Sustain-COAST

REDUCE · RECYCLE · REUSE · RECOVER

# Deliverable 2.1: Report on the real sites characterization

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[1] Dissemination level: **PU** = Public, **PP** = Restricted to other programme participants (including the JU), **RE** = Restricted to a group specified by the consortium, **CO** = Confidential, only for members of the consortium
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## Deliverable abstract

Sustain-COAST "Sustainable coastal groundwater management and pollution reduction through innovative governance in a changing climate" is an R&I project co-funded under the PRIMA 2018 programme section II, for 3 years starting from June 2019. The Sustain-COAST consortium is led by the Technical University of Crete (TUC) and is composed of a multidisciplinary team of seven partners from six countries. Sustain-COAST intends to develop a calibrated multi-criteria decision supporting system (DSS) and a web Geographical Information System platform accessible for water stakeholders and policy-makers.

The current document presents the first step for an optimal selection and implementation of the best methodologies, i.e. a sound characterization of the four case study sites.

The scientific team in this document collects and analyses all the available data for the proposed sites in Greece, Italy, Tunisia and Turkey and makes an assessment on how the real situation is in each site.

These data consist of surface-water related data like stream flows, rainfall, temperature etc., groundwater related data like hydraulic head levels and pumping rates, data on the water governance scheme in the area and all other relevant water quality data.

After the analysis of available data, the scientific team (TUC, UNISS, CERTE and MEU) compiles a report on the status of surface water and groundwater resources, water quality and the used governance system in their respective areas.



**List of acronyms and abbreviations**

RIA: Research and Innovation activities

DSS: decision support system

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# 1. Sustain-COAST project overview

The need for the implementation of innovative governance of coastal aquifers taking into account the technological development as well as socio-economic factors, has become a worldwide necessity. In compliance with the challenges and scope of the PRIMA call topic 1.1.2 "Sustainable, integrated water management", Sustain-COAST was designed to explore innovative governance approaches of coastal aquifers among multiple water users and beneficiaries, under the uncertainties posed by the changing climate conditions, in four Mediterranean countries.

Sustain-COAST "Sustainable coastal groundwater management and pollution reduction through innovative governance in a changing climate" is an R&I project co-funded under the PRIMA 2018 programme section II, for a period of 3 years starting from June 2019. Sustain-COAST consortium is led by the Technical University of Crete (TUC) and is composed of a multidisciplinary team of seven partners from six countries.

Sustain-COAST intends to develop a calibrated multi-criteria decision supporting system (DSS) and a web Geographical Information System platform accessible for water stakeholders and policy makers. The DSS and platform, combined with a specific animation activity will allow: i) the engagement of social actors in a learning process around water issues at catchment scale based on visualization of interactive thematic maps, ii) the use of advanced technologies and tools, such as optical sensors and remote sensing capacities for participatory monitoring of water, iii) the use of calibrated numerical models for the time-space simulation of water quantity and quality progress.

Sustain-COAST will explore new governance approaches to effectively support the coastal aquifer conservation against anthropogenic and climatic pressures, through the promotion of innovative water management concepts based on the 4R principles: Reduce; Recycle; Reuse and Recover.

Thanks to Sustain-COAST, new options will be available to private and public bodies for sustainable Mediterranean coastal groundwater management based on an improved response-ability of all concerned actors taking into account the local environmental and socio-economic context.

# 2. Objectives

The objective is to present a sound characterization of the 4 real case study sites.

Hence, the scientific team in this document collects and analyses all the available data for the proposed sites in Greece, Italy, Tunisia and Turkey and makes an assessment on how the real situation is in each site.

These data consist of to collect and analyse all the available data consisting of:

- surface-water related data like
    - stream flows,
    - rainfall,
    - temperature etc.,
- groundwater related data like
    - hydraulic head levels and
    - pumping rates,
- data on the water governance scheme in the area and
- all other relevant water quality data

Analysis of available data, compiling a report for each site

# 3. Case study description

The main characteristics of the four case studies are summarized in Table 1. At first glance, there are differences in the size, population, and specific problems of the areas, while the climatic data, i.e. the mean annual precipitation and temperature have lower discrepancies among the sites. The size ranges from 35 to 475 km², the population from 3 900 to 35 700 people, while mean annual precipitation ranges from 500 to 815 mm and mean annual temperature from 16.7 to 18.7 °C.

**Table 1: Coastal aquifer where the integrated social learning processes in the Sustain-COAST project will be developed.**

| Characteristics | Wadi El Bey, Tunisia | Erdemli, Turkey | Arborea, Italy | Malia, Greece |
|---|---|---|---|---|
| **Size (km²)** | 475 | 45 | 60 | 35 |
| **Population** | 24 336 | 35 700 | 3 900 | 5 500, during summer >20 000 |
| **Mean Annual Precipitation/ Temperature** | 500 mm/ 18.7 °C | 600 mm/18.6 °C | 570 mm/16.7 °C | 815 mm/ 17.6°C |
| **Specific Problems** | High N and P levels from point and diffuse sources contribution | High N and P levels from urban and agricultural sources | High N and P levels from agricultural sources | Salt water Intrusion, High $Cl^-$, over-pumping resulting to low aquifer levels |

## *Wadi El Bey, Tunisia Case Study*

Wadi El Bey Watershed is located in the north-east of Tunisia, in the south-west of the Cap Bon peninsula (figure 1). The study area is made up of a vast plain with a slight slope (0 to 3%). It is bordered to the north by the Gulf of Tunis, to the south by Jebel Reba El Ain, to the east by the anticline of Jebel Abderrahmane and the west by the Jebels of the Tunisian ridge and the northern region of the north-south axis (Ennabli, 1980).

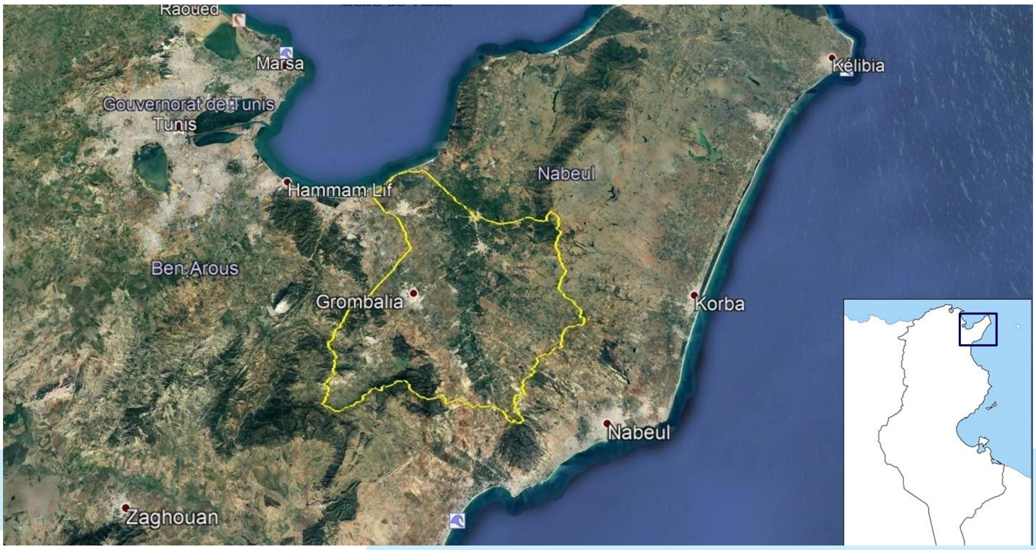


**Figure 1: Geographic location of Wadi El Bey watershed (Google Earth)**

The Wadi El-Bey watershed covers a total area of 467 $km^2$ and brings together several urban agglomerations including Soliman, Bou Argoub, Grombalia, and Menzel Bouzelfa. 259 companies, installed in the study area, are distributed in four industrial zones. The Soliman industrial area, which covers 13ha, is comprised of 82 manufacturers that are specialized mainly in textile and clothing, agrifood, and miscellaneous. The Menzel Bouzelfa industrial zone includes 17 production units that employ 2312 peoples in clothing, toys, electrical and electronic industries. Apparel products are almost all for export. The industrial zone of Grombalia, which has been established since 1979 over 56 ha, there is 134 industrial units in shoes, food, metallurgical, electrical, and clothing manufactures. In Bouargoub, the industrial area covers 27.8 ha includes 26 industrial units in the food, building, mechanical and chemical sectors (Nabeul governorate, 2020).

Irrigated agriculture is well developed in this study area where arboriculture, citrus, vines, and market gardening are grown. Besides, cereals are cultivated in the rainfed system. The cultivated land is dominated by wines grapes in Grombalia; with more than 2760 ha of the vineyard, the city is considered "The international city of the vine". The production of the citrus fruit in Menzel Bouzelfa contributes to 60% of the national citrus export.

With more than two hundred thousand inhabitants, the Wadi el Bey watershed density is around 394 hab/km2, which can be considered a highly dense region as the average density at the country level is about 71 inhabitants/km2. As it is a coastal region, there are some hotels and many estival residences. Therefore, the population fluctuates between summer and winter. 92.2 % of this population enjoyed the house connection to drinking water service that is managed by the national water utility. Part of the drinking water supplied to the local population is taken from the groundwater. Almost all localities have an improved sanitation connection to the national sanitation utility network. The wastewater treatment plants of the national sanitation utility discharge the treated water in the wadi El-Bey and its tributaries.

Another ecological feature of the case study is the coastal wetland, the Sebkhet Soliman, which is a Ramsar site of 880 ha. The site is representative of the wider coastal plain in a near-natural state and includes a lagoon, salt flat, and dunes. It provides an important refuge to species and water birds whose original habitats have been lost, particularly as it is close to the capital Tunis, and other nearby wetlands have been lost. It is hosting breeding populations and contains a typical wetlands flora. This wetland drains the rainwater of the wadi El-Bey watershed. The site is one of the few places in the area that retains water throughout the summer. The El-bey stream discharge into the sebkhet that receives also the treated water of Soliman WWTP. This ecosystem plays an essential self-purification role of wadi El-Bey water.

## Water resources issues /stresses

The Wadi El-Bey watershed bears significant anthropic pressures. Three mains issues characterize water resources management in this study area. On one hand, the groundwater resources are overexploited. At present, the rate of exploitation exceeds 200% (DGRE 2015). The unsustainable use of this coastal aquifer has led to progressive and continuous degradation of its chemical quality and the saltwater intrusion. Besides, the aquifer displays an important decline in the water level. During the last 50 years a drop in the level of 12 to 14 m is observed. On the other hand, the surface water resources and the ecosystems, Sebkhet Soliman, in particular, suffer from pollution at the highest degree. Despite the legal framework that regulates the quality of water that can be released into the environment, in practice, not all wastewater discharged into the water bodies (wadis El-Bey, its tributaries, and Sebkhet Soliman) meet the required standards. it is estimated that up to 25% of the water discharged is raw water. The third concern is associated with agriculture practices. The intensive irrigation, and the excessive use of chemical fertilizers damage soil and groundwater qualities.

### ***Analysis of Surface-Water Related Data***

The case study is located under a climate that ranges from the semi-arid to the sub-humid Mediterranean climate, which is characterized by a mild winter and a relatively hot and dry summer. It is subject to maritime and continental influences that affect the temperature level.

#### Stream Flows

The hydrological system of the Wadi El-Bey watershed is fairly extended. It mainly includes El-Bey stream and their tributaries Ellouza, Tahouna, and El-Maleh. The Average annual input the El-Bey stream is about 15.18 M $m^3/s$, the low flow rate is 0.10 $m^3/s$, and its annual flood rate is 34.13 $m^3/s$ (MEDD 2008).

The upstream part of Wadi El-Bey, of 35 to 40 km, has several tributaries located on the southwest edge of the watershed. In particular, Tahouna stream, in the west of Grombalia, flows over 25 km to reach the El-Bey stream, and Bou Argoub stream crosses the agglomerations of Bou Argoub, Sidi Dhaher, Belli, and Nianou over 20 km.

The highest points of the El-Bey hydrological network have an altitude of 644 m, recorded on Wadi El Masri and Wadi Tahouna, which perimeters are 31 km and 14.6 km respectively. These two streams flow through El-Melah that reaches the starting point of El-Bey stream. Then, the water continues to flow to the outlet that is the Sebkha Soliman, also called Sebkhet El-Melah. The El Bey wadi water reaches the Gulf of Tunis, and then, the Mediterranean Sea via the Sebkhet Soliman.

Sebkhet Soliman is a coastal wetland located in the southwest of the Cap Bon peninsula, on the border of the governorate of Ben Arous and east of Soliman Plage. The water body area is approximately of 225 hectares and exchanges a daily flow of 90,000 m3 with the Gulf of Tunis. The Sebkhet has two regimes: a hydrographic regime determined by the tide and a hydrological regime depends temporarily on the floods of wadi El-Bey. This ecosystem plays an essential self-purification role of wadi El-Bey water (MEDD, 2008).

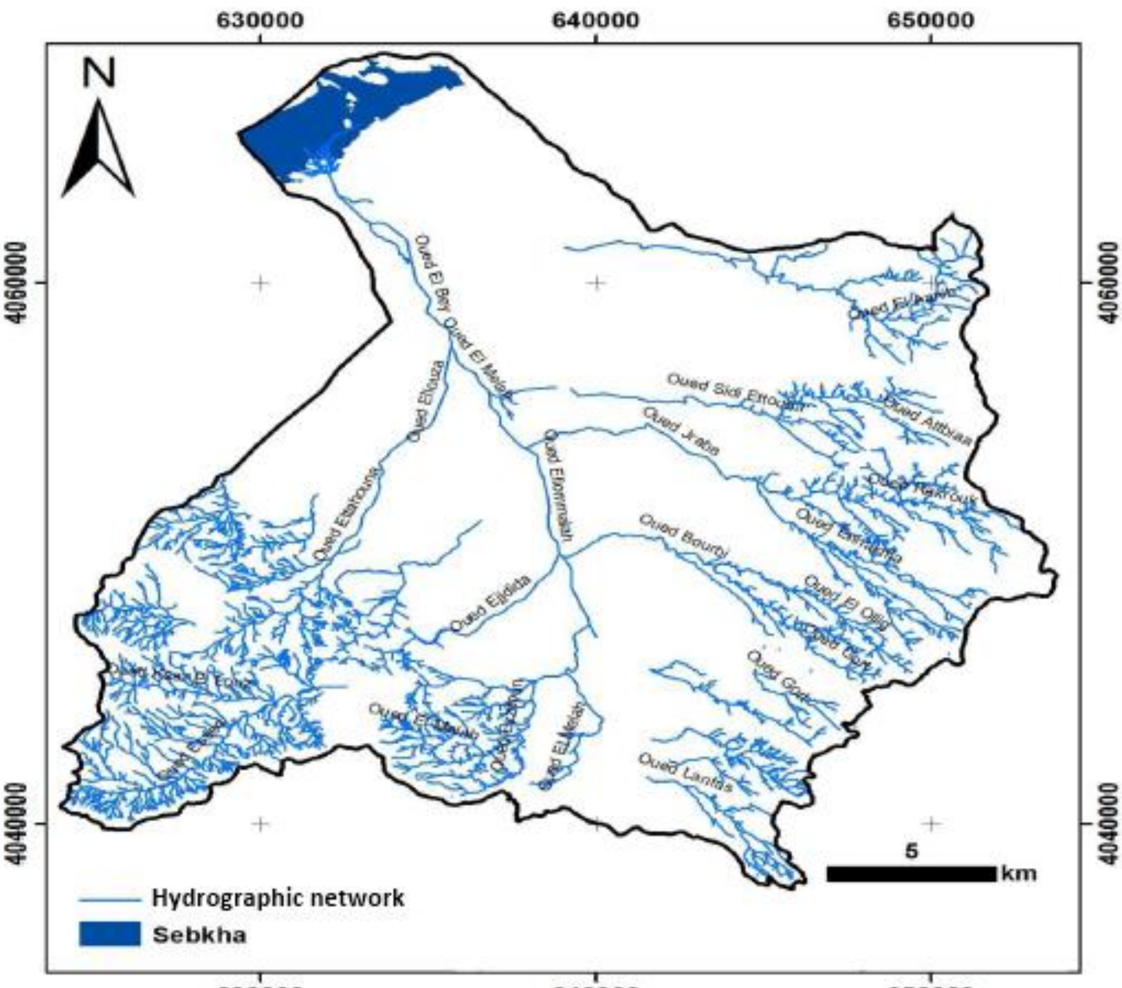


**Figure 2: Hydrographic network (Ben Salem, 2016)**

## Rainfall

By referring to the National Observatory of Agriculture in Tunisia (ONAGRI) and by basing on rainfall data for a time period of more than 50 years, we note that the study area belongs to a moderately rainy area with an interannual average of around 494 mm/year. The rainy season extends from September (46.3 mm) to May (21.5 mm) and the dry season includes June (12 mm), July (3.9 mm) and August (10 mm).

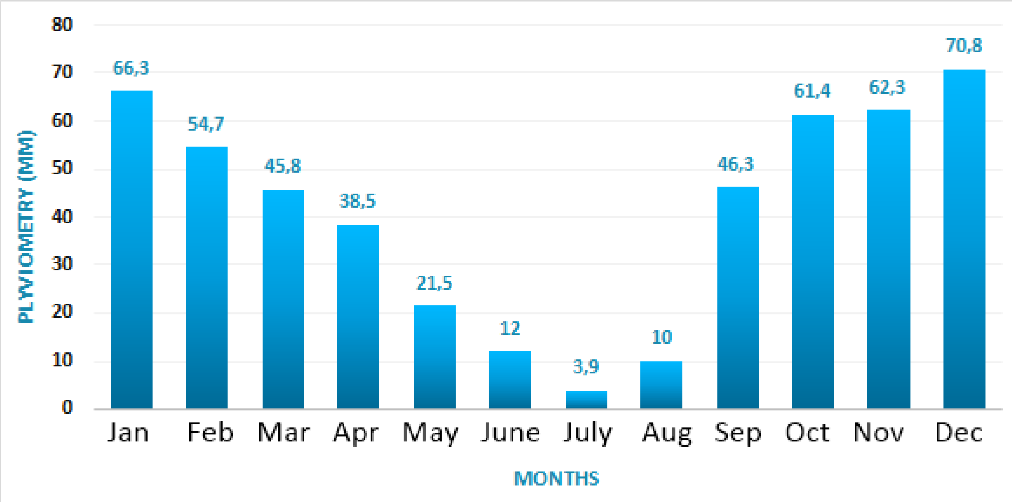


**Figure 3: Average monthly rainfall variation**

### Temperature

The average monthly temperature variation between 2008 and 2018 at the meteorological station of the Citrus Technical Center (CTA) in Beni Khalled shows that the temperatures in the study area are moderate in both winter and summer. The annual average is around 19° C. The summer season is characterized by relatively high temperatures with a peak recorded in July (27.16° C on average). The minimum temperatures are recorded during the winter season. Indeed, the lowest temperatures are observed in February.

