Innovative and Sustainable Groundwater Management in the Mediterranean

D 5.1: Report on Site Characterization and Hot Spot Identification

VERSION 1.0

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Executive Summary

The overall objective of the InTheMED project is to implement innovative and sustainable management tools and remediation strategies for MED aquifers (inland and coastal) in order to mitigate anthropogenic and climate-change threats by creating new long-lasting spaces of social learning among different interdependent stakeholders, NGOs, and scientific researchers in five field case studies. These are located at the two shores of the MED basin, namely in Spain, Greece, Portugal, Tunisia, and Turkey. InTheMED will develop an inclusive process that will establish an ensemble of innovative assessment and management tools and methodologies including a high-resolution monitoring approach, smart modelling, a socio-economic assessment, web-based decision support systems (DSS) and new configurations for governance to validate efficient and sustainable integrated groundwater management in the MED considering both the quantitative and qualitative aspects.

The current document presents a report on the five case studies characterization. The scientific team in this document collected and analysed all the available data for the demo sites in Tunisia, Portugal, Spain, Greece and Turkey and made an assessment on how the real situation is in each site.

All five sites are investigated through a detailed SWOT analysis to identify the main groundwater problems, hotspots and key stakeholders, which are needed in WP2 (Task 2.1) and WP4 (Task 4.1).

D5.1 highlighted the main issues such as water supplies, wastewater production, stream flows, rainfall, groundwater levels, pumping rates, water threats, hotposts needing immediate intervention and summarize the status of the aquifer

The deliverable 5.1 aims to help the setup of the best monitoring strategy for each case study using the HRMA, which will be carried out in Task 2.1 (WP2).

1. Introduction

The objective is to present a detailed characterization of the 5 real sites.

Each scientific team, in this deliverable, collects and analyses all the available data for the proposed sites in Spain, Portugal, Tunisia, Greece and Turkey and performed a SWOT analysis to identify the main problems related to remediation strategies in each site.

This document collects and analyses all the available data consisting of aquifer description (hydraulic levels, pumping rates, quality and pollution…..) and surface water (rainfall, temperature, climate change and activities related to groundwater situation (hotspots points, water quality status). Furthermore, a focus on the governance schema on groundwater uses will be presented.

2. Objective

The objective is to identify and select prevention, remediation and mitigation options in order to reduce groundwater degradation and optimize its sustainable use considering the local context of each case study.

3. Cases Studies Description

The main characteristics of the five 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 30 to 62000 km², the population from 7 276 to 3 000 000 people, while mean annual precipitation ranges from 356,5 to 567 mm and mean annual temperature from 12 to 22 °C. Table 1: Coastal aquifer where the integrated social learning processes in the InTheMED project will be developed.

The table 1 summarises the main global characteristics for the 5 cases study.

Table 1. Cases Studies Characteristics

Characteristics	Requena-Utiel, Spain	Tympaki, Greece	Castro Verde, Portugal	Grombalia, Tunisia	Konya, Turkey
Size (km^2)	1360	55	30	363	62000
Population	30,000	25,000	7,276	201,836	~3,000,000
Location	Inland	Coastal	Inland	Coastal	Inland
Mean P &T ($mm\ y^{-1}$/ºC)	440/13	500/15	567/16	356,5/22	387/12
Principal groundwater users	Agriculture, urban	Agriculture	Urban, mining	Agriculture, industry, tourism	Agriculture, urban
Overexploited	Yes	Yes	No	Yes	Yes
Groundwater pollution	No	Nitrate, salinity	Mine wastes	Nitrate, salinity	Nitrate, salinity

3.1. Grombalia, Tunisia Case Study

3.1.1. Biophysical Attributes

The Grombalia region is located in south-western part of the Cap Bon Peninsula (Tunisia) and covers a surface of about 363 km^2, and brings together several urban agglomerations including Soliman, Bou Argoub, Grombalia, Beni Khalled and Menzel Bouzelfa. The basin is bordered by the Gulf of Tunis (N), the Takelsa Syncline (N-E), the anticlinal of the Abderrahmane Mountain and the oriental coastal plain (E), the plain of Hammamet (S) and the Bouchoucha and Halloufa reliefs (W) (Fig. 1).

Figure 1. Georaphic location of Grombalia Region, Tunisia (Google earth credit)

3.1.1.1. Climate

The long-term average annual rainfall ranges between 356 and 536 mm (INM, 1985 -2005). Grombalia plain is characterized by a semi-arid to sub-humid Mediterranean climate with an average annual precipitation of 492 mm as based on more than 50 years of rainfall records of 10 rain gauge stations. About 80% of this precipitation occurs between September and March, followed by dry spring and summer months. Autumn and winter are the wettest period with 200 mm on average. Spring comes in second with an average rainfall of 100 mm. Summer is dry with an average of 20 mm (IAEA). The annual average temperature is about 19 °C. The summer season is characterized by relatively high temperatures with a peak recorded in July with 27.16° C as average. The minimum temperatures are recorded during the winter season. Indeed, the lowest temperatures are observed in February with 11.42 ° C as average and potential evapotranspiration can reach 1500 mm resulting in an annual average deficit of 1000mm.

During the period 1989-2005, the evaporation values which are recorded at the Nabeul station show that evaporation reached its maximum in July (185 mm) and its minimum in December

(35 mm). On a seasonal scale, the potential evapotranspiration is greater in summer, with an average of 172 mm, while in winter it is minimal with 50 mm (IAEA).

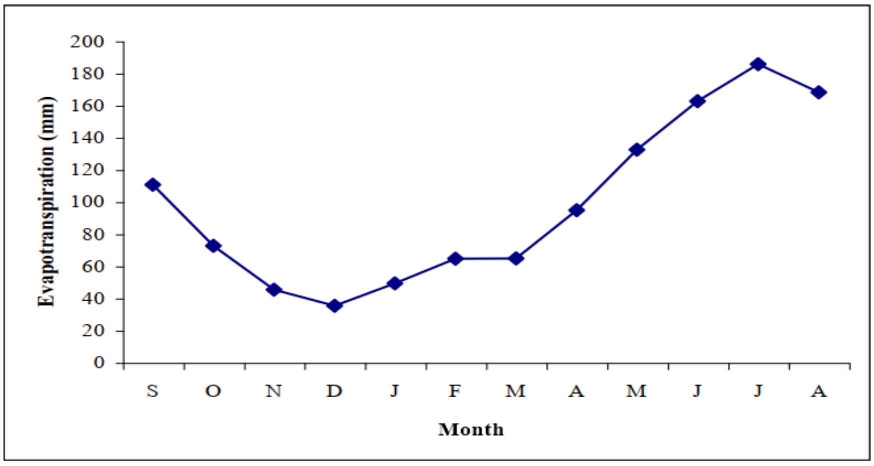


Figure 2. Average monthly evapotranspiration at the Nabeul station (1989-2005) (IAEA)

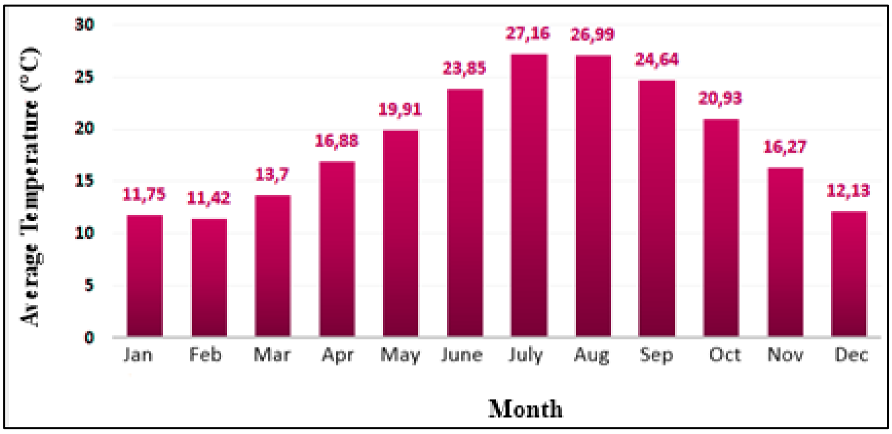


Figure 3. Average monthly temperature variation at Beni Khalled station (2008-2018)

3.1.1.2. Hydrological Context

The Cap Bon region is a basin-oriented NW-SE and filled with Quaternary sediments whose edges were linked to two normal faults that appeared in the Middle Miocene (Hadj Sassi et al., 2006; Charfi et al., 2013). It is formed by a series of Quaternary, marine and continental terraces. Quaternary detrital sedimentation mainly consists of fine coarse-grained sands, clay sands, sandstones, silt and abundant evaporated deposits (Schoeller, 1939; Colleuil, 1976; Ben Salem, 1995; Ben Moussa et al., 2010; Charfi et al., 2013).

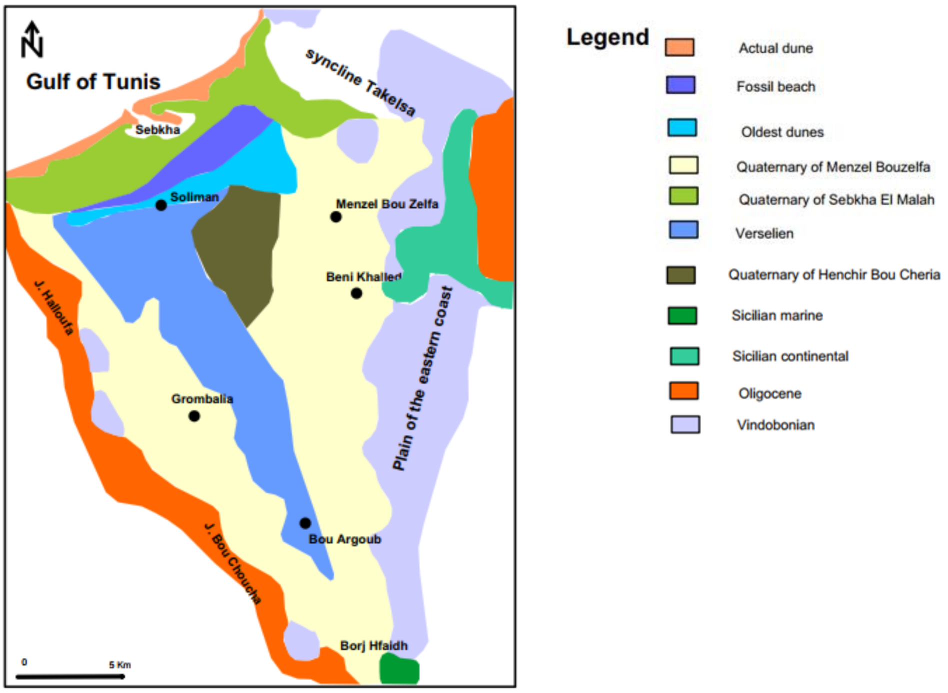


Figure 4. Geological Map of the plain Grombalia[2] (Source: Charfi et al., 2013 according to Castany, 1948)

The aquifer system of the Grombalia plain has three layers. The first is the shallow aquifer, with an average of about 50 m depth, it communicates with a semi-deep aquifer exploited by drilling less than 100 meters deep and a deep aquifer operated up to 200 meters deep (Ennabli, 1980).

The average thickness of the phreatic aquifer of Grombalia which is located in a Plio-Quaternary sedimentary fill is about 25 meters (Hamza et al., 2010).

The deep aquifer is composed of the Mio-Plio-Quaternary (Segui Formation), Miocene (Beglia Formation), and Oligocene series. The Mio-Plio-Quaternary is characterized by lithological and geometric complexities and it is formed by intercalation of sand, sandy clay and clay deposits (Lachaal et al., 2016).

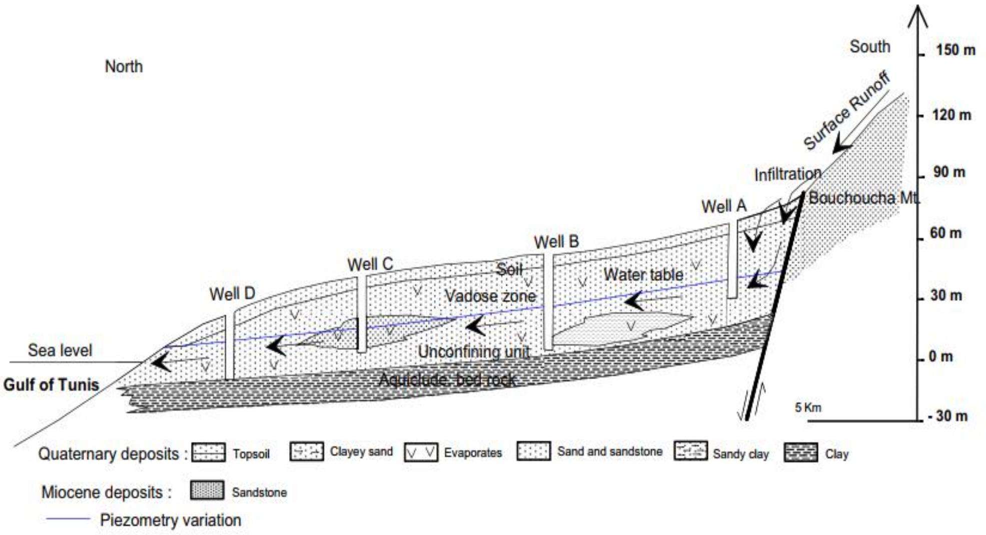


Figure 5. Hydrogeological cross section of the Grombalia aquifer (Ben Moussa et al., 2010)

The main rivers crossing the study area are Wadi Defla, Wadi El Jorf, Wadi Sidi Saïd, Wadi Belli, Wadi Tahouna, Wadi Bezirk and Wadi El-Bey (Hamza et al., 2010) which is the main Wadi in the hydrological system in the study area. It is 35 to 40 km in length.

The water flows from Wadi Masri and Wadi Tahouna passing through Wadi el Melah until arriving at the starting point of Wadi el Bey. The water continues to flow from this point and finally arrives at Sebkha El Melah, the outlet, which is a flooded wetland with an overall area of approximately 225 hectares. The Sebkha is in the southwest of the Cap Bon peninsula (Nabeul governorate), on the border of the governorate of Ben Arous and east of Soliman Plage (Mhamdi et al., 2017). The indirect contributions of the sebkha are made by tide action. The Sebkha exchanges a daily flow of 90,000 m3 per day (MEDD, 2008).

