Deliverable C4.1: Report on the estimation of future climate change impacts on the water resources of Cyprus, Crete and Sicily

Date: September 2017
Acknowledgements

This report was produced under co-finance of the EC LIFE programme for the Environment and Climate Action (2014-2020), in the framework of Action C.4 “Assessment of the vulnerability of agriculture to climate change” of the project LIFE ADAPT2CLIMA (LIFE14 CCA/GR/000928) “Adaptation to Climate Change Impacts on the Mediterranean islands' Agriculture”.

The project is being implemented by the following partners:

- National Observatory of Athens – NOA
- Agricultural Research Institute - ARI
- Institute of Biometeorology - IBIMET
- National Technical University of Athens – NTUA
- Department of Agriculture, Rural Development and Mediterranean Fisheries, Region of Sicily – SICILY
- Region of Crete - CRETE
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Executive Summary

Agriculture is an economic sector highly affected by climate change, since it is directly dependent on climatic variables (e.g. precipitation) and the availability of surface and groundwater resources for irrigation. Most of research referring to climate change impacts on water resources has been focused on impacts to surface water. However, groundwater is also considered vulnerable to climate change as groundwater recharge through rainfall is expected to be altered and surface water resources shortage is expected to reinforce the use of groundwater to cover irrigation needs.

The scope of Action C.4.1 is to evaluate the impacts of climate change and agricultural management practices (e.g. irrigation) in groundwater quality and quantity through the use of simulation models. The ADAPT2CLIMA project implementation area comprises of three of the largest islands in the Mediterranean region, the islands of Crete (Greece), Cyprus and Sicily (Italy). However, in order to estimate future climate change impacts on the water resources groundwater simulation models, have been developed in eight indicative agricultural pilot areas at the three islands of interest.

Crete is facing increasing water demand imposed by the growth of agriculture and tourism during the recent decades. The pilot areas of Crete, Chania and Messara Plains (Figure 1a), are important agricultural areas of Greece, highly dependent on groundwater resources. Agriculture sector in Cyprus is already facing water shortage and a significant part of irrigation needs are covered by Conveyor projects in order to preserve groundwater resources. As pilot areas in Cyprus, four representative agricultural areas were selected; Acheleia, Kiti, Pegeia and Xylofagou (Figure 1b). In Sicily the general scarce water availability is a limiting factor for the Sicilian agricultural and rural development. The two pilot areas of Sicily are located in Trapani and in Dittaino Valley in the provinces of Enna and Catania respectively (Figure 1c).

Groundwater flow models have been developed for each pilot area. The models have been calibrated and validated based on historical groundwater level measurements provided by previous field campaigns and in situ measurements performed by the NTUA team with the contribution of the local partners - ARI in Cyprus, Region of Crete in Crete and Region of Sicily in Sicily. Then, a characteristic mean hydrological year was selected at each pilot area to approximate the current state of the aquifer with respect to water table and contaminant mass transport. Finally, a series of simulation runs were performed in all pilot areas in order to estimate changes in groundwater parameters under pressure of a foreseen extreme dry hydrological year based on Regional Climate Models MPI-RCA4 and MOHC-
RCA4 (Action C.3). In some pilot areas nitrate and/or salinization problems were also investigated based on available reliable data. For that purposes, simulation runs are also performed to estimate nitrate and chloride concentration changes under the future climate change scenarios considered.

Based on the developed groundwater flow simulation models, the future climate change impacts on the groundwater availability can be summarized as follows:

- In Crete pilot areas, a significant additional decrease of 4 (Chania Plain) to 12 (Messara Plain) m in groundwater level is expected.
- In Cyprus, not significant changes in groundwater recharge through precipitation are expected. Projected rainfall in extreme hydrological years is in comparable levels of the current mean hydrological years or slightly drier. Consequently, the groundwater flow models in Cyprus pilot areas do not denote significant groundwater depletion for the future.
- In Sicily pilot areas, a mean additional decrease of about 0.5-2m in groundwater level is expected. However, groundwater level fluctuation differs significantly between regions and in specific pilot areas a greater groundwater depletion is foreseen, implementing the need of adaptation strategies.

Nitrate concentration in groundwater seems not to be altered by changes occurred to groundwater flow due to climate change. However, high nitrate concentrations observed in many monitoring wells in Crete, Cyprus and Sicily pilot areas denote the need for changes in the applied fertilization practices in order to confront the already existing problem. For Cyprus, the main challenge regarding groundwater quality is salinization through sea water intrusion and return irrigation flows. The problem is highlighted by historical data of chloride concentrations, as well as the high chloride concentrations measured in groundwater samples collected from the pilot areas during the field campaigns. Although climate change projections do not indicate significant groundwater depletion, it is foreseen that groundwater salinization, mainly due to over pumping for irrigation purposes, will remain an important issue in Cyprus pilot areas. This is especially true for Kiti aquifer, which shows the highest groundwater level decline for projected future dry years.

For the sake of completeness of the analysis, the impacts of climate change on drought events in Crete, Cyprus and Sicily have been assessed by estimating the Standardized Precipitation Evapotranspiration Index (SPEI). SPEI has been estimated in selected areas in Crete, Cyprus and Sicily, in areas where dams mainly used for irrigation purposes are located. SPEI estimation has been conducted as it has been observed that SPEI evolution is correlated with changes in water storage (Vicente-Serrano and López-Moreno, 2005). During the entire period of analysis (i.e. 1972-2098), SPEI evolution has shown a downward trend, indicating more severe and intense drought events, in all selected locations within the three islands. Comparing the SPEI analysis results subject to the two RCP scenarios under consideration, it is observed that, despite the variation of the estimated SPEI values under the various scenarios, the use of different RCP scenarios has not led to significantly different conclusions regarding the climate change impacts on drought events in the specific locations.
1 Water resources for agricultural use and climate change

1.1 Introduction

Agriculture is an economic sector vulnerable to climate change, as it is highly dependent on climatic conditions (precipitation, temperature, soil moisture, air humidity) and on the availability of surface and groundwater resources for irrigation purposes. Extreme events as floods and extended periods of drought, as well as insufficiency in irrigation practices can be threatening for agricultural productivity (Brown et al., 2015; FAO, 2008). During the recent decades, various studies have investigated climate change impacts on water resources quality and quantity. Most of research referring to climate change impacts on water resources has been focused on impacts to surface waters, as climate change impacts on surface water resources are more obvious and easily understood. Climate change affects surface water directly through changes in the major climate variables such as air temperature, precipitation, and evapotranspiration (Singh and Kumar, 2010). On the other hand, research concerning groundwater quantity vulnerability to climate change is relatively limited.

However, most of research on climate change impacts on groundwater quantity indicates the effects on groundwater recharge. Predicted changes on precipitation and surface water availability may cause variations on groundwater systems recharge (Dragoni and Sukhija, 2008; Singh and Kumar, 2010). In addition, surface water resources shortage will also reinforce the use of groundwater to cover water needs, leading to groundwater depletion. Although there is a raising concern on groundwater quantity, groundwater quality is also expected to be affected by climate change (Green et al., 2011). For instance, decrease on groundwater recharge could affect nitrate concentration on pumped water (Stuart et al., 2011). Moreover, a decrease on surface water resources availability and the consequent further overexploitation of the aquifers may also lead to more intense seawater intrusion problems in coastal areas (Green et al., 2011).

The aim of the present study is to assess future hydrological conditions related to agriculture, based on the methodological approached proposed in Chapter 2. A detailed analysis of the future climate change impact on groundwater resources of the ADAPT2CLIMA pilot areas are presented in Chapter 3. Additionally, the impacts of climate change on drought events in Crete, Cyprus and Sicily have been assessed by estimating the Standardized Precipitation Evapotranspiration Index (SPEI) in selected representative areas (Chapter 4).

1.2 The case of Crete, Greece

Agriculture is an important economic activity in Crete. The utilised agricultural area (consisting of arable land, permanent crops, pastures - transitional forest/shrubland, pastures - combined shrubland/herbaceous plants, Pastures and Heterogeneous agricultural areas) occupies approximately 70% of the total area of Crete and amounts to 653,305ha (Hellenic Statistical Authority, 2000/2010). About 42.3% of the cultivated land is irrigated (LIFE ADAPT2CLIMA, Deliverable C1.1, 2016).
During the recent decades, the increasing water demand imposed by the growth of agriculture and tourism has had a strong impact on the water resources of Crete. Regarding future water availability, climate change seems that will contribute to a greater water shortage. A recent research on climate change impacts in Crete concluded to a significant a decrease of average annual water availability, defined as the sum of runoff and infiltration, ranging from 10% to 30% and affecting the availability of fresh groundwater (Koutroulis et al., 2016).

Messara and Chania Plains are the most representative agricultural areas in Crete and for that reason they have been selected as pilot areas in ADAPT2CLIMA project. The two pilot areas are located in the Prefectures of Herakleion and Chania respectively (Figure 2). In these two areas farmers have already faced problems with agricultural water availability and quality.

1.3 The case of Cyprus

Agriculture is an important sector of Cyprus economy and at the same time the most water-intensive sector, followed by the domestic sector (Papadaskalopoulou et al., 2015). Agri-farm structure of 2013 reports that the total utilized agricultural area in Cyprus was 109,332 ha (Statistical Service, 2014). The agricultural sector in Cyprus is already facing water shortage in spite of the various measures implemented by the government and the irrigation needs cannot be always met. Climate change is expected to cause greater problems on groundwater quality and quantity in the future, such as increased water demand for irrigation, decreased water availability and deterioration of water quality (CYPADAPT, 2013).

As pilot areas in Cyprus, four representative areas in agricultural sectors of the Island were selected; Acheleia, Kiti, Pegeia and Xylofagou (Figure 3). In these pilot areas, despite of the adopted measures
such as construction of dams and irrigation conveyor systems, water quantity and quality for agricultural use is still problematic.

![Figure 3 Cyprus pilot areas](image)

### 1.4 The case of Sicily, Italy

Agriculture is a major pillar for the economy of Sicily. Sicily agricultural area mainly consists of arable land, vineyards, permanent crops, kitchen gardens, permanent grassland, pastures and meadow, occupying approximately 89% of the total utilised agricultural area of Sicily and 54% of the total area of the island (Italian Statistical Authority, 2010 Agricultural Census). However, the general scarce availability of water is a limiting factor for the Sicilian agricultural and rural development.

The two pilot areas selected in Sicily are Trapani Region and the Dittaino Valley located in the provinces of Trapani and Enna respectively (Figure 4). In Trapani Region, vineyards are the most important crop followed by olives and cereals, while in Dittaino Valley only the latter seems to cover the majority of the area.
Figure 4 Sicily pilot areas
2 Methodological Approach

2.1 Methodological approach for the assessment of future climate change impacts on water resources’ quality and quantity

The methodology followed on Action 4.1 involves groundwater simulation models developed for all project pilot areas in order to achieve an estimate of future climate change impacts on their groundwater resources’ quality and quantity. Groundwater flow models are developed for each pilot area in order to evaluate the impact of future climate change and irrigation practices on groundwater availability. Groundwater flow models developed rely on the hydrological and hydrogeological characteristics of each pilot area, derived from historic bibliographic data and in-situ measurements whereas historic meteorological data provided by NOA were also used as inputs. In pilot areas where reliable nitrate and chloride concentration data were available contaminant mass transport simulations were also performed. The calibration and validation of groundwater models in all pilot areas were performed based on historic series measurements of water table elevation and nitrate and/or chloride mass concentrations where available obtained from the local partners - ARI in Cyprus, Region of Crete in Crete and Region of Sicily in Sicily. Then, a characteristic mean hydrological year was selected at each pilot area to approximate the current state of the pilot area with the respect to water table and contaminant mass. Finally, a series of simulation runs were performed in all pilot areas in order to estimate changes in groundwater parameters under pressure of a foreseen extreme dry hydrological year based on the Regional Climate Models MPI-RCA4 and MOHC-RCA4 (Action C.3). The steps followed to develop groundwater flow models are displayed in Figure 5.