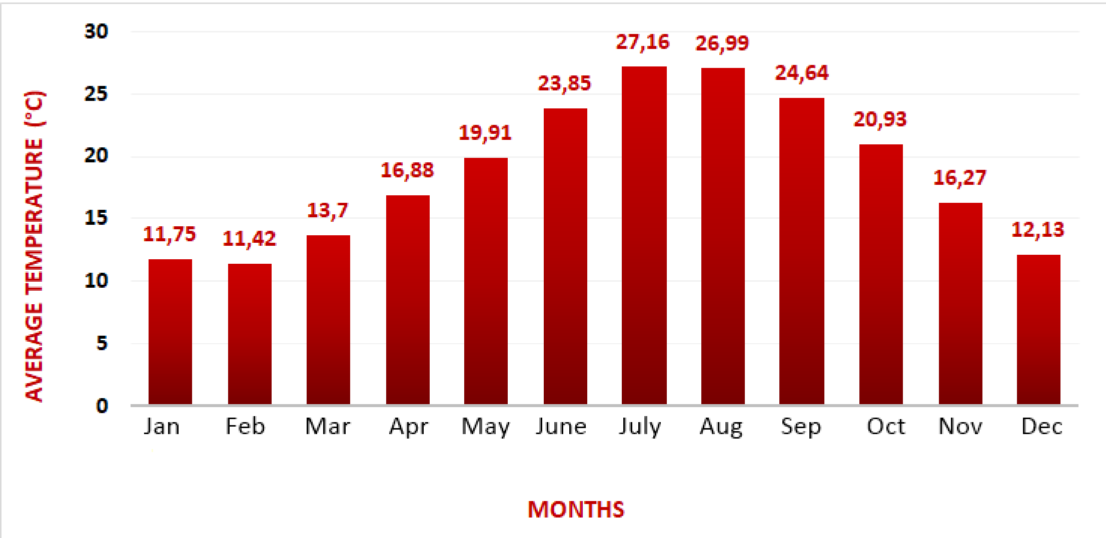


**Figure 4: Average monthly temperature variation (2008-2018)**

**Evapotranspiration**

The average annual evapotranspiration at the meteorological station in Grombalia is approximately 1699 mm. The monthly average recorded in the same station is 144 mm.

The maximum monthly average evapotranspiration is observed in July with 275 mm and the minimum is observed in January with 54.7 mm.

**Table 2. Evapotranspiration (source CRDA, 2015)**

| Month | Sep | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Average (mm) | 184.5 | 113.7 | 77.02 | 59.03 | 54.7 | 57.6 | 86.9 | 114.9 | 164.2 | 224.1 | 275 | 251.9 | 1669 |
| Max (mm) | 329.4 | 251.7 | 143 | 102.2 | 127.7 | 103.7 | 136.8 | 157.8 | 246.7 | 275.76 | 346.4 | 329.7 | 2551 |
| Min (mm) | 110.1 | 64.5 | 46.8 | 20.1 | 20 | 3.5 | - | 71 | 84 | 145 | 203 | 192.6 | 961 |

## ***Analysis of Groundwater Related Data***

The phreatic aquifer of Grombalia (Figure 2) covers an area of 392 km2. It is located in a plain between latitudes north 545432.32 and 565382.32 m and longitudes east 352399.6 and 385249.6 m (Lambert North Tunisia coordinates). The average of thickness of that aquifer located in a Plio-Quaternary sedimentary fill is about 25 meters. The main rivers crossing the aquifer are Wadi El Bey, Wadi Defla, Wadi Sidi Saïd, Wadi El Jorf, Wadi Tahouna, Wadi Belli, and Wadi Bezirk (Hamza and al., 2010).

The Grombalia water table is overexploited at an unsustainable rate. The intensive exploitation of the aquifer has led to a drop in the piezometric level with an average rate of 0.32 m/year (Hammami, 2012). The area is under artificial recharge from 33 infiltration basins in three places located between Menzel Bouzelfa and Beni Khalled in the eastern part of the aquifer. Recharge water is provided by the local dam. The water quality in the area has been significantly deteriorated as wadi El-Bey is the outlet for runoff, domestic effluents, industrial effluents, and discharges from agricultural drainage, which are sometimes well treated.

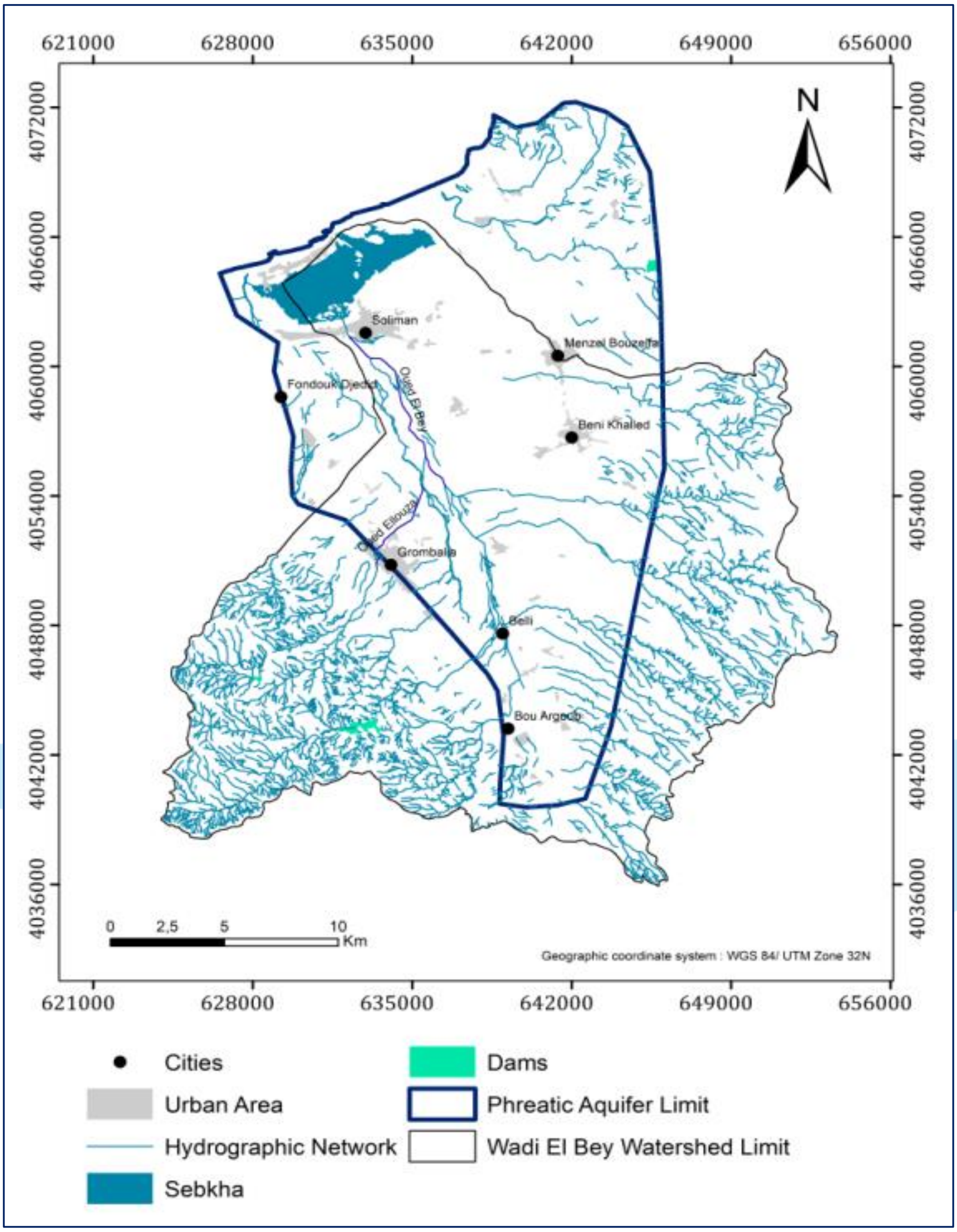


**Figure 5: Geographic location of Grombalia phreatic aquifer**

### Hydraulic Head Levels

The intensive exploitation of the aquifer has led to a drop in the piezometric level. The average decrease over the extent of the aquifer from the level of this aquifer is 0.32 m/year (Hammami, 2012).

Despite the artificial recharge operations and the irrigation by the waters of the Mejerda-Cap Bon canal, the piezometry of this aquifer was in general decline in 1998. The 1997-1998 piezometric drop is in the range of 0.2 to 4.6 m. Only a few wells recorded a slight rise of less than 1m (DGRE, 1998). In 1999, the piezometry of this aquifer was in general decline. The 1998-1999 piezometric drop is in the range of 0.2 m to 4.8 m. Only a few wells recorded a slight rise of less than 0.4m (DGRE, 1999). This general lowering of the water table is due to the intense overexploitation that this water table has known and especially during the last forty years.

The figure 6 shows the temporal evolution of the piezometry at the level of control wells. The piezometric fluctuations of the Grombalia aquifer from 1972 to 2015 show that the aquifer shows significant fluctuations in all of the control wells. The maximum variation of the piezometric load can exceed 9 m (Well 1).

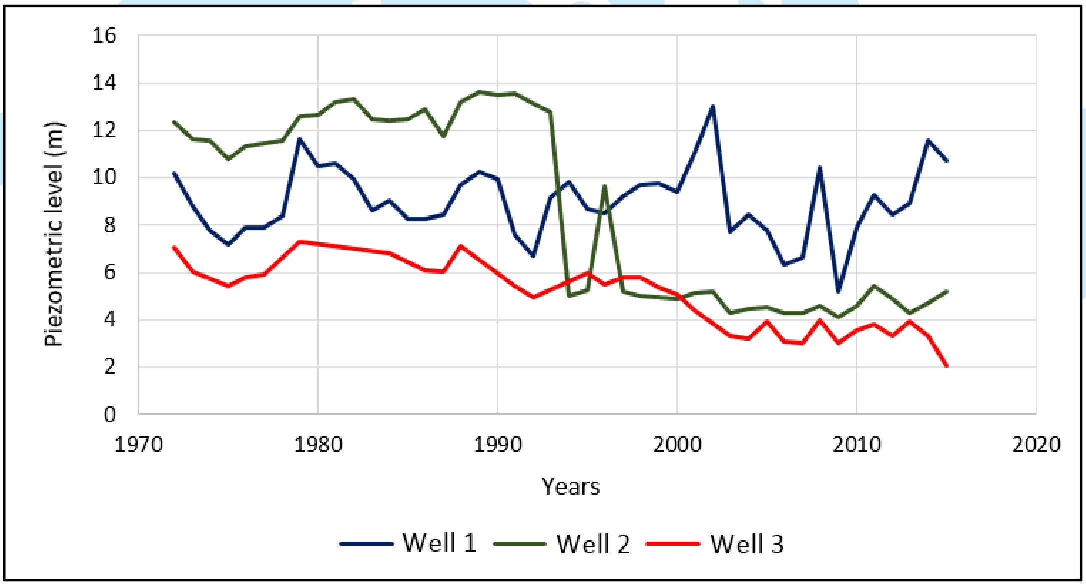


**Figure 6: Fluctuation of the piezometric levels of the Grombalia water table from 1972 to 2015**

The piezometric difference map (Figure 7) shows the temporal evolution of the piezometry level between 1948 and 2015 and indicates the presence of two piezometric behaviors:

- A decrease in water level in aquifer upstream, downstream, and boundaries areas (in west side of Grombalia city, in the East side of Bou Argoub, Menzel Bouzelfa, and Beni Khalled cities). The piezometric drawdown is varying between 0 and -18 m.

- An increase of piezometric level of 5 m is observed in the area between Grombalia, Beni Khalled, Menzel Bou Zelfa, and Soliman cities and in the North of Bou Argoub city (Lachaal, 2016).

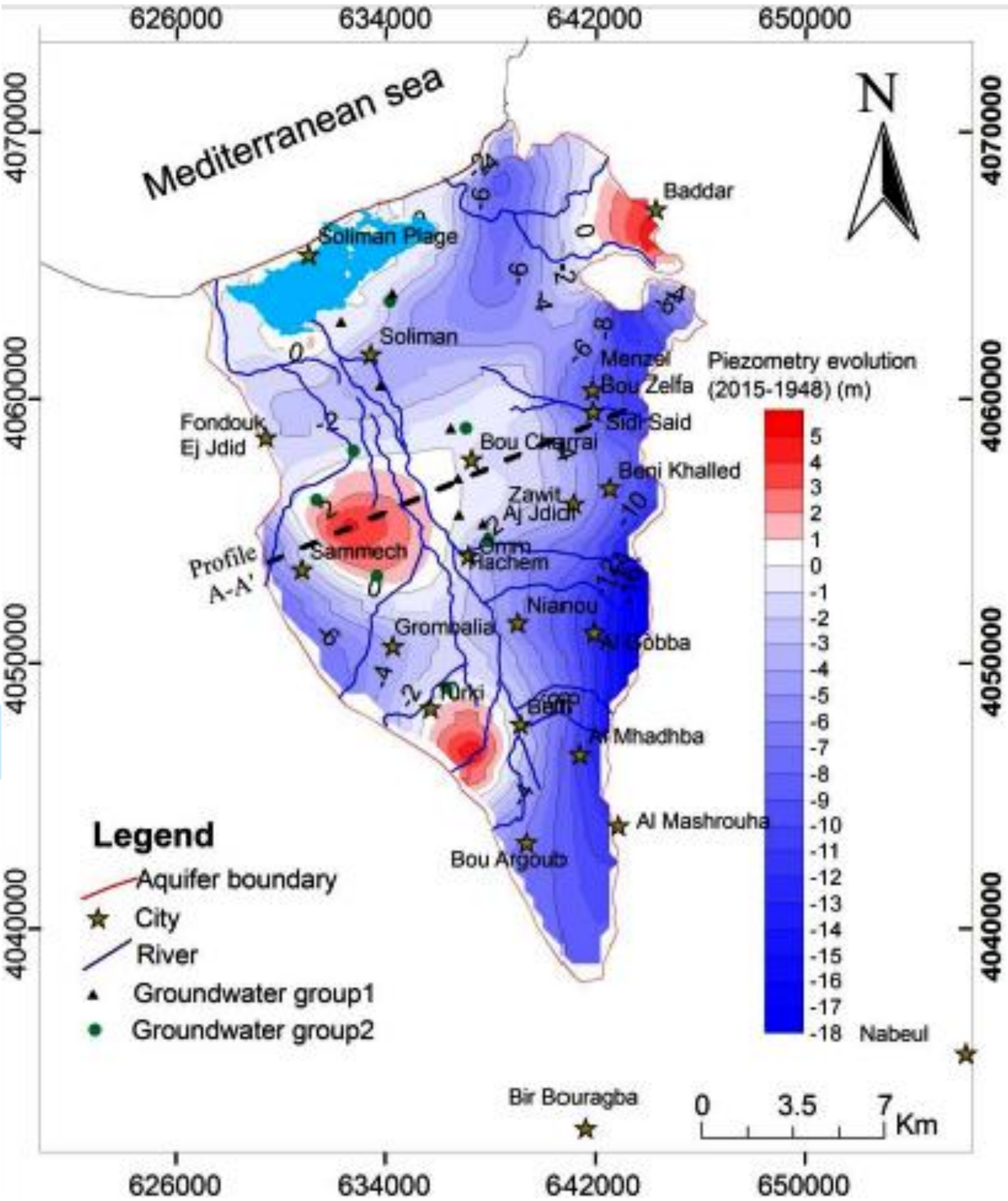


**Figure 7: Piezometric difference between 2015 and 1948 of Grombalia shallow aquifer (Lachaal, 2016)**

**Transmissivity**

| | |
|---|---|
| ***Phreatic aquifer of Grombalia*** | $1.10^{-4} – 75.10^{-4}$ ($m^2$/s) |

**Pumping Rates**

The Grombalia aquifer resources are currently used by 8 841 shallow wells; 6,910 of which are equipped with submerged pumps. The water abstraction reaches 106 Mm$^3$ / year even though the exploitable resources are assessed at 51Mm3/year. This groundwater is overexploited at the rate of 208%. (DGRE 2015).The wells are generally located on the eastern and western borders of the plain, and the average operating flow per well is around 0.44 l/s. The exploitation of the Grombalia phreatic aquifer began around the 1970s. At that date, 41 Mm$^3$ are withdrawal by 5000 surface wells. since the exploitation rate and the number of wells has continued to increase (Table 3 & Figure 8).

