoir.

“% of variation” is the runoff variation, calculated by ArcSWAT and expressed in percentage of water reduction of water level in the Reservoirs.

Furthermore, for each scenario, the degree of fulfillment of water demand (Eq. 4.2) is computed by dividing the volume of water available for irrigation with the theoretical water demand for that particular Reservoir, which is the sum of the different withdraw from the various Consortium for the BS (1976-2005).

$$\boldsymbol{degree\ of\ fulfillment, res_{(s)}}[\%] = \frac{\boldsymbol{future\ availability, res}_{\ (s)}}{\boldsymbol{water\ demand, tot\ con\ (BS)}} \tag{4.2}$$

Where: “degree of fulfillment, res $_{(s)}$ [%]” is the balance between supply and demand (S:D ratio) in the reservoirs;

“water demand, tot con (BS)” is the sum of Consortia’s demands for the considerate Reservoir.

II) A<u>t Reclamation Consortia level</u>, the availability of water for the various scenarios (Eq. 4.3) is computed according to the degree of fulfillment of the different Reservoirs (see Eq. 4.2) multiplied by its theoretical water demand (Supply-Demand ratio - S:D), which correspond to the BS one (1976-2005):

$$\boldsymbol{tot\ water\ available, con}_{\ (s)}\left[\boldsymbol{Mm^3}\right] =$$
$$= \sum_{\boldsymbol{reservoirs}} \boldsymbol{degree\ of\ fulfillment, res_{(s)}}[\%] * \boldsymbol{water\ demand, con\ (BS)}$$

(4.3)

Where: “tot water available, con $_{(s)}$ [Mm^3]” is the estimation of the water quantity that will be available for each Consortia in future scenarios.

The degree of fulfillment for each Consortia is later calculated as the ratio between the water availability for each scenario and its theoretical water demand, which correspond to the BS one (1976-2005) (Eq. 4.4).

$$\boldsymbol{degree\ of\ fulfillment, con_{(s)}}\ [\%] = \frac{\boldsymbol{tot\ water\ available,con}_{\ (s)}}{\boldsymbol{tot\ water\ demand,con}\ (\boldsymbol{BS})} \quad (4.4)$$

Where: “degree of fulfillment, con $_{(s)}$ [%]” is the percentage of water that Reclamation Consortia could fulfill in the future considering the future S:D ratio of the Reservoirs and the Reclamation Consortia actual demand.

Finally, the hazard score is calculated as in Eq. 4.5. Obtained scores are into a numerical scale between 0 and 1, and this facilitates the calculation of the total risk, in fact this normalization allows the comparison among hazard and vulnerabilities (which are also with scores between 0 and 1), that together compose the (relative) risk.

$$\boldsymbol{Hazard, con_{(s)}} = \boldsymbol{1} - \boldsymbol{degree\ of\ fulfillment, con_{(s)}}\ [\%] \quad (4.5)$$

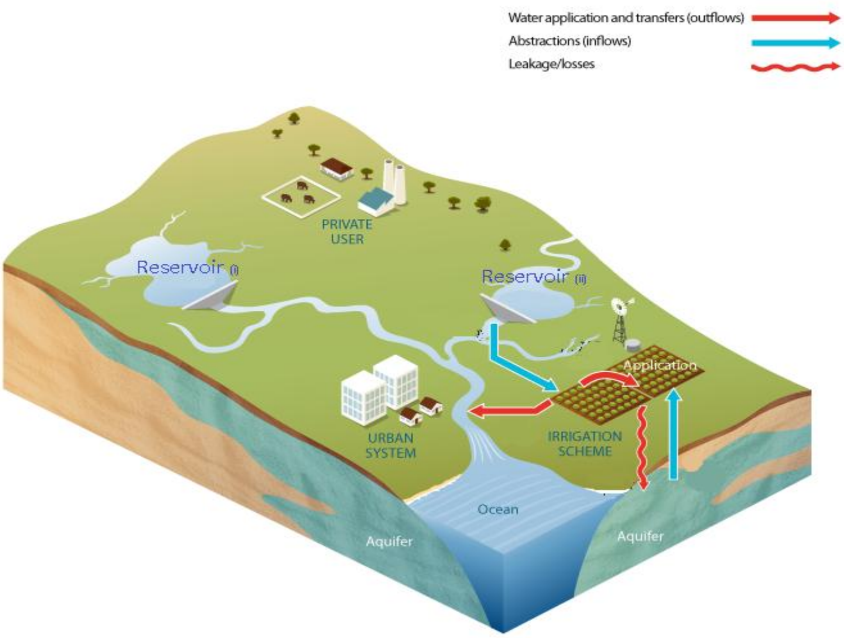


Figure 4.1 Schematic general diagram of the water stores and systems within Puglia Region

4.3. Exposure assessment

The second step of the RRA Methodology is the exposure assessment which is aimed to identify, select and classify receptors that could potentially be adversely affected by drought events because of its spatial and physical characterization, namely: losses of (valuable) irrigated crops.

In the exposure assessment an exposure score equal to 1 is assigned to cells where the receptors are located and equal to 0 in case of absence of the receptor (e.g. not irrigated lands). The main output of this step is the exposure map (Sect. 5.3) showing the presence and the localization of crops at risk from hydrological drought. In order to keep the highest feasible detail, according to the available dataset, the exposure assessment was based on spatial units (e.g. grid cells) of 25 m.

In this case study the Italian land use data set provided by the ISTAT sixth agricultural census (ISTAT, 2014) and CORINE Land Cover (CLC) dataset (CORINE, 2006) has been consulted in order to identify the most valuable irrigated for the Puglia Region.

4.4. Vulnerability assessment

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 Equation 4.6.

$$\boldsymbol{Vulnerability}_{(crop,cons)} = \boldsymbol{V1}_{(crop)} * \boldsymbol{V2}_{(cons)} * \boldsymbol{V3}_{(cons)} \tag{4.6}$$

Where: V_1 is Hydro-demand presents crops vulnerability;

V_2 is Degree of efficiency - system losses vulnerability;

V_3 is Degree of diversification of sources vulnerability.

Subscripts indicate of what vulnerability factors are function: crops V_1 and Consortia V_2 and V_3.

These three (vulnerability) factors have been chosen in compliance with the state of art (FAO, 2015; Renault et al., 2013; IPCC, 2014).

The factors, explained in detail on 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 into a common closed numerical scale (0–1) (Zabeo et al., 2011).

4.4.1 V_1. Hydro-demand presents crops.

The first vulnerability factor aims to evaluate the degree to which the crops are influenced by water stress, due to climatic factors. 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 agronomic properties.

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 (Steduto et al., 2012). It indicates the relation between the water deficit and the reduction of efficiency.

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

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

The vulnerability normalized score V_i is calculated by dividing the Ky mean value of each crop for the Ky maximum according to the following (Eq. 4.7):

$$\boldsymbol{V1} = \frac{\boldsymbol{K_y mean}}{\boldsymbol{K_y max}} \tag{4.7}$$

In Table 4.1 V_1 scores are indicated according to their relative classes of vulnerability. Every score is divided into five classes, from 0 to 1, where 0 represent the class with where the vulnerability factor is absent and 1 represent the class with the vulnerability maximum.

Table 4.1 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)

4.4.2 V_2. Degree of efficiency - system losses.

Not all water taken from a source (river, well) reaches the root zone of the plants. Part of the water is lost during transport through the canals and in the fields. The remaining part is stored in the root zone and eventually used by the plants. In other words, only part of the water is used efficiently, the rest of the water is lost for the crops on the fields that were to be irrigated (Brouwer et al., 1989). Losses entities of irrigation systems depends on different factors, such as the efficiency of water transport in canals, the technique of irrigation (e.g. sprinker, underground irrigation, sub-irrigation, etc.) and the level of maintenance, the level of farmer discipline, the water evaporation and the crops typology (Figure 4.2) (Brouwer et al., 1989; European Commission, 2011). System losses decrease the efficiency of the system and increase their vulnerability to climate change impact. It is very common that in the irrigation scheme there is wasted water that result by losses in the distribution networks; on average, near to 30% of the total water introduced in the irrigation system network is lost (European Commission, 2011).

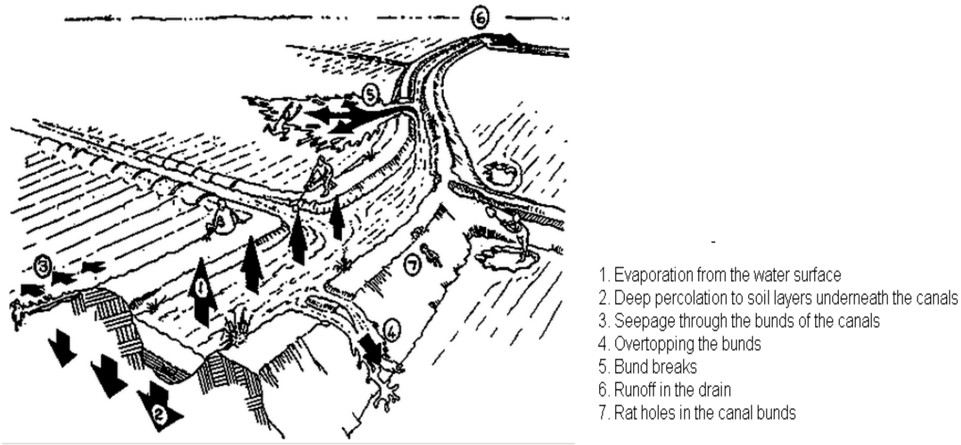


Figure 4.2 Irrigation water losses in canals (Brouwer et al., 1989).

The increasing percentage of water losses of each Consortia has been divided into five classes for increasing vulnerability scores (Table 4.2). The maximum vulnerability 2 score is 1 (one) that correspond to 50% of losses, this value has been chosen because normally in literature, irrigation networks don't exceed the 50% of losses.

Table 4.2 Vulnerability of degree of efficiency (V_2)

Percentage of losses	**V2. Score**	**Vulnerability class**
0 - 10 %	0.2	very low
10 – 20 %	0.4	low
20 - 30 %	0.6	medium
30 – 40 %	0.8	high
40 - 50 %	1	very high

4.4.3 V_3. Degree of diversification of sources.

Diversifying the sources tends to mitigate the risk. In fact, if the surface resources (Reservoirs) were absent, the underground supply could help to fulfill the demand (Cotecchia and Polemio, 1995). As a consequence, lower vulnerability scores are associated with Reclamation Consortia that rely on different sources to fulfill their demand, either than Reservoirs. The scores are divided into four classes as the inverse of the rate supplied by underground waters (Table 4.3).

Table 4.3 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)

4.5 Risk assessment

The last step of the RRA Methodology is the Risk assessment which is aimed to integrate information about the hydrologic drought hazard of a given climate change scenario, with the spatial exposure and vulnerability assessments in order to identify and prioritize receptors and areas at risk in the case study area.

As from literature (Landis, 1997), risk results from the interaction of vulnerability, exposure and hazard, expressed by the Equation 4.8:

$$\boldsymbol{Risk\ (R) = \ Hazard_{(s)}(H) * Exposure\ (E) * Vulnerability_{(crop,cons)}(V)}. \quad (4.8)$$

Where: $Hazard_{(s)}$ is the degree of fulfillment of each Consortia (see Sect. 4.2);

Exposure is the localization of receptors (see Sect. 4.3);

and Vulnerability $_{(crop,\ cons)}$ is the total vulnerability (see Sect. 4.4).