The steps followed to develop contaminant mass transport models are displayed in Figure 6 and Figure 7.
The necessary data were obtained from local partners - Region of Crete, Agricultural Research Institute and Region of Sicily - for all pilot areas under study. The data collected refer to hydro-geological and geochemical parameters (e.g. hydraulic conductivity, infiltration rate), series of water table measurements, nitrate and chloride concentration, rivers’ flow data, dams’ capacity, irrigation and fertilization practices. The obtained data were evaluated and customized in the appropriate format.
2.1.2 In situ water measurements and water quality sampling

In the framework of the project, field campaigns were performed in all pilot areas in order to carry out recent measurements for validation purposes. For improving the accuracy of the groundwater models, in-situ hydrological measurements in each pilot area have been obtained twice a year (wet and dry period). Groundwater level has been monitored in selected locations and water quality samples were collected in agreement with the sampling and storing methods described in Stamatis et al. (2011). An estimation of nitrate and chloride concentrations on the collected samples was performed by an ion chromatography system (Dionex ICS-3000) at the Laboratory of Reclamation Works and Water Resources Management NTUA and a photometer (NOVA 60 Spectroquant) at the Unit of Environmental Science and Technology NTUA (UEST). An estimate of major elements (K⁺, Na⁺, Mg²⁺, Ca²⁺) concentrations was performed by an Atomic Absorption Spectrometer (Agilent AA240FS) at the Unit of Environmental Science and Technology NTUA. The pH and conductivity values were determined on site after collection with portable meters (PT-370 pH meter, CON 5 conductivity meter).

2.1.3 Hydro-geological characterization and simulation model development

Groundwater flow model for all pilot areas was developed using the US Geological Survey MODFLOW model (McDonald and Harbaugh, 1988), a block-centered finite-difference computer code that solves the groundwater flow equation. Visual MODFLOW Flex (Waterloo Hydrogeologic, 2017) was used as a pre- and post-processor for the USGS MODFLOW.

For pilot areas facing salinization problems, SEAWAT model was used to simulate seawater intrusion impacts. SEAWAT is a coupled version of MODFLOW 2000 (Harbaugh et al., 2000) and MT3DMS (Zheng and Wang, 1999), used in order to simulate the variable density effects on transient groundwater flow (Langevin et al., 2007).

For nitrate fate and mass transport simulation, MT3DMS (Zheng and Wang, 1999), a solute transport package included with Visual MODFLOW Flex 4.0, was used. The developed model simulates the movement and chemical alteration of nitrates as they move with groundwater through the subsurface.

The groundwater flow and contaminant mass transport model development relied on the hydrological and hydrogeological characteristics of each pilot area, derived from the data collection. Historic meteorological data obtained from the National Observatory of Athens were used to provide a representative assessment of climatic conditions in each pilot area which affect the natural recharge of the pilot areas under study (Giannakopoulos et al., 2016; 2017). In all 3 islands considered in the project, evapotranspiration plays a significant role in the hydrological budget, especially during the dry period (April-September), therefore the temporal distribution of precipitation determines how much and when recharge of the aquifers by means of infiltration of precipitation can take place. Evapotranspiration and surface runoff have been considered in all pilot areas to estimate the potential aquifer recharge. The spatial distribution of this recharge has been determined based hydrogeology (permeability of geological formations) and aquifer slope. Irrigation return flow, mainly during the irrigation season, has been estimated and included into the model as additional recharge for the pilot.
Historic hydraulic heads measurements were used to calibrate subsurface flow in the pilot areas while pumping rates were estimated based on previous reports and data obtained from the local farmers. The models have been calibrated for hydrogeological variables (hydraulic conductivity, storage coefficient, etc.) in transient conditions, based on historic data series of hydraulic head measurements, chloride and nitrate concentrations. Since calibration had been completed, the models were validated based on the additional available historic data and on data derived from the field campaigns organized during the ADAPT2CLIMA project.

### 2.1.4 Climate change projections

In order to assess future climate change impacts on agricultural water availability, future precipitation projections derived from sets of Regional Climate Models (RCMs) simulations carried out in the framework of Action C3.1 (LIFE ADAPT2CLIMA, Deliverable C3.1, 2017) were used as input on the developed hydrological models in order to estimate the future recharge in the pilot areas. As initial conditions (i.e. initial heads, initial contaminant concentrations) the outputs of the models obtained at the end of the base hydrological year have been used. As far as the pressures to the groundwater system, it has been assumed that irrigation and fertilization practices won’t be differentiated in the future.

Future precipitation data used are based on the RCA4 Regional Climate Model of the Swedish Meteorological and Hydrological Institute (SMHI) (Strandberg et al., 2014 and references therein) driven by two different global climate models:

- the Hadley Centre Global Environmental Model version 2 Earth System called HadGEM-ES (HadGEM) of the Met Office Hadley Centre (MOHC) hereafter MOHC-SMHI (Collins et al., 2011; Martin et al., 2011) and
- the Max Planck Institute for Meteorology model MPI-ESM-LR hereafter MPI-SMHI (Popke et al., 2013).

Based on the evaluation carried out in Action C3.1, the MOHC-SMHI and the MPI-SMHI models capture the observed seasonal patterns of the temperatures and precipitation in the three islands of interest.

The climatic models have a horizontal resolution of 12km (0.11°) and they were developed within the framework of EURO-CORDEX (Coordinated Downscaling Experiment - European Domain). Present day simulations cover the period 1971-2000 were used here as reference for comparison with future projections for the period 2031-2060 under the new IPCC RCP4.5 and RCP8.5 scenarios.

In the Fifth Assessment Report of IPCC, the scientific community has defined a set of four new scenarios, denoted Representative Concentration Pathways (RCPs). Those new scenarios include four pathways: RCP8.5, RCP6, RCP4.5 and RCP2.6. Together they reflect the range of radiative forcing values for the year 2100 relative to 1750 ranging from 2.6 to 8.5 W/m². In the framework of the project future RCM projections were based on the intermediate mitigation scenario (RCP4.5) and the high emission scenario (RCP8.5).

The RCP4.5 was developed by the GCAM modeling team at the Pacific Northwest National Laboratory’s Joint Global Change Research Institute (JGCRI) in the United States. It is a stabilization scenario in which...
Total radiative forcing is stabilized shortly after 2100, without overshooting the long-run radiative forcing target level (Clarke et al. 2007; Smith and Wigley 2006; Wise et al. 2009). This scenario also suggests that various climate policies are implemented (Thomson et al., 2011). It suggests the implementation of strong reforestation programs, the use of cropland and grassland decreases, following considerable yield increases and dietary changes (van Vuuren et al., 2011). In addition, CH₄ emissions are expected to remain stable, while CO₂ emissions are allowed to increase slowly until 2040, when a decline starts taking place. RCP4.5 depicts declines in overall energy use, as well as declines in fossil fuel use compared to the reference case, while substantial increases in renewable energy forms and nuclear energy both occur (Thomson et al., 2011).

The RCP8.5 was developed using the MESSAGE model and the IIASA Integrated Assessment Framework by the International Institute for Applied Systems Analysis (IIASA), Austria. RCP 8.5 is characterized by increasing greenhouse gas emissions over time, representative of scenarios in the literature that lead to high greenhouse gas concentration levels (Riahi et al. 2007). It represents a future state where no climate policies aiming at the reduction of GHG emissions are implemented (van Vuuren et al., 2011). CH₄ and N₂O emissions are expected to grow rapidly by the end of the century too (van Vuuren et al., 2011). The use of cropland and grasslands increases, mostly driven by an increasing global population. Given the overall slow rate of technological improvements in low-carbon technologies, the future energy system moves toward coal-intensive technology choices with high GHG emissions. Coal use in particular increases almost 10 fold by 2100 and there is a continued reliance on oil in the transportation sector (Riahi et al., 2011).

2.2 Methodological approach for the assessment of future climate change impacts on drought

SPEI has been calculated in selected locations in Crete, Cyprus and Sicily, mainly in areas where dams are located that are used for irrigation purposes. SPEI is a drought index based on climatic data introduced in 2010 and consists an extension of the widely used Standardized Precipitation Index -SPI (Vicente-Serrano et al., 2010). The main difference between SPEI and SPI is that SPEI captures not only precipitation but also temperature fluctuations and trends as it takes into consideration potential evapotranspiration (PET) as well (Vicente-Serrano et al., 2010). SPEI uses the difference between precipitation and PET to represent a simplified climatic water balance. Consequently, SPEI values lower than zero indicate dry periods. As it has been observed at water dam locations SPEI evolution is correlated with changes in water storage (Lorenzo-Lacruz et al., 2010). Specifically, the SPEI-12 (12-months time step) was estimated as medium time scales (SPEI timescales range from 1-48 months) in order to capture better variations of reservoir storages (http://spei.csic.es/home.html).

SPEI has been estimated for the period 1972-2098 through the SPEI R Package (Begueria and Vicente-Serrano, 2017). As input parameters for the period 1972-2004, gridded observational data from the EOB-S dataset (Haylock et al., 2008) is used. For the period of 2005-2098, climatic data produced by the Regional Climate Model MOHC-RCA4 forced by the RCP emission scenarios 4.5 and 8.5 is used.
3 Estimation of future climate change impacts on water resources

3.1 Estimation of future climate change impacts on water resources in Crete

3.1.1 Messara Plain

3.1.1.1 Pilot area characterization

Messara Plain, located in the central-southern part of Crete, is an important agricultural area of Greece (Figure 8). The main crops cultivated in the area are olives and grapes. The remaining cultivated land is used for vegetables, fruits and cereal growing. The main source of irrigation water is groundwater.

The pilot area consists of three sub-basins, which form the groundwater aquifer of Messara plain (GR130008): Moires sub-basin (namely GR1300083), Asimi-Bagionia sub-basin (GR1300084) and Praitoria sub-basin (GR130085) (Figure 8, in red). Messara aquifer system is characterized as over-exploited and vulnerable to nitrate pollution (Special Secretariat for Water, 2015). The area is crossed by Geropotamos and Anapodiaris rivers. The central part of the aquifer consists of alluvium and conglomerate formations, which are characterized as medium permeability formations (Figure 9). The Neogene sediments at the northern boundaries of the aquifer are showing low to very low permeability, as well as the flysh and gneiss formations that consist the southern boundaries of the pilot area. However, in specific parts of the southern part, the aquifer neighbors with karstified limestones.
Up until 2013, the main source of irrigation water for the area has been groundwater, which has led to a significant drop of groundwater levels and depletion of the aquifer system, especially in Moires sub-basin, which is the most cultivated area of the three sub-basins. In an attempt to restore groundwater levels in the wider area and meet irrigation water needs, the Faneromeni dam has been constructed at the riverbed of Koutsoulidis stream. The construction of the dam was concluded in 2005. The reservoir capacity is 17 M m$^3$ and its main purpose is the irrigation of 20 km$^2$. Messara plain began receiving irrigation water from the dam in 2011. However, due to mismanagement of (combined) surface water and groundwater in the area, groundwater levels have not fully recovered. Figure 10 shows the evolution of the groundwater table in Moires basin, for the hydrological years 1980-81 to 2012-13 (groundwater level is estimated as the mean level averaged over 30 boreholes). Figure 10 shows that groundwater levels have not further declined since the hydrological year 2007-2008, which is a result of reduced pumping and use of surface water for irrigation from the dam of Faneromeni. Figure 11 shows the groundwater evolution for selected boreholes for the hydrological years 2007-2008 and 2008-2009. In April 2017 and September 2017, field campaigns were performed in selected locations in Messara pilot area to collect water samples (Figure 12).
Figure 10 Evolution of groundwater level for Moires basin

Figure 11 Evolution of groundwater level for Messara plain – Moires sub-basin (selected boreholes)
Estimation of Cl⁻, NO₃⁻, Na⁺, K⁺, Mg²⁺ and Ca²⁺ concentrations was performed in the lab of the Unit of Environmental Science and Technology NTUA (UEST). The elevated nitrate concentrations in groundwater (Table 1) denotes that Messara Plain is vulnerable to nitrate pollution. The chloride concentrations measured are below the upper acceptable limit, as salinization problems are not observed in the area.
Table 1 Water level and quality in-situ measurements (Sampling periods: April 2017 and September 2017) – Messara Plain

<table>
<thead>
<tr>
<th>Well Name</th>
<th>Water depth</th>
<th>Cl</th>
<th>NO₃</th>
<th>Na⁺</th>
<th>K⁺</th>
<th>Mg²⁺</th>
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<th>Cond.</th>
<th>pH</th>
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<td>mg/L</td>
<td>mg/L</td>
<td>mg/L</td>
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<td>mg/L</td>
<td>µS/cm</td>
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<td>0.005</td>
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April 2017

<table>
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<th>K⁺</th>
<th>Mg²⁺</th>
<th>Ca²⁺</th>
<th>Cond.</th>
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September 2017

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<th>K⁺</th>
<th>Mg²⁺</th>
<th>Ca²⁺</th>
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<td>mg/L</td>
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<td>mg/L</td>
<td>mg/L</td>
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<td>µS/cm</td>
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3.1.1.2 Assessment of current water resources state (Messara Plain)

The hydrological budget of Messara Plain has considerably changed during the last 30 years (Figure 10) as a result of extreme groundwater exploitation, which began in 1981. Overpumping has led to a continuous drop of groundwater levels in the area, during the last 30-35 years. Inflow to the area, apart from direct infiltration from precipitation, comes from infiltration from Geropotamos, Lithaios and Anapodiaris rivers and from the secondary hydrographic network of the wider area watersheds (Lithaios and Plakiotissa), as well as extra infiltration from the northern Neogene formations. On average, evaporation represents 70% of precipitation for the area, and the remaining 30% represents surface runoff and infiltration. Of this 30%, it is estimated that 21% infiltrates the alluvium while 19% infiltrates the Pleistocene formations of the area. The mean annual direct infiltration from precipitation is estimated at 25 Mm³, while infiltration from the hydrographic network is estimated at...
11 Mm$^3$. Although evaporation is considerably high for the area, a small amount of infiltration from return irrigation is estimated at 2 Mm$^3$/year. Water abstracted for irrigation purposes is estimated between 37.5-45.5 Mm$^3$. Other outflows are rivers recharge (river-aquifer interaction) during the dry season (4 Mm$^3$/year) and aquifer outflows to the neighboring basins through Faistos and Harakas passages (1.5-2 Mm$^3$/year).