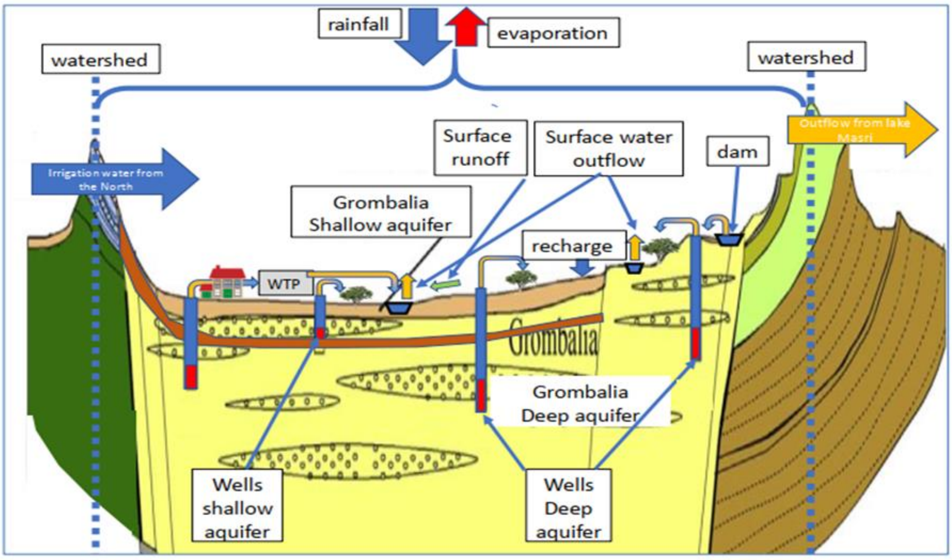


Figure 6. Hydrogeological cycle of the Grombalia watershed zone (SWIM & H2020 SM)

3.1.1.3. Aquifer Characteristics

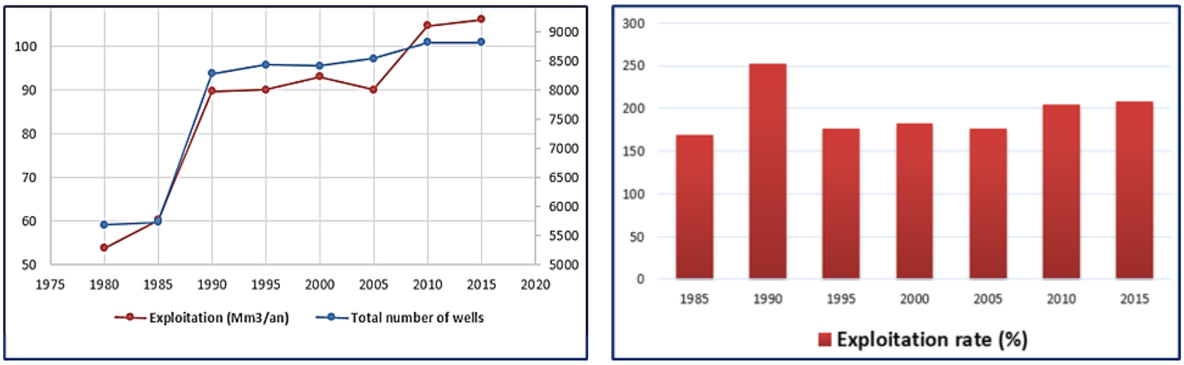
- Pumping Rates

This aquifer represents the principal source of water supply. In 2009, the annual exploitation in the region was estimated at 250 Mm3/year. The general direction of groundwater flow is toward the Gulf of Tunis from the relief of Jebel Abderrahman, Bouchouchaand Halloufa.

An increasing trend was recorded in the quantities of water withdrawn from the shallow and deep aquifer. In 2014, the phreatic aquifer was exploited from 94% of all wells and only 6% of these wells were installed in deep aquifer (Slama et al., 2020).

- Shallow Aquifer

The abstracted water volume has increased from 53.8 to 106 Mm3.y-1 comparing 1980 to 2015 (DGRE, 1980, 2015). The renewable resources of the phreatic aquifer of Grombalia was 35.7 Mm3.y-1 in 1985 against 51 Mm3.y-1 in 2015. The water balance deficit is estimated at about 55Mm3. Furthermore, the frequency of pumping wells has increased sharply from 5, 689 in 1980 to 8, 814 in 2015 (Figure 7) whereas the number of equipped wells has increased from 4, 675 to 6, 910 for the same period (Table 1). These wells fail to meet the irrigation water requirements (Chenini et al.2015).



(a) (b)

Figure 7. (a) Evolution of the exploitation and the number of wells of the Grombalia water table (b) Exploitation rate of Grombalia phreatic aquifer

Table 2. Evolution of the number of wells, exploitation and estimated renewable resources of the Grombalia water table (DGRE, 2015)

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

- Deep Aquifer

The exploitation of deep aquifer has increased from 2.16 Mm3/year in 1990 to 20 Mm3/year in 2012 (Figure 8) which can be explained by the increase in the number of pumping wells from 62 in 1989 to 526 in 2012 (Lachaal, 2016).

Agricultural and industrial activities in the study region use significant quantities of water which is extracted mainly from the deep groundwater. Indeed, the farmers use deep aquifer in citrus irrigation especially in Beni Khalled, Menzel Bouzelfa, and Soliman regions because of its good quality. In the industrial sector, a volume of 613,194 m3/year was pumped from 9 wells from the deep groundwater in 2012 (Lachaal, 2016).

The deep aquifer is used also for potable water with about 1.2% of all wells (Shallow and deep) used for this purpose.

600 wells are the total number of illegal wells installed until the end of 2017 estimated by the DGRE with an average annual volume of 6000 m3/well (Slama et al., 2020).

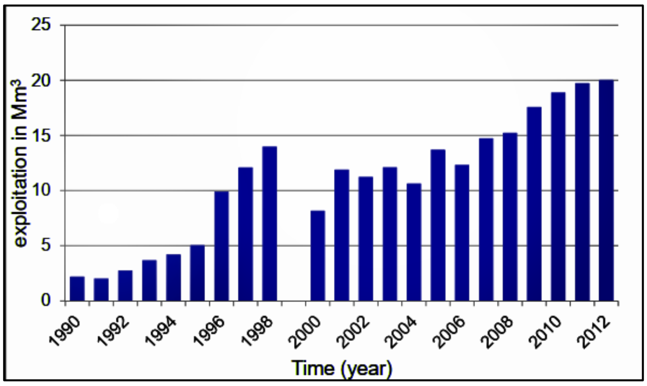


Figure 8. Evolution of Grombalia deep aquifer abstraction during 1989-2013 period (Lachaal et al., 2016)

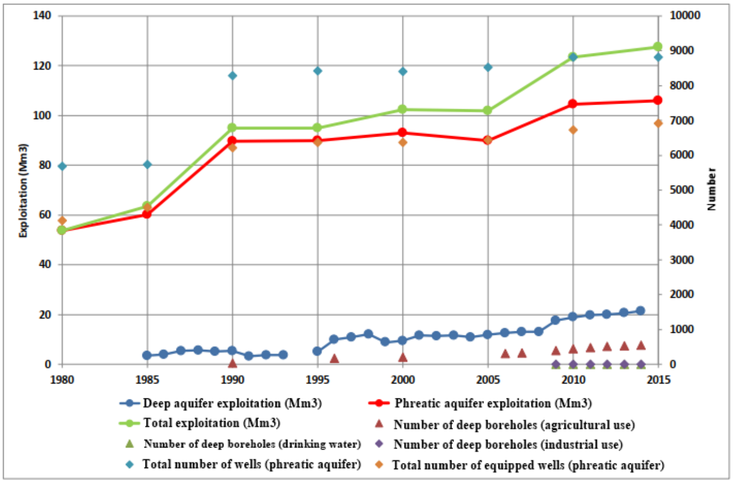


Figure 9. Exploitation of the phreatic and deep groundwater from 1980 to 2015 (SWIM & H2020 SM)

- <u>Hydraulic Head Levels</u>

Castany established the first piezometric map for the study area in 1948 (Castany, 1948). This map shows a piezometric level varying between 10 and 60 m and a flow diverging from the aquifer limit to Sebkhat El Maleh and to the Mediterranean Sea. The water flow is mainly from the south-east to the north-west.

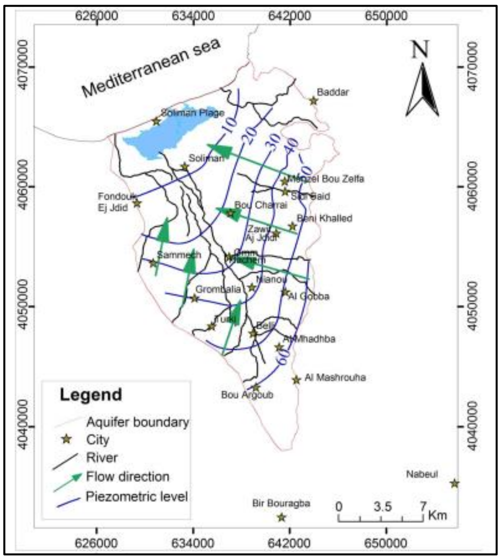


Figure 10. Piezometric head of shallow aquifer of Grombalia in 1948

In 2012, the value of piezometric level decline was 10 m. (Charfi et al., 2013).

Fig.11 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 a 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).

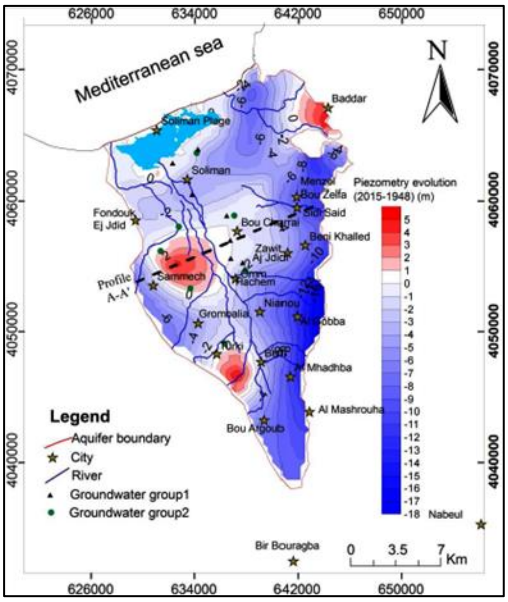


Figure 11. Piezometric difference between 1948 and 2015

In 1972, the average level of phreatic groundwater was + 10.1m. In 1975 and 1992 this level also dropped to + 7.1m. After these years, the groundwater level has recovered within a few years. (SWIM & H2020 SM, 2019)

Since 1992 and according to (Lachaal et al., 2016), the groundwater has risen-up to within two meters of the ground surface, causing agricultural, environmental, and economic problems linked to suffocation of plants, trees and crops. The increase of water level is correlated to both deep groundwater pumping and the use of North-West water for irrigation (Lachaal et al., 2016).

- <u>Quality and Pollution</u>

- Groundwater Salinization

The combination of excess irrigation with over-fertilization has led to deleterious effects on the environment through water contamination and increased Grombalia groundwater salinity. The TDS values of groundwater range from 0.75 to 5.6 g/l (Charfi et al., 2013).

(Slama et al., 2020) reveals that the dominance of Cl^-, SO_4^{2-}, Na^+, and Ca^{2+} controls the hydrochemistry of the shallow aquifer. The high salinization of Sebkhet El Maleh, leaching of hydromorphic soil layers, anthropogenic implications, seawater intrusion, and the upward leakage of highly saline water can explain the distribution of concentration rates (Figure 12).

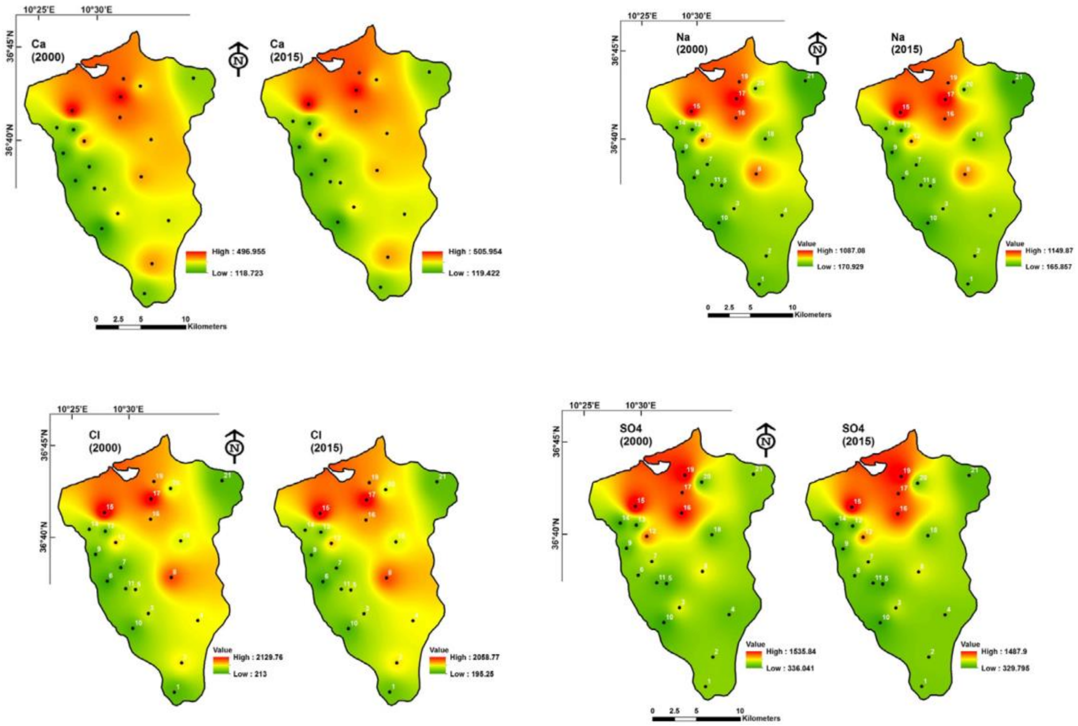


Figure 12. Spatial distribution of major ions in GB aquifer during 2000 and 2015. Concentration values are in mg/L (Slama et al., 2020)

The spatio-temporal variations (200-2015) of SAR (Sodium adsorption ratio), TDS (Total dissolved solids) and SSP (Soluble-sodium percentage), which allow us to evaluate the suitability of water for irrigation, indicates that the most suitable water for irrigation are about 23.8% for the entire investigated aquifer and in the western part (Slama et al., 2020).