The combination of these factors, for the different climatic scenarios, allows to produce risk maps related to hydrological drought for the irrigation compartment in the considered Region. Within study area, zone at risk will be highlighted, in respect to zone that no requires attention. Again, also risk maps have risk scores in the range between 0 and 1 (values near 1 mean very high risk, while, values near 0 correspond to a relative low risk), where classes has been defined using Equal Interval GIS tool.

The outcomes of this exercise can be used in a wide variety of decision making processes, such as the management of irrigation systems and related agronomic policies.

It is important to underline that risk scores, obtained through the presented methodology are not absolute predictions about the risks for crops, rather is more useful analyze integrally this methodology, that, in the complex, provides the ranking of the areas and hotspots at risk that are more vulnerable and possibly more affected by hydrological drought within the investigated region.

This practical methodology is flexible as it can be adapted to several case studies. As in the RRA methodologies done in the past, the results could help to evaluate risk, in order to develop an idea over the benefits of different risk prevention scenarios (e.g. baseline and alternative scenarios) where measures are implemented or, to underpin risk prevention measures and, therefore, to communicate to decision makers and stakeholders the potential implications of water deficit in non-monetary terms. On this base, 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 in the whole society (Ronco et al., 2014).

5. Application and results

The RRA methodology described and presented in Chapter 4 was applied to assess the impact of hydrologic droughts due to climate change to a large irrigation-fed agricultural area in Puglia Region, Italy. The application of the RRA methodology consisted in i) data collection, ii) development of tailored GIS tools (ArcGIS, http://www.arcgis.com/features/) to classify and process the dataset, iii) production of GIS-maps representing the spatial variability of hazard, exposure, vulnerability and risk patterns, iv) production of statistics, graphs and other tools to support the establishment of a complete and robust base of knowledge regarding the impacts hydrological drought in the case study.

Finally, the outputs of this application aim to support relevant stakeholders along the decision making process, in order to establish relative priorities for intervention and to provide the basis for (science-based) land use planning. Data collected, resulting maps and statistics from the application to the case study area, will be presented and discussed in the following paragraphs.

5.1. Data characterization

Climatic simulations and projections were performed by using the Regional Climate Model (RCM) with COSMO-CLM[9] (Rockel and Geyer, 2008). Further, statistical downscaling was performed at site level for 31 and 21 meteorological stations, as far as precipitation and temperature parameters are concerned, in order to support basin scale hydrological analyses. On these basis, further extreme indicators have been calculated from downscaled simulations across different time frames and scenarios.

Water stocks (availability) in selected Reservoirs have been modelled by means of ArcSWAT model to quantify and analyze changes in terms of: i) average trends (annual, seasonal, monthly) hydrological conditions; and ii) occurrence of extreme events of temperature, precipitation, streamflow (e.g. heat waves, dry spell, low flow periods) (CMCC, 2015).

Changes in these indicators across the different emission scenarios and time frames have been assumed as proxies of changes in the streamflow annual mean and inter-annual variability. Variation of runoff, in particular, has been used to calculate hazard scores, according to the procedure presented in Sect. 4.2.

[9] **Regional Climate Model (RCM) simulations with COSMO-CLM** at project level for the westernmost part of SEE domain (Italy and surrounding), to dynamically downscale (at 0.0715°, ca. 8 km horizontal resolution) the atmospheric component of GCM 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/)

According to the same procedure and to complete the assessment of hazard, the downstream water demand for irrigation purposes have been calculated by using the available dataset for the Puglia Region, named “Piano Tutela delle Acque” (2009). This regional plan includes a detailed spatial database where the state of regional water resources, problems and issues related to the preservation of the same and, finally, guidelines for the sustainable use of water resources are presented. Further, remaining, information have been obtained by the “Relazione Bilancio Idrico Potabile” (2010); here, the overall water balance of Puglia’s territory based on the principle of priority allocation of resources qualified to domestic uses is presented (Article 9 of the RD n°1775/1933, as amended by Legislative Decree n°152/2006).

Data for the characterization of the Exposure assessment namely the spatial characterization of valuable irrigated crops, are based on the CORINE Land Cover IV level dataset (CLC, 2006; Büttner and Kosztra, 2006). CORINE is one of the largest cartographic inventory where the land covers are classified in 44 different classes. This database is operationally available for most areas of Europe (Büttner and Kosztra, 2006). In Italy, the project is implemented by ISPRA (Istituto Superiore per la Protezione e la Ricerca Ambientale) and, in Puglia, available on (regional) web site (spatial scale 1:1.000.000) (http://webgis.sit.puglia.it/sit-help/SIT-Puglia/Guida/Sit-Cittadino/Dati-Tematici/Uso-Del-Suolo.html;http://webapps.sit.puglia.it/freewebapps/UDS2006/).

The spatial pattern of the considered Reclamation Consortia boundaries has been characterized by using the available maps from the Ministry of Infrastructures and Transport databases (*Ministero delle “Infrastrutture e dei Trasporti*: *Ambiti Amministrativi dei Consorzi di Bonifica pugliesi”*, Viceconte, 2003). Finally, administrative boundaries were identified by means of ISTAT maps (based on Census 2010) for framing the area (http://www.istat.it/it/archivio/104317).

For the Vulnerability assessment, regarding the factors related with Consortia (V_2 and V_3), data of irrigation, efficiency of the distribution networks, and diversification of sources 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). Instead for the vulnerability correlated with crops (V_1), the dataset is the same of exposure: CORINE Land Cover IV level dataset (CLC, 2006; Büttner and Kosztra, 2006).

5.2. Hazard scores and maps

Hazard maps aims to represents the spatial pattern of affliction to hydrological drought for the different Reclamation Consortia.

Within this case study, the impact is caused by the alteration of the precipitation pattern due to climatic change and the reduction on the total volume of water available for irrigation purposes is forecasted.

According to the algorithms presented in Sect 4.1, hazard index has been calculated as the degree of fulfillment of each Consortia's demand (Table 5.1), if compared with the (forecasted) total water availability stored in the different Reservoirs. Current water demands are assumed to be constant over the time, while the availability of water stocks in the various reservoirs are simulated with the ArcSWAT hydrological model for the different scenarios (Table 5.2).

Table 5.1 Water demand for the different Reclamation Consortia, divided per reservoir and for the different uses (from: Relazione Bilancio Idrico Potabile, 2010; Puglia Piano Tutela delle Acque, 2009)

			Water demand for different uses [Mm^3]/year				
Reclamation Consortia	**Basin**	**Reservoir**	**Agricultural**	**Agricultural private**	**Domestic**	**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	4.2				
		Locone	3.1				
		Total Locone					7.2
		Santa Venere	3.1			8.8	
		Santa Venere	4.0				
		Total Santa Venere					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

Table 5.2 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

Hazard scores, at Reclamation Consortia level, depend on the degree of fulfillment of water demand: less is the degree of fulfillment, expressed as the ratio between the forecasted water availability for that particular Consortia with its theoretical (current) water demand, higher is the hazard score.

The hazard scores are presented in the following tables according to the different analyzed scenarios.

Table 5.3 Hazard scores for the baseline scenario (1976-2005) (see Sect. 4.2)

BASELINE SCENARIO					
Reclamation Consortium	Reservoir	% fulfillment per Reservoir	Real fulfilled demand [Mm^3]	% fulfillment per Consortia	HAZARD scores
Capitanata	Occhito	102.7%	78.4		
	Santa Venere	132.2%	40.1		
	Total Capitanata		118.5	100.0%	0.00
Terre d'Apulia	Locone	106.22%	7.2		
	Santa Venere	132.22%	15.8		
	Total Terre d'Apulia		23.1	100.0%	0.00
Stornara e Tara	San Giuliano	181.96%	16.4		
	Monte Cotugno	105.24%	22.5		
	Total Stornara e Tara		38.9	100%	0.00

Table 5.4 Hazard scores for the scenario RCP4.5 2021-2050

RCP4.5 2021-2050					
Reclamation Consortia	Reservoirs	% fulfillment per Reservoir	Real fulfilled demand [Mm^3]	% fulfillment per Consortia	HAZARD scores
Capitanata	Occhito	74.0%	58.0		
	Traversa Santa Venere	93.5%	37.5		
	Total Capitanata		95.50	80.6%	0.19
Terre d'Apulia	Locone	85.1%	6.15		
	Travesa Santa Venere	93.5%	14.79		
	Total Terre d'Apulia		20.94	90.8%	0.09
Stornara e Tara	Invaso San Giuliano	148.1%	16.43		
	Monte Cotugno	76.6%	17.24		
	Total Stornara e Tara		33.67	87%	0.13

Table 5.5 Hazard scores for the scenario RCP4.5 2041-2070

RCP4.5 2041-2070					
Reclamation Consortia	Reservoirs	% fulfillment per Reservoir	Real fulfilled demand [Mm3]	% fulfillment per Consortia	HAZARD
Capitanata	Occhito	66.2%	51.9		
	Santa Venere	82.7%	33.1		
	Total Capitanata		85.05	71.8%	0.28
Terre d'Apulia	Locone	80.7%	5.84		
	Santa Venere	82.7%	13.09		
	Total Terre d'Apulia		18.92	82.1%	0.18
Stornara e Tara	San Giuliano	131.1%	16.43		
	Monte Cotugno	68.1%	15.33		
	Total Stornara e Tara		31.76	82%	0.18

Table 5.6 Hazard scores for the scenario RCP8.5 2021-2050

RCP8.5 2021-2050					
Reclamation Consortia	Reservoirs	% fulfillment per Reservoir	Real fulfilled demand [Mm3]	% fulfillment per Consortia	HAZARD
Capitanata	Occhito	65.2%	51.1		
	Santa Venere	78.7%	31.6		
	Total Capitanata		82.71	69.8%	0.30
Terre d'Apulia	Locone	85.8%	6.20		
	Santa Venere	78.7%	12.47		
	Total Terre d'Apulia		18.67	81.0%	0.19
Stornara e Tara	San Giuliano	141.5%	16.43		
	Monte Cotugno	73.2%	16.47		
	Total Stornara e Tara		32.90	85%	0.15

Table 5.7 Hazard scores for the scenario RCP8.5 2041-2070

RCP8.5 2041-2070					
Reclamation Consortia	Reservoirs	% fulfillment per Reservoir	Real demand fulfilled [Mm3]	% fulfillment per Consortia	HAZARD
Capitanata	Occhito	49.4%	38.8		
	Santa Venere	61.6%	24.7		
	Total Capitanata		63.44	53.5%	0.46
Terre d'Apulia	Locone	73.3%	5.30		
	Santa Venere	61.6%	9.75		
	Total Terre d'Apulia		15.05	65.3%	0.35
Stornara e Tara	Invaso San Giuliano	108.6%	16.43		
	Monte Cotugno	56.9%	12.79		
	Total Stornara e Tara		29.22	75%	0.25

Hazard scores have been classified into five clusters and one color was given to each one (Table 5.8, a), in order to visualize clearly the relative difference between Consortia's scores. The equal interval classification has been used to split the range of attribute values into equal-sized sub-ranges and, in this sense, this method shows what Consortia is affected by more hazard and in what scenario support the ranking of area and hotspots more at risk, within the studied area. Specifically, low values represent the class with lower emergency drought, while high values represent the class with higher probability of drought events in the study area. Hazard scores range varies between 0.00 and 0.46. Comparison with standard class interval (table 5.8, b) that are used on RRA methodology, shows that case study hazard scores fall in the first three classes of classic intervals (very low to medium hazard classes).