For Praitoria sub-basin, the over pumping observed since the 1980s, resulting in a significant lowering of the water table, has been reduced after the hydrological year 2007-2008 following regulations imposed from the Region of Crete, bringing the hydrological budget of the area in equilibrium. This sub-basin also receives significant amount of infiltration water from the northern Neogene formations as well as from surface runoff of the hydrographic network north of Anapodiaris River. Asimi-Bagionia sub-basin has been also overexploited since the 1980s, however after 2008-2009 the hydrological budget has returned in equilibrium due to reduced pumping regulated by the Region of Crete. A characteristic of the area is the relatively low groundwater yield of the pumping wells (<30 m$^3$/h). Moires sub-basin, on the other hand is the most exploited sub-basin of the three, with water needs for irrigation as high as 32 Mm$^3$/year. The water deficit of the area is estimated at 8 Mm$^3$. However, after 2012, the area started receiving irrigation water from the dam of Faneromeni resulting in rising of the water table. The percentages of surface water (Faneromeni) and groundwater used for irrigation purposes vary every year. Surface water used ranges between as high as 80% to as low as 20%.

The transient calibration and validation of the developed groundwater flow model was performed for the hydrological years 1980-1981 to 2009-2010. Conductivity values, infiltration rates and pumping rates have been fine-tuned to meet the historic groundwater level measurements. On April and September 2017, groundwater level measurements were obtained in Messara Plain pilot area for validation purposes (Table 1). Groundwater levels for a mean hydrological year in the period 2006-2016, which is representative of the current water resources status, are shown in Figure 13.
3.1.1.3 Assessment of future climate change impact on water resources (Messara Plain)

The groundwater model development is followed by groundwater flow simulations in order to assess the impact of the future climate change on the groundwater level. Foreseen extreme dry hydrological years, under the different models and scenarios, show annual precipitation as low as 140 mm. To facilitate realistic projection of groundwater levels in Messara Plain, it has been assumed that for such dry climatic years, infiltration from surface runoff, recharge from Neogene formations, and contribution to irrigation water from Faneromeni dam are minimal. Therefore, intensive pumping, relevant to recent years, is assumed to cover irrigation needs and direct infiltration from precipitation is foreseen to be at minimum. The results of the numerical simulations forced by the different IPCC RCP scenarios studied (RCP 4.5 and RCP 8.5) and the various Regional Climate Models outputs are presented on Figure 14 to Figure 17.
Figure 14 Predicted groundwater level in Messara pilot area for extreme dry hydrological year, based on the MOHC-SMHI model, under RCP 4.5 – Results of numerical simulations: (a) end of wet period and (b) end of dry period.

Figure 15 Predicted groundwater level in Messara pilot area for extreme dry hydrological year, based on the MOHC-SMHI model, under RCP 8.5 – Results of numerical simulations: (a) end of wet period and (b) end of dry period.
Figure 16 Predicted groundwater level in Messara pilot area for extreme dry hydrological year, based on the MPI-SMHI model, under RCP 4.5 – Results of numerical simulations: (a) end of wet period and (b) end of dry period

Figure 17 Predicted groundwater level in Messara pilot area for extreme dry hydrological year, based on the MPI-SMHI model, under RCP 8.5 – Results of numerical simulations: (a) end of wet period and (b) end of dry period
Based on the climatic projections for meteorological variables produced by the MPI-SMHI and the MOHC-SMHI model, the simulation results have shown an average of 7 m drop in groundwater levels for the wet season of an extreme dry hydrologic year (compared to an average hydrological year), while approximately 12 m drop is estimated for the dry season of an extreme hydrological year.

3.1.2 Chania Plain

3.1.2.1 Pilot area characterization

Chania Plain is located on the north part of the Chania Prefecture (Figure 18). It is mainly an agricultural area, where perennial crops such as olives, avocados and citrus and annual crops such as tomatoes are cultivated. In the coastal part of the pilot area, tourist activity is quite large, putting additional pressure on water resources.

The pilot area is part of the granular aquifer of Chania, with the reference code GR1300022. The major hydrolithological units present are classified as: alluvium deposits, medium permeability rocks which consist of the Quaternary deposits as well as the Miocene to Pliocene conglomerates and marly limestones, low permeability rocks which consists of the Pliocene to Miocene marls and impervious rocks which mainly consist of the phyllites–quartzites unit (Figure 19). The southern part of the aquifer neighbors with high permeability rocks which comprise karstic limestones. The pilot area is crossed by Tavronitis and Keritis rivers. The aquifer is characterized as satisfactory in terms of groundwater quality.
and quantity (Special Secretariat for Water, 2015). However, due to the intense agricultural activities in the area, awareness on groundwater management should be raised.

Figure 19 Hydrogeological map of Chania pilot area

In April and September 2017, field campaigns were performed in selected locations (Figure 20). The low chloride concentrations that were detected on the collected samples (Table 2) confirms the absence of salinization problems on the area. Figure 21 presents the groundwater level evolution for boreholes G188 and G122.

Figure 20 Chania sample points
Figure 21 Groundwater level evolution for selected boreholes in Chania plain
Table 2 Water level and quality in-situ measurements (Sampling periods: April 2017 and September 2017) – Chania Plain

<table>
<thead>
<tr>
<th>Well Name</th>
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<th>K⁺</th>
<th>Mg²⁺</th>
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April 2017

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September 2017

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<th>K⁺</th>
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3.1.2.2 Assessment of current water resources state (Chania Plain)

Chania Plain groundwater flow was simulated using the methodology shown in Figure 5, as there is no seawater intrusion problem. The groundwater system is enriched through rainfall infiltration, rivers-aquifer interactions and Ayia springs. Based on the available historic head data series (Figure 22), even though a balance between groundwater withdrawal and recharge is observed, from dry to wet period an approximately 3.5 m groundwater occurs.
(a) Wells location in Chania Plain pilot area

(b) Historic hydraulic head measurements (m a.m.s.l.) – DL29

(c) Historic hydraulic head measurements (m a.m.s.l.) – PL23

(d) Historic hydraulic head measurements (m a.m.s.l.) – PL24

Figure 22 Groundwater level on head observation wells in Chania Plain pilot area
The groundwater flow model developed was calibrated for transient conditions for the hydrological years 2004-2008. Hydraulic conductivity values and pumping rates obtained from previous reports and the literature have been fine-tuned to match historical groundwater level data. Groundwater flow conditions for the area have been simulated for the period 2006-2017, to assess the current state of water resources in the area. The period 2008-2017 has served as a validation test for the model. Simulated groundwater levels in selected observation wells for the hydrological year 2016-2017 were compared to the observed ones during the field campaigns that took place on April and September 2017 (Table 2).

Mean water balance of the pilot area during the calibration period is presented Table 3. Irrigation in Chania Plain is achieved through both surface and groundwater resources. It is estimated that around 21-22 Mm$^3$ of water are consumed annually for irrigation purposes. Around 3.6-3.7 Mm$^3$ of this water is directly pumped from the porous aquifer of Chania plain, while approximately 4 Mm$^3$ originate from the Karstic aquifer of Ayia, 0.4 Mm$^3$ come from Keritis river (surface water) and around 10 Mm$^3$ through the irrigation network of OAK SA, that collectively distributes water coming from different sources in the wider area, mainly from the artificial lake of Ayia and the karstic springs of Ayia and Meskla. Another 0.9 Mm$^3$ are pumped from the porous aquifer for other uses (domestic water supply, industry, tourism).

<table>
<thead>
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<th>Table 3 Water balance in Chania pilot area (Charchousi et al., 2017)</th>
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<tr>
<td>Direct Recharge (precipitation)</td>
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<td>INFLOW (cm/year)</td>
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<tr>
<td>Pumping</td>
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<td>Outflow to the Sea</td>
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<td>Total Outflow</td>
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</table>

Groundwater levels for a mean hydrological year in the period 2006-2017, which is representative of the current water resources status, are shown in Figure 23. An average drop in groundwater level of 2.5-3 m is observed between the wet and dry season. However, groundwater levels are generally recovered during the wet season of the following hydrological year, and groundwater resources are replenished, showing that the hydrological budget of the area is in equilibrium.
3.1.2.3 **Assessment of future climate change impact on water resources (Chania Plain)**

The groundwater model development is followed by groundwater flow simulations in order to assess the impact of the future climate change on the groundwater level. To facilitate realistic projection of groundwater levels in Chania Plain, it has been assumed that for the predicted dry climatic years, infiltration from surface runoff (Keritis and Tavronitis rivers and the secondary hydrographic network), aquifer recharge from the springs of Ayia and Meskla, and return irrigation are considered to be greatly minimized, following the estimation of the predicted hydrologic budget for the area. Therefore, intensive pumping, relevant to past very dry years (e.g. 1991-1992 and 1999-2000), is assumed to cover irrigation needs and direct infiltration from precipitation is foreseen to be at minimum. The results of the numerical simulations forced by the different IPCC RCP scenarios studied (RCP 4.5 and RCP 8.5) and the various Regional Climate Models outputs are presented on Figure 24 to Figure 27.

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**Figure 23** Groundwater level in Chania Plain pilot area for the base hydrological year – Results of numerical simulations: (a) end of wet period and (b) end of dry period

**Figure 24** Predicted groundwater level in Chania Plain pilot area for extreme dry hydrological year, based on the MOHC-SMHI model, under RCP 4.5 – (a) end of wet period and (b) end of dry period
Figure 25 Predicted groundwater level in Chania Plain pilot area for extreme dry hydrological year, based on the MOHC-SMHI model, under RCP 8.5 – (a) end of wet period and (b) end of dry period.

Figure 26 Predicted groundwater level in Chania Plain pilot area for extreme dry hydrological year, based on the MPI-SMHI model, under RCP 4.5 – (a) end of wet period and (b) end of dry period.

Figure 27 Predicted groundwater level in Chania Plain pilot area for extreme dry hydrological year, based on the MPI-SMHI model, under RCP 8.5 – (a) end of wet period and (b) end of dry period.
Groundwater flow simulations for the Chania pilot area, using climatic projections for meteorological variables produced by the MPI-SMHI and the MOHC-SMHI model forced by the IPCC RCP 4.5 and 8.5 scenarios, have shown an additional decrease of the water table of approximately 4 m, during the dry period of predicted dry years. The highest drop in groundwater levels (9-10 m) is observed in the area of the alluvial deposits of Keritis river, where groundwater pumping for irrigation purposes occurs, and recharge from Ayia springs is reduced due to decreased infiltration of the karstic aquifer recharging the springs.

3.2 Estimation of future climate change impacts on water resources in Cyprus

3.2.1 Kiti pilot area (Larnaka)

3.2.1.1 Pilot area characterization

Kiti pilot area that coincides with Kiti aquifer, known as CY-3 groundwater system, is located in South Cyprus, in Larnaca district (Figure 28). The area is mostly agricultural, but in its coastal parts tourism is rapidly developed. A significant part of irrigation needs in Kiti area are covered by the Southern Conveyor Project (Figure 29). Southern Conveyor Project basic objective of the project is to collect and store surplus water flowing to the sea and convey it to areas of demand for both domestic water supply and irrigation. Basically the project aims at the agricultural development of the coastal region between Limassol and Famagusta, as well as to meet the domestic water demand of Limassol, Larnaca, Famagusta, Nicosia, a number of villages and the tourist and industrial demand of the southern, eastern and central areas of the island (Ministry of Agriculture, Natural Resources and Environment, 2000).