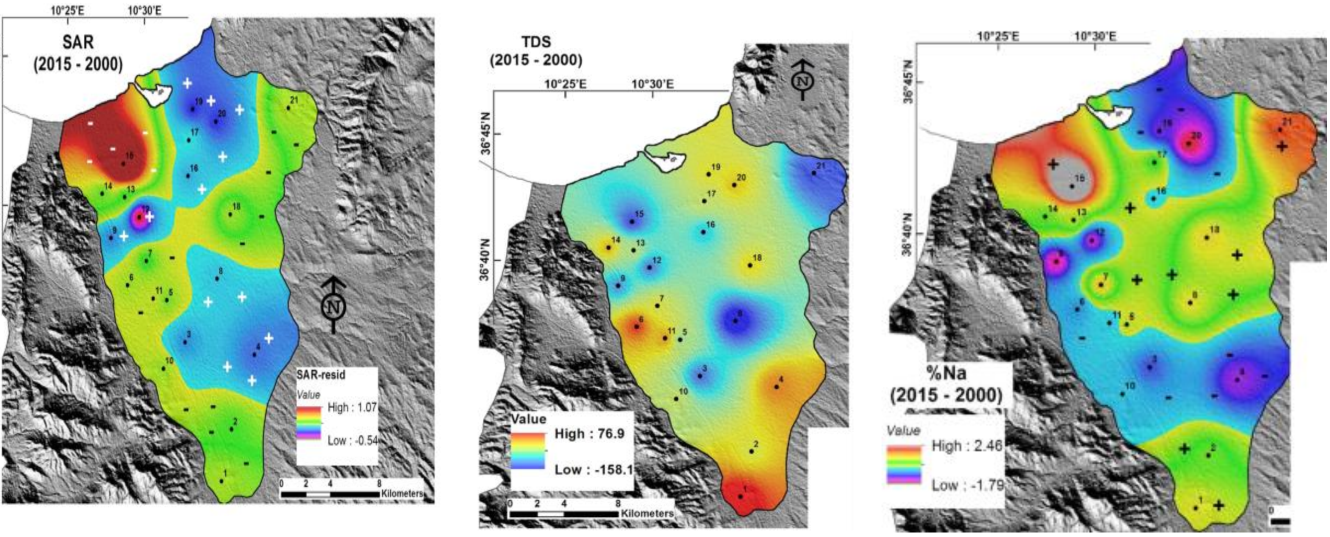


Figure 13. Geospatial distribution of SAR, TDS and SSP values during 2000 and 2015 campaigns (Slama et al., 2020)

- *Groundwater Nitrate Contamination*

According to WHO standards (WHO, 2017), 50 mg/L is defined as the nitrate concentration threshold for drinking water. However, the average nitrate concentration of Grombalia groundwater is about 138.69 mg/L which is higher than the above threshold value (Lachaal et al., 2016).

On the other hand, the deep aquifer is less polluted by nitrate than the shallow aquifer with nitrate concentrations ranging between 7.3 and 38.5 mg/L (Lachaal et al., 2016) which remained well below the WHO limit.

Indeed, the shallow aquifer is more likely exposed to the anthropogenic activities compared to the deep aquifer and then to the contamination which due mainly to the use of fertilizers in agricultural activities which have intensified in the area between Grombalia, Soliman, Beni Khalled, and Menzel BouZelfa (Lachaal et al., 2016).

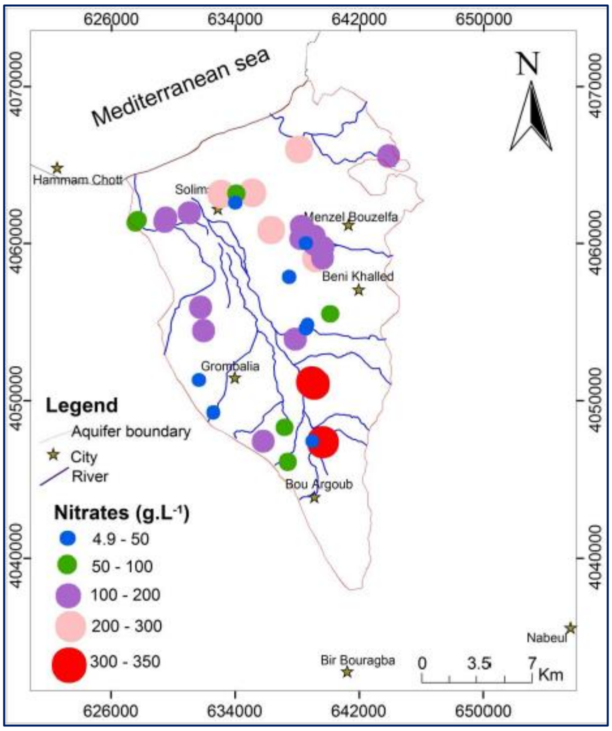


Figure 14. Spatial distribution of nitrate in the Grombalia aquifer (Lachaal et al., 2016)

Several factors influence the hydro chemical system of the Grombalia aquifer. Indeed, the northern part of the aquifer is impacted mainly by the coastal-Sebkha natural system. However, the hydrographic network and the principal rivers play an active hydrochemical regulation role in the western region. And not forgetting the impact of cation/anion exchanges as well as reverse transfers in the aquifer for the maintenance of the hydrological system (Slama et al., 2020).

3.1.1.4. Land Use

The Grombalia basin is principally dominated by citrus, vines, grain, and vegetable crops.

In the Beni Khalled and Menzel Bouzelfa regions 77% of the irrigated areas are intended for citrus cultivation. The latter has an important economical income to the region since it accounts for more than 78% of the citrus production at the national level (Lakani, 2014).

At the Grombalia city, the most farmed crops are cereals and olive trees with minor vines and citrus whereas in the region of Bou Argoub, the irrigated area is occupied by citrus, vineyards and olive trees.

In 2014, the Safeguard irrigated perimeters (SIP) cover a total surface of 137.5 km2 of farming area from which 88% are intended for citrus trees and are located in Beni Khalled, Menzel Bouzelfa, Soliman, Grombalia, and Bou Argoub delegations. The Public irrigated perimeters (PuIP) which covers approximately 130 km2 intended mainly for vegetables, strawberry with fruit trees and field crops cultivation (Lachaal et al., 2016).

Many industrial units are installed in the study area, where the largest gathering are the industrial zones of Grombalia, Bouargoub and Solilman. The industrial activities are numerous (tanning, paper production, production of food flavor and food additives, soft drinks production, laundering, metal industrialisation, wine production, dairy plants, etc.).

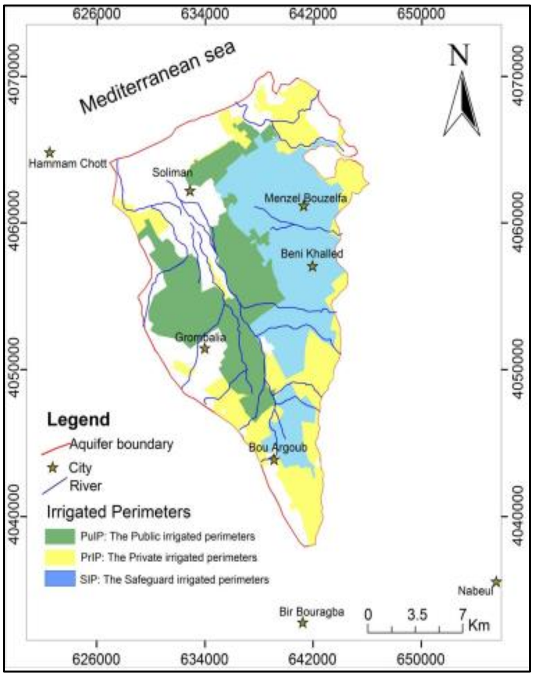


Figure 15. Irrigated perimeters in Grombalia aquifer area (Lachaal et al., 2016 according to Ministry of Agriculture, 2000)

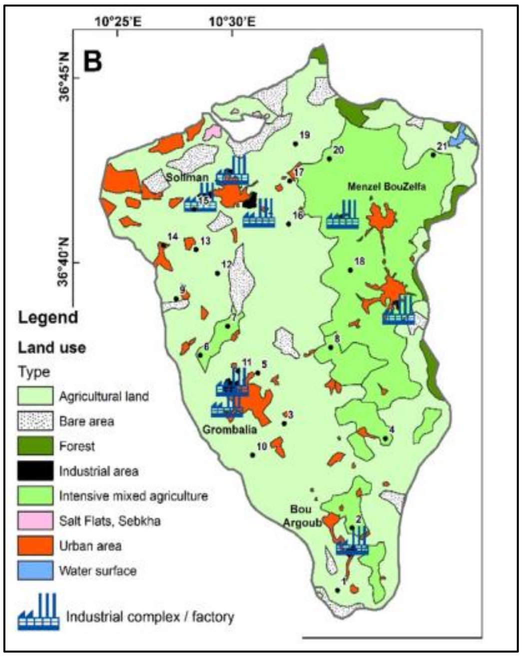


Figure 16. Land use map (Salama et al., 2020 modified from Ben Moussa et al. 2009)

3.1.2. Water Development And Management

3.1.2.1. Water Supply

- Surface Water Transfer From North-West Tunisia

Due to the local lack in water availability, water is transferred from the northwest of Tunisia to the Grombalia region. Since 1984, these water resources have been used by the Ministry of Agriculture to balance the water budget of the Cap-Bon region and cover the water deficit due to the groundwater pumping in irrigated perimeters. This water reaches the distribution stations and dams located in the study area by the transfer of water from Medjerda-Cap Bon Canal through a network of canals that connects the distribution stations located in the vicinity of Medjerda-Cap Bon. According to CRDA of Nabeul, the supplied water volumes for irrigated public areas in 3 delegations in the study region has increased from 15.6 in 2009 to 18.5 Mm3 in 2014 (Lachaal et al.., 2016).

- Dams

In order to increase the local available water resources, the government constructed some dams. The principal reservoirs are:

1- Bezigh dam was built in 1954, with a capacity of 6.5 Mm^3/year. It located upstream of Menzel BouZelfa city
2- Tahouna dam built in 1967 with 0.96 Mm^3/year
3- El Masri dam built in 1968 with 6.9 Mm^3/year capacity and located upstream of Bou Argoub city

- Groundwater Aquifer

The current management of the water resources in the Grombalia region relies on water supply from various sources including both shallow and deep aquifers.

3.1.2.2. Water Uses

- Agriculture

- Safeguard Irrigated Perimeters (Sip):

*Total surface = 137.5 Km^2 (88% are intended for citrus trees)

*SIP extends over 97.13 km^2 of the Grombalia shallow aquifer (28.91% of the aquifer area)

The required water volume is partially supplied from the North-West surface water while farmers provide the remaining water needs through the exploitation of groundwater resources essentially from deep aquifers.

- Public Irrigated Perimeters (Puip):

* Total surface = 130 Km^2 (intended mainly for vegetables, strawberry with fruit trees and field crops cultivation)

* The water needs for PuIP are supplied from the North-West surface water.

- Private Irrigated Perimeters (Prip):

* Total surface = 70.83 Km^2

* About 21.1 % of groundwater abstraction in the area

- Urban

With more than two hundred thousand inhabitants, the study site density is around 394 hab/km^2, which can be considered a highly dense region.

92.2 % of this population enjoyed the house connection to drinking water service that is managed by the national water utility (ONAS). 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 (Lachaal et al., 2016).

- Industrial Use

Industrial units installed in the study site use an important quantity of water which is extracted mainly from the deep groundwater. More than six hundred thousand m^3/year was pumped from the deep groundwater in 2012 (Lachaal, 2016).

3.1.2.3. Main issues

Inventory of water threats, Hotspots points' identification

- Anthropic pressures
- Overexploitation of the groundwater resources
- Degradation of the aquifer chemical quality
- Saltwater intrusion
- Decline & rise in the water level
- Pollution of Sebkha Soliman

3.1.3. Groundwater governance system

The water governance in Tunisia functions according to a centralized model. The water resources are managed according to a hierarchical approach and the water planning authority makes decisions centrally. The Ministry of Agriculture, Hydraulic Resources, and Fishing (MARHP) is designated as the main water authority, which plans water development, decides on allocations, and coordinates and controls the interests. Its mandate includes the protection of the national water resources. ; its regional departments (CRDA) execute the national water policy, while at the local level, water user associations manage water in irrigated lands, but they do not participate in the decision-making process. The National Water Utility (SONEDE), which is under the control of the Ministry of Agriculture, holds the monopoly on drinking water supply over the entire country, otherwise some water user associations manage drinking water for some rural populations (Mellah 2018).

3.1.3.1. Actors and Institutions Involved in Water Management

At the regional level, the Regional Department of Agricultural Development (CRDA) manages water resources and sets up the public water policy at the regional scale. The Water Users Associations (GDA), which are private non-profit organizations, recognized as being of public utility, manage water for irrigation purposes in the agricultural areas equipped by the state.

The GDA signs a management and irrigation contract with the CRDA in order to have access to water for irrigation.

Below we present a short inventory of the stakeholder at the local level:

- Public Actors

- Commissariat régionale du développement Agricole à Nabeul (CRDA-Nabeul) (Regional department of agriculture Nabeul governorate)
- CTV : Territorial agricultural extension unit of Grombalia
- Municipalities of Soliman, Menzel Bouzelfa., Bouargoub and Grombalia
- Regional department of ANPE (National Agency for the Protection of the Environment)
- 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 Nianou, GDA Menzel Bouzelfa (Water users associations
- CERTE (Water Research and Technology Center)

3.1.3.2. Water Policy and Current Instruments of Water Regulation

The water resources are considered as a public hydraulic domain according to the Tunisian Water Act. Access to water is regulated by a water abstraction-licensing scheme. Users apply for licenses and the Water Commission of the Ministry of Agriculture, assesses the applications and then issues or denies licenses. The General Directorate of Water Resources (DGRE-MARHP) prepares the technical decision that will be examined by the Water Commission.

The mandate of the ministry of Agriculture includes the protection and the monitoring of the water resources. In addition, the Ministry of Health monitors drinking water safety and the National Agency of Environmental Protection (ANPE) plays the role of the environmental regulator. The inspectors under the Ministry of Health and the ANPE ensure that the official regulations are respected.

3.1.3.3. Water Remediation Strategies Used

Grombalia groundwaters are an important resource for drinking water, agricultural and industrial usages in the region thanks to their good quality. However, overexploitation, improper waste disposal practices, and accidental spillage of hazardous chemicals have caused a worrying quality degradation. High nitrate contents were detected in Grombalia groundwater. They are mainly caused by agricultural activities and domestic uses (kammoun, 2018).

The groundwater remediation strategies can follow either the in-situ approach or the ex-situ approach:

In situ approach, which takes place on-site, treats contaminated groundwater in place. This approach had the advantage of being economic. However, it requires a thorough understanding of subsurface conditions.