Figure 5.1 represent the spatialization of hazard scores of the four analyzed scenarios. In accord to RCPs definitions (see Sect. 2.2), can be noted that RCP8.5 have higher hazard values respect RCP4.5. Moreover, on both RCP's the long term present worst hazard previsions. Into Consortia, Capitanata Reclamation

Consortia is the most exposed to hazard, because it supplies by Occhito and Santa Venere, the Reservoirs, that have, in average, the higher percentage of water reduction. The other two Consortia present a relatively better situation, with low and very low scores. With the exception of RCP8.5 2041-2070, in which, hazard values of all three Consortia, are inserted in the worst classes (medium, high and very high).

Hazard maps can be used to help to understand, on a regional scale, the Reservoirs that will suffer more of water deficit and Consortia that can not fulfill their demand and in which future scenario.

Table 5.8 Hazard scores and classification into classes of ORIENTGATE-RRA methodology (a) and Standard RRA methodology (b).

a.

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

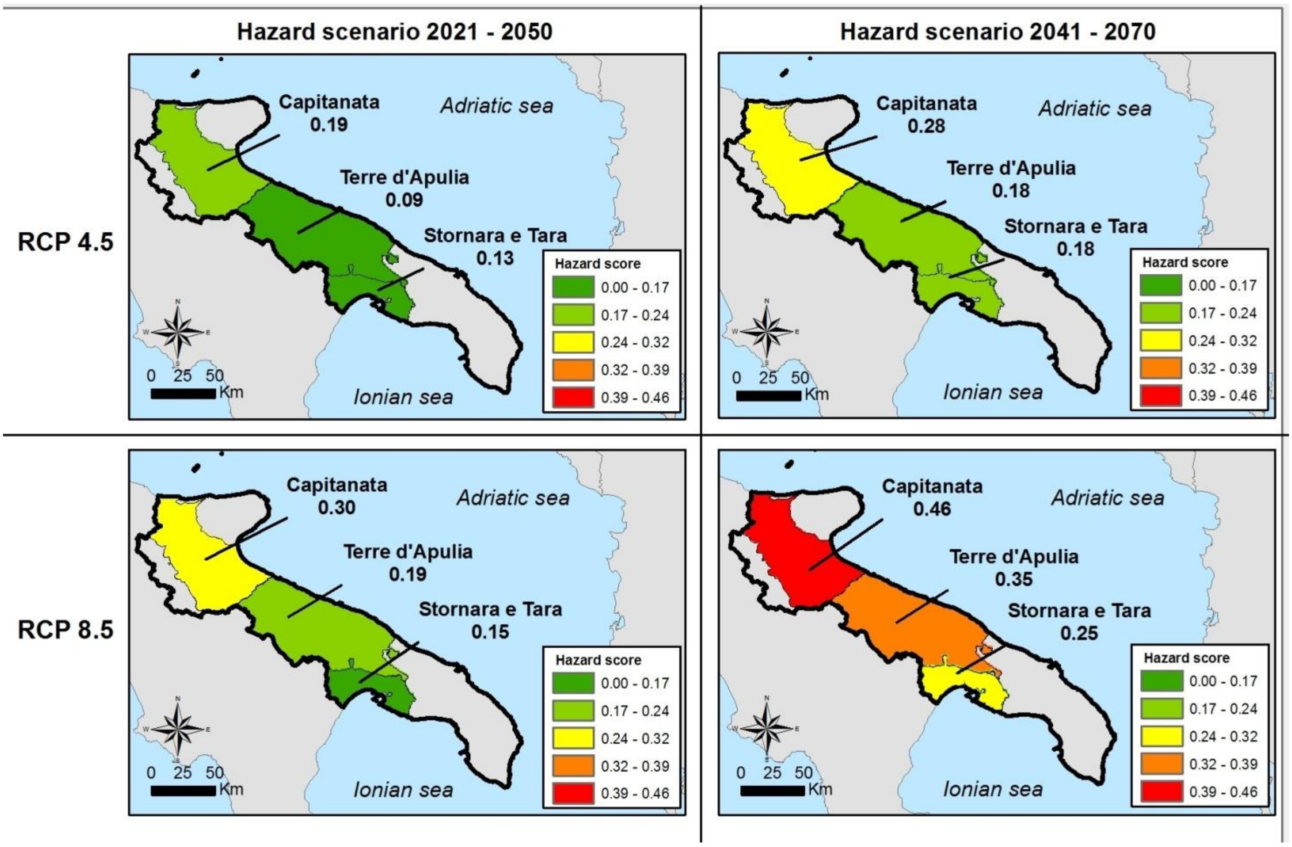
b

Hazard Classes	Score
Very low	0 - 0.2
Low	0.2 - 0.4
Medium	0.4 - 0.6
High	0.6 - 0.8
Very high	0.8 - 1

Table 5.10 Hazard scores per scenarios and relative classes.

Reclamation Consortia	H RCP4.5 2021-2050		H RCP4.5 2041-2070		H RCP8.5 2021-2050		H RCP8.5 2041-2070	
	score	class	score	class	score	class	score	class
Capitanata	0.19	2	0.28	3	0.30	3	0.46	5
Terre d'Apulia	0.09	1	0.18	2	0.19	2	0.35	4
Stornara e Tara	0.13	1	0.18	2	0.15	1	0.25	3

Figure 5.1: Hazard map for emission scenarios RCP4.5 and RCP8.5 and the two considered time frames: 2021-2050 and 2041-2070.



5.3 Exposure map

The characterization of the Exposure assessment aims to describe the spatial pattern of irrigated crops which could be adversely affected by a reduction of water availability. In this case study, four main crops represent the majority of irrigated areas. The coverage of these crops is expressed in Table 5.11.

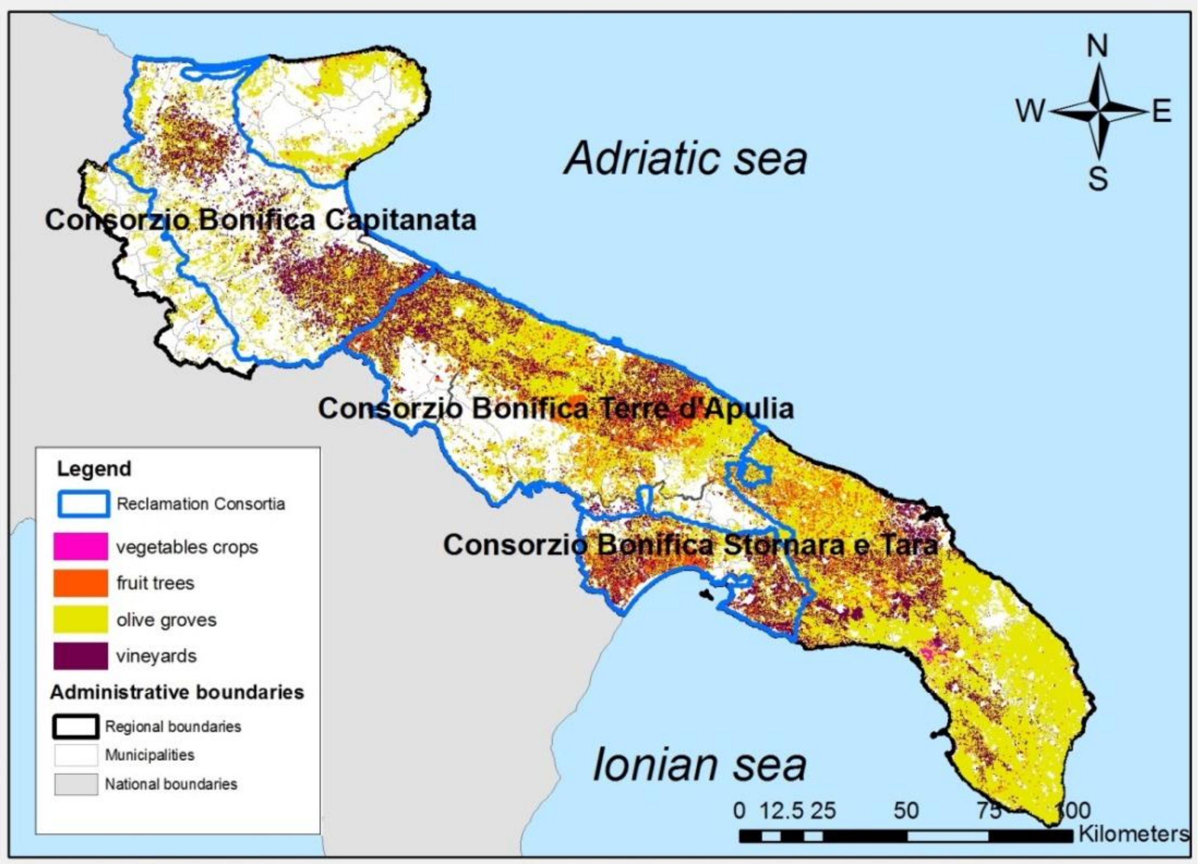
Table 5.11 Coverage and CLC classes of mainly irrigated crops of Puglia Region (CORINE, 2006).

Crops typology	Coverage [km^2]	CORINE Land Cover classes
Olive groves	2045.54	2.2.3
Vineyards	1050.60	2.2.1
Fruit trees	437.64	2.2.2
Vegetable crops	2.85	2.1.1.2

As already described, Reclamation Consortia considered in the case study are Capitanata, Terre d'Apulia and Stornara e Tara (blue lines). They cover the largest area of Puglia region, with exclusion of the Gargano and Salento provinces: this areas were excluded because the Reclamation Consortia, which manage the irrigated areas of these provinces, collect water from Reservoirs, that were not modeled about the run-off.

Exposure map, showed in Figure 5.2, evidence the prevalence of olive groves and vineyards, while the irrigation of vegetable crops and fruit trees cover a lower area (about 12%). Not irrigated lands and crops were not represented, because not included into the analysis (see Sect. 4.4).

Figure 5.2: Exposure map: spatial representation of the four mayor irrigated crops of Puglia Region.



5.4. Vulnerability scores and maps

Vulnerability maps are produced as a function of three selected vulnerability factors (see Sect. 4.4), reflecting the degree to which the crops could be affected by a drought hazard based on physical, agronomic and structural (site-specific) characteristics of the systems, by means of simple GIS tools, (all vulnerability factors were analyzed with 25 meters special scale), as follow:

5.4.1 Hydro-demand of crops: V_1

A specific value of hydro-demand has been assigned to each exposed crops according to the Yield-Response factor (Ky) indicator (see Sect. 4.5). The most important irrigated crops in Puglia are vineyards, olive groves, fruit trees and vegetables[10], and the respective values of Ky are as follow:

- Vegetables (tomato, onion, peppers, peas) → Ky = 1.1- 1.2 (vegetables are very sensitive to water deficit, with a notable yield reduction when the water is reduced).
- Fruit trees → Ky = 1 (the change in productivity for fruit trees is proportional to the reduction of water).
- Vineyards → Ky = 0.85 (vineyards are more tolerant to water stress, showing a reduction in productivity that is less pronounced with respect to the reduction of water).
- Olive groves → Ky = 0.2 – 0.6 (olive groves are very much resilient to severe water stresses. Excess irrigation does not benefit the production).