![Figure 28 Kiti pilot area](image)
The limited precipitation observed during the recent years has led to diminished direct natural recharge of Kiti aquifer. The Water Development Department of Cyprus\(^1\), responsible for the protection, rational and sustainable development and management of the country’s water resources, has characterized the specific aquifer as poor quality and quantity groundwater system, as a result of the over-pumping activity in the area for irrigation purposes. As reported by the Water Development Department, the most productive parts of the aquifer have faced salinization problem and they have been abandoned. Also the less productive parts are depleted and borehole yields have dramatically dropped (WDD and FAO, 2002). Kiti aquifer is also vulnerable to nitrate contamination due to agricultural activities, as reported on the ‘Report on the Implementation of Council Directive 91/676/EEC concerning the Protection of Waters against Pollution caused by Nitrates from Agricultural Sources’ (Ministry of Agriculture, Natural Resources and Environment, 2015).

Kiti pilot area is crossed by Tremithios river. In 1964, Kiti dam was constructed. The aquifer at its western boundary is in hydraulic connection with the Tremithios river alluvial deposits (WDD and FAO, 2002). At its north-east boundary the aquifer neighbours with two salt lakes, while its south and south-east boundaries is shoreline. The aquifer system is layered (Figure 30). The impervious base of the aquifer consists mainly of Pliocene marls. The sediments of the aquifer consist of Pleistocene marine terrace deposits such as silts, gravel and sands, whereas the aquifer sediments along the Tremithios riverbed consist of river alluvial deposits (WDD and FAO, 2002; Milnes and Renard, 2002).

---
\(^1\)http://www.moa.gov.cy/moa/wdd/Wdd.nsf/
Groundwater level has been monitored in June 2016 and September 2017 and water quality samples were collected in selected locations (Figure 31). Collected samples were analyzed at the NTUA laboratory. The elevated Cl\(^-\), Na\(^+\) and K\(^+\) concentrations in groundwater as well as the observed high conductivity values (Table 4) denote an input of seawater intrusion into Kiti groundwater system. The obtained pH values of collected water samples indicate the slightly alkaline nature of groundwater in the area.

Figure 30 Simplified geological N–S-cross-section through the Kiti aquifer system (Milnes and Renard, 2002)

Figure 31 Kiti sample points
## Table 4 Water level and quality in-situ measurements (Sampling periods: June 2016 and September 2017) – Kiti pilot area

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<th>Well Name</th>
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<th>Ca²⁺ mg/L</th>
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<td>Maximum permitted concentration</td>
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### June 2016

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### September 2017

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### 3.2.1.2 Assessment of current water resources state (Kiti pilot area)

In Kiti aquifer, as in numerous coastal aquifers, over-exploitation has led to groundwater quality degradation during the past decades. Locally, over-exploitation temporarily diminished the hydraulic head by as much as 12 m below sea-level in the early 80s leading to pronounced landward directed gradients, and thus to an acceleration of seawater intrusion (Milnes and Renard, 2002). Groundwater abstraction, mainly for irrigation, was an average of 3×10⁶ m³/year in the 1980s but was subsequently reduced to 1.8×10⁶ m³/year by the mid-90s (Milnes and Renard, 2002) and to 1.3-1.5×10⁶ m³/year in recent years. The water table recovered somewhat in the 90s, due to reduce groundwater pumping but is still below sea level during the main dry season. Figure 32 shows groundwater level evolution for the 2 monitoring boreholes (wells location in Figure 31), where groundwater levels were also measured during the field surveys. Chloride concentration for these boreholes is also shown in Figure 33.
Figure 32 Groundwater level (m a.m.s.l.) evolution for selected monitoring boreholes in Kiti aquifer

Figure 33 Chloride concentration (mg/L) for selected monitoring boreholes in Kiti aquifer
As Kiti aquifer is a typical case of salinization problem in Cyprus, SEAWAT has been used to simulate variable density flow and seawater intrusion. The transient calibration was performed for the hydrological years 2008-2009 and 2009-2010. Observed hydraulic head measurements and chloride concentrations for the period 2006-2017 have been used for model validation.

Historical hydraulic head measurements and chloride concentration data show that hydraulic depressions and seawater intrusion has advanced far inland. In the central part of the pilot area, where the saturated alluvial aquifer thickness is only a few meters and pumping for agricultural purposes is intensive (mainly for citrus), a large circular-like high salinity anomaly is observed, which is laterally disconnected from the seawater front in a zone of approximately 3 km inland.

Along the northern boundary of the aquifer, a lateral flux boundary condition was imposed (Neuman boundary), corresponding to the recharge from upstream carbonates. In SEAWAT, Neuman boundaries can be imposed as General Head Boundary Conditions. General Head Boundary Conditions were also imposed along the coastline, to simulate sea level heads and potential seawater intrusion. Chloride concentration values have been expressed relative to that of seawater (22 g/L). Consequently, relative chloride concentration at the sea boundary is equal to 1. Pumping wells were implemented in the alluvial aquifer assuming an initial pumping schedule for the wet and dry seasons, which was subsequently modified, along with hydraulic conductivities, during model calibration to match observed hydraulic head measurements. All other model boundaries were defined as no flow boundaries. Apart from direct infiltration, return flows from irrigation and infiltration from surface runoff constitute inflows to the groundwater system.

Groundwater levels for the base–mean- hydrological year, which is representative of the current water resources status in the pilot area, are shown in Figure 34. The extent of seawater intrusion front in the area is evident from groundwater levels distribution, in the south and central part of the aquifer. In the central part of the pilot area, the increased hydraulic depression observed from the historic hydraulic head measurements, is successfully simulated from the model. An average drop in groundwater levels of 2-2.5 m is observed between the wet and dry seasons, which is more pronounced in the central and south parts of the aquifer, where seawater intrusion occurs. A hydraulic depression of -2 to -4 m is observed during the dry season.
3.2.1.3 Assessment of future climate change impact on water resources (Kiti pilot area)

The results of the numerical simulations forced by the different IPCC RCP scenarios studied (RCP 4.5 and RCP 8.5) and the various Regional Climate Models outputs are presented on Figure 35 to Figure 38.

Figure 34 Groundwater level in Kiti pilot area for the base hydrological year – Results of numerical simulations: (a) end of wet period and (b) end of dry period

Figure 35 Predicted groundwater level in Kiti pilot area for extreme dry hydrological year, based on the MOHC-SMHI model, under the RCP 4.5 scenario – Results of numerical simulations: (a) end of wet period and (b) end of dry period
Figure 36 Predicted groundwater level in Kiti pilot area for extreme dry hydrological year, based on the MOHC-SMHI model, under the RCP 8.5 scenario – Results of numerical simulations: (a) end of wet period and (b) end of dry period

Figure 37 Predicted groundwater level in Kiti pilot area for extreme dry hydrological year, based on the MPI-SMHI model, under the RCP 4.5 scenario – Results of numerical simulations: (a) end of wet period and (b) end of dry period
Based on the extreme dry climatic projections for meteorological variables produced by the MPI-SMHI and the MOHC-SMHI model, the simulation results have shown an additional decrease of the water table of approximately 1 m, during the dry period of a predicted dry year both for the RCP 4.5 and RCP 8.5 scenario studied. The largest decrease in groundwater levels (~ 2 m) is predicted for RCP 4.5 scenario under the MPI-SMHI model. For this case, seawater intrusion is predicted to move further inwards, and groundwater levels as low as -8 m to -10 m are predicted form the southcentral part of the alluvial aquifer.

### 3.2.2 Pegeia pilot area (Paphos)

#### 3.2.2.1 Pilot area characterization

Pegeia pilot area that coincides with Pegeia aquifer, known as CY-13 groundwater system, is a limestone aquifer in the western part of Cyprus (Figure 39). Pegeia is a traditional banana and citrus crop field area. Pegeia aquifer has been subjected to intensive overpumping and seawater intrusion has been observed in some locations. However, most of the aquifer’s area is included in Pafos Irrigation Project area, which covers an important part of the irrigation needs in the western coastal area of Cyprus (Figure 40). An additional pressure has been created on Pegeia groundwater system due the increased demand for potable water due to the expansion of tourism infrastructure and the increasing urbanization of the region.
Pegeia pilot area is a semiconfined coastal aquifer developed in a karstified reef limestone. A hydraulic connection and water interchange with the sea occurs at the southwestern boundary of the aquifer. The aquifer is outcropping in its middle part, and its western part is confined between impermeable
The aquifer base elevations range from 400 m a.m.s.l. in the upstream area to about -350 m a.m.s.l. near Agios Georgios Aspros River area. The aquifer thickness ranges from 20 m in the south and thickens towards the northwest to 300 m. The general dip direction is oriented to the west in the upstream area and to the north-west in the coastal area. This is due to both tectonic tilting of the sedimentary units and thickness changes. For instance, towards the north of the upper part, the fractured middle Lefkara is progressively reduced, so that the dipping of the basement is less pronounced. Towards, the south, a general thickening of the aquifer can be inferred from the borelogs.

The impervious base of the aquifer consists mainly of Palaeogene (Lefkara formation) marls, chalks and chalky marls. The karstified reef limestone belongs to a member of Lower Miocene age (Pachna formation) known as Terra limestone. Middle Pachna formation chalks, sandstones, sandy marls and marls cover the northeastern part of the aquifer. It is assumed that part of aquifer’s recharge is coming from this formation. The ceiling of the confined part of the aquifer along the coastal zone, consists of Plio/Pleistocene marls and sandy marls of the Athalassa formation. It is assumed that there is a connection and water interchange between the calcarenites of this formation and the reef limestone aquifer (WDD and FAO, 2002). In Figure 41, the hydrological formations of the aquifer are shown.

In the framework of the project, field measurements were performed in two selected locations (Figure 42) in Pegeia pilot area. Groundwater measurements were performed in June 2016 and September 2017. Water quality samples were collected only in September 2017 and analyzed at the NTUA laboratory. The elevated detected chloride concentrations in groundwater samples in combination with the observed water table in the specific sample points (Table 5) denote the salinization problems of the area studied.
### Table 5 Water level and quality in-situ measurements (Sampling periods: June 2016 and September 2017) – Pegeia pilot area

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<td>Maximum permitted concentration</td>
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#### June 2016

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#### September 2017

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#### 3.2.2.2 Assessment of current water resources state (Pegeia pilot area)

Pegeia is an over-exploited aquifer, which has led to groundwater quality degradation during the past decades. It is estimated that in the past decade, approximately 1.0-1.2 Mm³ are abstracted, for irrigation of bananas and citrus, and for water supply of the booming tourist industry. Groundwater pumping has been slightly reduced compared to the 80’s and 90’s, which in combination with some consecutive wet years has resulted in the replenishment of the groundwater aquifer, which however still remains below sea level in certain parts, exhibiting extended sea water intrusion. Groundwater
abstraction occurs mainly from the north coastal and central part of the aquifer. The map in Figure 43 shows the location of pumping and monitoring wells in Pegeia aquifer.

![Figure 43 Location of monitoring and pumping boreholes in Pegeia aquifer (after Zambaz, 2005)](image)

Long-term assessment of the water table for boreholes close to the seashore show that water levels fluctuate around mean sea level. This is due to the existing marls of the upper Pakhna formation, which form a lid on the aquifer, preventing direct sea water intrusion (Figure 44, Zambaz, 2005). For observation wells, which are located in the central part of the aquifer, where extraction is the most intense and hydrogeologic formations allow sea water intrusion, water table remains mostly below sea level. Figure 45 shows long-term water table evolution for selected monitoring boreholes in Pegeia aquifer; their location is depicted in the map of Figure 46.

![Figure 44 Schematic illustration showing how the aquifer plunges below the sea in a northwestern direction, covered by low permeable marls of the upper Pakhna formation. The marls of the upper Pakhna formation form a ‘lid’ on the aquifer (after Zambaz, 2005)](image)
Figure 45 Long-term water table evolution (masl) for selected boreholes in Pegeia Aquifer
The groundwater flow and the seawater intrusion mechanism in Pegeia pilot area was simulated using the SEAWAT model. The transient calibration of the model has been performed for the hydrological years 2003-2004 to 2007-2008. Observed hydraulic head measurements and chloride concentrations for the period 2008-2017 have been used for model validation. Inflows to the groundwater system constitute direct infiltration from precipitation and return irrigation flows. In the Pegeia area, surface runoff is characterized by seasonal rivers of minor extent, which do not play a significant role to the hydrological budget. It is estimated that evapotranspiration accounts for around 85% of annual precipitation. Historical hydraulic head measurements and chloride concentration data show that Pegeia can be subdivided into three main areas, regarding piezometry. The “upstream area” located to the northeast, characterized by steep hydraulic gradients. In this area piezometric data is scarce as it is not exploited. It is a major area of aquifer recharge, and water table is mostly above 90-100 m a.m.s.l. The “central area” is where the main agricultural activity takes place and is characterized by a piezometric depression, which recovers more or less during the wet season, depending on recharge. This area is characterised by the most pronounced seasonal fluctuations, reflecting the impact of exploitation for irrigation and water purposes. Along the coastline the piezometric heads fluctuate around the mean sea level. Due to the small transmissivities observed from bore logs in this area, a piezometric dome, with hydraulic heads well above sea level, develops during the wet season of wet hydrologic years. Such a piezometric dome, located between the sea and the main agricultural area acts as natural hydraulic barrier to seawater intrusion. However, this piezometric dome is only present during wet years, when the threat of seawater intrusion is anyway reduced.