Ex-situ approaches are used to treat extracted groundwater off-site. The surface treatment can be done either on-site or off-site, depending on site-specific conditions. The main advantage of this approach is the easier control and monitoring during remedial activity implementation and the impossibility for any further damage to be done at the current location. If subsurface contaminant levels exceed those which can be treated via in situ remediations, ex situ remediation will be more beneficial.

Groundwater remediation techniques may be based on chemical, biological, and physical treatment technologies. Most groundwater treatment techniques utilize a combination of these technologies.

Re and al (Re, 2017) treated the nitrate contamination issue in Grombalia groundwaters by proposing a new approach, a socio-hydrogeology approach, based on the engagement of social dimension into hydrogeological investigations. They have studied the dynamic interactions and feedbacks between groundwater and people.

Chenini and al (Ismail chenini, Zguibi 2015) have adopted a modified DRASTIC method and a DRIST model based on the combination of topographical, lithological, and hydrogeological data factors using Geo Based Information System software for Grombalia aquifer. The used models for vulnerability assessment reveal the high vulnerability of the aquifer system due to the special effects of pollutants. This study has proposed some recommendation supporting the management and protection of the groundwater aquifer system of the Grombalia basin:

- Avoid any activity with a risk of pollution in areas with high vulnerability,
- Create hydrogeological parks with uncultivated land whose purpose is the preservation of groundwater areas where water quality has deteriorated
- Reduce any source of pollution to limit its effects on groundwater quality.

In the work of Hamza and al (Hamza, 2010), two vulnerability methods have been investigated to treat agricultural pollution by nitrates in the phreatic aquifers of Bizerte and Nabeul.

Generic DRASTIC and the Susceptibility Index (SI) are intrinsic and intrinsic and specific vulnerability methods respectively. A Geographical Information System (GIS) technology was used. Results showed that the SI method is the more valid method in the studied systems. This method, unlike the DRASTIC method, considers the pollutant’s nature as well as the factors managing the specific vulnerability as the land-use factor (Hamza, 2010).

Some sites with complex contaminants and conditions need to be remediated with more than one technology.

The multiple remediation methods are generally used sequentially or concurrently along with the primary treatment technology “treatment trains” (Reddy, 2008).

Typical treatment trains used in contaminated sites include soil flushing followed by bioremediation, pumping and treatment, and pump and treatment along with soil flushing or air sparging.

3.1.4. SWOT Analysis of Project Actions Related to Remediation Strategies

The goal of the remediation strategy that will be implemented in the Tunisian case study is designed according to four ‘R’ principles (Reduce, Recycle, Reuse and Recover). the strengths, the opportunities, the weakness and threats of the specific project actions are displayed below

Strengths	Weakness
• Existence of legal framework to regulate the overexploitation • Standards and norms related to wastewater management • Strategies to encourage water reuse and pollution reduction • In the med project will offer the framework for the social learning • Deep knowledge about the site situation that are scientific based	• Lack of stakeholders’ awareness about groundwater as a common • Lack of incentives to change behavior toward the sustainability for water actors • Misunderstanding of water cycle • No formal channels for the participation of researchers on the decision-making process regarding water management

Opportunities	Threats
• Awareness of farmers and industrials about the issue of water resources sustainability and water supply renewability • Public awareness about the pollution problematic • Shared expertise between Scientifics and actors in the design of appropriate remediation actions • Use of technological tools and solutions in assisting the decision-making processes	• State Limited capacities of law enforcement • Dependence of social learning process on the pandemic situation • Failure in the stakeholder's engagement plan • Failure to achieve consensus between different stakeholders

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3.2. Castro Verde, Portugal Case study

3.2.1. Biophysical Attributes

The Castro Verde case study is located in the Southern region of Portugal, in the district of Beja (Figure 17). The area of interest covers approximately 30 km^2. From a geological perspective, Castro Verde is located in the Iberian Pyrite Belt (IPB), one of the four domains belonging to the Portuguese South Zone (ZSP). This zone is in contact with the Ossa Morena Zone (ZOM) through the thrust fault Ferreira Ficalho and is constituted by the domains of IPB, Flysch Group of Baixo Alentejo (GFBA), Antiforma do Pulo do Lobo and SW Sector of Portugal.

Figure 17. Location map of the Castro Verde Aquifer study area (Portugal)

The IPB (Figure 18) is about 250 km long and between 30 to 50 km wide, stretching from the north of Grândola (under the Tertiary Basin of Sado, Portugal) close to Sevilla (under the Basin of Guadalquivir, Spain) [2].

Castro Verde aquifer is positioned in the Southern region of the Guadiana Basin, which extends in Portugal and Spain. Morphologically, the Guadiana Basin can be subdivided in 3 distinct zones: High, Medium and Low Guadiana. The Low Guadiana corresponds essentially to the Portuguese part of Guadiana Basin (Figure 19) [3] and covers an area of 11.534,13 km^2.

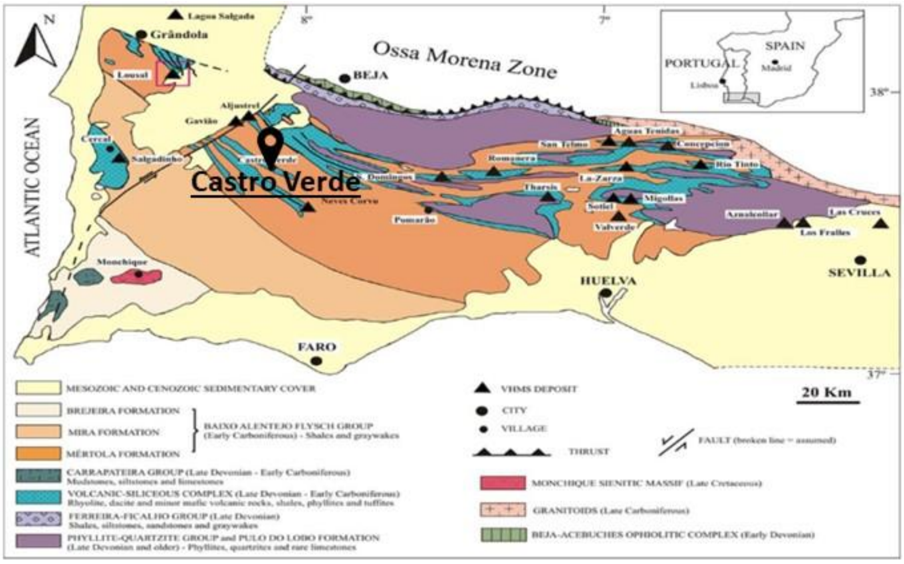


Figure 18. Geologic Map of the Iberian Pyrite Belt (IPB) [2]

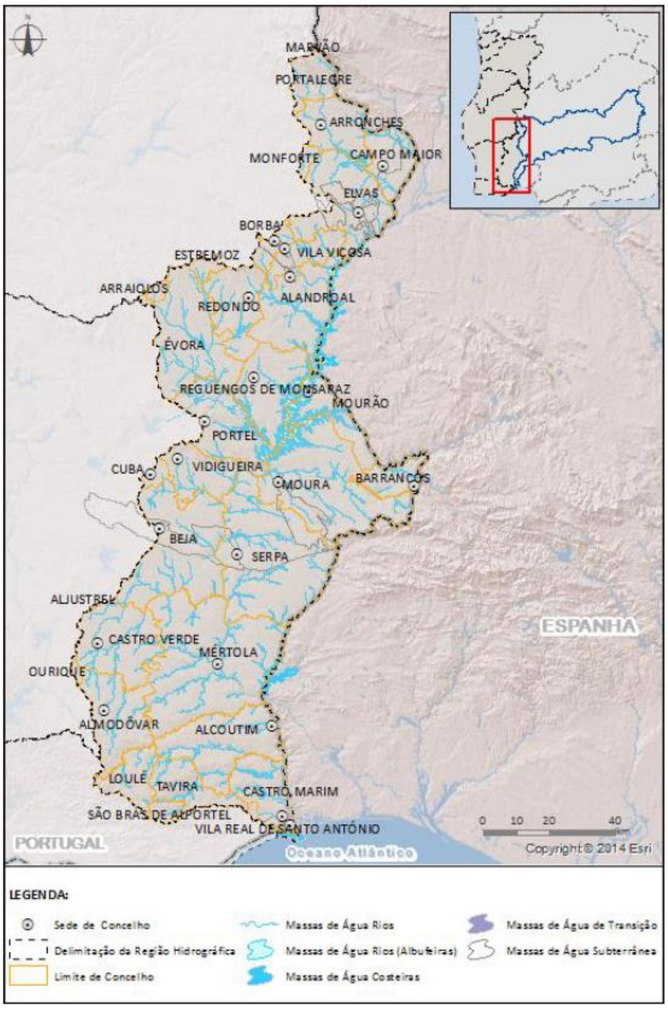


Figure 19. Delimitation of the Portuguese part of Guadiana Basin (APA) [3]

3.2.1.1. Climate

The climate in the region is characterized as semi-arid. We use the information collected by the meteorological station of Beja from IPMA (Instituto Português do Mar e da Atmosfera – Portuguese Institute of the Sea and the Atmosphere) [4] to characterize the temperature and precipitation in the study area. This station is the closest one to the location of the study area. The meteorological station was first installed in 1897, moved to its current installations at an altitude of 253 meters in 1953, and is still in operation as an automatic meteorological station.

Figure 20 shows that the average annual maximum temperature for the period 1960 – 2018 is 22.67 ºC, while the average annual minimum temperature for the same period is 10.53 ºC. The highest temperatures occur in August and the lowest in January.

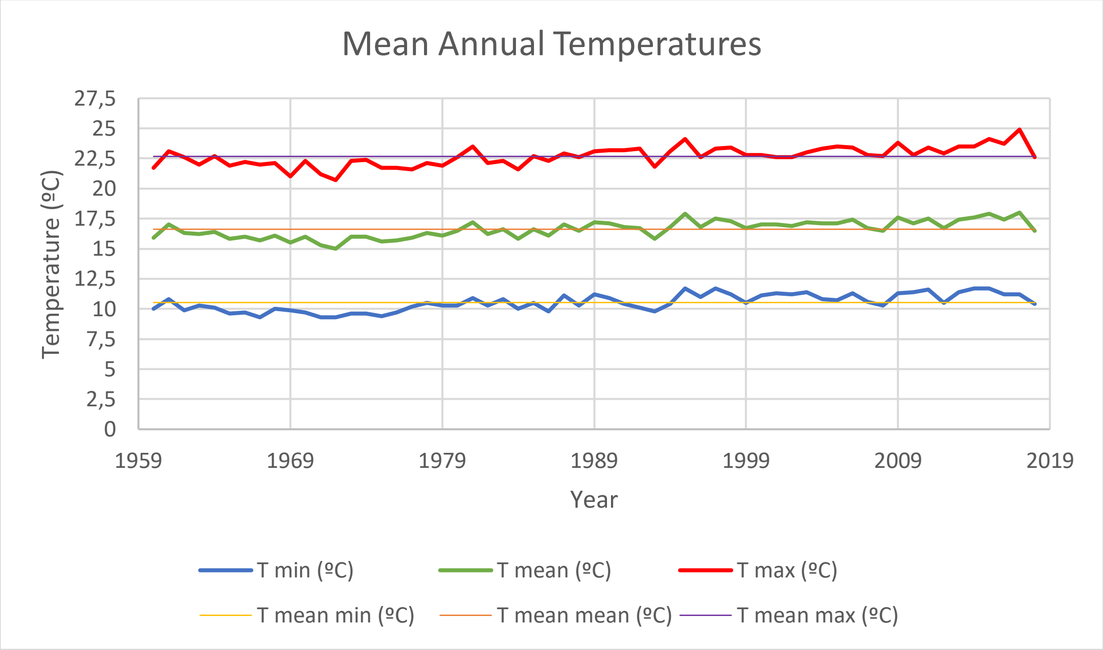


Figure 20. Mean annual temperatures (minimum, mean and maximum) for the period 1960-2018 (IPMA) [4]

Figure 21 illustrates the evolution of the mean temperature in the period 1960-2018. From the figure it is possible to identify an increase of 0.5 ºC in the mean temperature for the period comprised between 1994 and 2018.

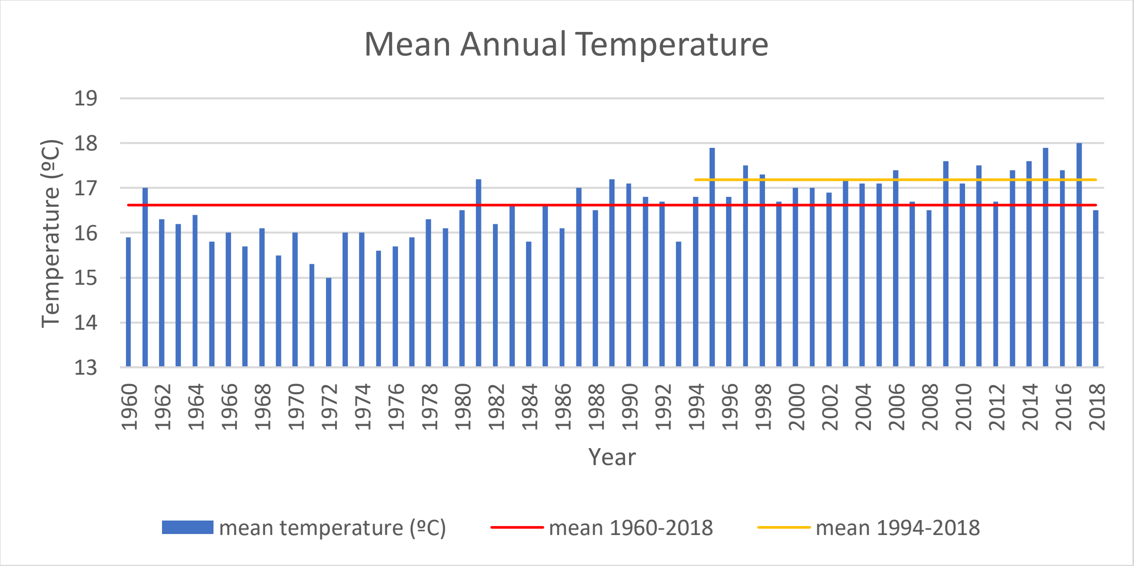


Figure 21. Mean annual temperature for the period 1960-2018 (IPMA) [4]

Regarding the mean rainfall evolution in the same period (i.e., between 1960 and 2018), Figure 22 shows some variability from year to year with a mean accumulated precipitation around 573 mm/y. The period of 1994-2018 shows a slight decrease of the mean accumulated precipitation to 558 mm/y.