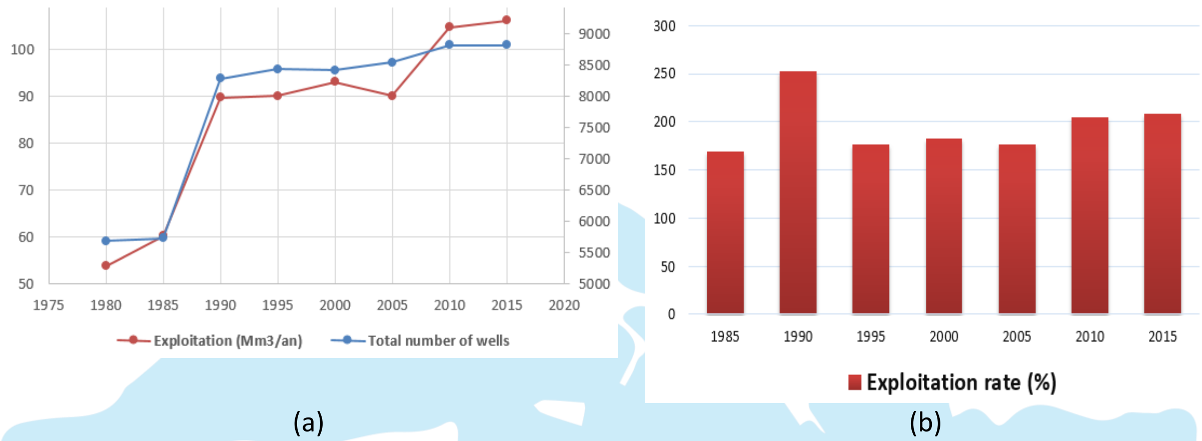


**Figure 8: (a) Evolution of the exploitation and the number of wells of the Grombalia water table (b) Exploitation rate of Grombalia phreatic aquifer**

**Table 3: Evolution of the number of wells, exploitation and estimated renewable resources of the Grombalia water table from 1980 to 2010**

| Years | Total number of wells | Number of equipped wells | | | Number of abandoned wells | Exploitation (Mm$^3$/an) | Estimated renewable resources (Mm$^3$/an) | Exploitation rate % |
|---|---|---|---|---|---|---|---|---|
| | | Electric groups | Diesel groups | Bucket | | | | |
| **1980** | 5689 | - | 4129 | 528 | 1032 | 53,8 | --.-- | --.-- |
| **1985** | 5733 | 1498 | 3010 | 193 | 1032 | 60.2 | 35.7 | 168.6 |
| **1990** | 8280 | 3652 | 2565 | 312 | 1529 | 89.7 | 35.5 | 252.7 |
| **1995** | 8430 | 3732 | 2635 | 300 | 1741 | 90 | 51 | 176.5 |
| **2000** | 8408 | 6367* | | 2041** | | 93 | 51 | 182.4 |
| **2005** | 8531 | 6446 * | | 2085** | | 90 | 51 | 176.5 |
| **2010** | 8814 | 6729 * | | 2085** | | 104,6 | 51 | 205 |
| **2015** | 8814 | 6910 * | | 1904 ** | | 106 | 51 | 207.8 |

* Well equipped ** Well not equipped (Source: CRDA Nabeul, 2015)

## ***Water Quality Status***

### Surface Water

Wadi El-Bey stream is the natural outlet for runoff, domestic effluents, industrial effluents, and discharges from agricultural drainage, which are sometimes insufficiently purified. The waters of this watercourse are characterized by a poor physicochemical and bacteriological quality.

The wastewaters discharged in the El-Bey stream and its tributaries have a neutral pH and poor in dissolved oxygen with the presence of a significant organic and mineral load. The water bodies suffer from significant microbiological pollution (Mhamdi, 2017).

The wastewater following Wadi El-Bey is characterized by inorganic pollution and contamination of MES with heavy metals (Cu, Ni, and Zn). This contamination increases from upstream to downstream under the effect of declared and undeclared releases. These polluting discharges are transferred to the Soliman Sebkha (Khadhar et al., 2013).

### Groundwater Resources

**Salinity**

The salinity of Grombalia aquifer water varies between 0.9 and 5.8 g L-1 . The salinity distribution map (Figure 9-a) has revealed the presence of salinization gradient from east to west in the direction to Sebkhat El Maleh, corresponding to the main groundwater flow direction. This salinity increase could be explained by a longer contact-time with rocks during water circulation. The high salinity is observed in the central and downstream aquifer which corroborates with the piezometric rise and groundwater management issues. The high salinity could be explained by returns of water irrigation and the high nitrate concentration in this area (Lachaal, 2016).

**Nitrate**

The Grombalia groundwater shows very high nitrate concentration varying between 4.97 and 343.45 mg L-1 (Fig. 9-b). The average nitrate concentration of Grombalia groundwater is about 138.69 mg.L-1 (Lachaal, 2016). This level is higher than 50 mg.L-1, which is defined as the nitrate concentration threshold for drinking water (WHO, 2017). Part of the drinking water supplied to the local population is taken from the groundwater.

The Grombalia shallow aquifer is more exposed to the anthropogenic activities and mainly to the use of fertilizers. The nitrate concentration is more exacerbated in the area between Grombalia, Soliman, Beni Khalled, and Menzel BouZelfa, where agriculture activities have intensified. These areas coincide with the groundwater rise zone and the saline zone.

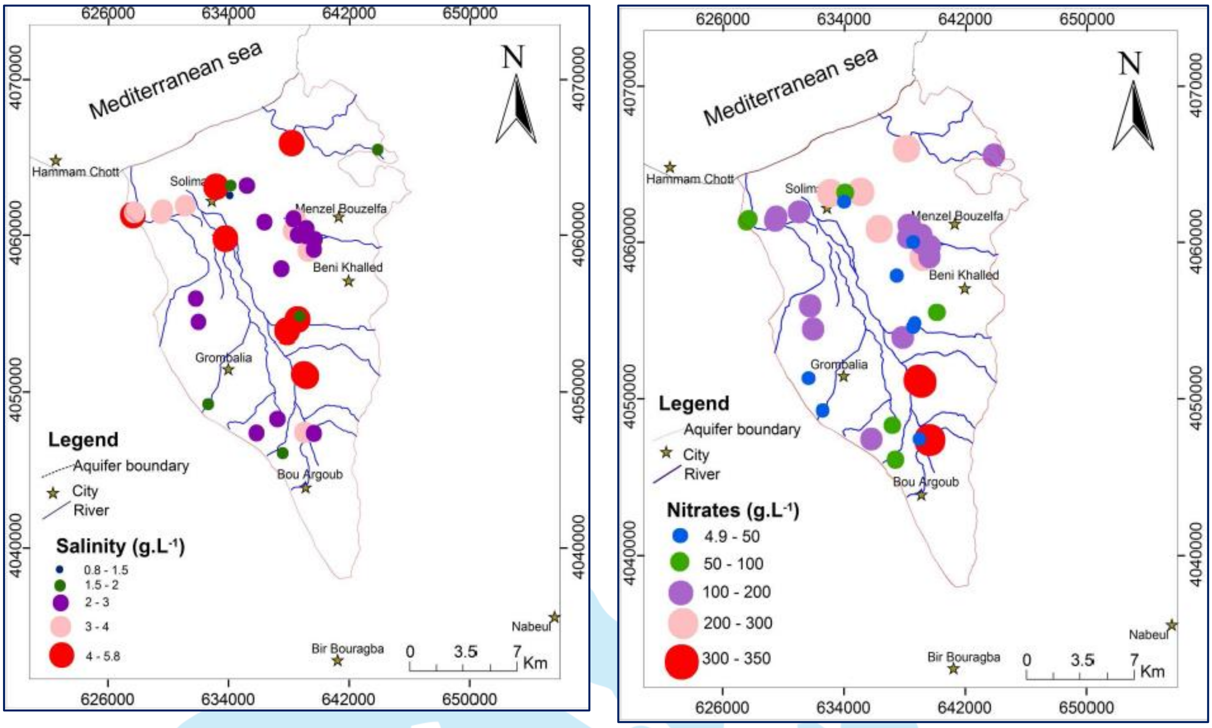


**Figure 9: Spatial distribution of the salinity (a) & nitrate (b) in the Grombalia aquifer in April 2015 (Source Lachaal, 2016)**

The nitrate concentrations are increasing rapidly. The concentrations in two control wells (Figure 10), taken as examples, are multiplied by 5 in 11 years, from 2008 to 2019, which reveals an alarming situation.

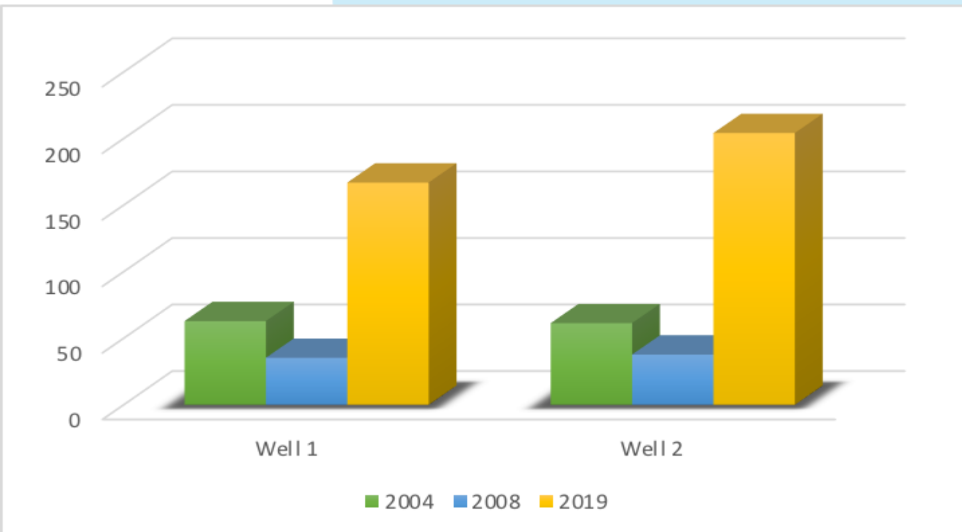


**Figure 10: Evolution of the nitrate concentration in two control wells ($NO_3$ mg/L)**

***Governance System Description***

The water governance in Tunisia is a centralized system where the control is practiced according to the top-down approach. The Ministry of Agriculture is also in charge of water resources management. This ministry is deconcentrated at the regional scale and its regional departments set up the public water policy in the regions. The regulation of the environment is assigned to the national agency of environmental protection. Two national utilities manage the drinking water service and the sanitation service in the country. The Ministry of Health controls also the quality of water. At the local level, the water users associations manage water at the irrigated land level in particular.

At the wadi El-Bey watershed level, different actors and stakeholders involved in the water resources management:

- Public actors:
  - Commissariat régionale du développement Agricole à Nabeul (CRDA-Nabeul) (Regional department of agriculture Nabeul governorate)
  - Centre de vulgarisation technique (CTV) (Territorial agricultural extension unit of Grombalia)
  - Municipality of Soliman
  - Municipality of Menzel Bouzelfa
  - Regional department of ANPE (National Agency of Environment Protection)
  - Regional department of ONAS (National sanitation utility)
  - Grombalia District- SONEDE (National Drinking water utility)
- Private Actors
  - Industries : Maghreb Tanning Factory – TMM / SOTIPAPIER (Paper Industry)/ CHAMS (Production of "Brik", ARALCO (Production of food flavor), SIPAC (Production of Food additives), SNBG (Soft drinks), Blanchisserie Centrale Hôtelière, Coccinelle (Laundry), SPIM (Metal industry promotion company), Establishment Latrous Driss (Wine production), GTS (Jeans washing), SOTUFRA (manufacturer of automotive harnesses and radiators), YAB (Dairy plant), Industrial Zone Management Company of Bouargoub
  - Farmers
- Civil Society actors:
  - Association of Environment and Development in Soliman (AEDS); Environmental association (REACT); JCI Grombalia; Radio Jeunesse Soliman
  - GDA Marja, GDA Boucharay, GDA Turki, GDA Nianon (Water users associations )
  - CERTE (Water Research and Technology Center)

## ***Identification of Sectors that Require Attention & Specific Challenges***

At the watershed level, two sectors require specific attention to address water damage control challenge:

- Industrial sector: the main objectives are (i) improve the treatment of produced wastewaters by different industrial activities and WWPT before their discharge in water bodies (ii) initiate new thinking and approaches to reuse treated wastewater in situ or others activities with respect of standards of reuse in each activity (Norme NT106.03)
- Agricultural sector: the actions will focus on (i) rationalize the irrigation in terms of water quantity (ii) increase farmers aware of the excessive use of chemical fertilizers and pesticide effects on water and the sustainability of farmer's activity.

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## ***Erdemli, Turkey Case Study***

The project area is located in Erdemli District (Mersin, Turkey). This area covers 37 $km^2$ and bordered by the Arpaçbahşiş town in the east part and the Kocahasanlı town in the west part, the Barbaros neighborhood in the north part and the Mediterranean Sea in the south part (Figure 11, Figure 12 and Figure 13). Agricultural (eg greenhouse, citrus and vegetable production) and small-scale industries (eg olive oil factories, packaging facilities, furniture production and automobile industry) activities and urbanization are very intense in the project area. Mersin province is a coastal city that has been rapidly urbanizing and industrializing especially in the last 20 years. For this reason, the demand for drinking and using and irrigation water is increasing day by day and the water need is mostly met from groundwater or surface water. In addition, various agricultural chemicals (eg pesticides, herbicides, fungicides, fertilizers, soil conditioners, desaliners) that are used in areas where agricultural activities are intensive are important threats to groundwater quality. Due to uncontrolled population migration and unplanned urbanization in recent years, many problems are encountered in the coastal aquifers in the region (eg saltwater aquifers due to a decrease in groundwater levels and seawater interference).

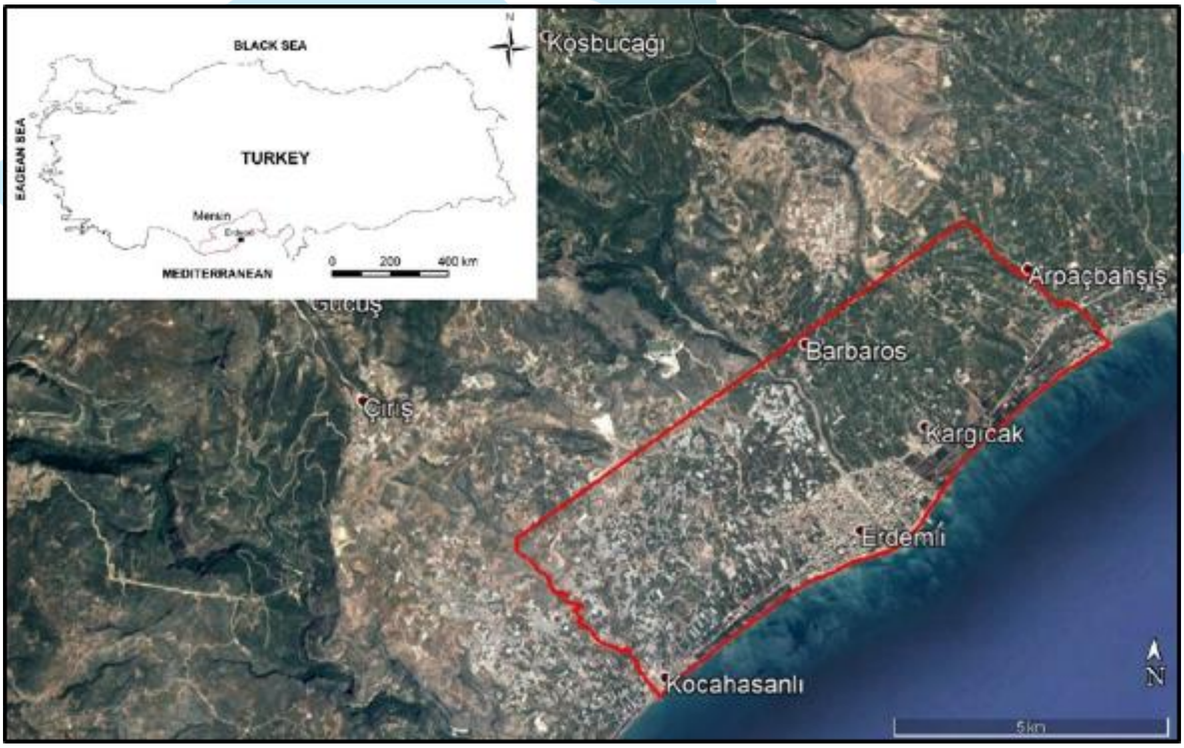



**Figure 11: Location map of the Erdemli Coastal Aquifer (ECA) study area (Erdemli, Mersin).**

**Figure 12: A view from Erdemli Coastal Aquifer (ECA) study area.**

**Figure 13: A view from Erdemli Coastal Aquifer (ECA) study area.**

Erdemli district has a very rich historical and cultural assets as a result of hosting many tribes and civilizations throughout the history. The main ones are Kizkalesi (Figure 14), Korikos and Elauissa Sebaste ancient cities and the surrounding castles, cisterns, aqueducts, churches, Ayas amphitheater, oxen, kanlidivane, roofeo, imrzelli, Akkale (Tirtar). Erdemli is becoming one of the important tourism centers of Mersin in the summer months, and its important beaches include Kızkalesi beach (Figure 14), Ayaş Yemişkumu beach (Figure 15), Kocahasanlı beach, Tömük beach and Kargıpınarı beach.

**Figure 14: The view of Kızkalesi.**

**Figure 15: The view of Ayaş Yemişkumu beach.**

## Morphology of the Study Area

In the study area (Erdemli Coastal Aquifer), which has a slightly uneven topography, the slope values are quite low, especially in the plains close to the Mediterranean coastline, and the heights vary between 0 m (sea level) and 250 m (Figure 16).