In SEAWAT, a General Head Boundary Condition was imposed along the seashore boundary to simulate sea level heads and potential seawater intrusion. Chloride concentration values have been expressed relative to that of seawater (22 g/L). Consequently, relative chloride concentration at the sea boundary is equal to 1. In order to simulate the Pakhna formation protective boundary “lid”, near the coast,
preventing sea water intrusion, zones of low hydraulic conductivity have been defined. Along the northeastern boundary, a lateral flux boundary was imposed (General Head Boundary) corresponding to recharge from water baring upstream Lefkara formation. Pumping wells were implemented in the ventral abstraction zone of the aquifer assuming an initial pumping schedule for the wet and dry seasons, which was subsequently modified, along with hydraulic conductivities, during model calibration to match observed hydraulic head measurements. All other model boundaries were defined as no flow boundaries.

Groundwater levels for the base hydrological year, which is representative of the current water resources status in the pilot area, are shown in Figure 47. In the central part of the pilot area, the piezometric depression observed from the historic hydraulic head measurements, is successfully simulated from the model.

![Groundwater level contour](image)

Figure 47 Groundwater level in Pegeia pilot area for the base hydrological year – Results of numerical simulations: (a) end of wet period and (b) end of dry period

3.2.2.3 Assessment of future climate change impact on water resources (Pegeia pilot area)

The results of the numerical simulations forced by the different IPCC RCP scenarios studied (RCP 4.5 and RCP 8.5) and the various Regional Climate Models outputs are presented on Figure 48 to Figure 51.
Figure 48 Predicted groundwater level in Pegeia pilot area for extreme dry hydrological year, based on the MOHC-SMHI model, under the RCP 4.5 scenario – Results of numerical simulations: (a) end of wet period and (b) end of dry period

Figure 49 Predicted groundwater level in Pegeia pilot area for extreme dry hydrological year, based on the MOHC-SMHI model, under the RCP 8.5 scenario – Results of numerical simulations: (a) end of wet period and (b) end of dry period
Based on the analysis of extreme dry climatic projections for meteorological variables produced by the MPI-SMHI and the MOHC-SMHI model, it is observed that groundwater recharge through precipitation infiltration is subjected to relative increase in respect to the current state. Climatic projections for meteorological variables produced by the MPI-SMHI and the MOHC-SMHI models show an increase in

---

Figure 50 Predicted groundwater level in Pegeia pilot area for extreme dry hydrological year, based on the MPI-SMHI model, under the RCP 4.5 scenario – Results of numerical simulations: (a) end of wet period and (b) end of dry period

Figure 51 Predicted groundwater level in Pegeia pilot area for extreme dry hydrological year, based on the MPI-SMHI model, under the RCP 8.5 scenario – Results of numerical simulations: (a) end of wet period and (b) end of dry period
precipitation, even for an extreme dry hydrologic year, compared to that of an average historic hydrological year. Therefore, an average increase in groundwater levels of 0.6-2.3 m, is predicted for the dry season of a predicted extreme dry hydrologic year (compared to an average hydrological year). The largest increase in groundwater levels (2.3 m) is predicted for the RCP 4.5 scenario under the MPI-SMHI model. For this case, a piezometric depression of ~2.5 m is predicted for the central part of the agricultural zone. Hence, based on the groundwater flow simulations for predicted extreme dry years, no additional pressure in groundwater availability due to climate change is foreseen both for the RCP 4.5 and RCP 8.5 scenario studied.

3.2.3 Xylofagou pilot area (Larnaka)

3.2.3.1 Pilot area characterization

Xylofagou pilot area is part of Kokkinochoria aquifer (Figure 52). Kokkinochoria aquifer is the largest aquifer in eastern Cyprus and a renowned potato field. It used to be one of the most productive aquifers on the island. However, extensive overpumping during the last 40 to 45 years has resulted in a dramatic depletion of this aquifer. It should be noted that in the last few years water levels in coastal areas have risen because of seawater intrusion. Kokkinochoria area was included in the Southern Conveyor Project irrigation areas (Figure 53).
The impervious base of the aquifer consists mainly of Palaeogene marls, chalky marls and upper Cretaceous bentonitic clays. The oldest sediments of the aquifer are the lower Miocene reef limestone, developed around Xylofagou and Paralimni villages. Plio/Pleistocene sediments consisting of sandstones, sands, gravels, conglomerates, silts, marls and all their possible combinations appear over the older sediments. The thickness of the aquifer at its deepest parts in Xylofagou, Liopetri and Phrenaros areas varies from 100 to 130 m (WDD and FAO, 2002).

Groundwater level measurements has been obtained in June 2016 and September 2017 and water quality samples from specific wells (Figure 54) were collected and analyzed at NTUA laboratory. The chemical analysis results are summarized on Table 6. The elevated Cl, Na+ and K+ concentrations in groundwater as well as the observed high conductivity values (Table 6) denote an input of seawater intrusion into Xylofagou pilot area.
Table 6 Water level and quality in-situ measurements (Sampling periods: June 2016 and September 2017) – Xylofagou area

<table>
<thead>
<tr>
<th>Well Name</th>
<th>Water depth (m below surface)</th>
<th>Cl (mg/L)</th>
<th>NO₃ (mg/L)</th>
<th>Na⁺ (mg/L)</th>
<th>K⁺ (mg/L)</th>
<th>Mg²⁺ (mg/L)</th>
<th>Ca²⁺ (mg/L)</th>
<th>Cond. (μS/cm)</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detection Limit</td>
<td>10</td>
<td>0.1</td>
<td>0.002</td>
<td>0.005</td>
<td>0.0005</td>
<td>0.003</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum permitted concentration</td>
<td>250</td>
<td>50</td>
<td>200</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

June 2016

<table>
<thead>
<tr>
<th>Well Name</th>
<th>Water depth (m below surface)</th>
<th>Cl (mg/L)</th>
<th>NO₃ (mg/L)</th>
<th>Na⁺ (mg/L)</th>
<th>K⁺ (mg/L)</th>
<th>Mg²⁺ (mg/L)</th>
<th>Ca²⁺ (mg/L)</th>
<th>Cond. (μS/cm)</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>H4106-0208</td>
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<td>265</td>
<td>130.2</td>
<td>55.7</td>
<td>5.2</td>
<td>54.3</td>
<td>101.5</td>
<td>1546</td>
<td>7.42</td>
</tr>
</tbody>
</table>

September 2017

<table>
<thead>
<tr>
<th>Well Name</th>
<th>Water depth (m below surface)</th>
<th>Cl (mg/L)</th>
<th>NO₃ (mg/L)</th>
<th>Na⁺ (mg/L)</th>
<th>K⁺ (mg/L)</th>
<th>Mg²⁺ (mg/L)</th>
<th>Ca²⁺ (mg/L)</th>
<th>Cond. (μS/cm)</th>
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<td>131.1</td>
<td>7.2</td>
<td>58.8</td>
<td>104.9</td>
<td>1713</td>
<td>7.22</td>
</tr>
<tr>
<td>H4107-0338</td>
<td>648</td>
<td>241.7</td>
<td>422.9</td>
<td>9.4</td>
<td>527.6</td>
<td>798.3</td>
<td>2700</td>
<td>7.10</td>
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</tr>
</tbody>
</table>

3.2.3.2 Assessment of current water resources state (Xylofagou pilot area)

The groundwater flow and the seawater intrusion mechanism in Xylofagou pilot area was simulated using SEAWAT model. The transient calibration was performed for the hydrological years 2010-2011 to 2013-2014. Historic hydraulic head data and chloride concentrations series for the period 2014-2015 to 2015-2016 have been used for model validation. Groundwater levels for characteristics period of the calibration period (end of dry and end of wet period, base hydrological year) are presented in Figure 55.
Groundwater level contour -10 m a.m.s.l.

Figure 55 Groundwater level in Xylofagou pilot area for the base hydrological year – Results of numerical simulations: (a) end of wet period and (b) end of dry period

3.2.3.3 Assessment of future climate change impact on water resources (Xylofagou pilot area)

The results of the numerical simulations forced by the different IPCC RCP scenarios studied (RCP 4.5 and RCP 8.5) and the various Regional Climate Models outputs are presented on Figure 56 to Figure 59.

Groundwater level contour -10 m a.m.s.l.

Figure 56 Predicted groundwater level in Xylofagou pilot area for extreme dry hydrological year, based on the MOHC-SMHI model, under RCP 4.5 – (a) end of wet period and (b) end of dry period
Figure 57 Predicted groundwater level in Xylofagou pilot area for extreme dry hydrological year, based on the MOHC-SMHI model, under RCP 8.5 – (a) end of wet period and (b) end of dry period

Figure 58 Predicted groundwater level in Xylofagou pilot area for extreme dry hydrological year, based on the MPI-SMHI model, under RCP 4.5 – (a) end of wet period and (b) end of dry period

Figure 59 Predicted groundwater level in Xylofagou pilot area for extreme dry hydrological year, based on the MPI-SMHI model, under RCP 8.5 – (a) end of wet period and (b) end of dry period
Based on the extreme dry climatic projections for meteorological variables produced by the MPI-SMHI and the MOHC-SMHI model, the mean groundwater level of the pilot area seems to be maintained during a foreseen extreme dry hydrological year. However, in vulnerable areas the simulation results have shown an additional decrease of the water table of approximately 0.8 m, during the dry period of a predicted dry year both for the RCP 4.5 and RCP 8.5 scenario studied.

### 3.2.4 Acheleia pilot area (Paphos)

#### 3.2.4.1 Pilot area characterization

Acheleia pilot area coincides with Paphos Coastal aquifer, known as CY-11 aquifer, a coastal aquifer along the western coastline of Cyprus (Figure 60). Its average width is about 3.5 km. The area of this aquifer coincides almost completely with the Pafos Irrigation Project area (Figure 40). The area is agricultural, but an important part of the area is covered by the town of Pafos. The southeastern part of the aquifer which extends south-southeast of Pafos town is crossed by the alluvial deltas of Diarizos, Xeropotamos and Ezousa rivers (WDD and FAO, 2012).

![Figure 60 Acheleia pilot area](image)

The Water Development Department of Cyprus has characterized the Paphos coastal aquifer’s status as satisfied in terms of water quality and quantity\(^2\). However, overpumping is observed in specific areas and awareness should be raised. The northern part of the aquifer (Figure 61) is also recently characterized as vulnerable to nitrate contamination (Ministry of Agriculture, Natural Resources and Environment, 2015), as a consequence of the intensive agricultural activity in the area.

\(^2\) [http://www.moa.gov.cy/moa/wdd/Wdd.nsf/]

53 | ADAPT2CLIMA-Deliverable C4.1
The impervious base of the aquifer in the southeastern part of the aquifer consists mainly of Miocene (Pachna formation) marls, chalks and chalky marls. In the northwest part the base of the aquifer consists of Palaeogene (Lefkara formation) marls, chalks and chalky marls and of Triassic/Cretaceous (Mamonia formation) clays, siltstones, mudstones, sandstones, diabase, serpentinites etc. The elevation of the impervious base of the aquifer is generally above mean sea level. In few places where the elevation of the impervious base is below sea level seawater intrusion problem appeared. The aquifer is mainly developed in the calcarenites of the Pleistocene Athalassa formation. These layers alternate with marls of the same formation (WDD and FAO, 2002).