Moreover, in order to aggregate the different factors for the computation of the total vulnerability index, a phase of normalization aimed at rescaling the relatives scores V_1 into a common closed numerical scale (0-1) is required (Zabeo et al., 2011).

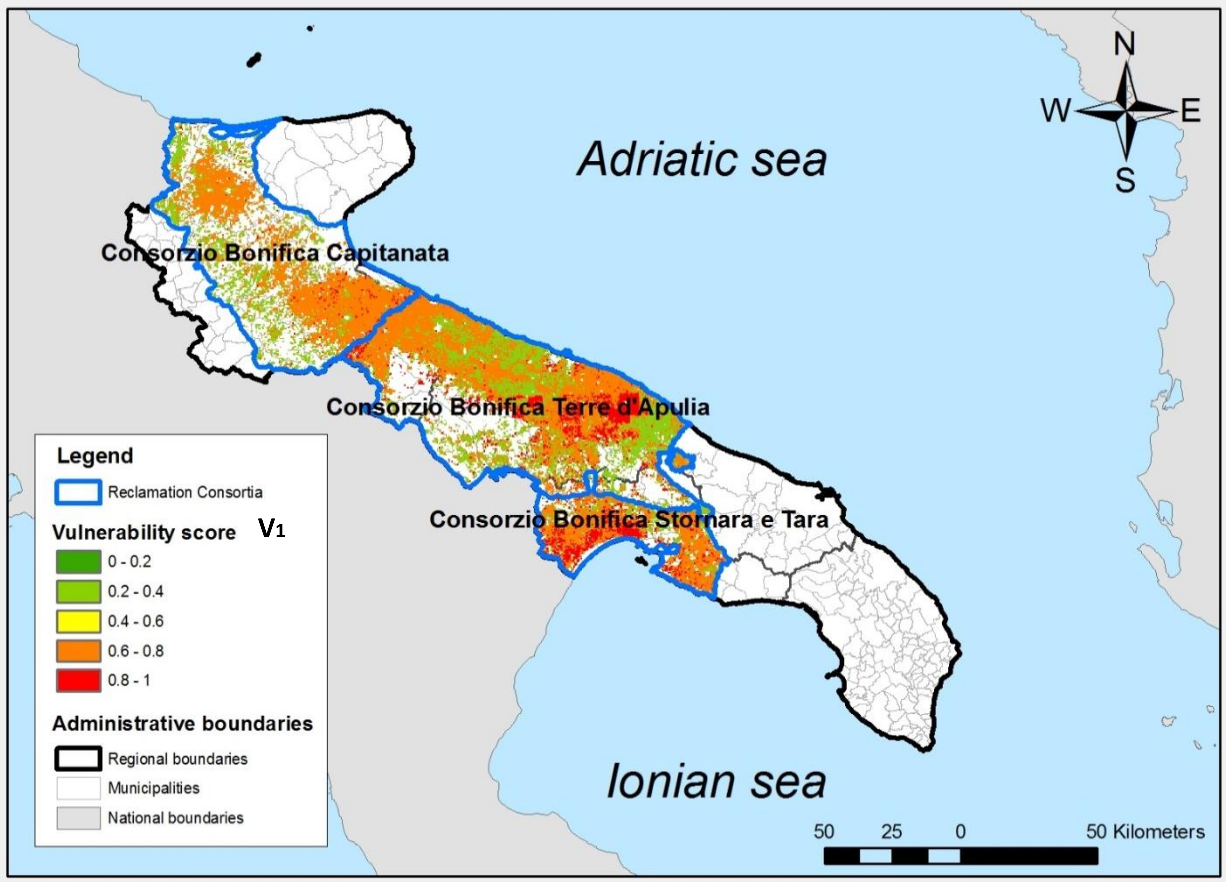
In Table 5.12 the V_1 scores and its relative classes of vulnerability are indicated, they are also represented in a GIS-based map (Figure 5.3). Relative scores are divided into five classes from 0 to 1, where 0 represents the class with no vulnerability and 1 represents the class with of the highest one.

Table 5.12 Vulnerability factor V_1: hydro-demand of crops

Crops and CLC class	Ky value	Ky mean	V1. 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)

[10] According to the nomenclature of the CORINE Land Cover at the fourth level (CORINE CLC, 2006).

Figure 5.3: Vulnerability 1 Map: spatial representation of different crops vulnerability.



As one can see from the map, only few areas are characterized by the very high vulnerability score V_1 (red zones), since the crops that have maximum score (between 0.8 and 1) are fruit trees and vegetables crops, and their coverage is limited (km^2). Moreover, is interesting to note that this zones are present almost entirely in Terre d'Apulia and Stornara and Tara Reclamation Consortia, while only a small presence appears on Capitanata Reclamation Consortia. The remaining part of the map, indicates the predominance of alternation of olive groves (low V_1) and vineyards (high V_1).

5.4.2 Degree of efficiency - system losses: V_2

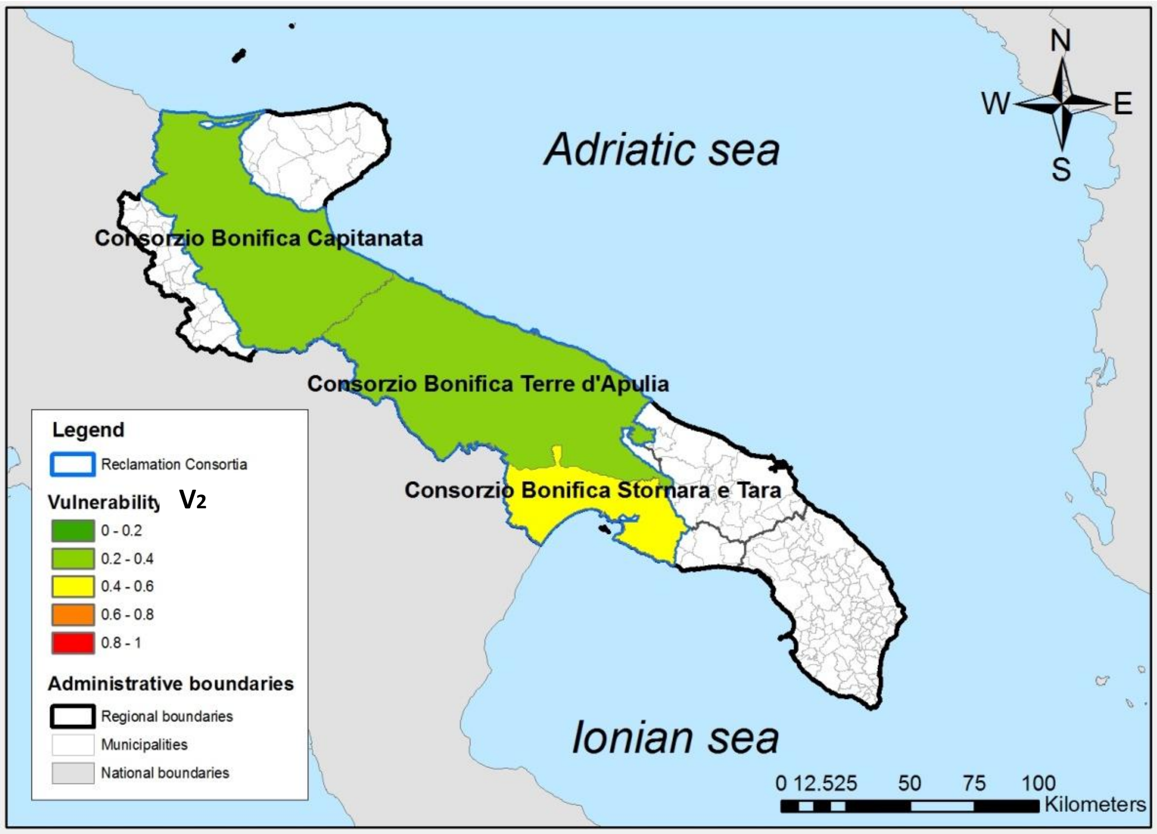
Each Reclamation Consortia have provided the values of system losses; this values were collocated in different classes according to the V_2 scores explicated in the methodology. Rates of water losses has been divided into five classes at increasing vulnerability (see Table 4.1) for each Consortia. The maximum value of losses, in percentage, has been fixed in 50% of the supplied water (see Sect. 4.4.3).

In Table 5.11 and Image 5.4 data about losses of the three Reclamation Consortia case study are indicated and represented. It can be noted that Capitanata and Terre d'Apulia Consortia have a percentage of losses between 15% and 20%, that correspond to class 2 (low vulnerability), while Stornara e Tara Consortia declare more losses, about 30%: medium risk.

Table 5.11 Score and classes of Vulnerability 2.

Reclamation Consortia	Percentage of losses data	V_2. Score	Vulnerability class
Capitanata	16.41 %	0.4	2 - Low (0.2-0.4)
Terre d'Apulia	15 - 20 %	0.4	2 - Low (0.2-0.4)
Stornara e Tara	29.18 %	0.6	3 - Medium (0.4-0.6)

Figure 5.4: Map of Vulnerability 2



5.4.3 Degree of diversification of sources: V_3.

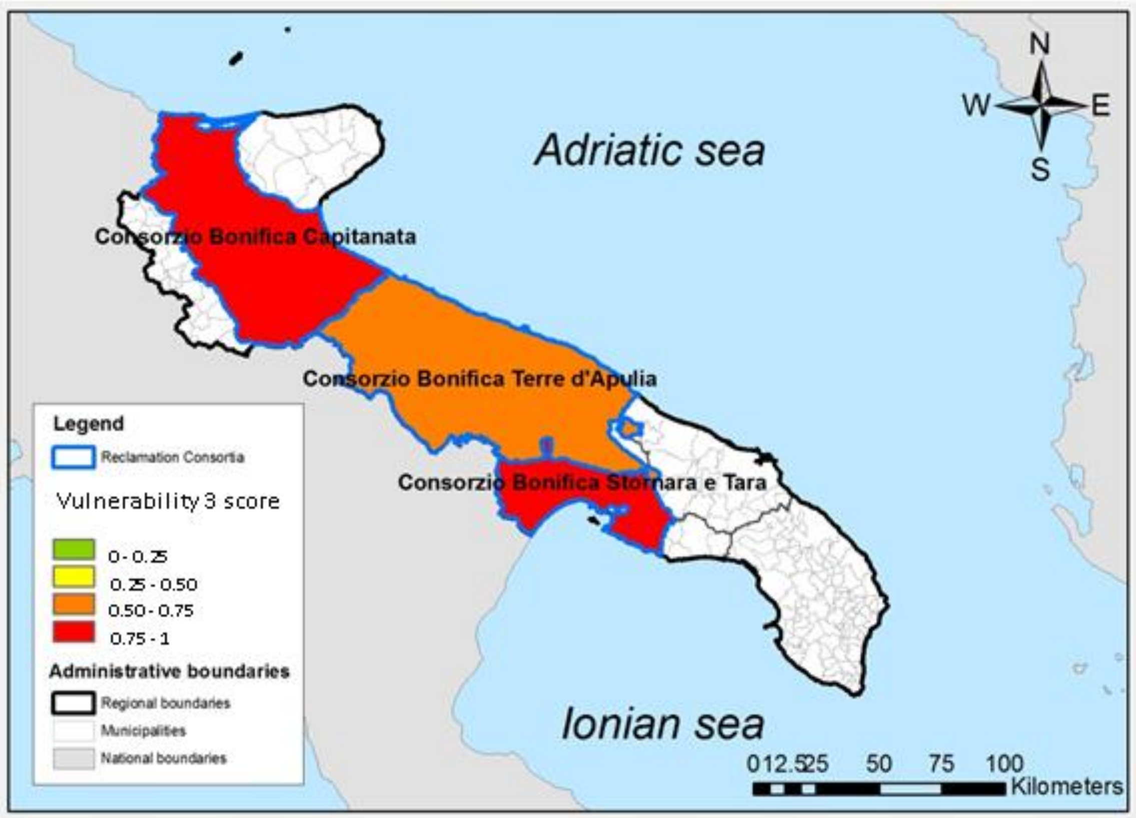
This vulnerability factors reflects the degree to which the different Reclamation Consortia rely on different sources (either than Reservoirs) to fulfill their demand (see Sect. 4.4). Among the selected Consortia, only one is supplied by groundwater (this limitation is, first of all, due to the excessive drilling of deep wells done in the past decades in Puglia Region, that has caused the recent drying up of millennial well-springs (Autorità di Bacino della Puglia, 2004)).