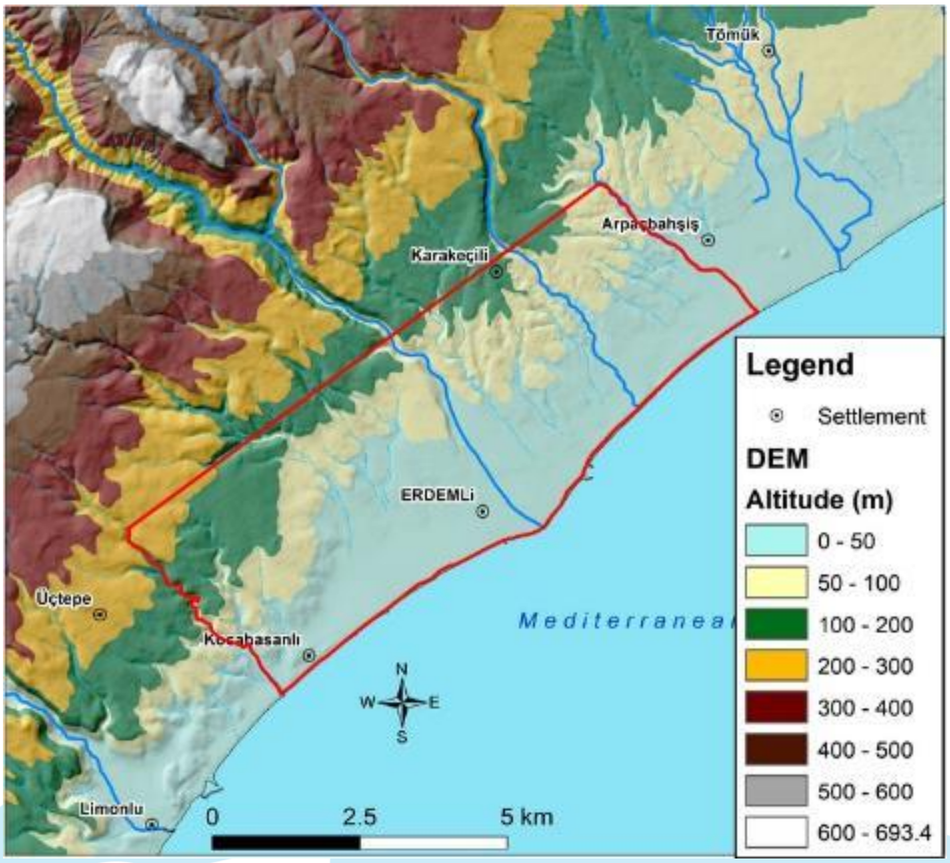



**Figure 16: Elevation map of the study area (numerical height model).**

**Population, Settlement and Agricultural Products**

Erdemli and its surrounding region hosted various civilizations from the Hittites to the Ottomans. Erdemli district, located approximately 37 km west from Mersin city center, is one of the important coastal settlements of the region. According to 2018 Address Based Population Registration System data, the total population living in the study area is 57,758 (Erdemli District Population Directorate). According to the obtained data of 2019; there are 5432 residences, 20 summerhouse sites and a total of 5528 housings, 76 of which are state institutions. In addition, there are 8 factories (eg olive oil factories, auto industry and furniture production), 7 fuel stations and 1 wastewater treatment plant in this region. Economic activities of the region are largely based on agriculture, animal production and tourism sectors. A significant part of the population of the region is engaged in various agricultural activities, lemon cultivation (Figure 17), avocado cultivation, banana greenhouse (Figure 18) and tomato greenhouse (Figure 19) in the areas close to the shore. About 65% of the total lemon production in Turkey is produced in Erdemli. In addition, Erdemli is an important tomato-produced location. On the mountainous areas in the north, especially ovine (goat and sheep) animal production activities are quite common. Due to the tourism activities intensifying along the Mediterranean coast and transhumance activities carried out in high areas, the population of the region increases by 3-4 times especially in summer season. Depending on this, water consumption increases considerably in the summer seasons.

**Figure 17: The lemon grown in the town of Erdemli.**

**Figure 18: Banana grown in the town of Erdemli.**

**Figure 19: Tomato grown in the town of Erdemli.**

**Land Use of Erdemli**

The land use map of Erdemli district is shown in Figure 20. The land use statistics are given in Table 4.

**Table 4: Land use features of Erdemli and their area.**

| Land Use Feature | Total Area ($km^2$) |
|---|---|
| Citrus Orchards | 13.56 |
| Greenhouses | 2.62 |
| Open-field Farms | 1.50 |
| Forest | 2.92 |

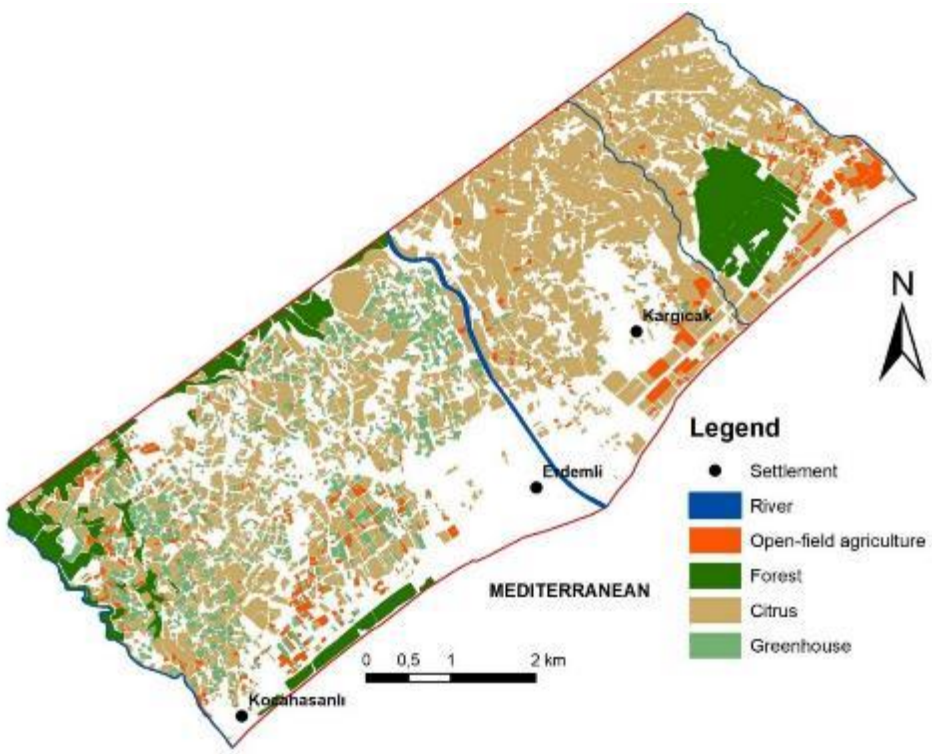



**Figure 20: The land use map of Erdemli.**

**Vegetation**

In the region, maquis (Mediterranean thickets) come to the fore as the dominant plant species. In the region, forest vegetation is common only in certain areas and does not have continuity (Erik and Sümbül, 1986[4]). According to the classification made based on heights from sea level; The vegetation cover in the study area consists of olive, carob, kermes oak, red pine and pistachio pine, which are common at heights between 0-500 m (Akman and Ketenoğlu, 1987[5]; Akman, 1995[6]).

## ***Analysis of Surface-Water Related Data***

### Stream Flows

The biggest streams in the Erdemli region are Arpaçbahşiş River, Alata River and Lamas River. The Lamas River is located to the west of the project area, Alata River passes through the middle of the

[4] Erik, S., Sümbül, H., 1986. Taşeli Platosu (İçel-Konya-Antalya) Florası Üzerinde Bir Araştırma. Proje No: TBAG-591, Türkiye Bilimsel Araştırma Kurumu Temel Bilimler Araştırma Grubu, Ankara.

[5] Akman, Y., Ketenoğlu, O., 1987. Vejetasyon Ekolojisi, Ankara Üniversitesi, Fen Fakültesi Yayınları No: 146, Ankara (Turkish).

[6] Akman, Y., 1995. Türkiye Orman Vejetasyonu, Ankara Üniversitesi, Fen Fakültesi Yayınları, Ankara (Turkish).

study area. Lamas River, which has a basin area of 1500 km$^2$ and originates from the Taurus Mountains, flows 130 km away and pours into the Mediterranean from the Limonlu neighborhood of Erdemli district. Lamas River, with an average flow of 4.275 m$^3$/s, is one of the largest streams in the region in terms of both river basin area and river length and is a continuously flowing stream (Yıldırım, 2018[7]). The highest flow in the river was measured in February with 10.410 m$^3$/s and the lowest in August with 0.409 m$^3$/s (Yıldırım, 2018). Alata River's discharges reach up to 0,963 m$^3$/s in the March and no flow is shown in summer sesions in the river (Yıldırım, 2018). Therefore it is described as an ephemeral stream. Arpaçbahşiş River has average discharge of the 0.094 m$^3$/s and the river flows continuously (Yıldırım, 2018). There is also a river called Kocahasanlı in the ECA. However this river just flow when the flash flooding occurs.

### Rainfall

Evapotranspiration is quite high in the summer, where the Mediterranean climate regime, which is typically hot and dry in summer, warm and rainy in winter (usually in the form of rain), is dominant in the region. The climate of the region is typically; it can be characterized by low precipitation, sunny days, hot summer months, high humidity and high evapotranspiration potential. In the region, the lowest precipitation is observed in August with an average of 2.4 mm, and the highest precipitation is observed in December with 126 mm (Figure 21). In the region where the most precipitation is observed in the winter sessions, especially in the summer sessions, no precipitation is observed for long periods (3-4 months).

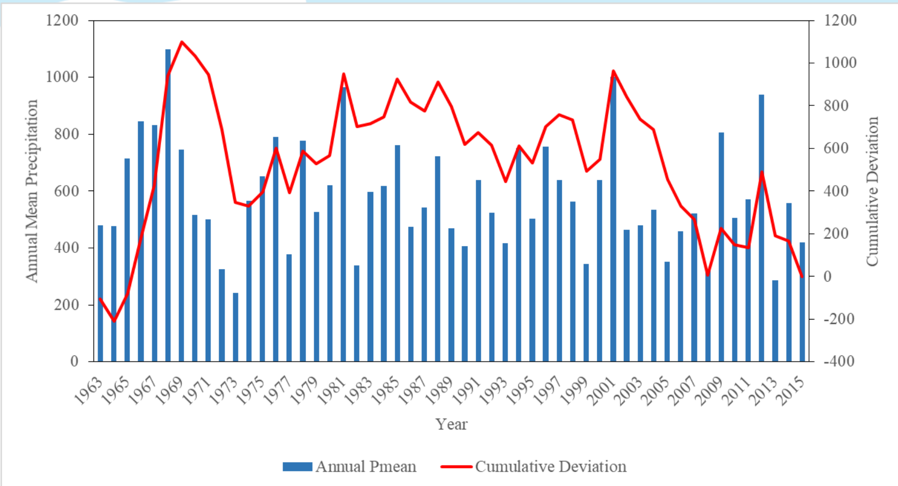



**Figure 21: Annual total rainfall and cumulative deviation of the Alata meteorology station (between 1963-2015) depending on time (TSMS8).**

[7] Yıldırım, Ü., 2018. Göksu Nehri Ve Tarsus Çayı (Mersin) Arasında Yer alan Akarsuların Morfometrik, Hidrolojik ve Hidrojeokimyasal Özelliklerinin Araştırılması. Mersin Üniversitesi Fen Bilimleri Enstitüsü, Doktora Tezi, Mersin, 248 sayfa (Unpublished, Turkish).

[8] Turkish State Meteorological Service.

**Temperature**

In the study area, where the average temperature value is 18.6 °C for many years, the lowest average temperature value is observed in January at 10 °C and the highest temperature value in August at 28 °C (Figure 22). Terrestrial climate is dominant in mountainous northern regions.

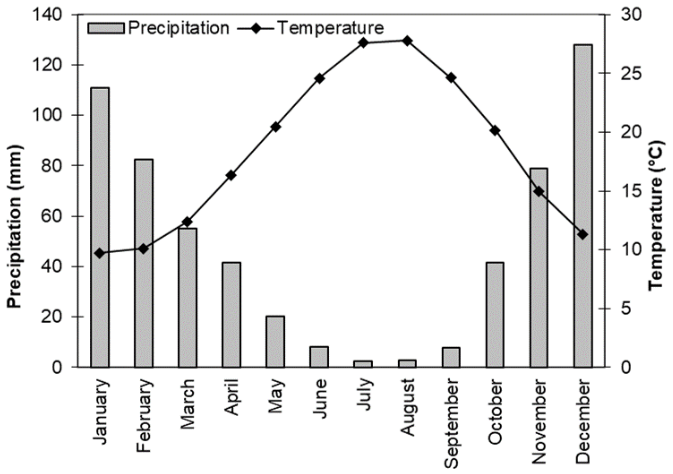



**Figure 22: Average precipitation and temperature values in Alata station between the period 1975 and 2015 (TSMS).**

## ***Analysis of Groundwater Related Data***

**Hydraulic Head Levels**

Will be measured by field study. It is postponed due to Covid-19 situation.

**Pumping Rates**

Will be measured by field study. It is postponed due to Covid-19 situation.

## ***Relevant Water Quality Data***

## ***Water Quality Status***

The measurements determine the current situation of water quality in ECA will be done by field study. The historical data about water quality is given below.

**Surface Water**

A study on streams in the project area was done by Yıldırım (2018). In this study, the lowest, highest and average values of some physical and chemical parameters of the three important streams of Erdemli district are given in Table 5 and Table 6.

**Table 5: The min, max and average values of some physical and chemical parameters of the three important streams of Erdemli.**

| River Name | | pH | EC (µS/cm) | DO (%) | Ca (mg/L) | Mg (mg/L) | Na (mg/L) | K (mg/L) | $HCO_3$ (mg/L) | $CO_3$ (mg/L) | Cl (mg/L) | F (mg/L) | $NO_3$ (mg/L) | $NO_2$ (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Arpaçbahşiş** | min | 7.22 | 514 | 54 | 70.91 | 11.26 | 2.47 | 0.00 | 191 | 0.00 | 12.87 | 0.06 | 10.57 | 0.01 |
| | max | 8.35 | 683 | 110 | 124.93 | 24.34 | 22.85 | 2.33 | 313 | 11.01 | 27.47 | 0.63 | 54.95 | 0.23 |
| | ave. | 7.81 | 615 | 74 | 99.86 | 17.63 | 12.64 | 1.58 | 270 | 0.92 | 18.77 | 0.22 | 26.05 | 0.08 |
| **Sorgun** | min | 0.00 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | max | 9.18 | 495 | 104 | 44.26 | 32.02 | 7.55 | 1.02 | 181 | 115.09 | 26.85 | 0.36 | 9.87 | 0.24 |
| | ave. | 8.64 | 238 | 81 | 36.67 | 22.83 | 5.52 | 0.74 | 134 | 29.31 | 9.23 | 0.11 | 5.38 | 0.04 |
| **Lamas** | min | 7.88 | 334 | 62 | 54.53 | 5.63 | 2.89 | 0.00 | 140 | 0.00 | 4.98 | 0.01 | 4.42 | 0.01 |
| | max | 8.33 | 512 | 131 | 86.63 | 14.84 | 8.98 | 0.98 | 252 | 13.01 | 14.50 | 0.66 | 12.03 | 0.05 |
| | ave. | 8.07 | 438 | 90 | 77.07 | 10.02 | 6.01 | 0.61 | 220 | 1.08 | 9.16 | 0.14 | 7.39 | 0.02 |

**Table 6: The min, max and average values of some physical and chemical parameters of the three important streams of Erdemli.**

| River Name | | $SO_4$ (mg/L) | B (µg/L) | Al (µg/L) | Si (mg/L) | Ti (mg/L) | V (µg/L) | Ni (µg/L) | Fe (µg/L) | Cr (µg/L) | As (µg/L) | Sr (µg/L) | Ba (µg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Arpaçbahşiş** | min | 13.16 | 17.77 | 0.00 | 0.35 | 38.00 | 1.08 | 1.34 | 0.00 | 0.00 | 0.00 | 158.20 | 36.00 |
| | max | 65.52 | 56.38 | 33.27 | 11.59 | 269.50 | 3.35 | 355.00 | 452.57 | 6.20 | 10.34 | 484.30 | 100.90 |
| | ave. | 34.53 | 37.25 | 10.48 | 5.68 | 179.26 | 2.43 | 58.42 | 108.55 | 1.35 | 2.56 | 325.98 | 71.09 |
| **Sorgun** | min | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | max | 14.49 | 27.13 | 149.50 | 5.00 | 101.80 | 2.90 | 7.44 | 219.90 | 7.22 | 0.55 | 150.40 | 28.86 |
| | ave. | 10.67 | 22.13 | 46.46 | 4.23 | 78.24 | 0.90 | 3.94 | 60.55 | 2.05 | 0.18 | 121.19 | 15.16 |
| **Lamas** | min | 5.71 | 9.76 | 0.00 | 0.29 | 25.50 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 96.12 | 13.50 |
| | max | 19.00 | 78.34 | 63.32 | 3.97 | 226.40 | 2.03 | 280.80 | 945.55 | 6.05 | 13.41 | 481.70 | 46.40 |
| | ave. | 15.64 | 24.26 | 13.67 | 2.45 | 146.48 | 0.91 | 42.42 | 152.84 | 1.73 | 2.69 | 222.23 | 26.82 |

**Erdemli Wastewater Treatment Plant**

Erdemli Wastewater Treatment plant has been designed according to the long aerated activated sludge (BNR) system that removes nitrogen and phosphorus. The first stage of the facility has been projected according to the equivalent population of 50,000 people/day until 2027. The second stage up to 100,000 people/day until 2042. The characteristics of the Erdemli wastewater treatment plant are given in Table 7.

**Table 7: The characteristics of the Erdemli wastewater treatment plant.**

| **Treatment Plant Type** | | **Current Capasity ($m^3$/day)** | **Amount of Treated Wastewater ($m^3$/sn)** | **Desharge to** | **Population Served** | **Amount of Sludge From Waste Water Treatment Plant (ton/day)** |
|---|---|---|---|---|---|---|
| **Biological** | **Advanced** | | | | | |
| Yes | Yes | 21,932 | 0.134 | Sea | It is designed to serve the population of 100,000 people for the year 2042. | 18 |

**Groundwater Resources**

The hydrological and hydrogeological data layers of the region, which covers the Erdemli Coastal Aquifer, was created using 1/25K scaled topographic maps in the GIS environment (Figure 23). Some hydrological properties of the Erdemli coastal aquifer are given in Table 8.