Groundwater level measurements has been obtained in June 2016 and September 2017 and water quality samples from specific wells (Figure 62) were collected and analyzed at NTUA laboratory. The chemical analysis results are summarized on Table 7. The elevated nitrate concentrations in monitoring well H6027-1560 denote groundwater nitrate pollution in the northern part of the pilot area.
Table 7 Water level and quality in-situ measurements (Sampling periods: June 2016 and September 2017) – Acheleia pilot area

<table>
<thead>
<tr>
<th>Well Name</th>
<th>Water depth m below surface</th>
<th>Cl$^-$ mg/L</th>
<th>NO$_3^-$ mg/L</th>
<th>Na$^+$ mg/L</th>
<th>K$^+$ mg/L</th>
<th>Mg$^{2+}$ mg/L</th>
<th>Ca$^{2+}$ mg/L</th>
<th>Cond. μS/cm</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detection Limit</td>
<td></td>
<td>10</td>
<td>0.1</td>
<td>0.002</td>
<td>0.005</td>
<td>0.0005</td>
<td>0.003</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum permitted concentration</td>
<td></td>
<td>250</td>
<td>50</td>
<td>200</td>
<td>10</td>
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</table>

**June 2016**

<table>
<thead>
<tr>
<th>Well Name</th>
<th>Water depth</th>
<th>Cl$^-$</th>
<th>NO$_3^-$</th>
<th>Na$^+$</th>
<th>K$^+$</th>
<th>Mg$^{2+}$</th>
<th>Ca$^{2+}$</th>
<th>Cond.</th>
<th>pH</th>
</tr>
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<tbody>
<tr>
<td>H6027-1560</td>
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**September 2017**

<table>
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<th>Cl$^-$</th>
<th>NO$_3^-$</th>
<th>Na$^+$</th>
<th>K$^+$</th>
<th>Mg$^{2+}$</th>
<th>Ca$^{2+}$</th>
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<td>807</td>
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</tbody>
</table>

Figure 62 Acheleia sample points
3.2.4.2 Assessment of current water resources state (Acheleia pilot area)

A groundwater flow model is developed following the methodology described in Figure 5. The transient calibration was performed for the hydrological years 2008-2009 and 2011-2012. Historic hydraulic head series have shown a slight variation between the hydraulic heads measured in the dry and the wet period. These smooth groundwater level fluctuations between dry and wet period is reflected on the model results (Figure 63).

![Groundwater level contour 10 m a.m.s.l.](image)

Figure 63 Groundwater level in Acheleia pilot area for the base hydrological year – (a) end of wet period and (b) end of dry period

3.2.4.3 Assessment of the future climate change impact on water resources (Acheleia pilot area)

The groundwater model development is followed by groundwater flow simulations in order to assess the impact of the future climate change on the groundwater level. The results of the numerical simulations forced by the different IPCC RCP scenarios studied (RCP 4.5 and RCP 8.5) and the various Regional Climate Models outputs are presented on Figure 64 to Figure 67.
Figure 64 Predicted groundwater level in Acheleia pilot area for extreme dry hydrological year, based on the MOHC-SMHI model, under RCP 4.5 – (a) end of wet period and (b) end of dry period

Figure 65 Predicted groundwater level in Acheleia pilot area for extreme dry hydrological year, based on the MOHC-SMHI model, under RCP 8.5 – (a) end of wet period and (b) end of dry period
Figure 66 Predicted groundwater level in Acheleia pilot area for extreme dry hydrological year, based on the MPI-SMHI model, under RCP 4.5 – (a) end of wet period and (b) end of dry period.

Figure 67 Predicted groundwater level in Acheleia pilot area for extreme dry hydrological year, based on the MPI-SMHI model, under RCP 8.5 – (a) end of wet period and (b) end of dry period.

The predicted precipitation for the extreme dry climatic projections produced by the MPI-SMHI and the MOHC-SMHI models is on the same level with the observed during a current mean hydrological year. As a result, not significant groundwater level variation is observed during a future dry year both for RCP 4.5 and RCP 8.5 scenarios.
3.3 Estimation of future climate change impacts on water resources in Sicily

3.3.1 Trapani pilot area

3.3.1.1 Pilot area characterization

A coastal aquifer in western Sicily has been selected as pilot area in the Province of Trapani (Figure 68). The pilot area is extended on the coastal plain area of Marsala-Mazara del Vallo (Figure 69a) and Castelvetrano-Campobello di Mazara (Figure 69b). The economy of the area is mainly based on intense farming of specific agricultural crops (i.e. citrus, grapes, olives and others in greenhouses). In order to satisfy the irrigation needs, numerous wells were drilled throughout the region, in some cases with a density of 10 wells/km² (Aureli et al. 2004). The uncontrolled groundwater exploitation in the last 10 years has resulted in a drastic decrease in groundwater table levels, consequently introducing extensive seawater intrusion. Based on historic data the pilot area is also vulnerable to nitrate contamination (Figure 70).

![Figure 68 Trapani pilot area](image-url)
Figure 69 Hydrogeological Basins of (a) Marsala-Mazara del Vallo and (b) Castelvetrano-Campobello di Mazara (Region of Sicily, 2005)

Figure 70 Sicily nitrate vulnerable zones (Ferraro, 2015)

The Marsala–Mazara del Vallo plain hydrogeological unit (Figure 69a) contains a multi-layered aquifer. The layers are conditioned by varied permeability of different calcarenitic levels, alternating with low permeable silty-clays units. The aquifer has, as basement, stratifications of clay and/or marl of the Cozzo Terravecchia Formation. The calcarenitic aquifer thickness varies from few meters to approximately 70 m (Aureli et al., 2004).

The Castelvetrano-Campobello di Mazara basin (Figure 69b) contains Pleistocene marine deposits (Calcareniti di Marsala Auct.) of sand and bioclastic calcareous gravel changing laterally and vertically, to calcarenites and calcirudites (Ruggieri et al., 1977; D'Angelo and Vernuccio, 1994, 1996), that
unconformity cover the marly-arenaceous Valle del Belice Formation (Ruggieri and Torre, 1973; Vitale, 1990), made up of a terrigeneous Plio-Pleistocenic sequence (sandstones and calcarenites with clay interbedded). Palustrines, dunes and eluvium colluvial deposits can be found along the coast and terraced alluvium are found near the main rivers.

The Castelvetrano-Campobello di Mazara is a multi-layered aquifer made up of:

- a shallow unconfined aquifer located in the upper calcarenitic portion with reduced thickness and a variable saturated zone (1m to ~ 10-20 m);
- a deep semi-confined aquifer contained in the calcarenitic-marly hydrogeological complex. It has elevated thickness, where the more massive portion of the complex (150 m) shows a very high transmissivity average (~ 5×10^{-2} m²/s).

During the analysis, field measurements were performed in five selected locations (Figure 71) in Trapani pilot area. Sampling has been performed in November 2016 and May 2017. The results of the laboratory analyses are presented on Table 8. The slightly elevated chloride concentrations in Ramisella sample point denote an evidence of seawater intrusion into the groundwater system.
Table 8 Water level and quality in-situ measurements (Sampling periods: November 2016 and May 2017) – Trapani pilot area

<table>
<thead>
<tr>
<th>Well Name</th>
<th>Water depth (m below surface)</th>
<th>Cl(^-) (mg/L)</th>
<th>NO(_3)(^-) (mg/L)</th>
<th>Na(^+) (mg/L)</th>
<th>K(^+) (mg/L)</th>
<th>Mg(^{2+}) (mg/L)</th>
<th>Ca(^{2+}) (mg/L)</th>
<th>Cond. (μS/cm)</th>
<th>pH</th>
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</thead>
<tbody>
<tr>
<td>Detection Limit</td>
<td></td>
<td>10</td>
<td>0.1</td>
<td>0.002</td>
<td>0.005</td>
<td>0.0005</td>
<td>0.003</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum permitted concentration</td>
<td></td>
<td>250</td>
<td>50</td>
<td>200</td>
<td>10</td>
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<table>
<thead>
<tr>
<th>Well Name</th>
<th>November 2016</th>
<th>May 2017</th>
</tr>
</thead>
<tbody>
<tr>
<td>Falletta</td>
<td>3.40 153.8</td>
<td>3.45 149.0</td>
</tr>
<tr>
<td>Bresciana</td>
<td>55.52 84.9</td>
<td>56.30 141.0</td>
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<tr>
<td>Ramisella</td>
<td>18.15 443.1</td>
<td>18.01 385.0</td>
</tr>
<tr>
<td>Petrosino4</td>
<td>18.63 54.1</td>
<td>18.42 36.0</td>
</tr>
<tr>
<td>Ferro</td>
<td>20.00 141.7</td>
<td>20.39 148.0</td>
</tr>
</tbody>
</table>

3.3.1.2 Assessment of current water resources state (Trapani pilot area)

A groundwater flow simulation model was developed using Visual Modflow Flex software. Geospatial data –presented in Figure 72 –deriving from SINAnet (http://www.sinanet.isprambiente.it)– and aquifer’s characteristics described by Aureli et al. (2004) were incorporated into the developed model. An estimate on the mean annual abstraction rate from the pilot aquifer –about 42 mcm/year– was provided by the stakeholders, based on data deriving from the Italian National Institute of Statistics (www.istat.it). Data regarding the actual well pumping locations is a common barrier on the development of a groundwater flow model, especially at regions with large number of unregistered illegal private wells. However, in case of Sicily, only information from municipality wells locations was obtained. Due to the lack of specific private wells locations data, it was decided to homogenously distribute the wells throughout the pilot area.
Figure 72 Geospatial data for Trapani Province [www.sinanet.isprambiente.it]

Historic hydraulic head data series provided by the Region of Sicily for 8 monitoring wells were used for model calibration and validation (Figure 73). The transient calibration of the groundwater flow model was performed for the wet and the dry period of the hydrological years 2006-2007 to 2009-2010. Historic hydraulic head data for the period 2010-2011 to 2012-2013 have been used for model validation. Groundwater levels for a base calibrated hydrological year are presented in Figure 74.
3.3.1.3 Assessment of future climate change impact on water resources (Trapani pilot area)

The numerical simulation results forced by the different IPCC RCP scenarios studied (RCP 4.5 and RCP 8.5) and the various Regional Climate Models (RCMs) outputs are presented on Figure 75 to Figure 78.
Figure 75 Predicted groundwater level in Trapani pilot area for extreme dry hydrological year, based on the MOHC-SMHI model, under RCP 4.5 – (a) end of wet period and (b) end of dry period

Figure 76 Predicted groundwater level in Trapani pilot area for extreme dry hydrological year, based on the MOHC-SMHI model, under RCP 8.5 – (a) end of wet period and (b) end of dry period
Based on the extreme dry climatic projections for meteorological variables produced by the MPI-SMHI and the MOHC-SMHI models, the simulation results have shown a mean additional groundwater table decrease of approximately 1-2 m, during the dry period of a predicted dry year both for RCP 4.5 and RCP 8.5 scenarios.
3.3.2 Enna pilot area

3.3.2.1 Pilot area characterization

The pilot area in the Province of Enna and Catania is located in the Dittaino Valley, between the northern edge of the Ibleo plateau and the southern slopes of Etna (Figure 79). The increased water demand for several uses (domestic, agricultural and industrial) has resulted in the overexploitation of the aquifer, which led to seawater intrusion. The most representative crops cultivated in the pilot area are cereals and citrus, which cover a significant portion of the modelled area, that is also crossed by the Simeto river.

To the south, the pilot area is bordered by a hilly relief consisting principally of tuffs, breccias and basalts, locally covered by calcarenites. The western boundary of the pilot area coincides with the western boundaries of the Simeto River Basin and the eastern boundary is the shoreline. The southern boundary of the Enna pilot area is the southern part of Catania alluvium aquifer, which neighbors with a volcanic rock complex. The north boundary of the aquifer is the flysh complex.

An important part of the pilot area is covered by the Catania alluvium aquifer (Figure 79). The main part of Catania aquifer consists of recent alluvial formations and sand dunes, as well as Sicilian sands and gravels (Figure 80). Catania alluvium aquifer is recharged through precipitation infiltration and from the rivers that cross Simeto Basin. The impervious base of this aquifer consists of clays. The rest of the pilot area is part of low permeability rock complexes (Figure 81).

![Figure 79 Enna pilot area](image-url)
Field measurements were performed in five selected locations (Figure 82) at Enna pilot area for validation purposes. Groundwater level measurements and groundwater sampling have been performed in November 2016 and May 2017. The results of the analysis are presented in Table 9. The elevated nitrate concentrations detected denote the nitrate vulnerability of the pilot area. According
to Ferraro et al. (2015), the origin of nitrate contamination at the aquifer is related to the intense agricultural activity.