Aside from underground water supplies, no one Consortia supply water by other (alternative) sources, that could be for example the use of purified waste water. Scores, include, then, only the percentage of underground water draw. For this reasons the vulnerability scores are necessarily high (Figure 5.5). Values are divided into four classes as the inverse of the percentage of supply by underground waters (see Table 4.1).

Table 5.12 Vulnerability scores of degree of diversification of sources

Reclamation Consortia	**Underground water drawn data**	V_3. **Score**	**Vulnerability class**
Capitanata	0 %	1	5 - Very high
Terre d'Apulia	29.9 %	0.75	4 - High
Stornara e Tara	0 %	1	5 - Very high

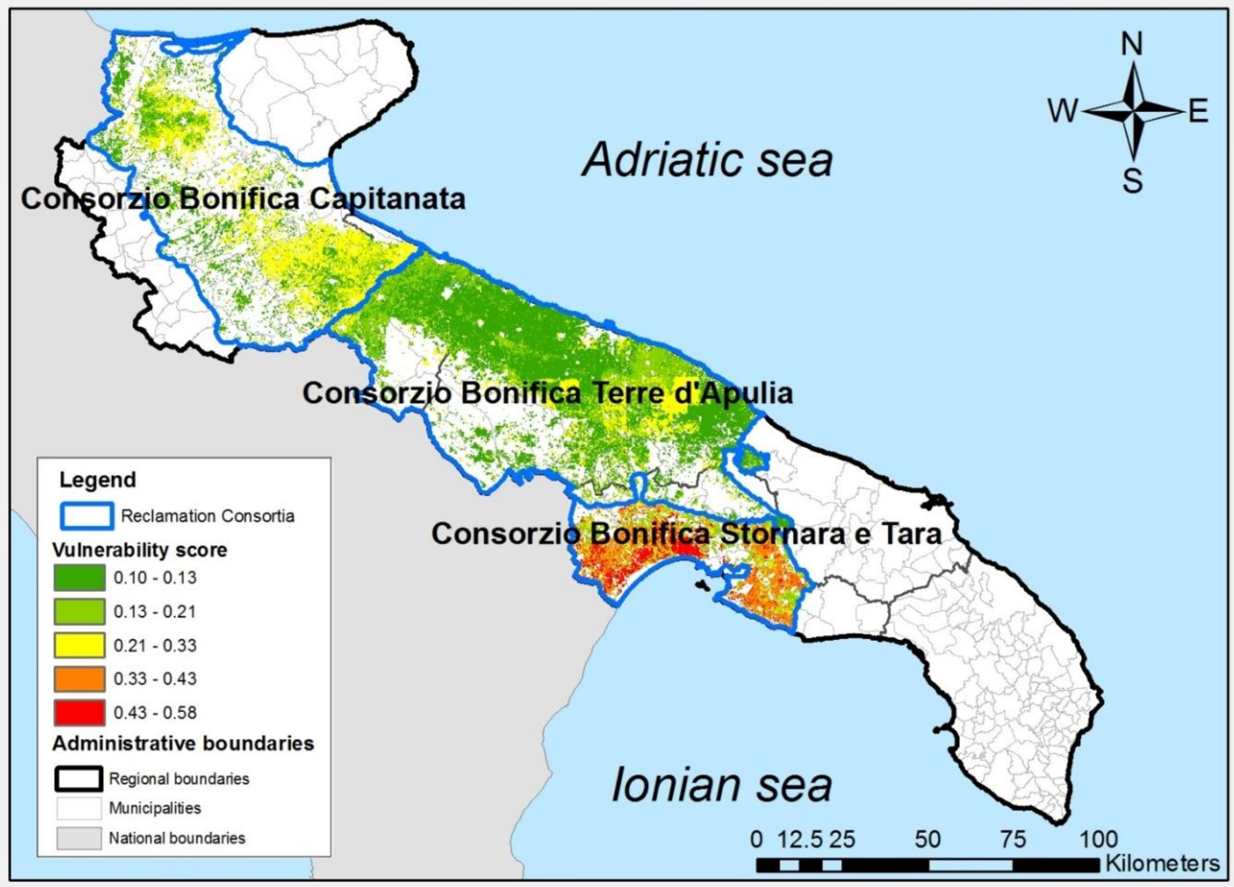
Figure 5.5. Map of Vulnerability 3



5.4.4 Total Vulnerability map and statistics

Final vulnerability score is obtained by multiplying the three vulnerability factors, according to Eq. (4.6). Resulting scores have been aggregated into five classes (one to five), by means of Equal interval classification, that (as for hazard maps) sets the value ranges in each category equal in size. The entire range of data values (*max (1) – min (0)*) is divided equally into five categories.

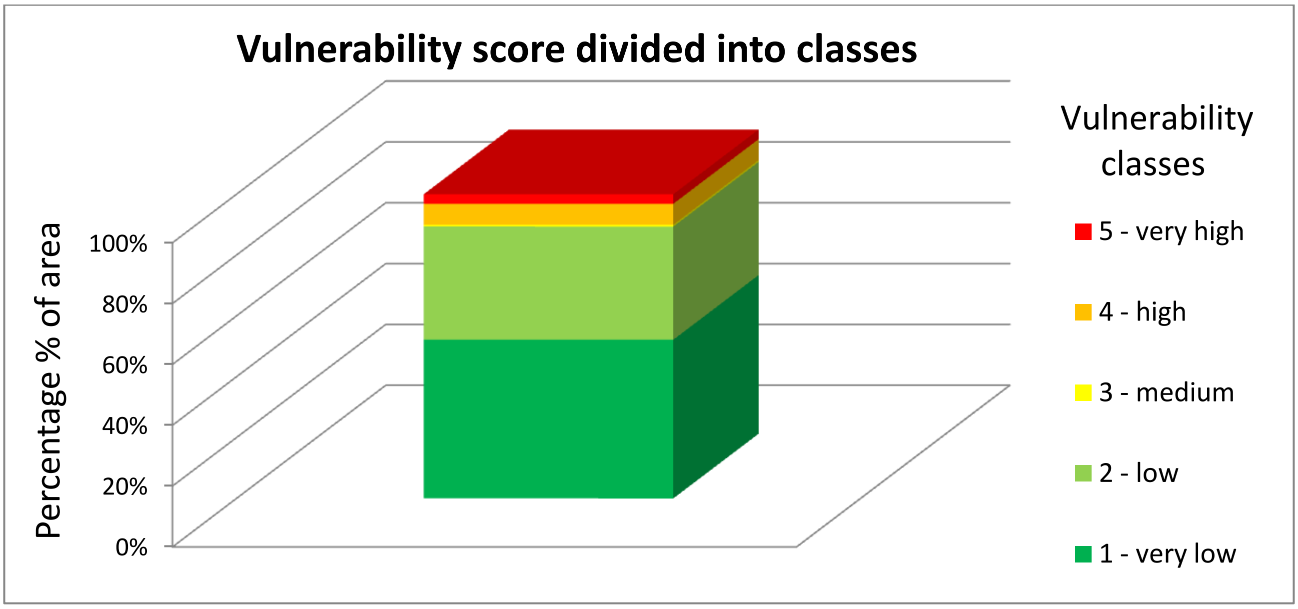
Figure 5.6 Total vulnerability map



As per the Final Map (Figure 5.6), most vulnerable areas are located in the Stornara e Tara Consortia, in middle-southern Puglia. In fact, this Consortium presents a high percentage of vulnerability crops (vegetables and fruit trees), with a relatively high rate of losses and no sources diversification. Capitanata and Terre d'Apulia Consortia are characterized by a lower vulnerability score (low to medium) mainly because there is a greater presence of olive groves and vineyards and in addition vulnerability of Terre d'Apulia crops is muffled by the fact that, the Consortia has a certain degree of diversification of sources.

A part from the GIS-based maps, some more considerations can be extrapolated from a simple statistician analysis of the data obtained. In fact, Figure 5.7 shows that approximately half (52.7%) of the area devoted to agriculture in Puglia is included into the lower class of vulnerability (class 1), while a further 37.2% is characterized by the low vulnerability class (2). Finally, the remaining 10.1% is included into the higher classes (medium: 3, high: 4 and very high: 5).