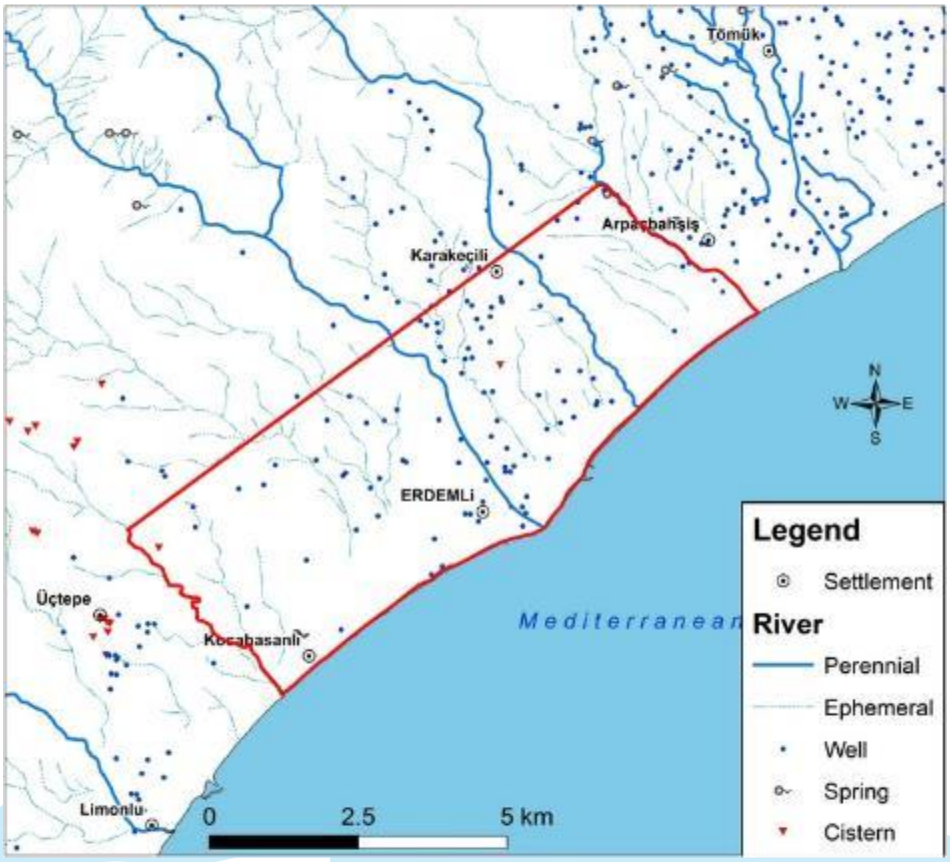



**Figure 23: The location of streams and various water points in the Erdemli district**

**Table 8: Some hydrological properties of the Erdemli coastal aquifer**

| **Place** | **Amount of annual water withdrawal from wells ($m^3$/year)** | **Number of wells (Registered)** | **Groundwater Reserve ($hm^3$/year)** |
|---|---|---|---|
| Mersin – Erdemli | 19,974.384 | 1,116 | 37.8 |

There is limited number of studies on the hydrogeology of the study area. The most important of which is a study published by Demirel and Güler (2006)[9], including the project area. In this study; by using the water chemistry data obtained from the groundwater system between Mersin and Erdemli, it was aimed to determine the main factors and mechanisms that control the chemistry of

[9] Demirel, Z., Güler, C., 2006. Hydrogeochemical evolution of groundwater in a Mediterranean coastal aquifer, Mersin-Erdemli basin (Turkey): Environmental Geology, 49(3), 477-487.

the groundwater in the region. As a result of geochemical models (inverse geochemical models) realized with PHREEQC software; the factors controlling water chemistry in the region are: decomposition of silicates; dissolution of various salts; Calcite, amorphous silica and kaolinite minerals were determined to have precipitation and ion exchange reactions. In addition, as a result of multivariate statistical analysis, it was determined that the anthropogenic pollution sources in the region show seasonality and generally depend on fertilization and fungicide applications. The sampling points in this study are given in Figure 24, and some physical and chemical properties of water samples are given in Table 9.

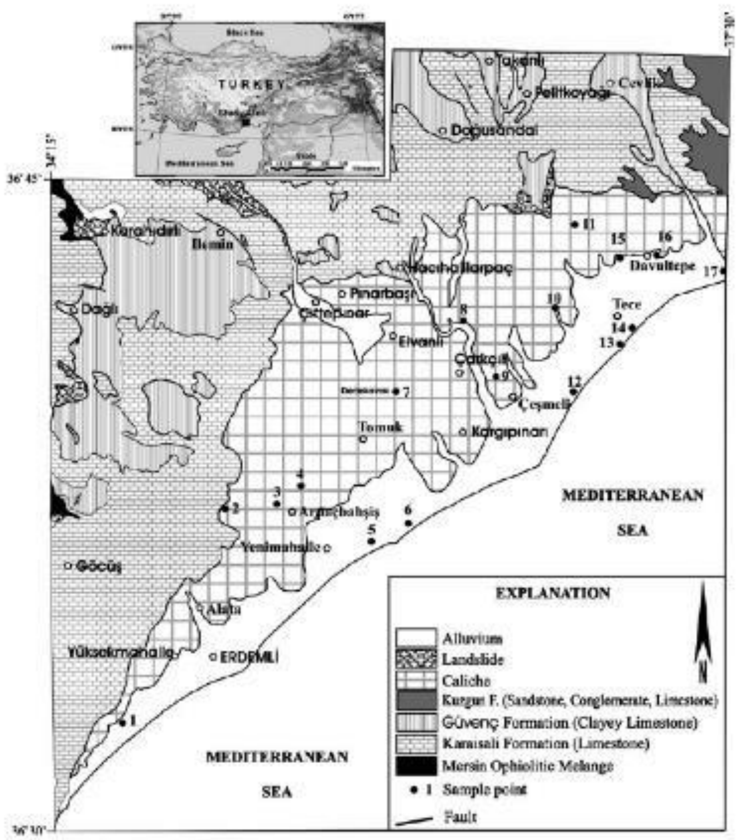



**Figure 24: Sampling points of the study of Demirel and Güler (2006).**

**Table 9: Analysis results of the study of Demirel and Güler (2006).**

| ID | Sample Source | Sample Date | EC (µS/cm) | pH | Ca (mg/L) | Mg (mg/L) | Na (mg/L) | K (mg/L) | Cl (mg/L) | $SO_4$ (mg/L) | $HCO_3$ (mg/L) | F (mg/L) | $SiO_2$ (mg/L) | $NO_3$ (mg/L) | Water Facies |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1* | Spring | 05/2002 | 600 | 7.60 | 72.8 | 20.3 | 12.0 | 1.0 | 22.6 | 14.6 | 317 | 0.2 | 11.3 | 0.10 | Ca-Mg-HCO3 |
| | | 08/2002 | 623 | 7.20 | 75.2 | 19.2 | 11.0 | 1.0 | 31.8 | 10.8 | 331 | 0.2 | 14.8 | 8.00 | Ca-Mg-HCO3 |
| 2* | Spring | 05/2002 | 492 | 7.90 | 51.6 | 20.9 | 8.0 | 1.0 | 16.1 | 12.4 | 263 | - | 10.0 | 10.00 | Ca-Mg-HCO3 |
| | | 08/2002 | 578 | 7.60 | 66.9 | 22.1 | 6.8 | 1.0 | 28.0 | 10.2 | 260 | 0.3 | 13.1 | 8.00 | Ca-Mg-HCO3 |
| 3* | Spring | 05/2002 | 500 | 7.80 | 77.5 | 11.7 | 6.0 | 1.0 | 8.8 | 11.9 | 293 | 0.2 | 10.0 | 7.60 | Ca-HCO3 |
| | | 08/2002 | 546 | 7.50 | 60.3 | 12.3 | 5.9 | 2.3 | 14.2 | 8.6 | 260 | 0.1 | 10.0 | 5.10 | Ca-Mg-HCO3 |
| 4* | Spring | 05/2002 | 774 | 7.40 | 65.0 | 42.4 | 34.0 | 4.4 | 34.7 | 43.6 | 419 | 0.5 | 28.5 | 12.90 | Mg-Ca-HCO3 |
| | | 08/2002 | 555 | 7.30 | 61.9 | 16.5 | 7.9 | 1.7 | 22.0 | 11.4 | 266 | 0.3 | 12.6 | 6.10 | Ca-Mg-HCO3 |
| 5* | Well | 05/2002 | 750 | 7.70 | 63.2 | 49.9 | 14.0 | 1.3 | 26.3 | 54.2 | 383 | - | 29.5 | 26.40 | Mg-Ca-HCO3 |
| | | 08/2002 | 730 | 7.90 | 48.1 | 47.9 | 15.6 | 1.3 | 38.0 | 38.2 | 343 | 0.7 | 31.0 | 17.90 | Mg-Ca-HCO3 |
| 6 | Well | 05/2002 | 645 | 7.50 | 54.7 | 32.9 | 11.0 | 1.7 | 21.4 | 39.6 | 311 | 0.3 | 18.4 | 13.60 | Ca-Mg-HCO3 |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 08/2002 | 685 | 7.40 | 61.0 | 37.6 | 9.4 | 1.3 | 32.0 | 31.6 | 326 | 0.4 | 22.7 | 17.30 | Mg-Ca-HCO3 |
| 7 | Spring | 08/2002 | 520 | 7.60 | 75.0 | 8.5 | 4.6 | 1.0 | 18.2 | 6.8 | 237 | - | 10.0 | 3.70 | Ca-HCO3 |
| 8 | Spring | 05/2002 | 413 | 7.80 | 45.6 | 17.6 | 6.0 | 1.0 | 8.4 | 15.1 | 233 | 0.3 | 10.0 | 6.50 | Ca-Mg-HCO3 |
| | | 08/2002 | 423 | 7.50 | 61.7 | 14.7 | 6.3 | 1.0 | 15.4 | 9.4 | 237 | 0.7 | 10.0 | 4.50 | Ca-Mg-HCO3 |
| 9 | Well | 05/2002 | 924 | 7.50 | 76.3 | 52.5 | 22.0 | 1.0 | 66.4 | 65.7 | 359 | 1.1 | 60.0 | 33.60 | Mg-Ca-HCO3-Cl |
| | | 08/2002 | 910 | 7.40 | 73.5 | 51.3 | 16.8 | 1.0 | 65.0 | 48.8 | 349 | 0.2 | 67.0 | 21.20 | Mg-Ca-HCO3-Cl |
| 10 | Well | 05/2002 | 1231 | 7.5 | 79.7 | 63.3 | 52.0 | 2.6 | 101.0 | 60.8 | 413 | 0.7 | 41.1 | 32.80 | Mg-Ca-Na-HCO3-Cl |
| | | 08/2002 | 793 | 7.40 | 54.7 | 47.1 | 39.7 | 3.0 | 78.8 | 32.8 | 337 | 0.6 | 30.0 | 1.40 | Mg-Ca-Na-HCO3-Cl |
| 11 | Well | 05/2002 | 631 | 7.50 | 100.0 | 5.9 | 11.0 | 1.0 | 17.9 | 6.3 | 347 | 0.3 | 12.0 | 6.60 | Ca-HCO3 |
| | | 08/2002 | 668 | 7.20 | 99.1 | 6.4 | 8.9 | 1.0 | 34.6 | 7.4 | 308 | 0.4 | 14.8 | 5.90 | Ca-HCO3 |
| 12 | Well | 05/2002 | 1386 | 7.80 | 64.7 | 57.1 | 132.0 | 8.5 | 184.0 | 60.5 | 431 | 0.5 | 53.0 | 41.00 | Na-Mg-Ca-HCO3-Cl |
| | | 08/2002 | 1512 | 7.40 | 67.2 | 61.6 | 135.0 | 9.6 | 187.0 | 74.4 | 426 | 0.6 | 53.0 | 22.00 | Na-Mg-Ca-HCO3- |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | | Cl |
| 13 | Well | 08/2002 | 939 | 8.00 | 68.2 | 64.0 | 18.8 | 1.0 | 54.4 | 61.8 | 420 | 0.2 | 36.0 | 17.60 | Mg-Ca-HCO3 |
| 14 | Well | 05/2002 | 1000 | 7.50 | 78.2 | 41.8 | 56.0 | 2.1 | 53.5 | 44.4 | 419 | 0.8 | 34.2 | 30.00 | Ca-Mg-Na-HCO3 |
| 15 | Well | 05/2002 | 700 | 7.50 | 70.0 | 23.1 | 28.0 | 1.9 | 55.5 | 18.3 | 347 | 0.3 | 40.1 | 16.20 | Ca-Mg-HCO3-Cl |
| | | 08/2002 | 731 | 7.70 | 68.2 | 26.9 | 26.0 | 1.6 | 80.8 | 17.6 | 278 | - | 42.0 | 9.60 | Ca-Mg-HCO3-Cl |
| 16 | Well | 05/2002 | 997 | 7.40 | 54.1 | 45.4 | 78.0 | 6.3 | 94.3 | 36.4 | 377 | 0.2 | 43.1 | 31.80 | Mg-Na-Ca-HCO3-Cl |
| | | 08/2002 | 1103 | 7.20 | 66.9 | 46.7 | 66.0 | 5.5 | 123.0 | 39.8 | 408 | 0.9 | 54.7 | 23.50 | Mg-Ca-Na-HCO3-Cl |
| 17 | Well | 05/2002 | 802 | 7.50 | 86.3 | 21.7 | 28.0 | 3.9 | 50.0 | 90.0 | 287 | 0.5 | 15.6 | 26.00 | Ca-Mg-HCO3-SO4 |
| | | 08/2002 | 849 | 7.20 | 86.9 | 21.9 | 29.2 | 3.9 | 72.2 | 66.4 | 284 | 0.9 | 18.8 | 18.80 | Ca-Mg-HCO3-Cl |
| 18 | Sea | 05/2002 | 58600 | 8.20 | 461.0 | 1480.0 | 12600.0 | 603.0 | 22560.0 | 3098.0 | 452 | - | - | - | Na-Cl |

*The points are located in ECA study area.

## ***Governance System Description***

**List of Erdemli stakeholders**

Erdemli District Governorship

Erdemli Municipality

State Hydraulic Works Mersin Regional Directorate

Erdemli District Health Directorate

Erdemli District Food, Agriculture and Livestock Directorate

Erdemli Kocahasanlı Irrigation Union

Erdemli Headmen Association

Erdemli Farmers

## ***Identification of Sectors that Require Attention & Specific Challenges***

The field studies are postponed because of the Covid-19.

## ***Arborea, Italy Case Study***

The Italian study area is the farming district of Arborea (about 60 $km^2$), located in the central-western Sardinia (Italy) (Figure 25). It includes the villages of Arborea, Marrubiu and Terralba with a population of around 18,800.


**Figure 25. Arborea Nitrate Vulnerable Zone (NVZ) and surrounding wetlands**

The Arborea plain was an insalubrious swamp infested by mosquitoes bearing malaria disease. During the years 1920–1930, a huge land reclamation work was implemented for the entire plain: sand dunes were flattened and transformed into agricultural land and brackish and salted wetlands were drained by pumping water from below the sea level. A fertile plain was generated which was organized in rectangular fields of 2 to 4 ha in size, with the long side oriented N-S, delimited and protected by eucalyptus edges and surrounded by a drainage network consisting of main channels and a dense network of smaller drainage channels with direction E-W and N-S. This drainage system includes also some dewatering pumping stations for the water flow regulation in the main channels. The reclaimed land was colonized in the 1930ies by peasants coming from north-eastern Italy. They formed a very cohesive community that evolved in a strong cooperative system. Nowadays, the farmers' cooperative includes more than 200 farms managing some 30,000 dairy cattle on a 6,000-ha irrigated plain, representing one of the most productive agricultural sites in Italy, and with a milk productivity among highest in Europe. The plain is surrounded by marsh wetlands (some 50% of the Island wetland heritage) which are protected under the EU Natura 2000 directive (Sites of Community Importance) and the Ramsar convention. Some of these shallow wetlands are used by local cooperatives for professional fishing.

The forage cropping systems for dairy livestock are nowadays based on the import of grains and plant proteins from abroad and the local production of fiber from the double cropping of silage maize (*Zea mays*) and Italian ryegrass (*Lolium multiflorum*) for hay or a winter cereal for silage, representing over 80% of the irrigated plain. Almost all the remaining area in the district is grown with meadows of alfalfa (Medicago sativa) and horticultural crops (watermelon, melon, strawberries etc.).

The soil of most of the Arborea plain originates from the anthropogenic transformation of coastal sand dunes and is classified as Psammentic Palexeralfs (USDA 2006): >95% sand, 1.4% soil organic C (0-30 cm), C/N = 10, pH 6.3; Olsen P 70 ppm. There are no data available on the original soil organic matter content, but it is clear that the topsoil organic layer found today is originated from the intensive input of animal effluents (slurry and manure) from the dairy livestock.

**Figure 26: Dairy cattle farming and double cropping system (Italian ryegrass and silage maize)**

The intensive dairy cattle system at Arborea is characterized by high levels of nutrients input, in particular N and P which, on the one hand, is the main driver of soil fertility and, on the other hand, is the main cause of groundwater pollution with nitrates and the eutrophication caused by phosphorus in the surrounding wetlands and lagoons. In the recent past, eutrophication caused some social conflicts between fishermen and farmers.

In 2005, following the (late) implementation of the Nitrate Directive 91/676, the Arborea district was identified as a “Nitrates Vulnerable Zone” (NVZ). The prescribed maximum N rate (170 kg $ha^{-1}$ N) is about half than the net N removal (some 350-400 kg N $ha^{-1}$ $year^{-1}$) of the intensive forage crop systems supplying the dairy farms, while the high annual output of animal effluents at each farm exceeds the ND’s prescriptions. To meet the ND’s prescriptions, the farmers had to face additional costs for purchasing mineral N fertilizers to meet the N crop requirements and for exporting the excess manure and slurry outside the NVZ. This situation has generated controversies about whether the implemented measures are consistent with the goals of reducing nitrate pollution and are compatible with the maintenance of profitability for the dairy sector, which is vital for the livelihood of this rural district. Considering the high sand and relatively high organic matter content of the topsoil, soil structure is not an issue in this area. However, soil fertility management is critical due to the Mediterranean climate, irrigation practices and sandy soil texture, thus, a reduction of the input of organic effluents is perceived by farmers as a threat for maintenance of long-term soil fertility.

## ***Analysis of Surface-Water Related Data***

### Stream Flows

There are no available streamflow data in the Arborea case study

### Rainfall, Temperature and Evapotranspiration

The climate is Mediterranean with mean annual temperature and precipitation (concentrated between October and March) of 16.7 °C and 575 mm, respectively and an annual average reference evapotranspiration of 1164 mm, corresponding to an aridity index of 0,49. Some 75% of the total average annual rainfall occurs between October and March.

Weather observations showed a clear trend in temperature rise (Nguyen et al., 2016) and ETo in the last three decades, while average monthly rainfall did not show a clear trend.