Figure 82 Enna groundwater sample points

Table 9 Water level and quality in-situ measurements (Sampling periods: November 2016 and May 2017) – Enna pilot area

<table>
<thead>
<tr>
<th>Well Name</th>
<th>Water depth m below surface</th>
<th>Cl(^{-}) mg/L</th>
<th>NO(_3) mg/L</th>
<th>Na(^{+}) mg/L</th>
<th>K(^{+}) mg/L</th>
<th>Mg(^{2+}) mg/L</th>
<th>Ca(^{2+}) mg/L</th>
<th>Cond. µS/cm</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detection Limit</td>
<td></td>
<td>10</td>
<td>0.1</td>
<td>0.002</td>
<td>0.005</td>
<td>0.0005</td>
<td>0.003</td>
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<tr>
<td>Maximum permitted concentration</td>
<td></td>
<td>250</td>
<td>50</td>
<td>200</td>
<td>10</td>
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<td></td>
</tr>
</tbody>
</table>

**November 2017**

<table>
<thead>
<tr>
<th>Well Name</th>
<th>Water depth m below surface</th>
<th>Cl(^{-}) mg/L</th>
<th>NO(_3) mg/L</th>
<th>Na(^{+}) mg/L</th>
<th>K(^{+}) mg/L</th>
<th>Mg(^{2+}) mg/L</th>
<th>Ca(^{2+}) mg/L</th>
<th>Cond. µS/cm</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Billota</td>
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<td>507.4</td>
<td>29.8</td>
<td>608.1</td>
<td>10.1</td>
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<td>245.9</td>
<td>4000</td>
<td>6.85</td>
</tr>
<tr>
<td>Mazzurco</td>
<td>3.80</td>
<td>161.8</td>
<td>111.3</td>
<td>75</td>
<td>2.7</td>
<td>36.7</td>
<td>218.0</td>
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</tr>
<tr>
<td>Viviano</td>
<td>2.42</td>
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<td>24.9</td>
<td>505.3</td>
<td>41.5</td>
<td>148.2</td>
<td>358.1</td>
<td>4600</td>
<td>6.76</td>
</tr>
<tr>
<td>Rosciglione</td>
<td>3.9</td>
<td>138.9</td>
<td>54.8</td>
<td>83.4</td>
<td>6.5</td>
<td>52.0</td>
<td>148.1</td>
<td>1291</td>
<td>7.32</td>
</tr>
</tbody>
</table>

**May 2017**

<table>
<thead>
<tr>
<th>Well Name</th>
<th>Water depth m below surface</th>
<th>Cl(^{-}) mg/L</th>
<th>NO(_3) mg/L</th>
<th>Na(^{+}) mg/L</th>
<th>K(^{+}) mg/L</th>
<th>Mg(^{2+}) mg/L</th>
<th>Ca(^{2+}) mg/L</th>
<th>Cond. µS/cm</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Billota</td>
<td>1.42</td>
<td>500.0</td>
<td>15.9</td>
<td>480.0</td>
<td>47.2</td>
<td>260.7</td>
<td>1314.0</td>
<td>4560</td>
<td>7.36</td>
</tr>
<tr>
<td>Mazzurco</td>
<td>4.06</td>
<td>194.0</td>
<td>158.0</td>
<td>480.1</td>
<td>9.7</td>
<td>136.9</td>
<td>254.4</td>
<td>1730</td>
<td>7.35</td>
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<tr>
<td>Viviano</td>
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<td>340.6</td>
<td>35.0</td>
<td>119.7</td>
<td>301.5</td>
<td>1428</td>
<td>7.32</td>
</tr>
</tbody>
</table>
3.3.2.2 Assessment of current water resources state (Enna pilot area)

Enna pilot area groundwater flow was simulated using the methodology shown in Figure 5. However, the small number of monitoring well locations (Figure 83) was a limitative factor for the development of a representative groundwater flow model. However, this limitation was overcome based on data derived from the performed field campaigns including groundwater level in-situ measurements, communication with local stakeholders and the literature, in order to adequately simulate the groundwater flow field in the pilot area.

Limited was the information related to pumping well location at Enna pilot area. However, an estimate of total annual abstraction rate per municipality has been provided by the Region of Sicily and assumptions have been made during the development of the model to estimate the amount of pumped water within the borders of the pilot area. In Figure 84, Municipalities, for which abstraction rate estimation has been provided, are marked in blue, whereas the pilot area is marked in red. The transient calibration was performed for the hydrological years 2006-2007 to 2010-2011. Historic data hydraulic heads for the period 2011-2012 to 2013-2014 have been used for model validation. Groundwater levels for characteristics period of the calibration period (end of dry and end of wet period, mean hydrological year) are presented in Figure 85.
3.3.2.3 Assessment of future climate change impact on the water resources availability (Enna pilot area)

The results of the numerical simulations forced by the examined IPCC RCP scenarios (RCP 4.5 and RCP 8.5) and the various Regional Climate Models outputs are presented in Figure 86 to Figure 89.
Figure 86 Predicted groundwater level in Enna pilot area for extreme dry hydrological year, based on the MOHC-SMHI model, under RCP 4.5 – (a) end of wet period and (b) end of dry period

Figure 87 Predicted groundwater level in Enna pilot area for extreme dry hydrological year, based on the MOHC-SMHI model, under RCP 8.5 – (a) end of wet period and (b) end of dry period
Based on the extreme dry climatic projections for all meteorological variables produced by MPI-SMHI and MOHC-SMHI models, the simulation results have shown an additional decrease of approximately 0.5 m of the groundwater table, during the dry period of a predicted dry year both for RCP 4.5 and RCP 8.5 scenarios.
3.4 Estimation of future climate change impacts on the water resources quality

The majority of previous research works concerning climate change impacts on groundwater resources focuses mainly on the changes on quantity, due to changes on precipitation and evapotranspiration rate, rather than quality (Meixner et al., 2016). However, within the framework of the ADAPT2CLIMA project, future climate change impacts on water resources quality have been estimated in selected pilot areas. The pilot areas where groundwater quality vulnerability is studied were selected taking into account the groundwater quality problems faced in each area and the availability of data required to develop reliable contaminant mass transport models. The quality problems faced in each pilot area have been indicated based on data provided by the local partners and the sampling analysis performed by the NTUA team in the framework of ADAPT2CLIMA project.

Aquifer characterization in terms of quality and groundwater quality model development are often confronted with difficulties deriving from insufficient water quality sampling sites and/or short monitoring periods (Oude Essink and Boekelman, 1996; Hantush and Wang, 2003; Ball and MacDonald, 2002). In addition, historic groundwater quality data series used for model calibration and validation should be subjected to detailed evaluation, as inconsistencies to sampling or/and analysis procedures may lead to incoherent results. Finally, regarding nitrate mass transport model, having a reliable estimate on actual fertilization rates applied in crops is not always feasible, as recommended fertilizers application rates are not always followed.

In the framework of the project, the MT3DMS model has been applied to simulate nitrate mass transport for the pilot areas vulnerable to nitrate pollution and SEAWAT model to assess seawater intrusion problems. In many cases, lack of sufficient input data precluded a complete validation of the models developed. However, in such cases, future climate change impacts on groundwater quality were qualitatively approached. Furthermore, as no significant changes in groundwater flow patterns are foreseen in pilot areas, groundwater pollution by nitrates is not significantly affected by climate change projections. The relatively high nitrate concentrations observed in groundwater samples from the pilot areas in Crete, Cyprus and Sicily, denote the need for introducing changes in agricultural practices and fertilization rates. For Cyprus, the main challenge regarding groundwater quality is salinization through sea water intrusion and return irrigation flows. The problem is highlighted by historical data of chloride concentrations, as well as the high chloride concentrations measured in groundwater samples collected from the pilot areas during the field campaigns. Although climate change projections do not indicate significant groundwater depletion and lowering of the water table, it is foreseen that groundwater salinization, mainly due to over pumping for irrigation purposes, will remain an important issue in Cyprus pilot areas. This is especially true for Kiti aquifer, which shows the highest groundwater level decline for projected future dry years.

For the above reasons and due to the considerable amount of simulations and related outcomes, it is underlined that, on the following paragraphs, only representative results on the assessment of future climate change impacts on groundwater quality are presented.
3.5 Assessment of future climate change impacts on groundwater quality in Crete pilot areas

The selected pilot areas in Crete are characterized as vulnerable to nitrate pollution. Therefore, the USGS MT3DMS model has been applied to simulate nitrate mass transport in each pilot area. Fertilization periods and mass of fertilizers applied have been devised based on data on the spatial distribution of the cultivated crops in the area, and knowledge of the cultivation and fertilization practices in each area. Nitrates mass infiltrated into the aquifer has been estimated as a percentage of N content of fertilizers, depending on the amount of fertilizers applied, the timing of application and estimated aquifer recharge in the period of fertilization. It has been applied as Recharge Concentration Boundary Condition in MT3DMS. In Messara plain, for example, where olive trees, fruit and vegetables are the main cultivated crops, fertilization occurs mainly during the following periods: (a) for olive trees the main fertilization period is between December and February each year, while additional fertilization occurs in June and then in August, (b) for fruit and vegetables the main fertilization occurs between March and April, while additional fertilization occurs again in August. It is bound that for summer fertilization a highest percentage of fertilizers applied infiltrate the aquifer, as surface runoff is minimal.

The developed models have been calibrated and validated based on historic nitrate concentration time series obtained from the Region of Crete. Mass of fertilizers applied in each fertilization period have also been adjusted during calibration. Water samples analysis performed by the NTUA team were also used to evaluate model performance. After model validation, simulation runs were performed to estimate groundwater vulnerability to nitrate pollution under the pressure of climate change. Based on the results, groundwater quality in terms of nitrate pollution seems not to be influenced by the climate change. In Figure 90 and Figure 91, representative results for Moires basin (which is the area under pressure and where historic data were available for model calibration and validation) and Chania Plain are presented, depicting the current state and the projected changes in nitrate concentrations under the RCP 4.5 scenario. Results shown highlight areas with elevated nitrate concentrations, a result of the locally cultivated crops and fertilization schedule, as well as the flow pattern of the area. Nitrate concentrations appear slightly elevated under the RCP 4.5, which can be explained by the reduced surface runoff that would dilute fertilizers applied.
Figure 90 Groundwater nitrate concentrations (mg/l) in Moires basin of Messara pilot area (a) for the base hydrological year, end of dry period (b) for extreme dry hydrological year, based on the MPI-SMHI model, under the RCP 4.5 scenario, end of dry period.
Figure 91 Groundwater nitrate concentrations (mg/l) in Chania Plain pilot area (a) for the base hydrological year, end of dry period (b) for extreme dry hydrological year, based on the MPI-SMHI model, under the RCP 4.5 scenario, end of dry period
3.6 Assessment of future climate change impacts on groundwater quality in Cyprus pilot areas

As reported on the ‘Report on the Implementation of Council Directive 91/676/EEC concerning the Protection of Waters against Pollution caused by Nitrates from Agricultural Sources’, Kiti, Xylofagou and part of Acheleia pilot areas are vulnerable to nitrate pollution (Ministry of Agriculture, Natural Resources and Environment, 2015). However, groundwater quality in terms of nitrate pollution is not subjected to deterioration due to future climate change, as in all pilot areas of Cyprus, no significant changes in groundwater availability are foreseen. According to Ministry of Agriculture, Natural Resources and Environment (2015), agricultural activities but also tourism and residential development are responsible for groundwater nitrate pollution. However, sea water intrusion is a far more serious problem in coastal aquifers in Cyprus, which are under pressure due to climate change, and therefore seawater intrusion is expected to increase as a result of the decrease in groundwater levels. Therefore, representative maps for Kiti, Xylofagou and Pegeia pilot areas are presented in the following paragraphs.

Details on historical data of observed chloride concentrations at monitoring boreholes in Kiti aquifer, as well as the results of the analysis of samples collected from selected boreholes in the area during the field surveys conducted in the frame of the project, are presented in detail in Chapter 4 (paragraph 4.1.2) of this report and are not repeated here. An analysis of the evolution of the front of seawater intrusion for an average hydrological year as well as for the 4.5 RCP and 8.5 RCP climate change scenarios is also given in paragraphs 4.1.2 and 4.1.3. As described in these paragraphs, the SEAWAT model has been applied to simulate variable density flow and predict the intrusion of seawater (estimation of chloride concentration distribution) for the coastal aquifer of Kiti. In the model, chloride concentrations are expressed relatively to that of seawater to give an immediate picture of seawater intrusion in the area. As seawater chloride concentration is taken equal to 22 g/L, a constant point source boundary of relative chloride concentration of 1 is imposed at the sea boundary.