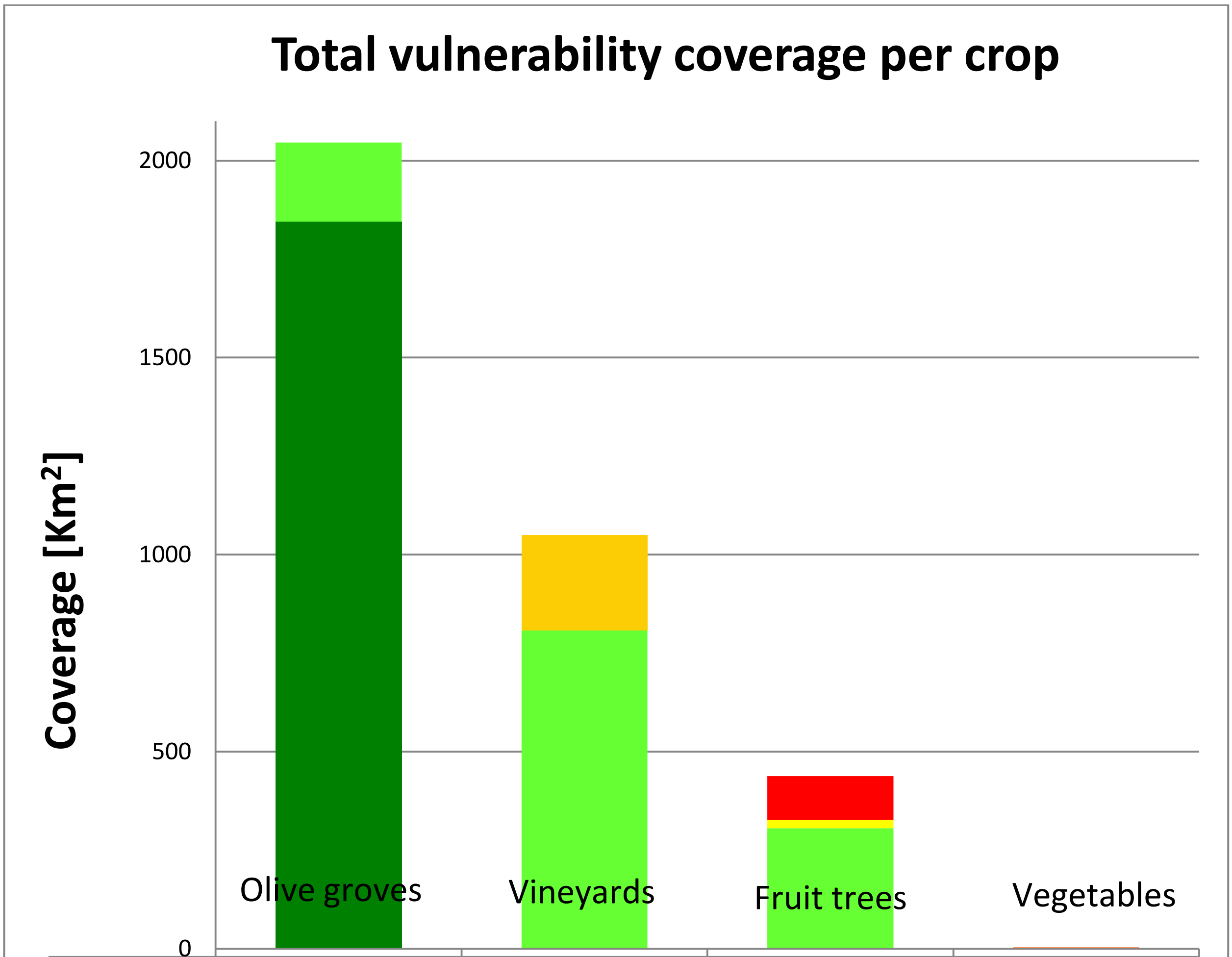
Figure 5.7 Distribution of vulnerability into five classes considering the territorial surface and the percentage of surface of the case study.



By analyzing separately each crops, the coverage, in terms of km^2, of the total vulnerability score (Figure 5.8) some interesting considerations can be argued. In particular:

- Olive groves are consistently characterized by the lower class of vulnerability, no matter about the factors V_2 and V_3 that are independent from the agronomic features.
- About one fourth of the vineyards coverage is characterized by the vulnerability class "high" mainly because they belongs to Reclamation Consortia that are strongly affected by water losses with no diversification of sources.
- A not negligible area (about a third) of fruit trees is characterized by the higher vulnerability score, both because of the agronomic influence (V_1 factor) and the allocation on more vulnerable Reclamation Consortia.
- 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 very well equipped to reduce losses and rely on other water sources (either than the Reservoirs).

Figure 5.8 Vulnerability score divided into classes. Extension [km^2] of crops are displayed.



	Olive groves	Vineyards	Fruit trees	Vegetables
5 - very high	0	0	110,9	0,4
4 - high	0	242,8	0	0
3 - medium	0	0	21,5	0,2
2 - low	200,6	807,8	305,2	2,3
1 - very low	1844,9	0	0	0

5.5. Risk scores and maps and discussion

Final outputs of the ORIENTGATE-RRA methodology are GIS based risk maps and related statistics that allow to identify and rank areas and hot spot at risk (namely: elements potentially most affected by hydrological droughts) within the case study area.

Normalized risks scores have been assigned to raster cells of 25 m resolution to allow a detailed visualization of the spatial variability of the total risk.

As for the hazard and vulnerability maps, relative risk scores have been divided into five colored classes that have been produced by means of equal interval classification, dividing the range of attribute values into equal-sized sub-ranges: Table 5.13. This method supports the identification of areas more affected by drought risk, according to the different scenarios.

The total surface at risk is equal to the extension of the study area: 3536.6 km^2, and the total risk index ranges between 0.00 and 0.38. This interval has been recalibrated to obtain a suitable classification to the values. In comparison with the standard RRA classification of 0-1 range (Table 5.13 - b) the case study risk values are all into the first two classes (very low and low risk).

Table 5.13 Risk scores and classification into classes of ORIENTGATE-RRA methodology (a) and Standard RRA methodology (b).

a.

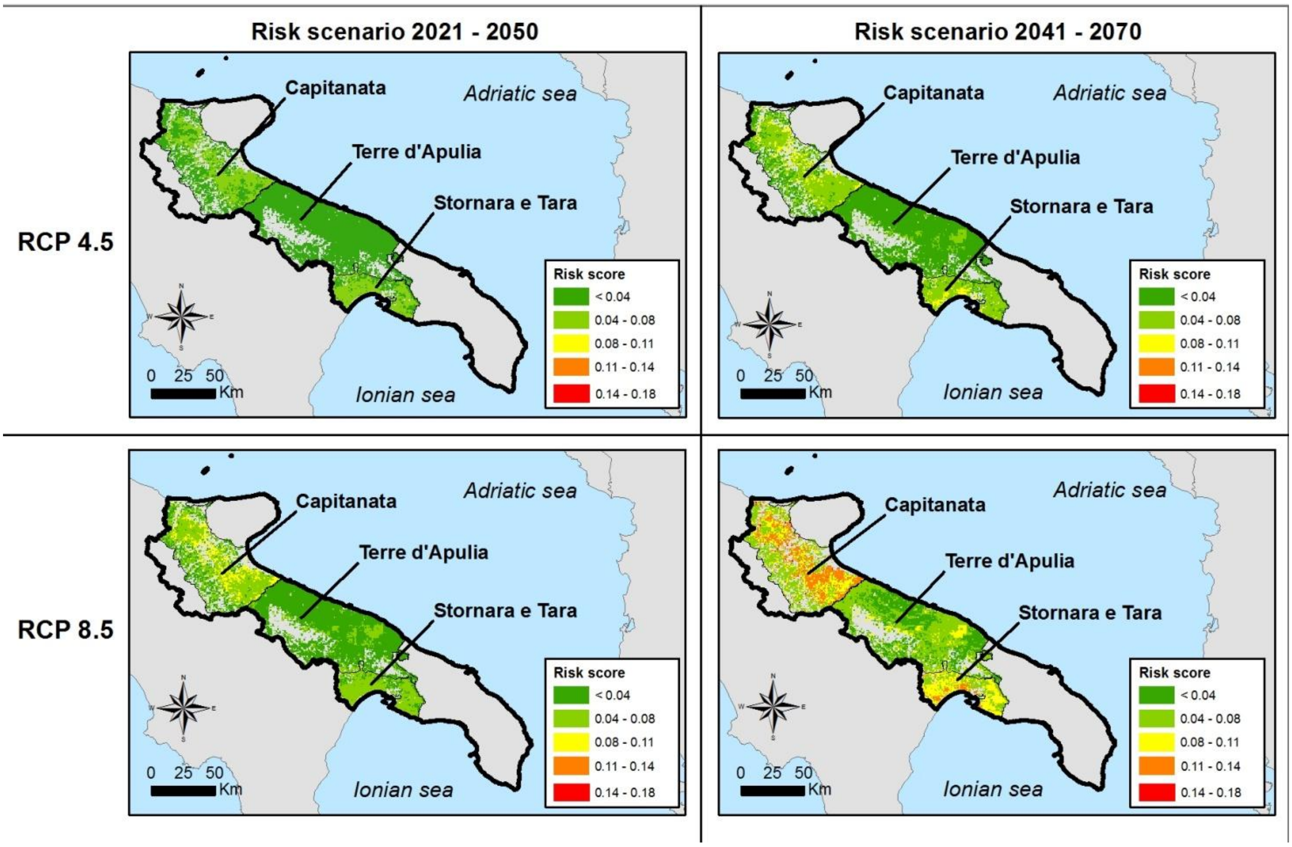
Classes	Risk scores
1 – very low	0.00 - 0.09
2 – low	0.09 - 0.17
3 - medium	0.17 - 0.24
4 - high	0.24 - 0.31
5 - very high	0.31 - 0.38

b.

Risk Classes	Score
Very low	0 - 0.2
Low	0.2 - 0.4
Medium	0.4 - 0.6
High	0.6 - 0.8
Very high	0.8 - 1

The Risk map, presented in Figure 5.9, shows the relative spatial distribution of drought risk in the case study. The map specifically points out the drought risk indicating hotspots and areas at risk in Capitanata and Stornara e Tara Consortia in RCP8.5 2041-2070 scenario. In the others scenarios, instead areas with low/very low risk prevail, with a scatter presence of a agricultural areas characterized by a medium risk. In next section (Sect. 5.5.6) some statistics will be discuss to help to understand better risk values in the different scenarios.

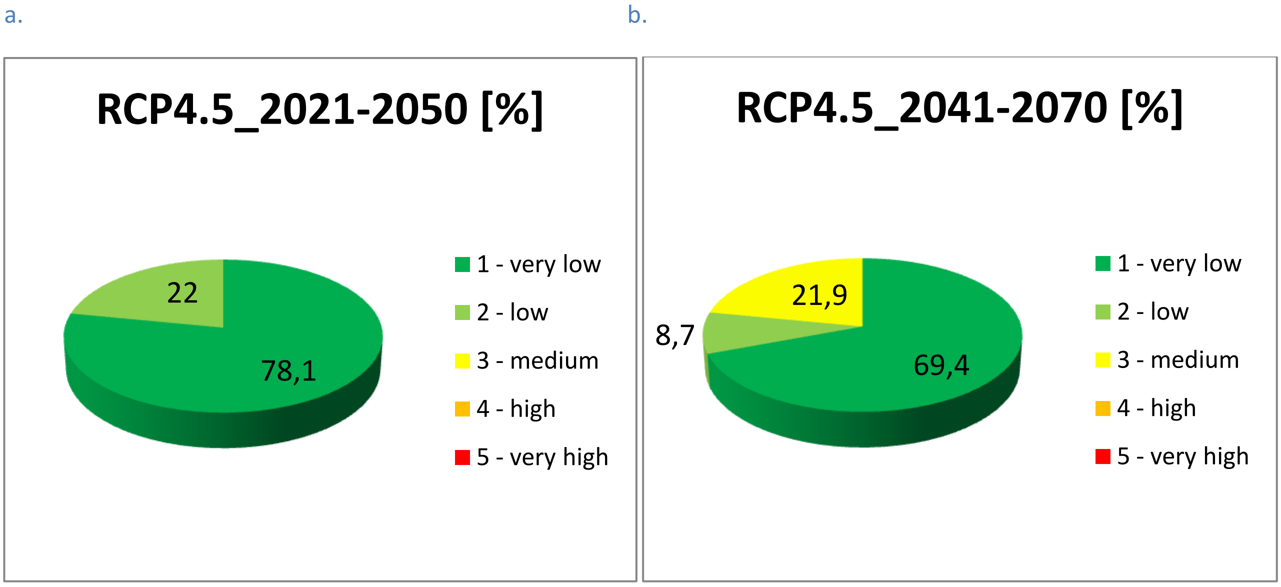
Figure 5.9 Risk maps considering the emission scenarios RCP4.5 and RCP8.5 for the two considered time frame: 2021-2050 and 2041-2070.