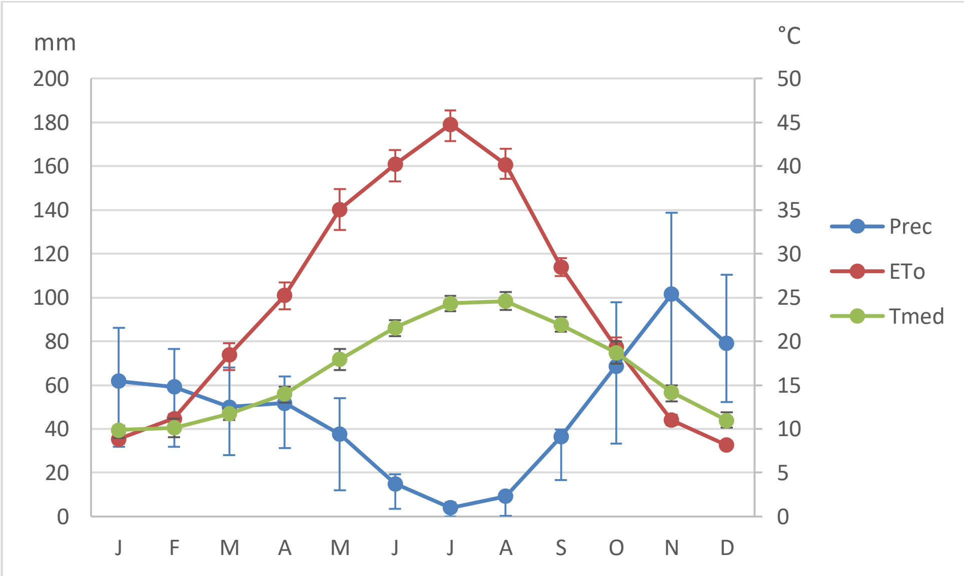



**Figure 27: Average monthly rainfall and reference evapotranspiration (ETo - Hargreaves) at Oristano Santa Lucia weather station (1959-2018; altitude = 10°; Latitude = 40°). Bars indicate 25th and 75th percentiles.**

### ***Analysis of Groundwater Related Data***

The Arborea plain occupies the northern part of the Campidano rift in which Quaternary deposits outcrop: littoral sediments (sands), lacustrine deposits (silt and clay), alluvial deposits along the rivers, continental deposits (gravel and sands). Two Hydrogeological Units (HU) have been identified:

- ✓ *Sandy Hydrogeological Unit (SHU)*. This unit is represented by a phreatic aquifer hosted in the Holocene littoral sands, cropping out in the plain. Discontinuous clay lenses of lagoonal origin, which gave rise to perched aquifers, characterize the aquifer; therefore, it can be considered locally confined. The aquifer has good porous permeability, with a K value ranging between $10^{-5}$ and $10^{-6}$ $ms^{-1}$. It is bounded at its base by a layer of lagoonal deposits made up of silt clays and peaty mud, which outcrop at the reclaimed Sassu Lagoon. As reported in Ghiglieri et al. (2016), in the southern part of the plain, lagoonal clays that delimit the bottom of the sandy aquifer are lacking, such that Holocene sands of the SHU and alluvial aquifers of the AHU (Pleistocene continental deposits) are in hydraulic communication with each other (Figure 28).

- ✓ *Alluvial Hydrogeological Unit (AHU)*. The Pleistocene continental deposits host a multi-layer aquifer. It consists of gravels with some sands or clayey sand outcrops throughout the area surrounding the Arborea plain up to Monte Arci. This aquifer is confined in the plain because of the aforementioned clay layer, which separates it from the sandy aquifer (SHU). The impermeable layers are represented by the lagoonal clays. This hydrogeological unit also includes good permeability (K=$10^{-4}$–$10^{-5}$ms$^{-1}$) gravelly-sand formations, deposited by fluvial action and intercalated within the continental deposits. The permeability decreases in the sand-clay layers.

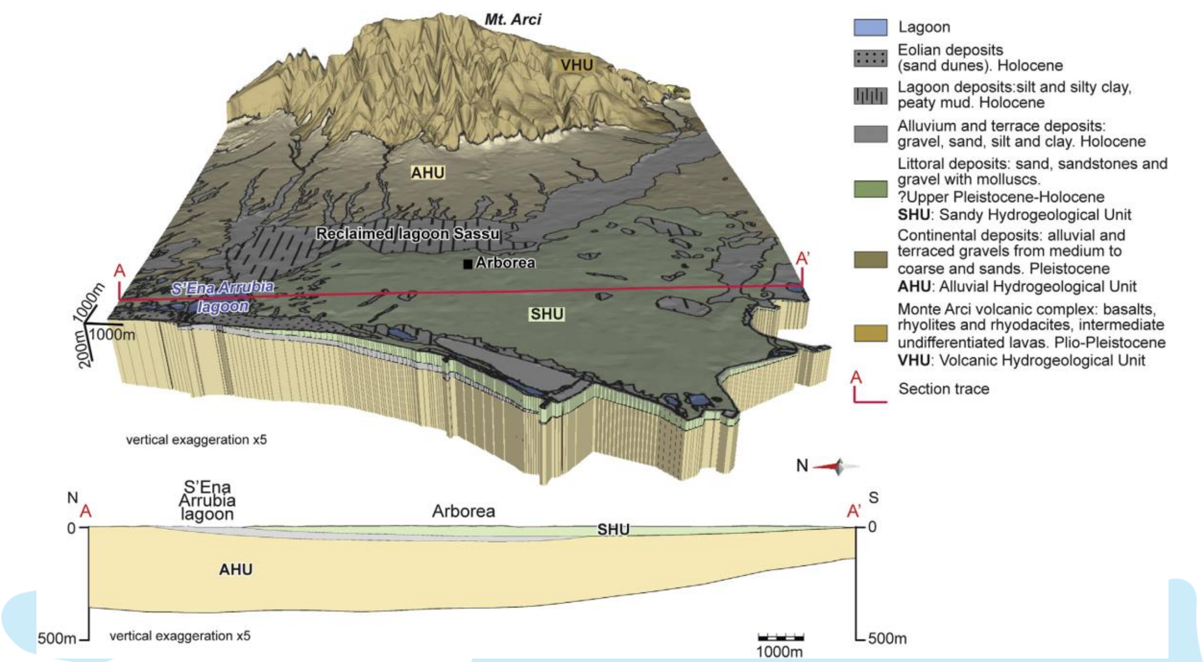



**Figure 28: 3D hydrogeolological model (Ghiglieri et al., 2016)**

From 2010 to 2015, NRD-UNISS carried out a hydrogeological study in the Arborea plain to assess the nitrate pollution of groundwater. Around 350 wells related to both SHU and AHU aquifers were investigated.

### Hydraulic Head Levels

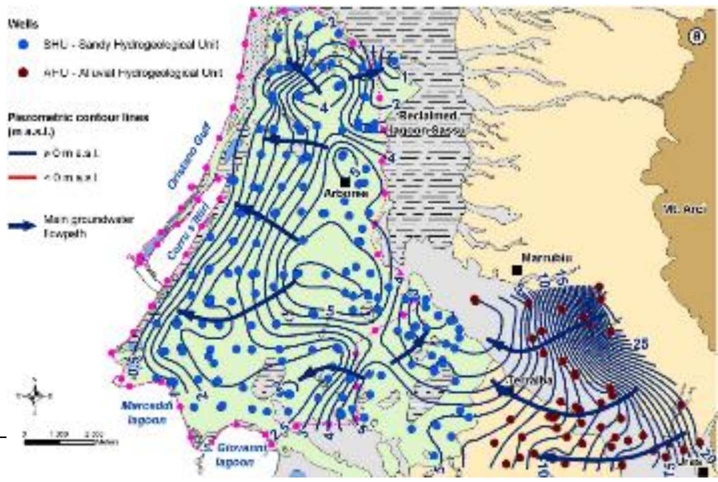


**Figure 29: Piezometric contour lines and main groundwater flow directions (SHU) (modified from Ghiglieri et al., 2016)**

In the central part of the Arborea NVZ, the piezometric surface indicates a zenithal local recharge area for the SHU aquifer with its flow path directed towards the sea. In the southern part the piezometric contour lines indicate a general flow from east to west, with a gradient which decreases in this direction showing an increase of the transmissivity. The flow paths suggest a lateral recharge from AHU to SHU aquifer.

**Pumping Rates**

The Arborea farming district receives high-pressure irrigation water from the Eleonora d'Arborea dam (some 35 $Mm^3$ $year^{-1}$) located some 35 km away and at an elevation of 110 m asl. This surface water is currently distributed at field scale by the Oristanese Land Reclamation Consortium through permanent sprinkler system. However, the supplement of water from the dam to the farms is made through a channel system and hence water is pumped by the Consortium before its distribution at farm level. Groundwater, mainly from the SHU aquifer, is used by farmers only for the cattle watering (80 - 100 L $day^{-1}$ per livestock unit, i.e. potentially up to some 1 $Mm^3$ $year^{-1}$) and for the washing of the livestock facilities. However pumping rates are largely unknown. The Farmers' Cooperative and the Milk Processing Cooperative 3A use groundwater from the AHU aquifer for the industrial processes in their facilities (some 1400 $m^3$ $day^{-1}$ i.e. some 0.5 $Mm^3$ $year^{-1}$).

## ***Relevant Water Quality Data***

## ***Water Quality Status***

**Surface Water**

The ARPA regional environmental Agency has monitored the quality of surface water in the NVZ since 2007. The field monitoring over 5 surface water bodies (ponds and lagoons) and includes a set of parameters including pH, temperature, dissolved oxygen, oxygen saturation, electric conductivity and salinity. A series of lab analysis including nitrate and ammonium N, soluble and total phosphorus, Chlorophyll a, turbidity and microbial and algal growth are also made systematically (ARPAS, 2017).

All the monitoring data indicate that the concentration of nitrates rarely reached the threshold of 50 mg $L^{-1}$ (only detected systematically in one of the channels) being most frequently below 20 mg $L^{-1}$. The concentration of nitrates in the ponds and lagoons was always below 0,6 mg $L^{-1}$ over the entire monitoring period. Nitrate concentration in surface water, after an initial decrease following the implementation of the ND, increased up to the values observed in 2007.

In the same ponds, the concentration of total phosphorus in water samples reached up to over 2.0 mg $L^{-1}$. These data indicate that eutrophication can be attributed more to phosphorus than to nitrate concentration. The interannual dynamics of phosphorus does not reveal a clear trend and then seems independent of the ND implementation (ARPAS, 2017).

**Groundwater Resources**

NRD-UNISS carried out an agronomic study at field scale in the Arborea area to evaluate the impact of four fertilization systems on nitrate losses in the double crop system (maize and Italian ryegrass). A monthly monitoring of the nitrate concentrations in the soil solution was carried out from June 2009 to May 2012 using 10 cm diameter disk lysimeters. A clear seasonal dynamics of nitrate concentration was observed in the three years, with maximum occurring in autumn–winter (Figure 30).

Main findings of this study showed that: (i) replacing organic with mineral sources of N did not substantially reduce nitrate leaching; (ii) nitrate leaching is unavoidable in autumn-winter, even without any fertilization for the autumn-spring crop; (iii) nitrate concentrations were still high at the end of the maize crop cycle despite the high N removal of the maize crop; (iv) the lowest nitrate concentration during the leaching period was observed when using only organic high C/N ratio as fertilizer for the ryegrass, but crop yield was halved because of the nitrogen stress observed at the end of the winter.

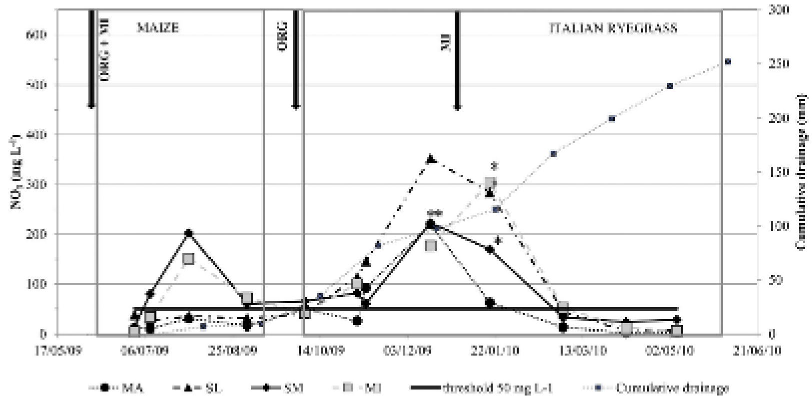
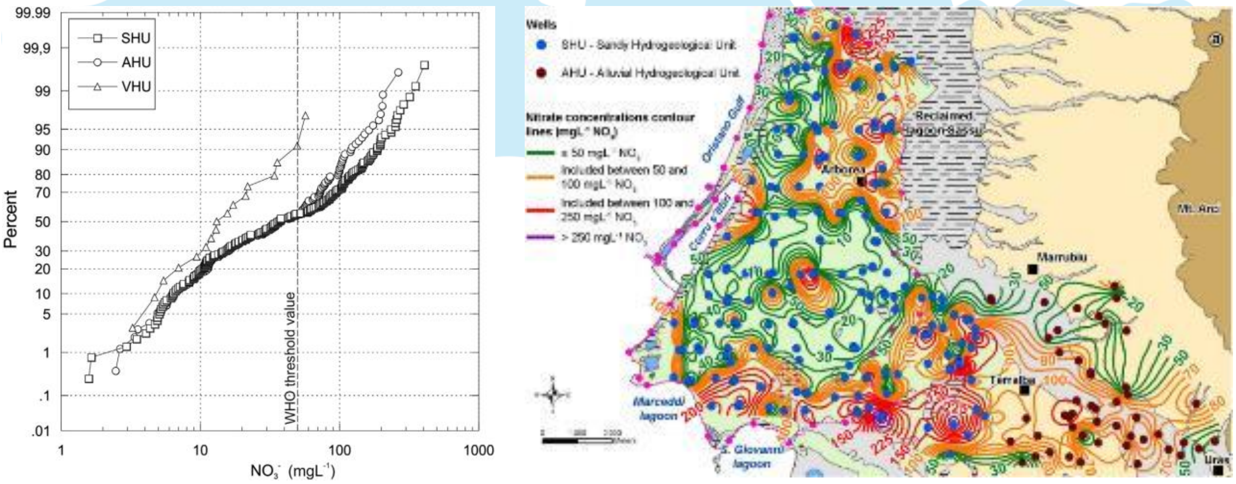



**Figure 30: Dynamics of the NO3 concentration in the soil solution and soil water percolation as simulated by EPIC model during the silage maize–Italian ryegrass rotation (2009–2010) for the different treatments. MA = cattle manure; SL = cattle slurry; SM = cattle slurry + mineral; MI = mineral (Demurtas et al., 2016)**

The nitrate concentration measured on samples taken from 350 wells in the plain ranged between 1.58 and 406 mg $L^{-1}$. As reported in Figure 31, almost 50% of SHU and AHU waters exceeded the 50 mg $L^{-1}$ threshold value recommended by WHO; the maximum value of 406 mg $L^{-1}$ was observed in SHU samples.

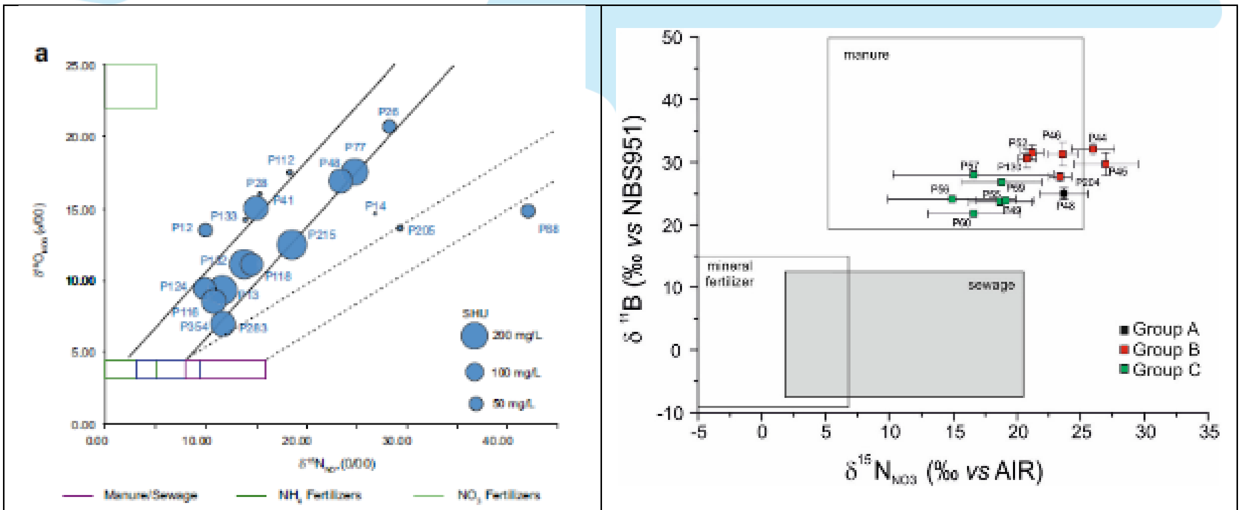



(a) (b)

**Figure 31: (a) Cumulate distribution function plot for NO3 concentrations in the SHU, AHU; (b) NO3 concentration contour lines (SHU) (modified from Ghiglieri et al., 2016)**

In the southern part of the plain, the concentrations were almost uniformly above 50 mg $L^{-1}$. An increasing trend from east to west in the direction of the main groundwater flow prevailed, highlighting an additional pollution source located outside the Arborea NVZ. Contributions from nitrate sources located within the southern part of the NVZ directly affect SHU. A second highly polluted area was identified in the NE sector of the NVZ. In this area, the recharge of SHU is local, and there is no contribution from AHU outside of the NVZ. Therefore the high nitrate concentrations were attributed to the local anthropogenic activities.