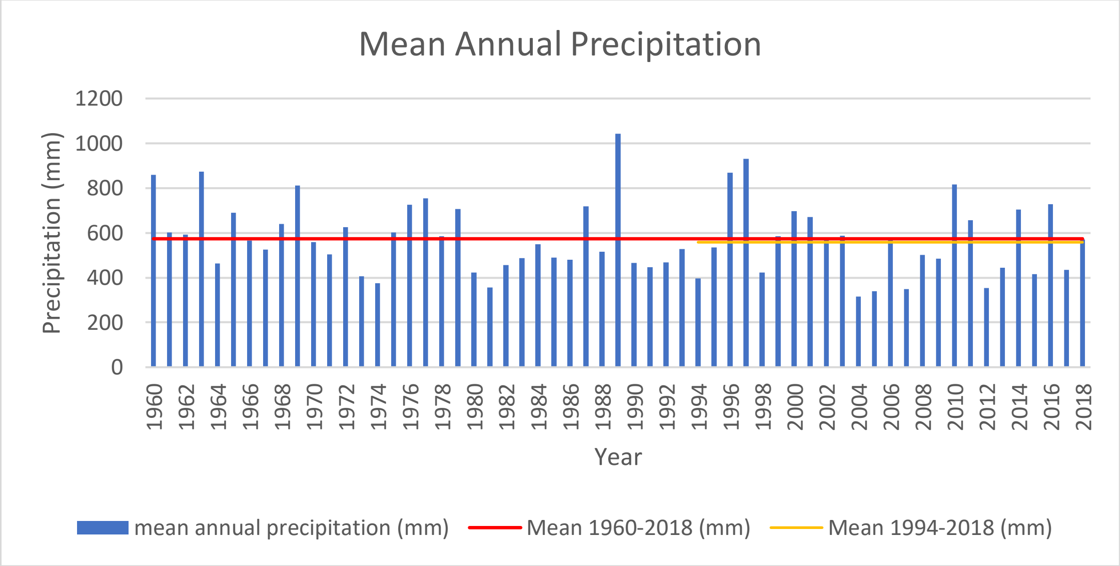


Figure 22. Mean annual precipitation for the period 1960-2018 (IPMA) [4]

We focus on the mean precipitation per month. July is the month when it rains the least (1.8 mm), while December is the rainiest month, characterized by a mean rainfall value of around 81 mm (Figure 23).

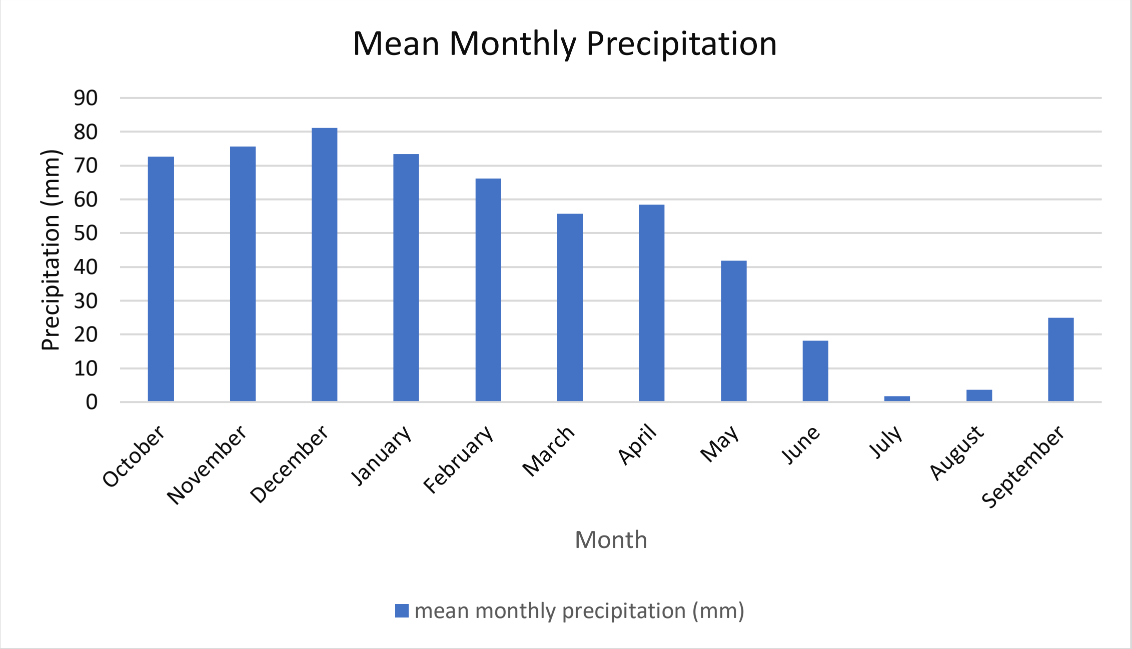


Figure 23. Mean monthly precipitation for the period 1960-2018 (IPMA) [4]

The average annual evapotranspiration for the period 1971-2000 is presented in Figure 24 [5], showing a slight increase of the annual evapotranspiration in the recent decades.

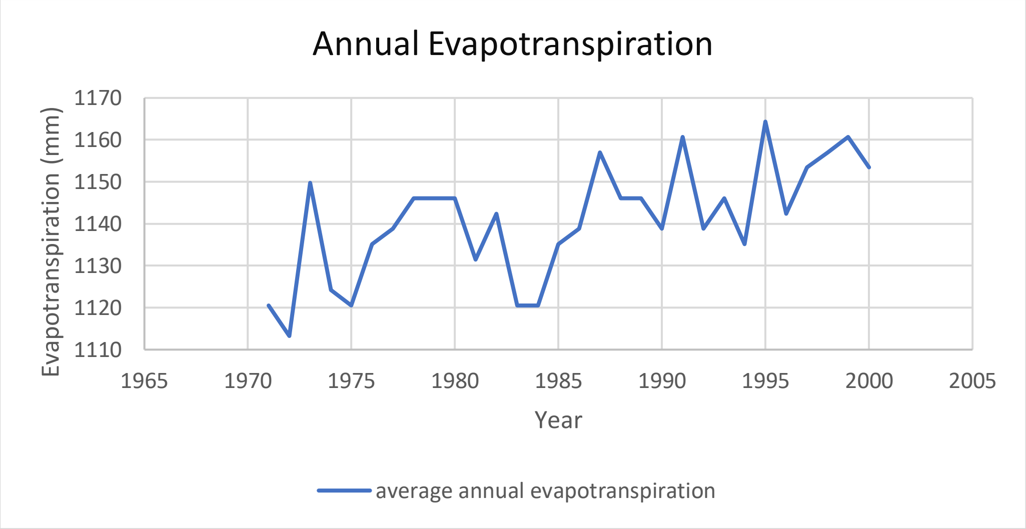


Figure 24. Mean annual evapotranspiration for the period 1971-2000 [5]

3.2.1.2. Hydrological Context

Castro Verde aquifer is located in the Guadiana Hydrographic Region, which is subdivided into 9 hydrographic basins, and is mainly part of Cobres hydrographic basin and south part of Guadiana hydrographic basin (Figure 25) [6].

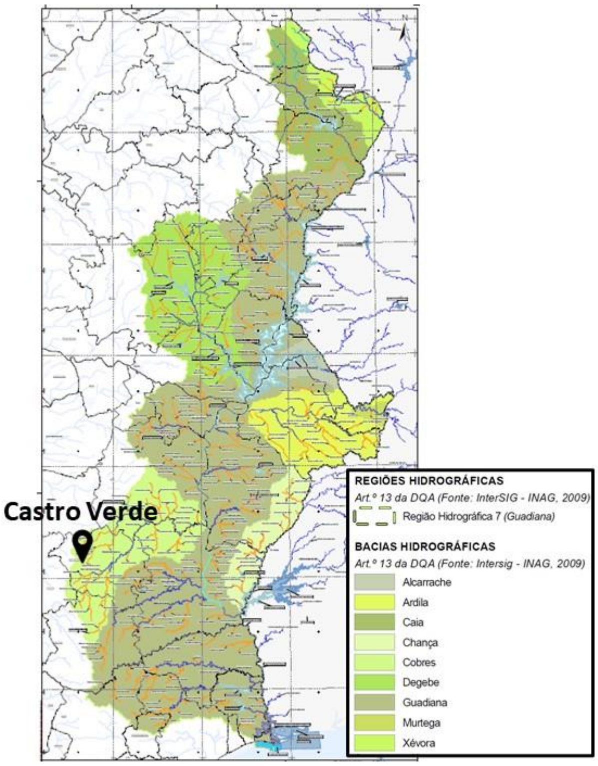


Figure 25. Hydrographic Basins defined in the Portuguese part of the Guadiana Basin (APA) [6]

In the area under study (Figure 10), the water lines belong to both Cobres and south part of Guadiana hydrographic basins. The major watercourse is the Guadiana River, with affluents on the right bank, such as rivers Oeiras, Terges, Cobres and Carreiras (Figure 26) [6].

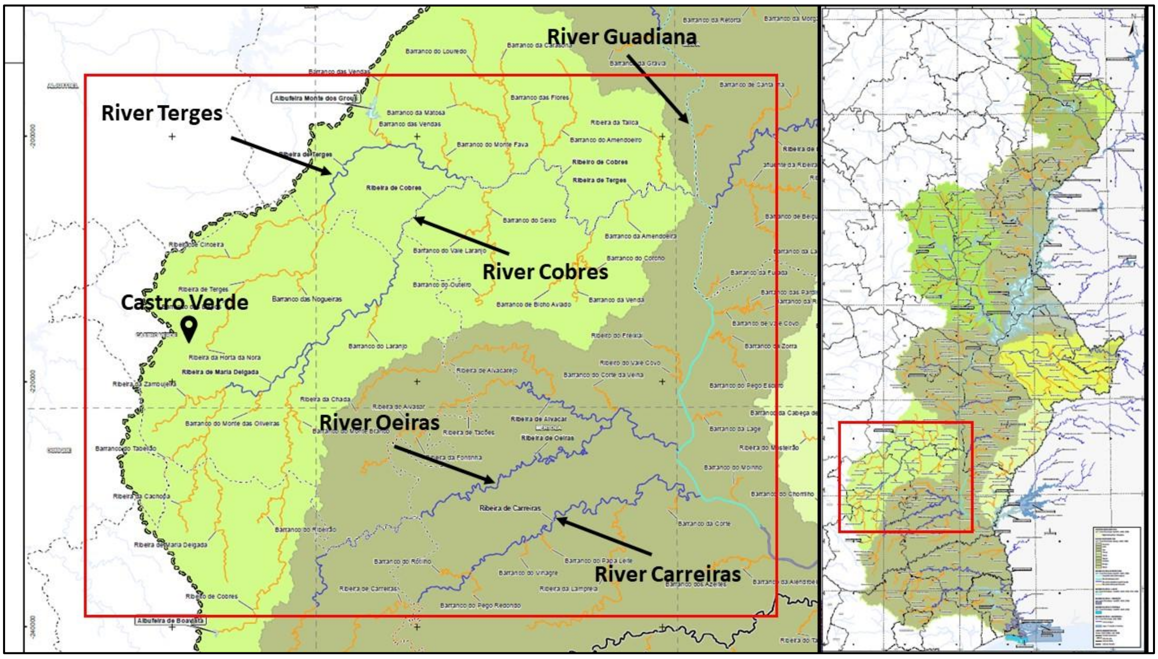


Figure 26. Hydrological setting, Castro Verde, Portugal (APA) [6]

The volumes of river flow at the river mouth of the different hydrographic basins for dry, normal and wet years, are shown in Table 1 [6].

Table 3. River flow volumes at the river mouth of the different hydrographic basins (APA) [6]

Hydrographic Basin	Flow Volume (hm^3)		
	Dry Year	Normal Year	Wet Year
Alcarreche	32.6	114.2	242.0
Ardila	150.6	448.6	869.8
Caia	44.3	118.3	279.1
Chança	55.5	258.6	566.1
Cobres	35.8	104.7	341.4
Degebe	127.2	159.4	362.2
Guadiana	1545.6	4409.3	9398.6
Murtega	34.3	119.0	212.0

Xévora	50.3	118.9	290.9

3.2.1.3. Aquifer Characteristics

Our case study belongs to the water body of the Portuguese South Zone of the Guadiana Basin (Figure 11) [3].

Figure 27. Delimitation of the groundwater bodies of the Hydrographic Region of Guadiana (APA)[3]

The Portuguese South Zone is mostly constituted by a thick succession of shale of carbonic age, arranged in rhythmic sequences (i.e., of facies type flysch) superimposed by a set of acidic and basic volcanic rocks of the upper Devonian, and limestones (Figure 27) [7].