5.5.1. Statistics for RCP4.5 and RCP8.5 in the two temporal scenarios.

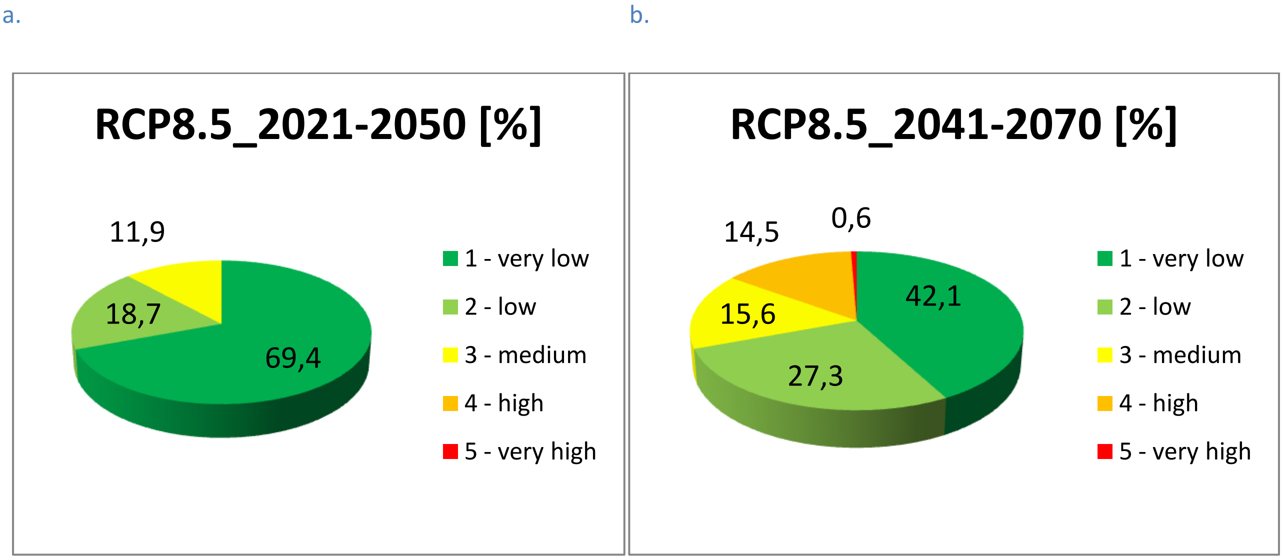
Results from the application of the ORIENTGATE-RRA methodology to the RCP4.5 scenario demonstrates that, overall, the (relative) risk magnitude is moderate. In the timeframe 2021-2050 the risk score is comprised within the "very low" and "low" classes in almost all the area. In the timeframe 2041-2070 there is also a fair area where the (relative) risk score is "medium" (776.16 km^2 over 3536.63 km^2, about the 22%).

Figure 5.10. Percentage of relative risk into classes for (a) RCP45 2021-2050 (b) RCP4.5 2041-2070



Risk maps obtained from the application of the ORIENTGATE-RRA methodology to the RCP8.5 scenario, that considers a business as usual emission management, reveals a more pronounced and heterogeneous trend. In fact, projections of risk are worst respect to the RCP4.5, in particular for the long-term timeframe (2041-2070), where almost 30% of the irrigated areas are characterized by a (relative) risk score in the range “medium-high-very high”. Moreover, within the timeframe 2021-2050, relative risk scores are limited for the larger part of the irrigated area, with only some 12% characterized by a medium risk score.

Figure 5.11 Percentage of relative risk into classes for (a) RCP8.5 2021-2050 (b) RCP8.5 2041-2070



Some more statistics can be derived from the general (relative) risk assessment. In particular, in the following Figures one can see the pattern of risk regarding the different selected crops, by considering their respective coverage. Figure 5.13 refers to the RCP4.5 Scenario while Figure 5.14 refers to RCP8.5 one. Y-axis indicates the crops absolute coverage [km^2], with labels indicating the relative value [%].

On these basis, some more considerations are presented below.

- **Olive groves** are included in the lower class of risk, with except from some limited area (30% of the total coverage) in the upper class along with the RCP 8.5 2050-2070 scenario. Therefore, the overall impact of (future) droughts events to this crop can be considered as negligible.

- **Vineyards** maintain, into RCP's, the same percentage trends. In RCP4.5 the share is, approximately, 40%-60%; the 40% corresponds to the lower class of risk, instead, the 60% are differentiated between the two timeframe: the class with "low" risk in 2021-2050 timeframe shift to the upper level ("medium" risk) in the following scenario (2041-2070).
  The same shift to the upper level classes, can be noted also for RCP8.5. The 40%-20%-40% , of "very low"-"low"-"medium" respectively, in the 2021-2050 timeframe, increase by one class in the 2041-2070 timeframe: rising at "low"-"medium"-"high" risk. For this RCP the stress, is, then, not negligible, overall on the long term, considering that the 40% of this crop is at high risk.
  In general, vineyards that present low risks, are due to the localization on Consortia more resilient. Is expected, in fact, that this shift, not results from crop specific vulnerability.

- In RCP4.5 **fruit trees** show the same trend in the two temporal scenarios: in 2021-2050 timeframe, the only classes of risk presented are 1 and 2 (70% "very low" and 30% "low"); in 2041-2070 the same percentages calculated for 1 and 2 describe instead classes 2 and 3 (70% "low" and 30% "medium"). RCP8.5 have in the 2021-2050 timeframe a prevalence of fruit trees percentage in class "low" risk, with only a 4.9% in class "medium" risk. In the long term (2041-2070), about a 70% and a 25% occupy, respectively "medium" and "high" classes, and the remaining 5% is in the class with "very high" risk. Falling in the last two classes, then, about the 30% can be deemed at strongly risk if we continue with an approach "business as usual".

- **Vegetables**, along with fruit trees, are mostly impacted crops. The trend is very similar at fruit trees for RCP4.5, the 80% - 20% of "very low"- "low" risk in the medium term, shift on "low"- "medium" risk, in the long term. In RCP8.5, instead, the percentages vary a little: in the medium term the majority part (80%) is on “low” risk, and the remaining part splits in a 13% of “medium” risk and a 7% of “high” risk. The long term the situation gets worse and shows a scenario not negligible, with an 80% on “medium risk” and a 20% on “very high” risk.

Figure 5.13 RCP4.5 Risk per crop and per scenario. On the x-axis: histograms divided per timeframe and per crop. On y-axis: coverage [km^2]. On labels: percentage [%] of coverage of each crop shared into the five risk classes.

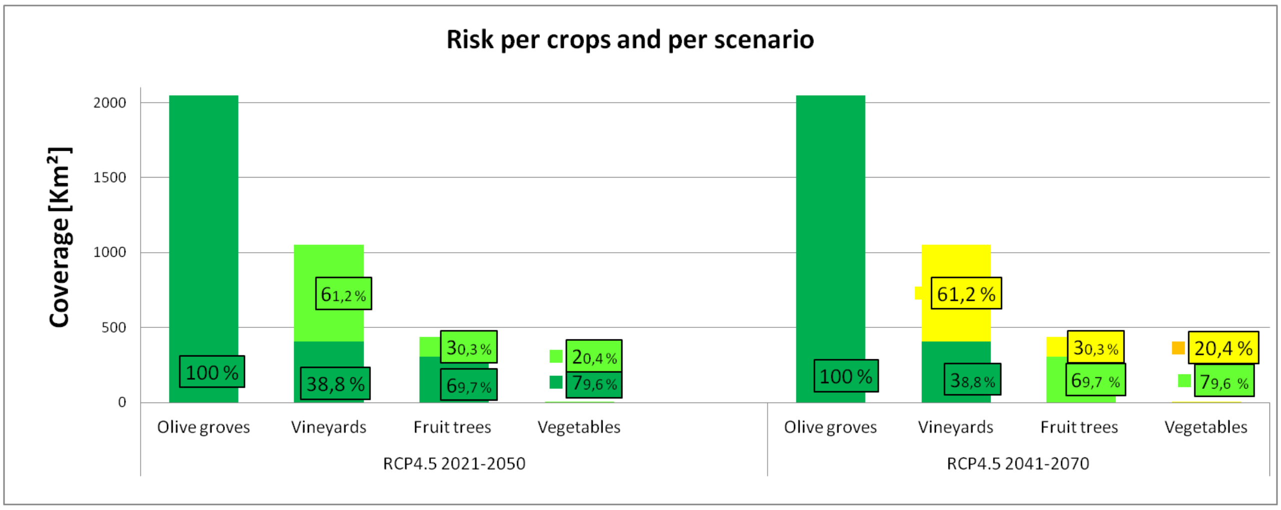
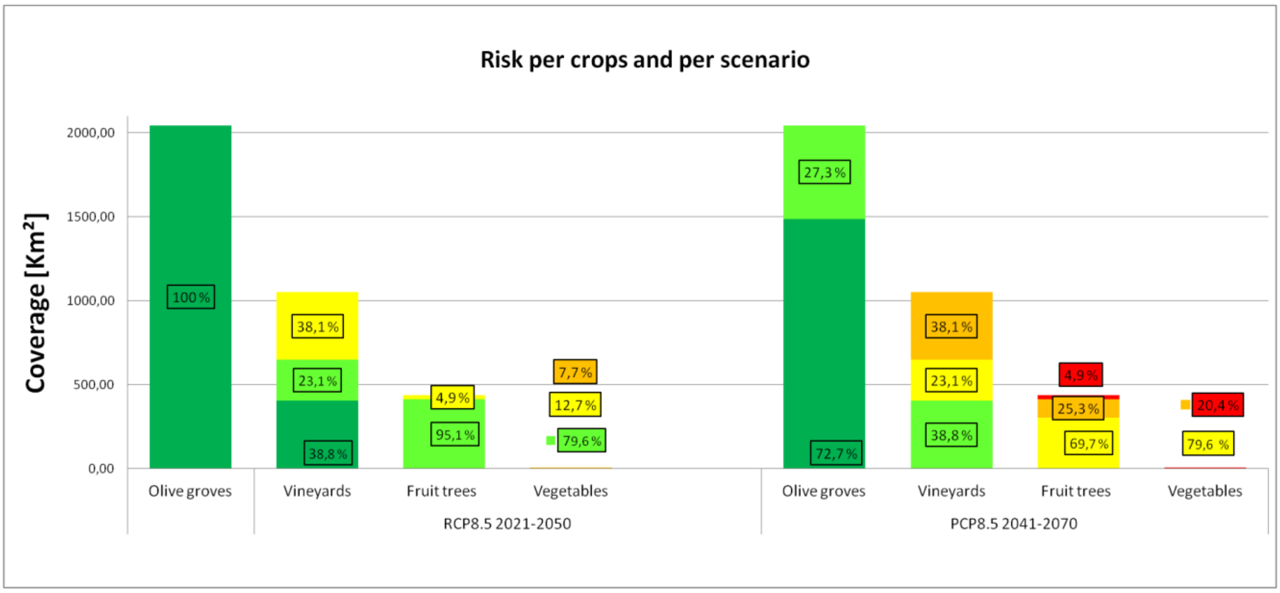


Figure 5.14 RCP8.5 Risk per crop and per scenario. On the x-axis: histograms divided per timeframe and per crop. On y-axis: coverage [km^2]. On labels: percentage [%] of coverage of each crop shared into the five risk classes.