Hydrogeochemical and multi-isotopic surveys made by combining environmental isotopes ($\delta^{15}N$-$NO_3$, $\delta^{18}O$-$NO_3$, $\delta^{34}S$-$SO_4$, $\delta^{18}O$-$SO_4$, $\delta^{13}C_{DIC}$, $\delta^{11}B$), water quality and hydrogeological indicators was carried out to assess the nitrate source and fate in groundwater and the occurrence of nitrate attenuation processes such as denitrification. Combinations of $\delta^{15}N$ and $\delta^{18}O$ of dissolved nitrate were used to trace N sources. Besides, nitrate isotope measurements proved to be a useful tool to trace nitrate transformation processes such as denitrification. The isotope composition of SHU samples suggests a mixed source of nitrate both synthetic and organic fertilizers, but this attribution is not sharp (Figure 32). The nitrate isotopic composition confirms the occurrence of denitrification processes which are consistent with other geochemical indicators such as low DO concentrations <2.0 $mgL^{-1}$ and low Eh values (-180 mV), indicating conditions suitable for denitrification in the aquifer (Pittalis et al., 2018). The integration of $\delta^{11}B$ data with $\delta^{15}N$ values allowed assessing the nitrate source in the study area. Results clearly showed that organic fertilizer were the main source of nitrates in groundwater (Figure 32) (Biddau et al.,. 2019)




| (a) | (b) |
|---|---|

**Figure 32: (a) 15N-NO3 vs 18O-NO3 (modified from Pittalis et al., 2018) (a) and 11B vs 15N-NO3 (modified from Biddau et al., 2019) (b) for the SHU aquifer**

### ***Governance System Description***

Besides the farming activities, many other activities take place in this district, including horticulture, aquaculture and tourism, resulting in the involvement of multiple stakeholders acting in the same area (Figures 33, 34). The main stakeholders groups (Figure 33) include farmers and fishermen, who are also experts in the use of the natural resources of the area: they know how interdependent natural and socio-economic cycles work in terms of their farms from their personal experience and they mainly have a problem-solving attitude. The majority of farmers belong to the Farmers' Cooperative (www.produttoriarborea.it) which provides them a number of services including the collective purchase of farm inputs (e.g. animal feeds), technical assistance and product marketing, and to the Milk Processing Cooperative (3A, www.arborea.it), which processes and sells dairy products. Most farmers in Arborea are members of Farmers' Unions, which provide technical and administrative support to farmers to ensure, for instance, access to EU subsidies and the implementation of agro-environmental measures through negotiation with the regional government. Other relevant stakeholder groups include the Oristanese Land Reclamation Consortium, in charge of the irrigation water management for the whole Oristanese district (some 50,000 ha), which also manages the drainage network, ensuring the cultivation of agricultural fields located below sea level through a system of pumping stations; policy makers and researchers, whose frameworks and theories support the evolution of policy and the design and implementation of research about the nitrate issue and agricultural development in general. Among the decision makers and implementers, the Regional Agency of the Hydrographical District (ADIS), the regional Environmental agency ARPAS, the Regional Agency of Agricultural Policies Application and Rural Development (LAORE) and the Regional Animal Husbandry Association (ARA) play a relevant role in the implementation of NDs in the NVZ. ADIS has a technical and operational role for protecting water ecosystems and for water-related policy measures. ARPAS provides technical support to the Sardinian government in the control of the application of agro-environmental measures at the farm scale and in monitoring water quality in wells, channels and wetlands. LAORE and ARA are intermediary organizations which operate as an extension service for agriculture (LAORE) and livestock (ARA).

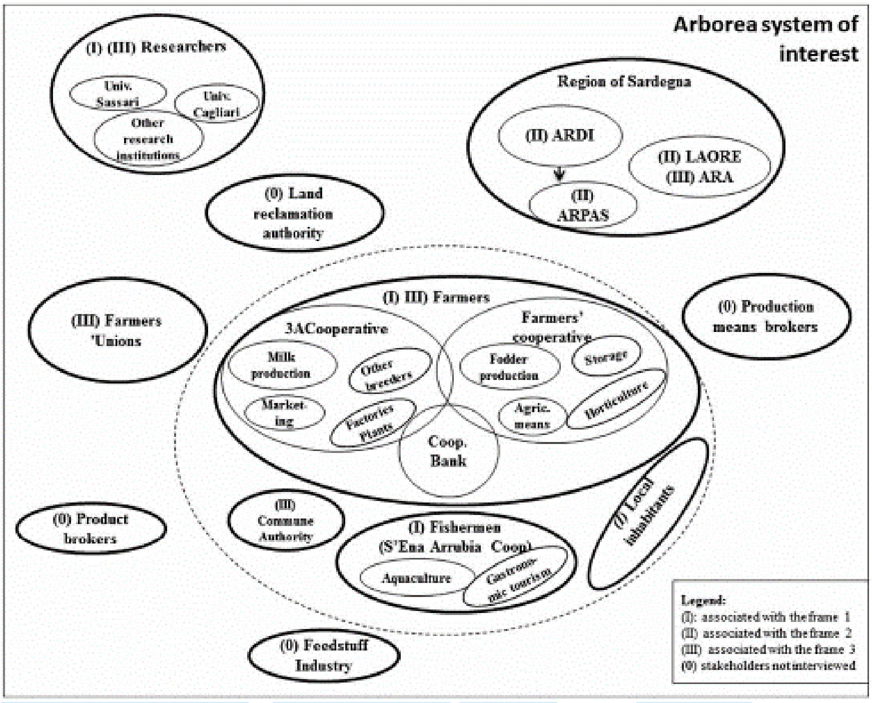



**Figure 33: Stakeholder map of the Arborea system (Nguyen et al., 2013)**

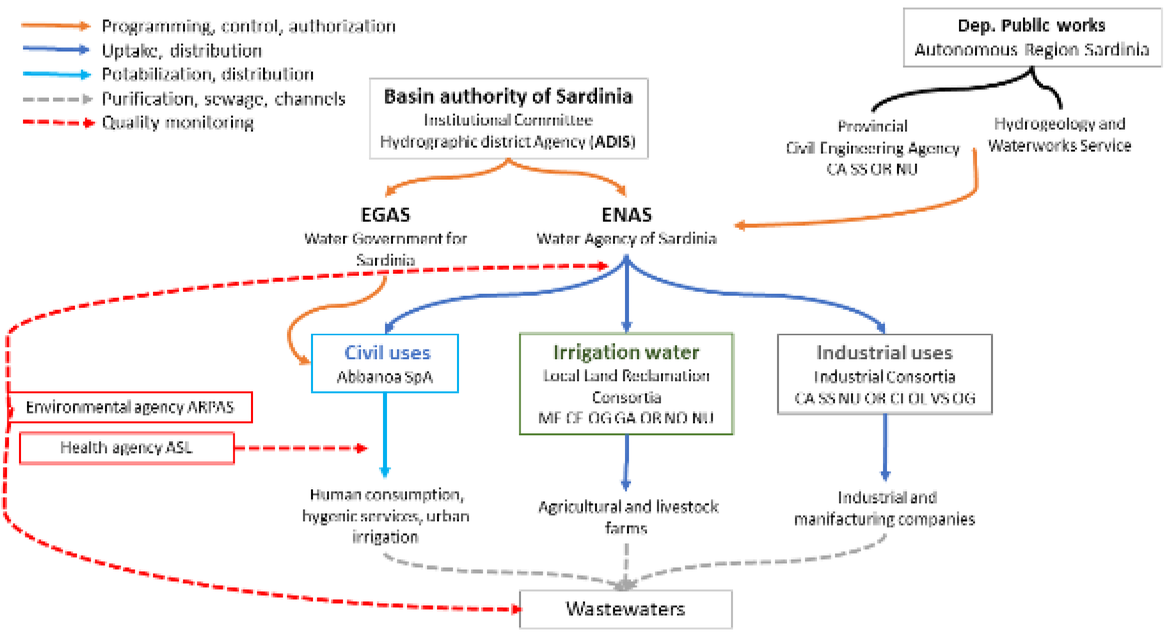



**Figure 34: Diagram illustrating the government of water in Sardinia (modified from Maurizi 2020)**

## *Identification of Sectors that Require Attention & Specific Challenges*

Sardinia is currently under infringement procedure because the nitrate concentration of groundwater in the nitrate vulnerable zone is not decreasing. This is threatening the EU funding in agriculture hence it is a major point of attention. At the moment ADIS is exploring for the Regional Government of Sardinia the request of the EU to set up some new NVZ in the island, following the outcomes of the monitoring made by ARPAS, revealing stable nitrate pollution of groundwater. The new zones also include an area south of Arborea.

UNISS is exploring with stakeholders a range of options to mitigate the N surplus in the Arborea plain, in the context of another two projects: (i) Interreg-MED Re-Live Waste, which is installing a plant to produce struvite from the liquid fraction of the digestate coming from a biogas digestor fed with animal effluents; (ii) MENAWARA, an ENI-CBC-MED project aiming at constructing a Forestry Infiltration Area south of Arborea in the context of a Managed Aquifer Recharge approach, using biologically purified non-conventional water (drainage water). In this context, SUSTAIN COAST will provide an ideal platform for stakeholders to explore these and other options to improve groundwater quality in this district.

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## ***Malia, Greece Case Study***

The catchment of Malia (Figure 35) is located in northern Crete, Greece, 34 km east of Heraklion and belongs to the Municipality of Hersonissos. Malia unit includes the villages of Mochos, Krasi, and Stalida, has a total land area of 60.72 km$^2$ with a population of 5,433.

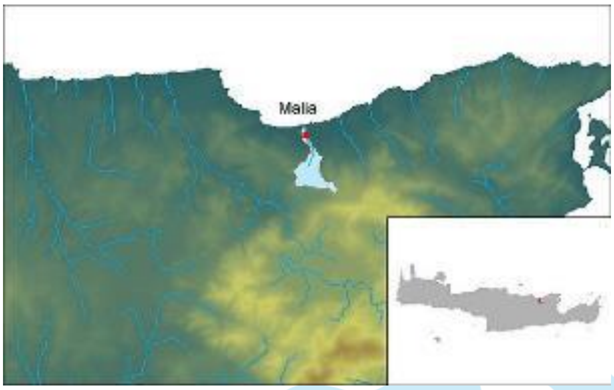



**Figure 35. Malia catchment belongs to Hersonissos Municipality.**

In recent years, Malia has experienced rapid tourism development and has become a well-known cosmopolitan tourist center in Crete, and generally in Europe. The fine sandy beach of Malia (Figure 36a) starts from the bottom of the strip and continues towards the east near to the Minoan Palace of King Sarpidon (Figure 36b), which is one of the three greatest Minoan palaces in Crete.

a.

b.

**Figure 36.Sandy beach (a) and Minoan Palace of King Sarpidon (b) in Malia.**

The residents are involved with olive cultivation as well as the cultivation of horticultural products, mainly potatoes and bananas in greenhouses. In the past, Malia was well known for its picturesque windmills, which provided water for the potato cultivation. Tourism and commerce are the main economic activities in the town.

The study catchment area of Sustain-COAST is 7.5 km$^2$, characterized by a gentle slope to the north of the town of Malia and by mountains to the south. The elevation varies from 0 to 200 m above mean sea level (amsl) over the coastal lowland and from 200 to 550 m amsl over the area south of the city of Malia and towards the south. The cultivated area of Malia is 1.75 km$^2$.

To the northeast, close to the archeological site of Malia Palace, there is located the beach Potamos, which is a significant area of 14.6 ha wetland (Fig. 37 a and b) with rare flora and fauna, where a small river flow. Malia natural wetland is recognized by the Greek Biotope/Wetland Center. It is covered by the water coming from the surface springs, in which the aquifer of the Selena Mountains exits to the surface, and through the spectacular river drains to the sea. The wetland today is a well-preserved coastal area, with a significant environmental value, since it enriches the aquifer, discharges groundwater, stabilizes the coastline from sea erosion and at the same time builds a firewall against salinization, thus preserving the arable land. Wetland reeds are an ideal refuge for several species of birds and animals, while several species of endangered coastal vegetation are also maintained there.

a. b.

**Figure 37. Natural wetland of Malia.**

### Stressors in Malia

Malia area has significant quality and quantity problems. Surface water and groundwater are used to support the extensive agricultural activity in the area (Fig. 38a), while the last 20 years the increased touristic development has raised significant water consumption demands (Fig. 38b).

a. b.


**Figure 38. Extensive agricultural activity (a) and increased touristic development (b) in Malia.**

The increased water demand has led to the depletion of groundwater level, causing extensive salt water intrusion of the aquifer, and subsequently the degradation of groundwater quality in the area. Therefore, high Cl- concentrations are found in groundwater which in conjunction with over-pumping result to low aquifer levels and groundwater degradation. In addition, increased nitrates concentrations are also found in groundwater due to the extensive agricultural activity in the area.

**Hydrogeological and hydrological setting**

The study area is characterized by a gentle slope to the north of the town of Malia and by mountains to the south. The elevation varies from 0-200 m over the coastal lowland and from 200-650 m over the area south of the city of Malia and near the city of Mohos. The mountainous terrain continues to the south of the model boundary reaching a maximum elevation of 1400 m over the Selena area.

The study area has no significant permanent flow rivers. Temporary flow streams are found on the mountainous area (Stena and Vitsilia) located outside the model domain.

The cultivated area of the Municipality of Malia is 1.75 $Km^2$. Sclerofyllous vegetation and complex cultivation patterns cover most of the study area. Other land uses include olive groves, natural grassland, non-irrigated arable land and a small area of discontinued urban fabric around the towns of Malia and Mohos.

The coastal karstic aquifer of Malia is developed in limestones of the Tripolis zone. Under these rocks, a series of alternating chloritic schistes, phyllites and quartzites belonging to the Phyllite-

Quartzite zone acts as the impermeable substrate of the extended region. The Tripolis series consists of faulted and karstified limestones, dolomites and calcareous dolomites (Jurassic-Critidic and Triassic-Jurassic) as shown in the geological map of Figure 3. The stratigraphy includes Neogene deposits that consist of bioclastic Messinian limestones and Quaternary clastic sediments. Along the coast, alluvial deposits and beach sand deposits are found (Quaternary deposits).

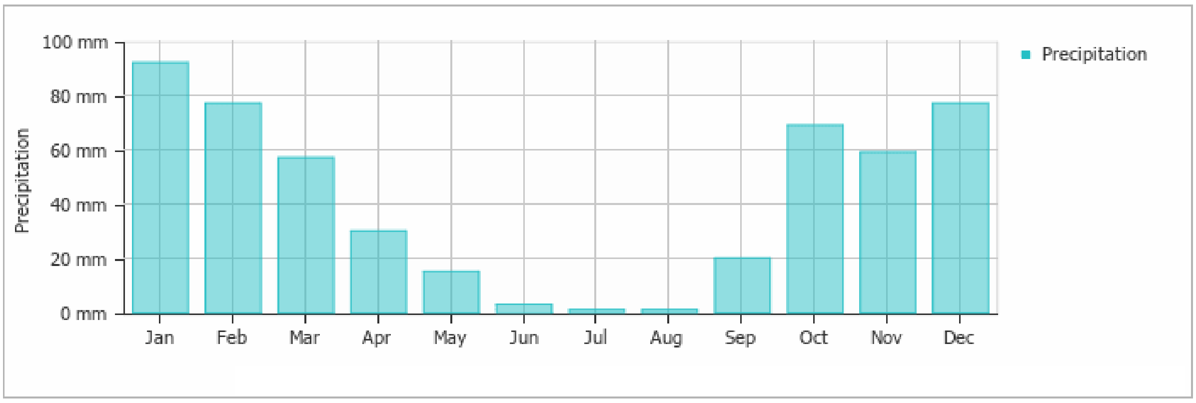
The rainfall distribution in the area was estimated so far using measurements from 3 meteorological stations (Neapolis, Avdou, Kasteli) located inside or very close to the study area and at elevations within the range of elevations encountered within the study area (280 m, 230 m and 340 m, respectively). The average rainfall from the three stations will be used as it provides a better representation of the conditions in the area than using the data from only one meteorological station.

## *Analysis of Surface-Water Related Data*

### Stream Flows

There are no streamflow data in the part of interest of the Malia case study

### Rainfall




- Average rainfall in Malia plain: 510 mm
- Average rainfall including the adjacent river basins: 1030 mm

### Temperature

The average temperature in the area of Malia is around 18.5 °C. The monthly variation is Presented in the following figure.

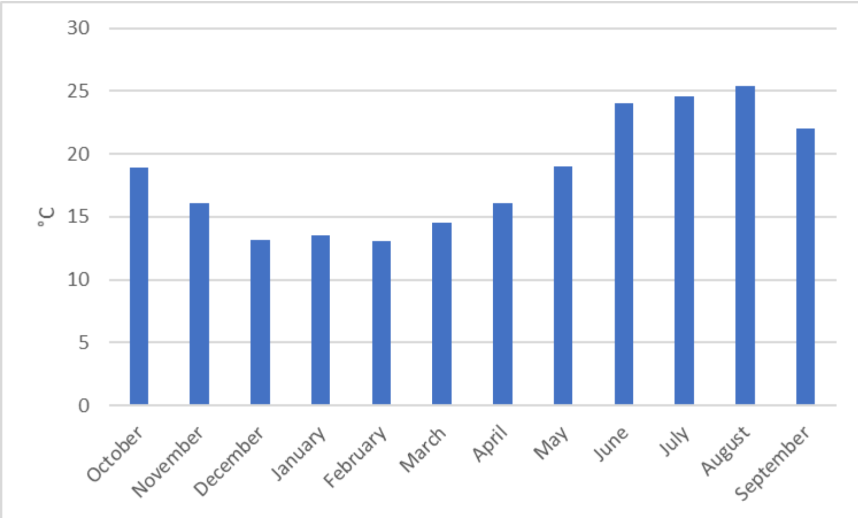



**Figure 39: Monthly temperature variation**

### Evapotranspiration

Estimation of mean values of evaporation in the study area was performed using data from the Kastelli meteorological station using various methodologies (Thornthwaite, Penman, Turk).