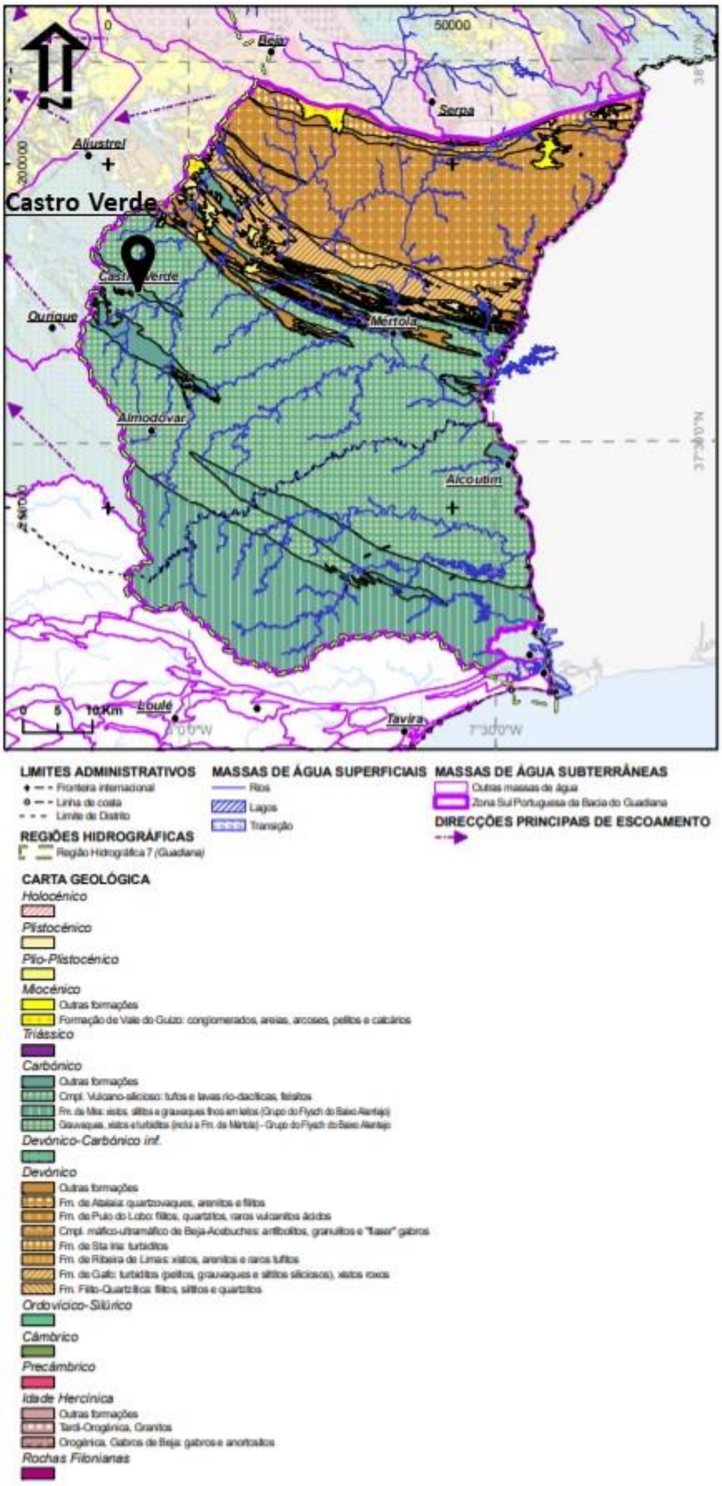


Figure 28. Geology of the groundwater body of the Portuguese South Zone of the Guadiana Basin (APA) [7]

The circulation of water in this zone is similar to the circulation occurring in fractured aquifers, because, although the capacity of direct infiltration in these rocks (shales with a high percentage of clay) is limited, the fractures and the superficial alteration have a decisive role in the quantity of water that infiltrates. However, the flow in the shales should be preferably superficial [7].

In detail, Castro Verde aquifer system is composed by three hydrogeological units (Figure 29) [8]:

- Superior System – is characterized as a free aquifer with superficial alteration zone, characterized by fractures and microfractures, and a thickness around 50 m. It is composed by bicarbonate waters with a temperature between 17 º to 20 ºC, less than 3 months age, and the recharge is superficial.
- Intermediate System – is characterized as an aquitard with low permeability, and a thickness of more than 50 m. The water is a mixture of bicarbonate and sodium chloride waters, which are aged with more than 3 months and circulate exclusively through faults and fractures.
- Lower System – is characterized as a confined aquifer with intense microfractures/fissures in the mineralization and high original confinement pressure (32 bar registered in the first access). Is composed by fossil water with a temperature up to 44 ºC (sodium chloride waters), aged with more than 40 years old, and characterized by rapid drainage.

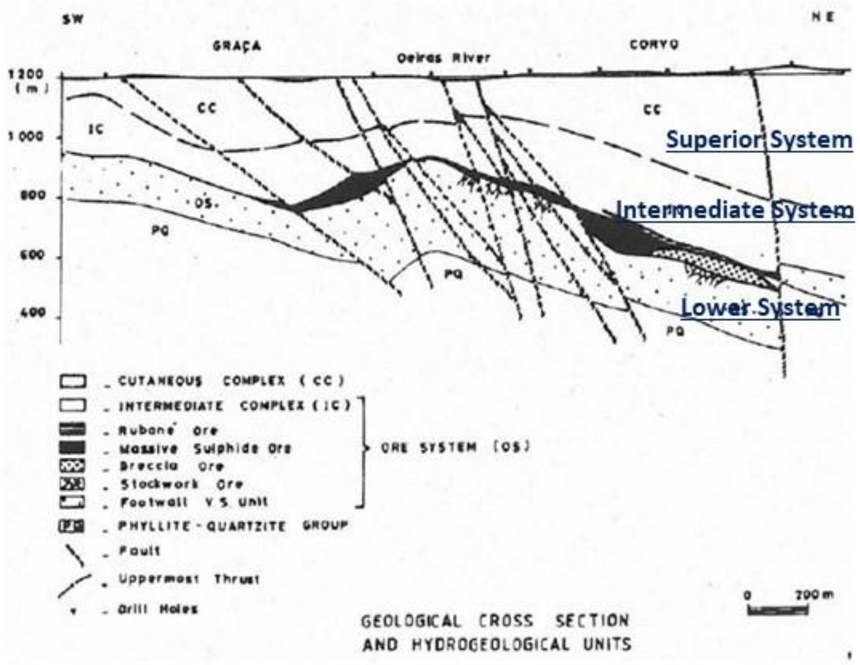


Figure 29. Geological cross section and hydrogeological units of Castro Verde aquifer system [8]

The Portuguese South Zone of Guadiana Basin has a wide piezometer network but with irregular frequency measurements. Figure 30 presents the relevant piezometers selected for the area under study.

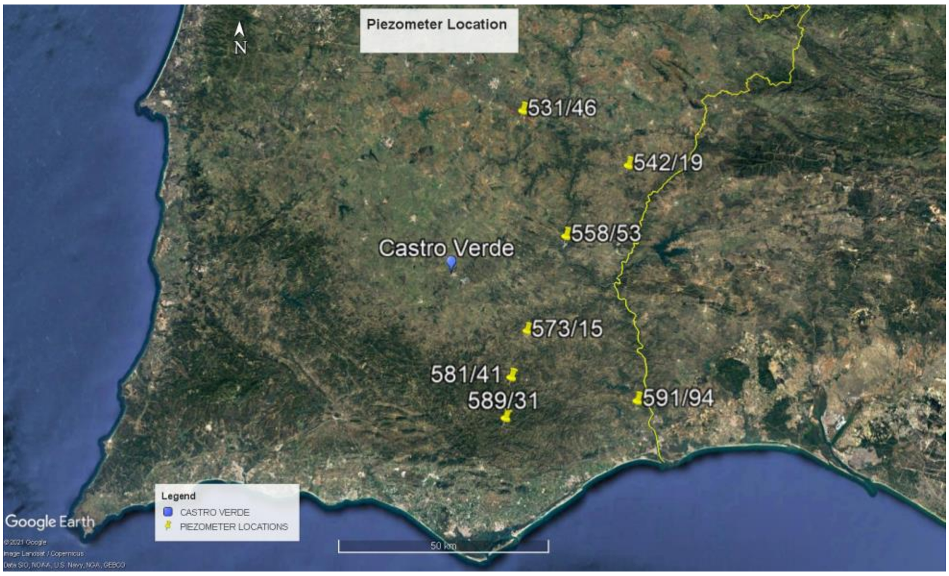


Figure 30. Piezometer Locations at the Portuguese South Zone of Guadiana Basin (SNIRH) [9]

Figure 31 shows the head level fluctuations at the respective locations.

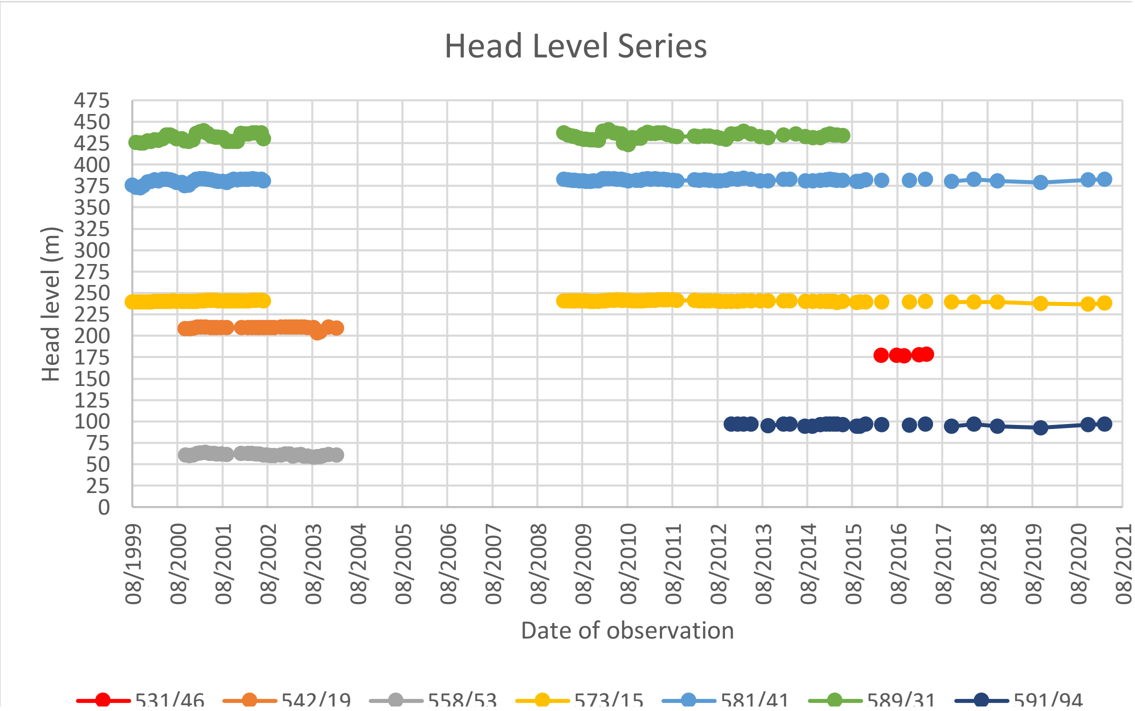


Figure 31. Head level series at the different Piezometer locations (SNIRH) [9]

The water level evolution at these locations shows that it has been experiencing a sustainable water level decrease.

There is also a groundwater quality monitoring network in the Portuguese South Zone of the Guadiana Basin, but the observation points are not the same as the piezometer network. This monitoring network has also some drawbacks, as it does not cover the entire area of the study case and the measurement frequency is irregular. Figure 32 shows the observation points of Nitrate concentration that best characterize the area under study [10].

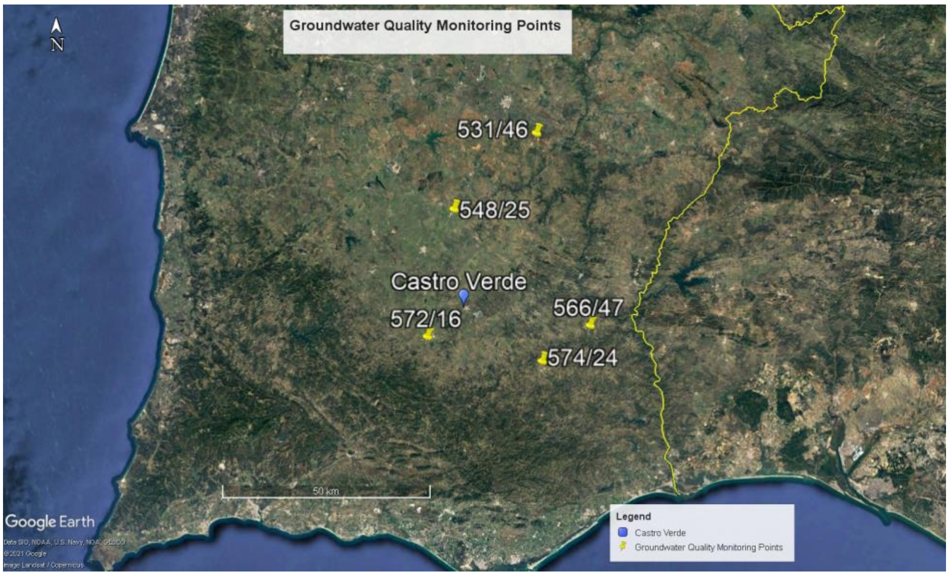


Figure 32. Location of the groundwater quality monitoring points at the Portuguese South Zone of the Guadiana Basin (SNIRH) [10]

Figure 33 shows the Nitrate concentration series measured at the groundwater quality monitoring points from 09/1999 until 09/2020. In the figure, it is also plotted the maximum admissible level for nitrate concentration defined in Annex I and Norm of decree nº 236/98 of 1st August, 1998 (50 mg/L).

The figure shows that all observations at the different monitoring points are characterized by values of nitrate concentration below the maximum admissible value as defined by the legislation. From a nitrate concentration perspective, the groundwater in the area under study is of good quality.