It is worth to notice that that within a long-term perspective, the “business as usual” emission pattern can lead to considerable impact on the agronomic performances of the irrigated compartment 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, with lower magnitude, vineyards, is expected, since these cultivation are expected to suffer from a “medium” to “very high” drought risk. By contrast, olive groves are projected to be less vulnerable, and therefore more resilient, to the scarcity of water, and in a future scenario when this deficiency will be even more evident, is very likely that this crop will increase its coverage.

Finally, the economic consequences of the (severe) climatic impact to these valuable crops can easily argued from a simple comparison of the average values per hectare of land for crop that INEA estimated in 2012, for the Puglia case study. The results confirms that vineyards, fruit trees and vegetable crops, the crops more at risk, present an higher economic value (cash) than the olive trees (Table 5.13) (Gioia & Mari, 2012). This means that, in addition to the environmental and landscape impact, object of this thesis, the climatic trend will have severe economic consequences.

Table 5.13 Average value per hectare of land for macro-culture in Puglia Region [€ / ha]. (Gioia & Mari, 2012).

Rainfed arable	Irrigue arable (included vegetables)	Fruit trees	Vineyards	Olive groves	Pasture	Woods
12’858	16’566	15’647	19’640	13’118	3’968	6’888

6. Conclusions

The present study aims at assessing the impact of hydrological droughts due to climate change on the irrigated agronomic compartment.

In particular, the research addressed the development of a state-of-the-art risk assessment methodology, based on theoretical framework of the Regional Risk Assessment (RRA) approach (Landis, 2005). Its subsequent application to the (extensive) irrigated cultivations is shown, covering the larger part of the Puglia Region, in southern Italy, within a scenario-based hazard framework. This case study has been selected mainly due to its particular climatic-agronomic pattern, that characterize this semi-dry Mediterranean Region where large irrigation schemes, managed by three Reclamation Consortia, are present.

Relative risk maps (GIS based) and related statistics, specifically referring to the impact of drought hazard to the selected receptors, have been produced allowing the identification of hot spots and area at risk as well as the spatial characterization of the risk pattern. Generally, and as expected from the RCP's emission pattern and relative assumptions, the results of the assessment have showed that within the RCP8.5 scenario a not negligible rate of agricultural (irrigated) areas are at high risk of climate change induced droughts, especially in a long term perspective, while the RCP4.5 scenario gives a less dramatic perspective.

More in particular, relative risk maps have showed that fruit trees and vegetables are the most affected (cash) crops within both RCP's scenarios, specially with higher risk scores in the long term for the "business-as-usual". A similar but less severe situation, happens to vineyards, that in the worst scenario present areas at high risk, while in the others scenarios the situation is tolerable.

Contrary olive groves are more resilient to hydrological stresses, with lower risk scores even in the most severe scenario.

The ultimate aim of risk assessments is to support the development of targeted and knowledge-based mitigation and adaptation strategies both at local and regional scale, to reduce the risk pattern at both agronomic level (preferring crops with low vulnerability score, as olive groves), at structural level (differentiating the water stocks and supplies and reducing losses and inefficiencies) and at governance level (optimization of demand pattern and networking among different Consortia).

The degree of uncertainly related with this study, is due to factors that are not considered in the methodology, but that may vary in future scenarios. This factors are for example, future soil moisture and freshwater quality; these interactions are often highly complex and influenced by a number of factors which are themselves influenced by climate (Falloon and Betts, 2009). In any case the level of uncertainly can be lowered enriching this methodology with further vulnerability factors, regarding both the vulnerability of crops and soil and the vulnerability of Reclamation Consortia. More variables will be considered, more the analysis of the future situation will be detailed.

Rather, the scores of this study provide relative classifications about areas that are more vulnerable and likely to be affected by hydrological drought with more adverse effects than others in the same region. Where higher vulnerability and risk scores are found, climate mitigation and adaptation measures are strongly recommended. Actions on both hazard and vulnerability levels can be undertaken. In particular, mitigation strategies, that can be reasonably established and implemented at large (global) scale only, aim to reduce greenhouse gases emissions, and therefore contribute in decreasing the gradient of change for the climatic (rainfall) pattern and, finally, the hazard levels.

Adaptation policies can regard, instead, even small scale measures where vulnerability factors may be also involved. 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. Here below some potential adaptation measures, accordingly:

i. supply side adaptation measures could be: increasing (water) storage capacity by building new reservoirs and dams and by restoring the existing ones; extraction and 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 adaptation measures can refer to: improvement of water-use efficiency by recycling water and wastewater re-use; promotion of indigenous practices for sustainable water use; household and industrial water conservation; reduction in water demand for irrigation purposes by adapting the cropping calendar, crop mix, irrigation method, and area planted; reduction in water demand for irrigation by importing agricultural products, e.g., 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, 2008).

Some of these adaptation strategies are already on the pipeline for several Reclamation Consortia. On the supply side, the construction of new reservoirs from some Consortia at risk is expected to reduce the current available water stock and, therefore, to reduce the (drought) hazard pattern (e.g. Capitanata Reclamation Consortia is planning to use the Palazzo d'Ascoli Reservoir to serve the irrigation area of Carapelle). The use of civil wastewater for irrigation is another possible option that some of the most important Puglia’s municipalities (e.g. provinces Bari and Barletta-Andria-Trani) are considering. The enormous potential benefits that can be obtained from the use of wastewater for irrigation, in fact, are well known from local stakeholders and authorities (Appendix 2). Some Consortia, instead, are currently planning new structural investments to reduce losses, and therefore decrease the vulnerability score, through a more efficient maintenance of irrigation systems. Common threads that binds these adaptation strategies, are the high monetary costs related.

Another aspect that cannot be overlooked is the changes in consumption patterns and competition for water between domestic, industrial and agricultural uses might alter the availability of freshwater for irrigation and other agricultural uses (Betts, 2005). Competition for freshwater already exists among the municipal, industrial and agricultural sectors in several regions. The consequence has been 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 alternative 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 fibre, for ecosystem services, and for healthy lives, and that do so by maximizing the agricultural methods that benefit society (Falloon & Betts, 2009).

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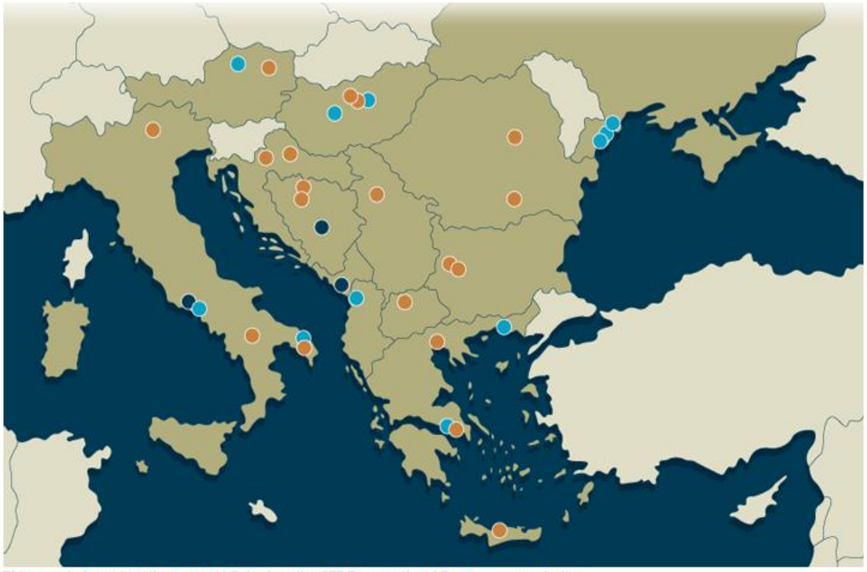
http://www.consorzio.fg.it/ : Capitanata Reclamation Consortia website, 2015

http://www.bonificastornaratatara.it/ : Stornara e Tara Reclamation Consortia website, 2015

Appendix 1: ORIENTGATE partners



This map is based on the map published on the SEE Transnational Programme website.

PARTNERS: Euro-Mediterranean Centre on Climate Change (IT), Forest Department, BMLFUW (AT), Ministry of Regional Development and Public Works (BG), National Institute of Meteorology and Hydrology (BG), Gradiška Local Development Agency (BiH), Hydrometeorological Service of Republika Srpska (BiH), Attica Region (GR), Center for Technological Research of Crete (GR), Goulandris Natural History Museum, EKBY (GR), City of Koprivnica (HR), Meteorological and Hydrological Service (HR), Hungarian Meteorological Service (HU), Regional Environmental Center (HU), Autonomous Province of Trento (IT), Basilicata Region (IT), Hydrometeorological Service (MK), Environmental Protection Agency of Covasna (RO), National Meteorological Administration (RO), Republic Hydrometeorological Service (RS).

ASSOCIATED PARTNERS: Regional Council of Shkodra (AL), Forest Service, Federal State Government of Upper Austria (AT), Ministry of Environment, Energy and Climate Change (GR), Municipality of Komotini (GR), 13th District of Budapest (HU), Municipality of Veszprém (HU),Ministry of the Environment, Land and Sea (IT), Region of Puglia, Mediterranean Department (IT), GFEAEI, Odessa Regional State Administration (UA), Odessa State Environmental University (UA), Vilkovo City Council (UA).

OBSERVING PARTNERS: Federal Hydrometeorological Institute (BiH), Union of Italian Provinces (IT), Ministry of Sustainable Development and Tourism (ME) (ORIENTGATE.org, 2015).

Appendix 2: Use of wastewater for irrigation

Reduce the pollution load of the water used by farmers, industries and urban settlements, would allows a largely reuse for irrigation. There are huge potential benefits that can be obtained from the use of wastewater for irrigation.

For example, a city with a population of 500’000 inhabitants and a water consumption of 120 liters daily, produces about 480’000 m^3/day of wastewater (assuming 80% of the water used reaches the public sewerage system). If this treated wastewater was used for irrigation, with careful monitoring, at a rate of 5000 m^3/ ha/year, it could irrigate about 3500 hectares.

The fertilizer value of the effluent is as important as the water itself. Typical concentrations of nutrients in treated wastewater are: nitrogen, 50 mg/; phosphorus, 10 mg/l; potassium, 30 mg/l. Using the effluent at a rate of 5000 m^3/ha/year, the annual contribution of fertilizer would be: nitrogen, 250 kg/ha; phosphorus 50 kg/ha; potassium, 150 kg/ha. Thus all the nitrogen and much part of the phosphorus and potassium normally required for the production of agricultural crops, may be supplied by the effluent. In addition, other micronutrients and organic matter contained in the effluent would provide additional benefits.

A further benefit is the fact that, since most of these nutrients are absorbed by the crop they are removed from the water cycle and therefore do not contribute to eutrophication of rivers and the creation of dead zones in coastal areas (FAO, 2002).