**Table 10: Monthly and seasonal distribution (%) of evapotranspiration**

| Month | Dec | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Percentage | 2.8 | 2.5 | 3.2 | 5.4 | 7.8 | 10.9 | 14.7 | 16.7 | 15.2 | 10.7 | 6.8 | 3.6 |
| Season | Winter | | | Spring | | | Summer | | | Autumn | | |
| Percentage | 8.5 | | | 24.1 | | | 46.58 | | | 21.08 | | |

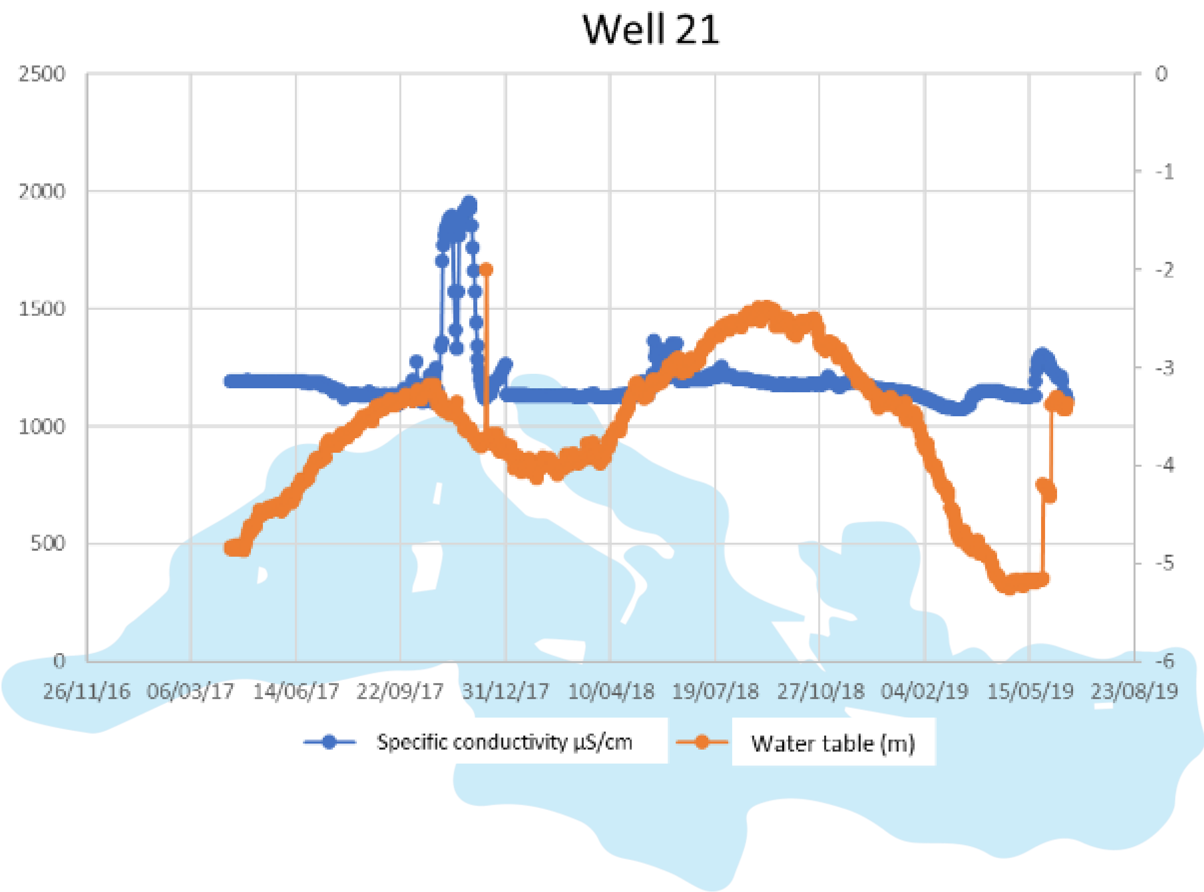
**Table 11: Mean evapotranspiration in mm**

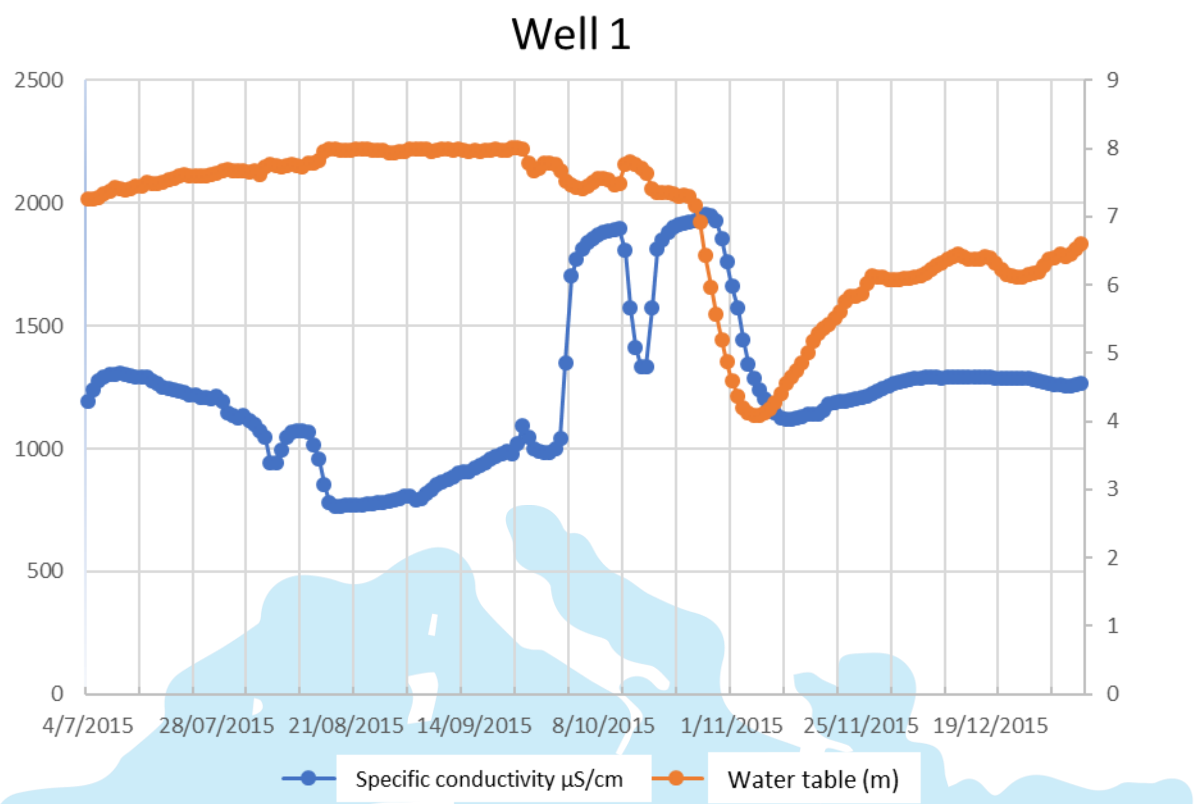
| Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 35 | 44 | 74 | 107 | 150 | 202 | 230 | 209 | 147 | 93 | 50 | 38 | 1376 |

- Potential evapotranspiration: 1376 mm

***Analysis of Groundwater Related Data***

**Hydraulic Head Levels**






- Well 21: multiuse (agricultural and touristic)
- Well 1: single use (agricultural)
- Major cultivation period (September-December / February-May)
- 280 Private pumping Wells: Irregular monitoring since 1981
- 2 Public wells daily monitoring
- 18 Drinking water wells: regular monitoring since 2004
- Monitoring of groundwater level, qualitative parameters and pumping rates

**Infiltration**

Infiltration represents the part of rainfall that penetrates the ground surface and reaches the groundwater. It depends on the soil moisture, lithology, slope, vegetation etc. For the estimation of the infiltration coefficient (percentage of rainfall that represents infiltration) for each geological formation, typical values from the literature were used in order to provide estimates for the study area (Table 12). These estimates were provided by Kallergis et al. (2000) in their hydrological report of the Malia region and are representative of the study area. The response time it takes for rainfall to reach the water table is in the order of a few days, according to previous studies.

**Table 12: Infiltration coefficient for different geologic formations of the area**

| Geologic formation | Limestones | Neogenic sediments | Quaternary deposits |
|---|---|---|---|
| Infiltration coefficient (%) | 44 | 21.5 | 15 |

**Pumping Rates**

The shallow well depth varies between 2-20 m and their average pumping rate is 15-20 $m^3$/h. Detailed information regarding the elevation, pumping rate, chloride concentration and hydraulic head of the wells (shallow and deep) is summarized in following Table 13.

**Table 13: Available information for the wells in the study area**

| Name | Elevation (m) | Pumping rate ($m^3$/h) | Average Hydraulic Head (m) | Average $Cl^-$ (mg/l) |
|---|---|---|---|---|
| **G.M.A.1** | 77.35 | 65 | 2.75 | 533 |
| **G.M.A.2** | 88.66 | 100 | no piezometer | |
| **G.M.A.3** | 108.34 | 60 | 4.84 | 43 |
| **G.M.A.4** | 194.61 | 20 | 9.11 | |
| **G.M.A.5** | 151.34 | 40 | broken piezometer | 54 |
| **G.M.A.6** | 152.7 | 54 | 3.3 | 174 |
| **G.M.A.7** | 172.07 | 40 | -2.93 | 57 |
| **G.M.A.8** | 194.13 | 30 | 2.73 | 60 |
| **G.S.T. 8** | 92.08 | 11 | 5.08 | 525 |

| | | | | |
|---|---|---|---|---|
| **G.S.T. 9** | 157.18 | 12 | 4.68 | 88 |
| **G.S.T.10** | 144.62 | | 11.12 | |
| **G.S.T.11** | 150.73 | 23 | broken piezometer | 1489 |
| **G.S.T.12** | 150.31 | 32 | 3.31 | 652 |
| **G.S.T.13** | 150.45 | 13 | 3.95 | |
| **G.MO.24** | 382 | 30 | 13 | 44 |
| **N1** | 44.00 | 50 | 4.00 | 420 |
| **N2** | 50.00 | 60 | 6.40 | 10 |
| **N3A** | 53.73 | 60 | 4.10 | 5 |
| **N3B** | 47.50 | 60 | -3.00 | 220 |
| **N4** | 58.00 | 60 | 5.10 | 5 |
| **N5** | 53.72 | 50 | 5.90 | 180 |
| **N6** | 52.14 | 60 | 10.10 | 310 |
| **N8** | 85.59 | 85 | -4.00 | 5 |
| **N9** | 91.20 | 10 | 12.10 | 5 |
| **D42** | 94.11 | 10 | -3.13 | 135 |
| **D66** | 75.45 | 50 | -0.47 | 152 |
| **B. 1** | 29.38 | 50 | | 854 |
| **B. 7** | 38.77 | 40 | | 390 |
| **B. 5** | 38.87 | 40 | -1.13 | 416 |
| **B. 6** | 46.70 | 40 | | 184 |
| **B. 9** | 72.16 | 70 | | 1585 |
| **B.14** | 59.83 | | | |

| | | | | |
|---|---|---|---|---|
| **B.15** | 59.50 | | | |
| **B.16** | 74.55 | 50 | | 376 |
| **B.17** | 80.00 | 60 | | 101 |
| **B.18** | 53.32 | 40 | | 29 |
| **B.19** | 66.59 | | | |
| **B.23** | 80.00 | | | |
| **B.27** | 80.00 | | 4.10 | 49 |
| **B.26** | 115.20 | | | |
| **B.25** | 40.03 | | | |
| **B.34** | 60.02 | | | |
| **W1** | 30.58 | 40 | | 285 |
| **W4** | 18.75 | 25 | 5.75 | |
| **W5** | 20.32 | 25 | 7.32 | 552 |
| **W9** | 10.58 | 20 | 2.58 | |
| **W11** | 8.58 | 15 | 0.58 | |
| **W12** | 15.81 | 20 | 0 | 423 |
| **W13** | 15.92 | 15 | 4.82 | |
| **W14** | 20 | 40 | 8.15 | |
| **W16** | 20.22 | 20 | | 319 |
| **W17** | 6.87 | 15 | 4.27 | |
| **W21** | 8.54 | 15 | 1.14 | |
| **W26** | 18.48 | 20 | 6.78 | |
| **W27** | 20.02 | 25 | | |

| | | | | |
|---|---|---|---|---|
| **W35** | 0.59 | 15 | -5.21 | |
| **W36** | 2.09 | 20 | -6.11 | |
| **W46** | 16.52 | 20 | 4.72 | 132 |
| **W51** | 16.6 | 20 | 7.7 | |
| **W53** | 15.03 | 20 | 5.83 | 141 |
| **W56** | 8.95 | 20 | 3.35 | |
| **W60** | 14.65 | 30 | 6.45 | |
| **W67** | 13.69 | 30 | 3.49 | 208 |
| **W69** | 9.16 | 15 | 3.46 | |
| **W72** | 3.36 | 20 | 1.66 | |
| **W79** | 5.21 | 20 | 0.81 | |
| **W84** | 13.28 | 30 | | 135 |
| **W85** | 11.79 | 30 | 0.59 | |
| **W90** | 3.03 | 0 | -1.47 | |
| **W91** | 2.18 | 20 | -1.52 | |
| **W102** | 10.72 | 15 | 7.92 | |
| **W103** | 11.18 | 15 | 8.68 | |
| **W108** | 6.3 | 20 | | |
| **W109** | 2.48 | 15 | 1.08 | |
| **W111** | 14.66 | 100 | 11.46 | |
| **W113** | 16 | 20 | 8.9 | 120 |
| **W115** | 25.83 | 20 | 9.73 | 393 |
| **W116** | 22.32 | 25 | 8.32 | |

| | | | | |
|---|---|---|---|---|
| **W119** | 11.33 | 30 | 3.53 | |
| **W122** | 15.03 | 25 | 2.93 | |
| **W123** | 21.02 | 25 | 5.72 | |
| **W124** | 22.39 | 25 | 6.49 | |
| **W126** | 19.05 | 20 | 8.55 | |
| **W127** | 22.59 | 20 | 1.24 | |
| **W130** | 17.86 | 20 | 7.76 | |
| **W131** | 15.4 | 20 | 2.9 | |
| **W133** | 26.89 | 20 | 6.64 | |
| **W136** | 18.26 | 20 | -0.14 | 107 |
| **W138** | 18.09 | 20 | 0.59 | |
| **W140** | 36.45 | 30 | 11.75 | 126 |
| **W142** | 28.43 | 0 | 3.13 | |
| **W143** | 33.38 | 30 | 2.58 | 134 |
| **W145** | 37.28 | 40 | | 265 |
| **W146** | 40 | 40 | | |

## ***Relevant Water Quality Data***

| Drinking water analysis | Specific Conductivity µS/cm | Hardness French Degrees (°f) | Total | | (e.g. Cl-) mg/l | Alkalinity (CaCO3) mg/l | Bicarbonate (e.g. HCO3-) mg/l | Sulfates ($SO_4^{=}$) mg/l | Nitrates (e.g. NO3-) mg/l | Nitrite (e.g. NO2-) mg/l | Ammonium (e.g. NH4+) mg/l | Calcium (e.g. Ca++) mg/l | Magnesium (e.g. Mg++) mg/l | Potassium (e.g. K) mg/l | Sodium (e.g. Na) mg/l |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Limit | 2500 | | | | 250 | | | 250 | 50 | 0.5 | 0.5 | | | 12 | 200 |
| Average | 883.30 | | 17.78 | | 184.26 | 178.36 | 216.20 | 41.08 | 7.25 | 0.02 | 0.17 | 82.56 | 21.50 | 2.72 | 90.76 |
| Min | 260.00 | | 11.25 | | 14.53 | 123.00 | 137.30 | 10.60 | 0.02 | 0.00 | 0.00 | 5.85 | 0.77 | 0.47 | 0.21 |
| Max | 4,440.00 | | 36.00 | | 1,489.00 | 323.00 | 439.34 | 359.00 | 30.20 | 0.42 | 2.41 | 191.00 | 98.00 | 31.80 | 719.00 |

| Drinking water analysis | Ferrous e.g. Fe++) mg/l | Residual chlorine mg/l | Total colloids colonies/100 ml | E.coli | Enterococcus | OMX 37°C colonies/ml | OMX 22°C | Aluminium Al µg/l | Boron B µg/l | Bromate Br mg/l | Fluorine F mg/l | Turbidity NTU | PH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Limit | 0.2 | | 0 | 0 | 0 | | | 200 | 1000 | 1.5 | | 1 | 6,5-9,5 |
| Average | 1.03 | <0,05 | <1 | <1 | <1 | 29.28 | 30.45 | 104.00 | 128.13 | 0.77 | 0.07 | 12.79 | 7.54 |
| Min | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.00 | 1.00 | 53.00 | 31.00 | 0.20 | 0.05 | 0.16 | 6.86 |
| Max | 18.90 | 0.05 | 61.00 | 38.00 | 27.00 | 238.00 | 193.00 | 155.00 | 483.00 | 2.02 | 0.08 | 398.00 | 8.00 |

## ***Water Quality Status***

**Surface Water**

There are no significant streams in the area, having surface flow for long periods of time. Small streams in the area, only transfer the excess water from high intensity rainfall events.

**Groundwater Resources**

The study area includes four (4) Underground Water Systems, as defined in the 1st Revision of the RBMP of Crete (http://wfdgis.ypeka.gr/).

a) EL1300072 (Porous Coastal North Heraklion), characterized by poor quantitative and chemical status. There is a point of the National Monitoring Network in the area (Malia). Probably monitored by the former IGME, now EAGME.

b) EL1300112 (Malia-Selena Karstic), characterized by good quantitative and chemical status. There are two points of the National Monitoring Network in the region, of which only one falls into the area of interest.

c) EL1300240 (Dikti Karstic), characterized by good quantitative and chemical status. There is a point of the National Monitoring Network in the area (Potamies), about which I do not know details.

d) EL1300312 (Heraklion Coastal Heraklion-Gouvon-Hersonissos), which is characterized by poor quantitative and chemical status (over-pumping and salinization). There is a point of the National Monitoring Network in the area (near the refinery unit of Aposelemi), about which I do not know details. It may be related to the monitoring of the dam's waters.

For the period 2005-2009, the Decentralized Administration had installed and monitored a station in Malia with coordinates (EGSA 87) x = 632,620 and y = 3,904,400. Today, this station does not work.

A well in Malia, previously used as a measurement point, is found at (EGSA 87) x = 633,720.78 and y = 3,906,093.58.

## ***Governance System Description***

The Municipality of Hersonissos is responsible for providing drinking water to the whole area and part of the agricultural water, through its dedicated company (DEYAH).

A nearby dam of Aposelemis is managed by the Development Organization of Crete (OAK) and can provide water for multiple purposes. Since the dam is quite new, it has not been extensively used for providing water to our area of study.

**List of Malia stakeholders**

- Hersonissos Municipality
- Decentralized Administration of Crete, Directorate of Water Resources
- Region of Crete, Directorate of Development, Environment and Infrastructure
- Organization for the Development of Crete S.A.
- F.O.D.S.A. Local Government Association, Operator for solid waste treatment and management in Voreia Pediada
- Water Supply and Sewerage Municipal Company of Malia, Hersonisos
- Social Ecological Cultural Network Associations of Hersonissos Municipality (KOIPODI)
- WWF, Volunteer Environmental Forum in Crete, Greece
- Environmental Ecological Association of Malia (Potamos)
- SARPIDONISTAS, Volunteer Environmental Forum in Crete
- Association for Development and Environment, Gournes
- Farmers Association of Malia
- Hoteliers Association of Heraklion (Hersonissos-Malia)

## ***Identification of Sectors that Require Attention & Specific Challenges***

**Sustain-COAST Scope in Malia**

- Extended and significant monitoring networks – improvement of regular monitoring
- Salt water intrusion study and groundwater flow modelling (FEFLOW)
- Towards pollution reduction in groundwater bodies
- Towards solutions to improve water quality and quantity
- Available water resources infrastructure can guarantee groundwater improvement
- Cost-benefit analysis to improve water resources management
- Governance and policy initiatives are necessary to reverse current conditions

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