Figure 92 (a) shows the spatial distribution of chloride concentrations for an average hydrological year (end of dry season), while, in comparison, Figure 92 (b) depicts simulated chloride concentrations for an extreme dry hydrological year as predicted by the MPI-SMHI model under the 4.5 RCP scenario. This actually represents the worst-case scenario in terms of water availability and groundwater levels for the area, and this is why it has been chosen for comparison with the current state of seawater intrusion in the area. As it can be drawn from Figure 92, it is predicted that seawater intrusion advances further inland under the under the 4.5 RCP scenario, in agreement with the estimated groundwater levels spatial distribution, while predicted future chloride concentrations show approximately a 1.2 to 1.5 fold increase, indicating the need for additional mitigation measures.
Figure 92 Results of numerical simulations for Kiti pilot area: Relative chloride concentrations (a) for the base hydrological year, end of dry period (b) for extreme dry hydrological year, based on the MPI-SMHI model, under the RCP 4.5 scenario, end of dry period

Similarly to Kiti pilot area, the SEAWAT model has been applied to simulate variable density flow and seawater intrusion in Pegeia pilot area. In Figure 93 a, simulations results for the end of the dry period of the base hydrological year are presented. Predicted relative chloride concentrations at the end of the dry period of an extreme dry hydrological year, as predicted by the MPI-SMHI model under the 4.5 RCP scenario, are presented in Figure 93 b. As it can be concluded from Figure 93, it is predicted that seawater intrusion is slightly reduced the under the 4.5 RCP scenario, in agreement with the estimated groundwater levels spatial distribution, while predicted future chloride concentrations show approximately a 2-fold decrease. It should be noted that in the figure, part of Pegeia aquifer is shown, where groundwater pumping induces sea water intrusion and monitoring and pumping borehole historic data exist for model verification; the boundaries of this sub-area are depicted in the upper right corner.
Figure 93 Relative chloride concentrations in Pengeia pilot area (a) base hydrological year, end of dry period (b) extreme dry hydrological year, based on the MPI-SMHI model, under the RCP 4.5 scenario, end of dry period

High chloride concentrations observed on the quality samples collected in the framework of the project denote an input of seawater intrusion into Xylofagou pilot area. However, not significant changes in groundwater flow under the pressure of future climatic scenarios do not lead to further deterioration of the groundwater quality, as shown in Figure 94. Nevertheless, independently of the influence of future climate change to the aquifer, changes in groundwater abstraction schedule should be adopted in order to confront salinization problems.

Figure 94 Relative chloride concentration characteristic contour in Xylofagou pilot area (a) base hydrological year, end of dry period (b) extreme dry hydrological year, based on the MPI-SMHI model, under RCP 4.5, end of dry period
3.7 Assessment of future climate change impacts on groundwater quality in Sicily pilot areas

Due to limited available data, not reliable mass transport models were able to be developed in Enna pilot area. However, based on the literature and the results of the water quality samples analysis performed by the NTUA team, adaptation measures and policies should be adopted to improve groundwater quality. Trapani pilot area suffers from salinization and nitrate pollution. As shown in Figure 95, groundwater quality monitoring wells are not satisfyingly distributed throughout Trapani pilot area. However, a preliminarily assessment of groundwater quality and its response to future climate change scenarios has been performed. In Figure 96, results for relative chloride concentrations in Trapani pilot area for a mean characteristic hydrological year are depicting seawater intrusion problem. Based on the simulation runs for the foreseen extreme dry hydrological year, not significant changes in salinization are observed. Nevertheless, independently of the influence of the climate change to the aquifer, changes in groundwater abstraction schedule should be adopted in order to confront salinization problems.

Figure 95 Groundwater quality monitoring wells in Trapani pilot area (TP01, TP03, TP04, TP05, TP06)
Figure 96 Characteristic chloride concentration contour in Trapani pilot area for a representative mean hydrological year, end of dry period.
4 Assessment of future climate change impacts on drought

4.1 Standardized Precipitation Evapotranspiration Index evolution in Crete

In the island of Crete, SPEI was estimated in two representative areas near Ayia springs and Faneromeni dam (Figure 97). Ayia springs consist an important drinking and irrigation water source. Faneromeni dam was constructed in order to cover part of the intensive irrigation needs of the greater area. However, the fact that in 2017 the dam was dried up has raised severe issues with respect to the sustainability of water resources in Messara plain. The evolution of SPEI for the aforementioned areas is presented in Figure 98 and Figure 99.

![Figure 97 Locations for SPEI estimation in Crete](image)

![Figure 98 SPEI values in Faneromeni Dam area](image)
4.2 Standardized Precipitation Evapotranspiration Index evolution in Cyprus

In Cyprus, SPEI evolution is estimated in three representative areas; Asprokremos, Kiti and Kouris dams (Figure 100). The aforementioned dams have significant role in covering water needs, however it has been observed that during dry years the amount of water in storage has been stressfully decreased. Figure 101 to Figure 103 present the estimated SPEI evolution in these areas for the period 1972-2098, showing a downward trend.

Figure 100 Locations for SPEI estimation in Cyprus
Figure 101 SPEI values in Asprokremos Dam area

Figure 102 SPEI values in Kiti Dam area

Figure 103 SPEI values in Kouris Dam area
4.3 Standardized Precipitation Evapotranspiration Index evolution in Sicily

In Sicily, Poma dam and Moganazzi areas were selected as implementation locations for SPEI assessment (Figure 104). During the studied period (i.e. 1972-2098) a downward trend is observed in these two areas indicating more frequent and intense drought periods (Figure 105 - Figure 106).

Figure 104 Locations for SPEI estimation in Sicily

Figure 105 SPEI values in Poma Dam area

Figure 106 SPEI values in Moganazzi area
5 Results Analysis

5.1 Future climate change impacts on groundwater resources: a comparative analysis

Based on the methodology followed in the framework of Activity 4.1, groundwater availability due to changes in groundwater recharge is estimated. In general, Cyprus is not expected to face significantly drier years than the ones met in the previous decades. Sicily will confront extreme dry year characterized with a decrease in precipitation of about 150 mm/year with respect to the amount of precipitation observed on a mean hydrological year. Crete pilot areas will confront extreme dry year characterized with a total annual precipitation almost half of the observed on a mean hydrological year.

In Figure 107, the standard deviation of the total annual precipitation observed during the four extreme dry years studied –MOHC-SMHI model outputs under RCP 4.5, MOHC-SMHI model outputs under RCP 8.5, MPI-SMHI model outputs under RCP 4.5, MPI-SMHI model outputs under RCP 8.5– is presented for selected pilot areas. It is observed that the use of different RCMs and RCP scenarios does not lead to results varying significantly in terms of total precipitation during the extreme dry year, so as to lead to significantly different conclusions regarding future climate change impacts on groundwater availability.

![Graph showing standard deviation between total annual precipitation rates obtained by different IPCC RCP scenarios and various Regional Climate Models (RCMs)](image)

**Figure 107 Standard deviation between total annual precipitation rates obtained by the different IPCC RCP scenarios studied (RCP 4.5 and RCP 8.5) and the various Regional Climate Models (RCMs)**

Based on the groundwater flow simulation runs, the future climate change impacts on the groundwater availability in the future at all pilot areas is summarized as follows:

- In Crete pilot areas, a significant additional decrease (~4-12 m, depending the pilot area) in groundwater level is expected.
– In Cyprus, not significant changes in groundwater recharge through precipitation are expected. Projected rainfall in extreme hydrological years is comparable to rainfall observed in current mean hydrological years. Consequently, the groundwater flow simulations in Cyprus pilot areas do not denote significant groundwater depletion. However, high chloride concentrations observed in almost all coastal pilot areas of Cyprus urged the need for to reschedule the applied pumping schemes.

– In Sicily pilot areas, a mean additional decrease of about 0.5-2m in groundwater level is expected. However, groundwater level fluctuation differs significantly between regions and in specific pilot areas a greater groundwater depletion is foreseen, implementing the need of adaptation strategies.

Foreseen mean groundwater level variation in all pilot areas, under the pressure of future climate change, is visualized in Table 10, using a color scale in order to summarize the results of the present report.

**Table 10 Foreseen mean groundwater level variation in ADAPT2CLIMA pilot areas, under the pressure of future climate change, with respect to the base year hydrological year**

<table>
<thead>
<tr>
<th>Pilot area</th>
<th>Foreseen mean groundwater level variation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Messara Plain</td>
<td>(-15)-(-5)</td>
</tr>
<tr>
<td>Chania Plain</td>
<td>(-5)-(-3)</td>
</tr>
<tr>
<td>Kiti</td>
<td>(-3)-(-1)</td>
</tr>
<tr>
<td>Pegeia</td>
<td>(-1)</td>
</tr>
<tr>
<td>Xylofagou</td>
<td>+1</td>
</tr>
<tr>
<td>Acheleia</td>
<td></td>
</tr>
<tr>
<td>Trapani</td>
<td></td>
</tr>
<tr>
<td>Enna</td>
<td></td>
</tr>
</tbody>
</table>

**Legend**

<table>
<thead>
<tr>
<th>Color scale</th>
<th>Groundwater level variation (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red</td>
<td>(-15)-(-5)</td>
</tr>
<tr>
<td>Orange</td>
<td>(-5)-(-3)</td>
</tr>
<tr>
<td>Light Green</td>
<td>(-3)-(-1)</td>
</tr>
<tr>
<td>Green</td>
<td>(-1)</td>
</tr>
<tr>
<td>Green</td>
<td>(+1)</td>
</tr>
</tbody>
</table>

Groundwater quality seems not to be altered significantly due to climate change. However, high nitrate concentrations in groundwater samples deriving from Crete, Cyprus and Sicily pilot areas and high chloride concentrations in Sicily and Cyprus denote the need for changes in agricultural practices including abstraction rates for irrigation and applied fertilization practices.
5.2 Future climate change impacts on drought: a comparative analysis

In Table 11 to Table 13, the mean SPEI values for two significant periods – the reference period and the period 2031-2060 – in all selected representative locations in Crete, Cyprus and Sicily are presented.

Specifically, for the case of Crete the mean SPEI values for the two significant periods are presented in Table 11. It is noted that both in Faneromeni and Ayia areas (Perfection of Heraklion and Chania, respectively), a SPEI negative trend is observed. In the area of Faneromeni dam, average SPEI value for the period 2031-2060 does not indicate foreseen (further) deterioration of surface water availability. However, SPEI deterioration is observed (mainly) in the period of 2070-2098. In Ayia area, SPEI indicates that the period 2031-2060 will be more stressful than the reference period in regards with water availability, under both RCP scenarios.

In Cyprus SPEI locations (Figure 100), a downward trend is observed indicating more frequent and intense drought periods (Table 12). As projected SPEI values are negative (lower than 0), additional stress on water storage capacity in Cyprus reservoirs is foreseen. Drought assessment based on SPEI analysis leads to the same conclusions independently from the selected RCP scenario.

In Sicily, the average estimated values of SPEI for the reference period and the period 2031-2060 point out the foreseen impacts of climate change in drought events (Table 13). The negative foreseen SPEI indicates additional stress on water resources subject to both RCP scenarios.

<p>| Table 11 Average SPEI values in Crete |</p>
<table>
<thead>
<tr>
<th>Area</th>
<th>Scenario</th>
<th>Reference period (1972-2000)</th>
<th>2031-2060</th>
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</thead>
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<tr>
<td>Faneromeni Dam</td>
<td>4.5</td>
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<td>0.05</td>
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<td>Faneromeni Dam</td>
<td>8.5</td>
<td>0.08</td>
<td>0.30</td>
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<tr>
<td>Ayia area</td>
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<td>-0.20</td>
</tr>
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<td>Ayia area</td>
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<td>-0.05</td>
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<p>| Table 12 Average SPEI values in Cyprus |</p>
<table>
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<th>2031-2060</th>
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<tr>
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<td>Asprokremos Dam</td>
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<td>Kouris Dam</td>
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<td>-0.29</td>
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Table 13 Average SPEI values in Sicily

<table>
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<td>Moganazzi</td>
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6 Conclusions

The Action 4.1 is focused on assessing the impacts of future climate on groundwater availability in important agricultural areas in the islands of Crete, Cyprus and Sicily. To this aim, groundwater flow simulations under the pressure of a foreseen extreme dry hydrological year were performed.

In general, Cyprus pilot areas have been fronted similar hydrological years during the last decades and it seems that future climate does not lead to significant changes in groundwater availability. However, Cyprus is already facing nitrate pollution and salinization problems and for that reason changes in irrigation and fertilization practices should be adopted. In Sicily pilot areas, although the mean groundwater level variation is expected to be decreased about 0.5-2m, greater groundwater depletion in specific areas are observed, denoting the need for changes in irrigation practices. Crete pilot areas are subject to more severe climate change impacts, as a mean groundwater level depletion of almost 12 m and 4 m are foreseen for Messara Plain and Chania Pilot area.

The foreseen extreme dry hydrological year for each pilot area obtained by the two RCMs and the two RCP scenarios examined in this project does not vary significantly leading to similar conclusions.

Based on the results of the climate change impact assessment on drought events, SPEI evolution has shown a downward trend in all implementation locations. Specifically, for the majority of the areas under consideration the average SPEI value during the period 2031-2060 is lower than zero, indicating intense drought events.

Comparing the SPEI analysis results subject to the two RCP scenarios under consideration, it is observed that, despite the variation of the estimated SPEI values under the various scenarios, the use of different RCP scenarios has not led to significantly different conclusions regarding the climate change impacts on drought events in the specific locations.
7 References (alphabetically)


Hellenic Statistical Authority www.statistics.gr


LIFE ADAPT2CLIMA (2017). Future projections on climatic indices with particular relevance to agriculture for the three islands (coarse resolution) and for each agricultural pilot area (fine resolution). Deliverable C3.1, project ADAPT2CLIMA LIFE14 CCA/GR/000928.