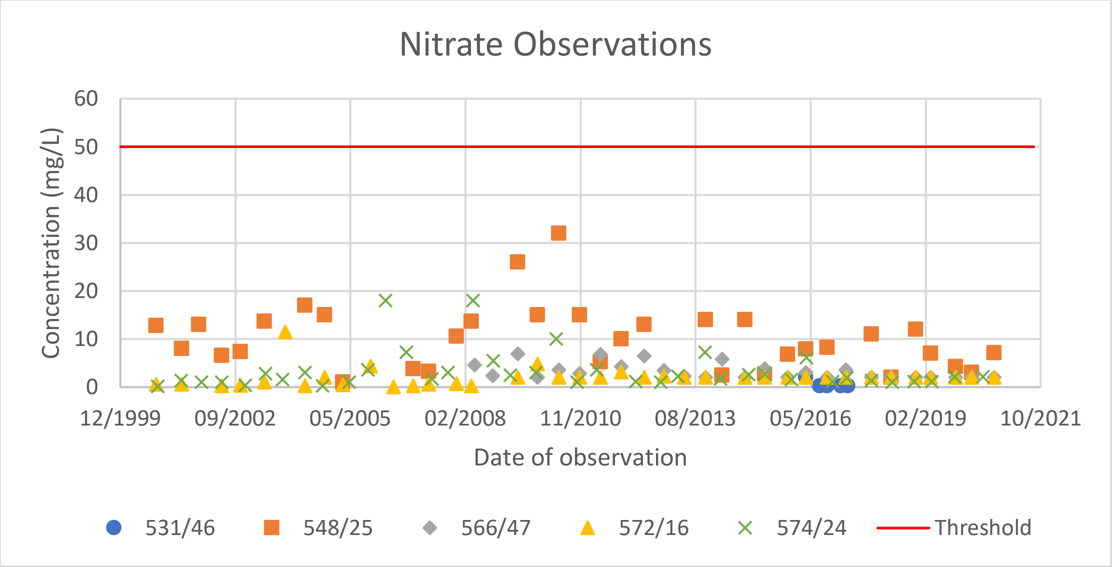


Figure 33. Nitrate concentration series measured at the groundwater quality monitoring points (SNIRH) [10]

3.2.1.4. Land Use

According to the Portuguese Environmental Agency (APA), the analysis and cartography produced in relation to land uses were carried out based on the methodology Corine Land Cover 2006 (Figure 34). The distinction used, taking into account the classes occurring and their representativeness in Guadiana Hydrographic Region, was as follows (Table 4) [11]:

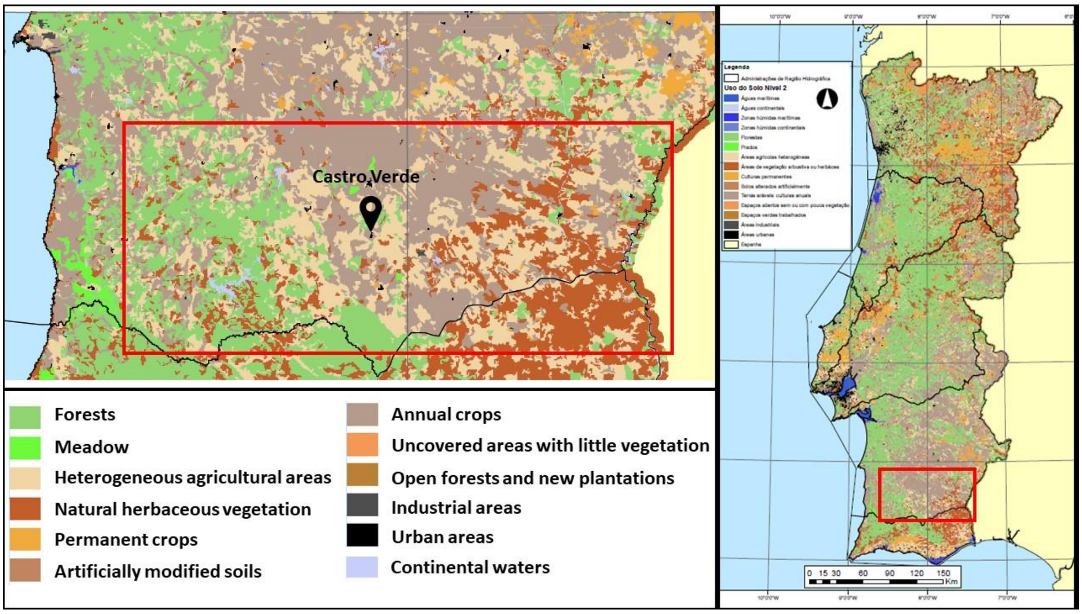


Figure 34. Land use map in the area under study [11]

Table 4. Groups and classes of land uses (APA) [11]

Group of Land Use	Class of Land Use
Artificial territories	Continuous urban fabric
	Discontinuous urban fabric
	Industry, commerce and general equipment
	Road and rail networks
	Port areas
	Airports and aerodromes
	Inert extraction areas
	Waste disposal areas
	Areas under construction
	Sports, cultural, leisure facilities and historic centers
Agricultural and agro-forestry areas	Temporary rainfed crops
	Temporary irrigated crops
	Rice fields
	Permanent crops
	Permanent pastures
	Heterogeneous agricultural areas
Forests and natural and semi-natural areas	Forests
	Natural herbaceous vegetation
	Sclerophilous vegetation
	Open forests and new plantations
	Uncovered areas with little vegetation
Wetlands	Marshland

	Salt pans and coastal aquaculture
Water bodies	Water courses
	Water plans
	River mouths
	Ocean

Considering the groups of land use, APA verified that the Agricultural and Agro-Forestry Areas (68.8%) and Forests and Natural and Semi-Natural Areas (28.1%) dominate the Guadiana Hydrographic Region. Following, in decreasing order of representativeness, are Water Bodies (2.2%), Artificial Territories (0.8%) and Wetlands (0.1%) [11].

The area under study is mainly located in the Cobres hydrographic basin of the Guadiana Hydrographic Region. Therefore, Table 5 and Figure 35 present the areas (ha) and percentages of groups of land use at the Cobres hydrographic basin.

Table 5. Areas (ha) and percentages of groups of land use in the Cobres hydrographic basin (APA) [11]

Group of Land Use	Cobres Hydrographic Basin	
	Area (ha)	**Area (%)**
Artificial Territories	705	0.6
Agricultural and agro-forestry areas	97 006	83.9
Forests and natural and semi-natural areas	17 589	15.2
Wetlands	0	0.0
Water bodies	313	0.3
Total	48.508	100.0

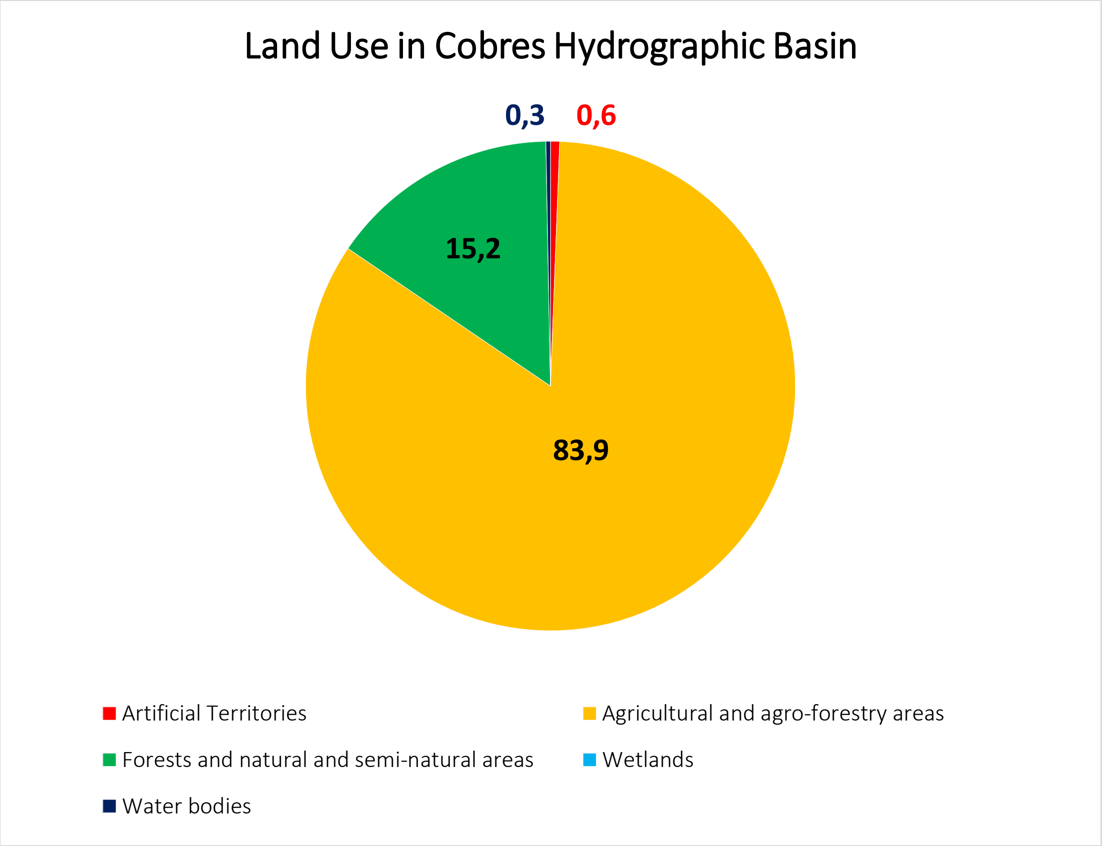


Figure 35. Area (%) of groups of land use in the Cobres hydrographic basin (APA) [11]

3.2.2. Water Development And Management

3.2.2.1. Water Supply

The water supply in the region under study is responsibility of a public company. The water has origin in both superficial and groundwater resources. Afterwards, it is necessary to carry out the proper treatment of the pumped water, which will be adapted according to the quality characteristics of the raw water collected and the existing infrastructure for this purpose. This treatment can range from a disinfection, which will be carried out in a simpler infrastructure such as the Chlorine Post, to a more complex treatment process to be carried out in a conventional Water Treatment Plant. Afterwards, the treated water is routed through water supply pipes to the reservoirs, from which the connection to the supply network is made [11]. Table 6 summarizes the number of abstraction points, lifting stations, water treatment plants, reservoirs and activity volume to supply the area under study.

Table 6. Summary of number of abstraction points, lifting stations, water treatment plants, reservoirs and activity volume, involved in the water supply to the region under study

Number of groundwater abstractions	307
Number of surface abstractions	17
Number of lifting stations	78
Number of Water Treatment Plants	*17*
Number of reservoirs	*276*
Activity volume (m^3/year)	19.888.066

3.2.2.2. Water Uses

Considering the water using sectors located in the Guadiana Hydrographic Region, the sectors that stand out for their importance in terms of water consumption, in descending order of importance, are Agriculture, Residential Sector, Industry, Commerce and Tourism.

In 2009, these sectors needed almost 196 hm^3 of water, with Agriculture concentrating 84.5% (165.4 hm^3) of these regional needs, followed by the Residential Sector with 10.8% (21.2 hm^3). The Industry Sector used 1.9% of water, and both Commerce and Tourism used 1.4% each (Table 7 and Figure 36) [11].

Table 7. Water consumption necessities by sector in the Guadiana Hydrographic Region (APA) [11]

Sector	Water Consumption Necessity	
	Hm^3	%
Agriculture	165.4	84.5
Residential	21.2	10.8
Industry	3.8	1.9
Commerce	2.7	1.4
Tourism	2.7	1.4
Total	195.9	100.0

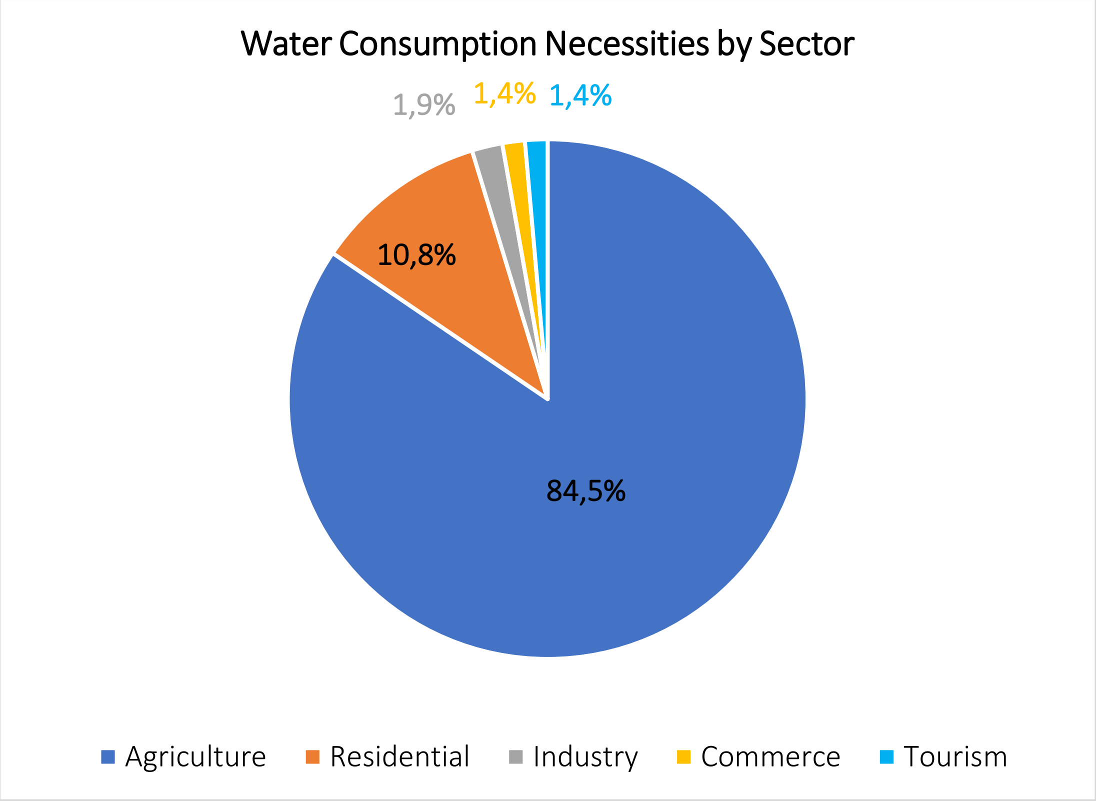


Figure 36. Distribution (%) of water consumption necessities by sector in the Guadiana Hydrographic Region (APA) [11].

Most of the water required to meet the consumption needs of Guadiana Hydrographic Region (96.4%) was collected in the region itself (189 hm^3), mainly from underground sources (107.2 hm^3). The volumes transferred/diverted from other regions to supply part of these needs, amount to only 6.8 hm^3, relating essentially to surface water originating from Sado/Mira basin (Table 8, Figures 37 and 38 – APA) [11].

Table 8. Region and type of water origin required to satisfy consumption necessities in the Guadiana Hydrographic Region (APA) [11].

Region of Water Origin	Water Origin Type		
	Superficial (hm^3)	Underground (hm^3)	Total (hm^3)
Guadiana Hydrographic Region	81.9	107	189.0
Sado/Mira Basin	6.8	0.0	6.8
Total	88.7	107.2	195.9

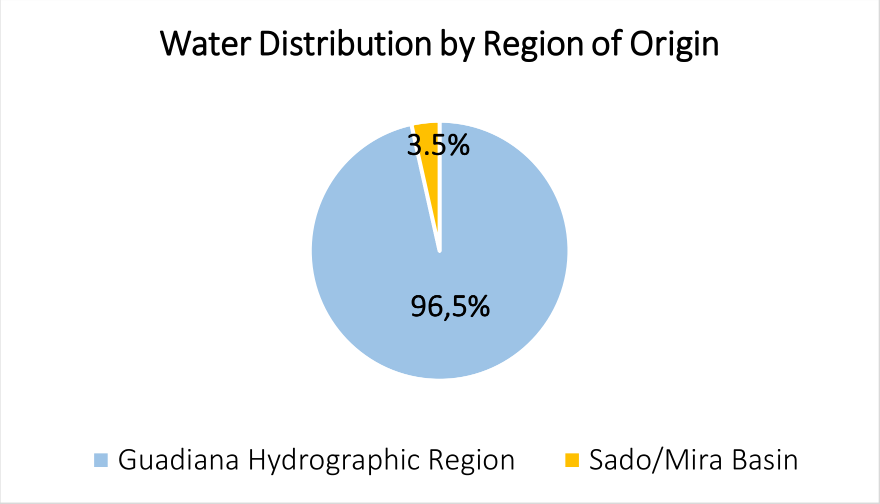


Figure 37. Distribution (%) of water consumption necessities by region of water origin (APA) [11].

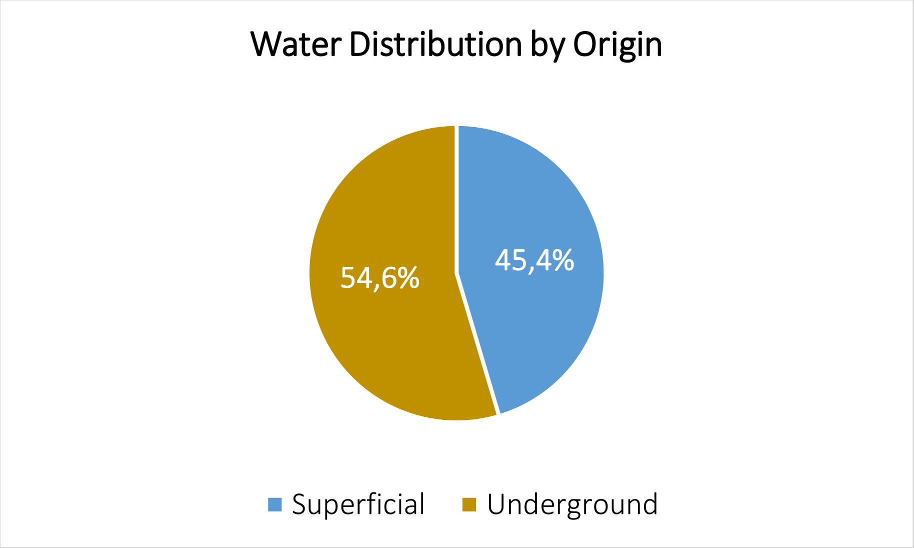


Figure 38. Distribution (%) of water consumption necessities by origin of water (APA) [11]

Table 9 shows in detail the water consumption necessities for agriculture in the different areas and groundwater bodies of the Guadiana Hydrographic Region (APA) [11].

Table 9. Water consumption necessities for agriculture in the different areas and groundwater bodies of the Guadiana Hydrographic Region (APA) [11]

Origin		Guadiana Hydrographi Region	
Region	Basin/Water Body	Volume (hm^3)	Volume (%)
Superficial	Guadiana	11.63	7.0
	Chança	0.46	0.3

	Cobres	1.58	1.0
	Ardila	0.68	0.4
	Murtega	0.00	0.0
	Degebe	8.44	5.1
	Alcarreche	0.28	0.2
	Caia	45.28	27.4
	Xévora	0.67	0.4
	Sub-total	**69.01**	**41.7**
Underground	Elvas – Campo Maior	3.97	2.4
	Elvas – Vila Boim	0.50	0.3
	Estremoz – Cano	0.97	0.6
	Gabros de Beja	11.12	6.7
	MAI da Bacia do Guadiana	70.83	42.8
	Monte Gordo	0.00	0.0
	Moura-Ficalho	4.10	2.5
	OMI da Bacia do Guadiana	0.00	0.0
	ZSP Transição Atlântico e Serra	0.23	0.1
	South Portuguese Zone of Guadiana Basin	4.69	2.8
	Sub-total	**96.41**	**58.3**
Total		165.42	100.0

The water consumption necessities for Urban Systems of public supply in the different areas and groundwater bodies of the Guadiana Hydrographic Region is shown in Table 10 (APA) [11].

Table 10. Water consumption necessities for Urban Systems of public supply in the different areas and groundwater bodies of the Guadiana Hydrographic Region (APA) [11]

Origin		Guadiana Hydrographi Region	
Region	Basin/Water Body	Volume (hm^3)	Volume (%)
Superficial	Guadiana	3.36	12.9
	Chança	0.00	0.0
	Cobres	0.14	0.5
	Ardila	0.45	1.7
	Murtega	0.15	0.6
	Degebe	4.81	18.5
	Alcarreche	0.00	0.0
	Caia	3.07	11.8
	Xévora	0.00	0.0
	Sub-total	**11.97**	**46.01**
Underground	Elvas – Campo Maior	0.00	0.0
	Elvas – Vila Boim	0.28	1.1
	Estremoz – Cano	3.25	12.5
	Gabros de Beja	0.28	1.1
	MAI da Bacia do Guadiana	3.32	12.8
	Monte Gordo	0.00	0.0
	Moura-Ficalho	1.42	5.5
	OMI da Bacia do Guadiana	0.00	0.0
	ZSP Transição Atlântico e Serra	0.00	0.0
	Portuguese South Zone of Guadiana Basin	1.20	4.6
	Sub-total	**9.76**	**37.6**
	Sado	1.62	6.2

Other Regions - superficial	Roxo	2.26	8.7
	Mira	0.37	1.4
	Sub-total	**4.25**	**16.4**
Total		25.98	100.0

The water balance of the groundwater body of the Portuguese South Zone of Guadiana Basin is presented in Table 11 (APA) [11].

Table 11. Water Balance of the Portuguese South Zone of Guadiana Basin groundwater body (APA) [11]

Groundwater body	Inflow (hm^3/year)	Outflow (hm^3/year)		Balance inflow-outflow (hm^3/year)	
		Known	Estimates	Known	Estimates
Portuguese South Zone of Guadiana Basin	123.34	31.75	39.21	91.6	84.1

3.2.2.3. Main Issues

The main issue in Castro Verde is related with the mining activity. The excavation in these areas can contribute to the exposure of piezometric levels, making the groundwater bodies vulnerable to possible contaminating substances that are introduced into the water environment. Associated with the exploitation of geological resources, heaps are also common, whose concentration of certain substances can be assumed as a pressure on the groundwater bodies [12].

Most of the land in the area under study is used for agriculture. The fertilizers used in this activity release contaminants that infiltrate and can contaminate the groundwater resources [12].

3.2.3. Groundwater Governance System

The Water Framework Directive (DQA - Directive 2000/60/CE, of the European Parliament and of the Council, of 23 October 2000) establishes a framework for community action in the field of water policy, recognizing that water is a heritage to be protected and defended.

The “Law of Water” (LA - decree nº. 58/2005, of December 29, amended and republished by decree-nº. 130/2012 of June 22, 2012), which transposes the DQA into national legislation, refers in its article 23, that “it is up to the State, through the national water authority, to institute an integrated water planning system adapted to the characteristics of the basins and hydrographic regions”. Article 24 establishes that "water planning aims to support and guide the protection and management of water and the compatibility of its uses with its availability", in order to ensure a sustainable use of water resources, provide allocation criteria to the various types of intended uses, and to set environmental quality standards and criteria relating to the state of water bodies.

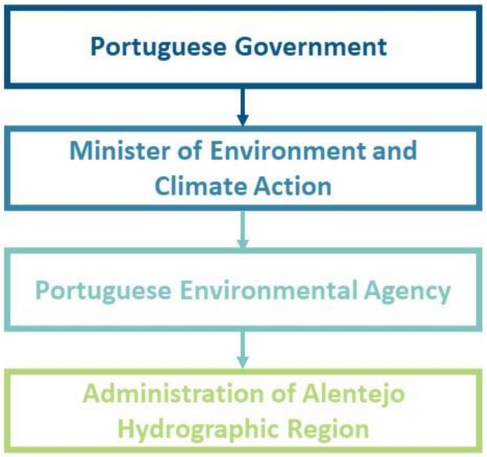
3.2.3.1. Actors and Institutions Involved in Water Management

In Portugal, the groundwater governance system is based on integrated management at national scale. The maximum authority is exercised by the Minister of Environment and Climate Action, who represents the position of the Portuguese Government regarding all environmental issues. Under his supervision, the Portuguese Environmental Agency (APA) is the national authority of water. This agency resulted from the merge of 9 organizations (decree nº 56/2012 of March 12, 2012) to become the national authority of water. APA is responsible for proposing, developing and supervising the execution of the national policies of water resources; ensure the protection, monitoring, planning and sustainable management of the water; promote the efficient use of water and supervise the compliance with its application; applying the economic regime of water resources.

The Administrations of Hydrographic Regions (ARH) are responsible for implementing and supervising the public policies for water resources at regional level. Regarding the Portuguese aquifer under study, the Administration of Alentejo Hydrographic Region is the regional authority. Figure 39 presents the authorities responsible for the water management in the area under study.

The Water Framework Directive (DQA)/Water Law (LA) clearly promotes increased transparency in decision-making processes and advocates greater public involvement in decision-making. In this context, public participation emerges as a fundamental dimension of the water planning and management process, based on which competences must be created and developed, the necessary means mobilized, and the mechanisms that enhance this involvement activated.

The active and proper sustained participation of all interested parties, whether institutions or general public, at all stages of the water planning process, is one of the requirements contained in the DQA (article 14) and in the LA (articles 26 and 84).



Portuguese Government

Minister of Environment and Climate Action

Portuguese Environmental Agency

Administration of Alentejo Hydrographic Region

Figure 39. Authorities responsible for the water management in the area under study

3.2.3.2. Water Policy and Current Instruments of Water Regulation

Several decades ago, Portugal realized that management of water resources should be done in an integrated way with other planning actions, namely those characterized by significant territorial implications. In that sense, the decrees nº 12/87 and 11/87 of April 7, 1987, introduce the principles of participation, coordination, accountability and recovery, concerning activities involving risk to the environment. A few years later, the Portuguese government published legislation regarding environmental impact studies (decree nº 186/90 of June 6, 1990), water quality norms (decree nº 74/90 of march 7, 1990), definition of the Legal Regime of the Public Water Domain of the State (decree nº 70/90 of march 2, 1990), regulation of the water resources planning process (decree nº 45/94 of February 22, 1994), and establishment of the Ministry of Environment and Natural Resources structure and services (decrees nº 183/93 and 195/93 of May 24, 1993). The published legislation imposed a new water management model with the creation of different institutions, each one with a specific role.

In 2005, the “Law of Water” was published (decree nº 58/2005 of December 29, 2005), transposing the Directive nº 2000/60/EC (October 23, 2000) of the European Parliament and Council, to the national legal order, and establishing the bases and institutional framework for sustainable water management. The objectives of “Law of Water” are:

- Prevent further degradation and protect and improve the state of aquatic and terrestrial ecosystems, as well as wetland directly dependent on aquatic ecosystems with regard to their water needs;
- Promote sustainable water use, based on long-term protection of available water resources;

- Achieve enhanced protection and improvement of the aquatic environment, in particular through specific measures for the gradual reduction and elimination of discharges, emissions and losses of priority substances;
- Ensure the gradual reduction of groundwater pollution and prevent further pollution;
- Mitigate the effects of floods and droughts;
- Ensure sufficient supply of good quality surface and underground water as needed for sustainable, balanced and equitable water use;
- Protect marine waters, including territorial waters;
- Ensure compliance with the objectives of the relevant international agreements, including those aimed at preventing and eliminating pollution in the marine environment.

To regulate the water policy, a National Water Plan (PNA), which defines the national strategy for integrated water management, was defined. It establishes the main options of the national water policy and the guiding principles and rules of that policy, to be applied by the management plans of hydrographic regions. This plan includes laws for the hydric resources ownership, norms for monitoring the water quality, use of water resources, underground water, residual water and hydric domain.

3.2.3.3. Water Remediation Strategies in Practice

Our case study is located under a mining site and the pressures from the mining activity have been identified. SOMINCOR (owner of the mining concession) has already put into practise some remediation strategies. The mine is supplied by surface water from the Santa Clara reservoir, which is in the Mira River basin, about 40 km from the site in the municipality of Odemira. To avoid the decrease of water level in this reservoir, SOMINCOR increased the use of recycled water for industrial purposes and reduced the amount of freshwater drawn from Santa Clara [13]. A part of the mining structure is also located nearby Oeiras river. Mine water drained from the mine and office wastewater from the mine complex is, along with water drained from the thickened tailings, recirculated for industrial purposes or treated at the Mine Water Treatment Plant and Reverse Osmosis Plant. Subsequently, the treated water is discharged into the Oeiras river, but only when it is under high flow conditions [13].

Following resolution of past water quality issues, SOMINCOR is investigating options to reduce fresh water supply requirements and introduce a passive wetlands treatment step, thereby controlling environmental issues throughout the water balance. For human consumption at the mine and three nearby villages (Neves da Graça, Senhora da Graça de Padrões and A-do-Corvo), water is treated at a Portable Water Treatment Plant. Regarding contaminated rainwater in the form of industrial runoff, it is diverted into 5 contaminated water retention dams and then recirculated for industrial purposes [13].

The Administration of Alentejo Hydrographic Region recognized the lack of knowledge in some areas of the region under study. To mitigate this issue, it is increasing not only the water quality and piezometer observation points but also the frequency of measurements. The communication between authorities and stakeholders (general public and farmers in particular) needs to be improved, and the Administration of Alentejo Hydrographic Region is making efforts in that direction [14].

3.2.4. SWOT Analysis of Project Actions

In the last decades, Portugal has been focusing on water environmental issues and published several laws to protect, monitor, plan and manage water resources in a sustainable way. This led to the identification of the main issues that the different water systems have been facing, and strategies to mitigate them could be put into practise.

Regarding Castro Verde aquifer, because it is located under a mining site, the main issue it suffers is related with mining activity, more specifically, decrease in water quality. There are other related issues, such as decrease in soil quality, degradation of the flora in the area, reduction of the fauna that lives in the region, water level decrease in some zones.

To mitigate these issues, SOMINCOR has already took actions:

- installed Water Treatment Plants;
- installed Mining Waste Treatment Plants;
- developed an intense analytical program with direct and indirect measurements to control the quality of the water;
- increased the use of recycled water for industrial purposes.

Although SOMINCOR has an intense network to control both water quality and piezometer levels, due to SARS-Cov-2 pandemics, the communication with them has not been efficient and these data is not yet available.

Several studies have been made in the Guadiana Hydrographic Region and the groundwater bodies are identified. Nevertheless, the groundwater body of the area under study still lacks in knowledge, and there is little data available regarding piezometer levels and water quality. A groundwater model of the case study should also be available. Table 12 shows the framework of SWOT analysis for Castro Verde aquifer.

Table 12. SWOT analysis for Castro Verde aquifer

Strengths	Weakness
- Adequate legislation regarding water resources management and sustainability - SOMINCOR awareness of water sustainability	- Lack of knowledge in the area under study - Lack of detailed characterization of the geological properties of the aquifer - Groundwater model not available - Poor hydrogeological characterization of the aquifer
Opportunities	**Threats**
- Increase water quality and piezometer level monitoring networks - Increase data availability - General public awareness for the water sustainability problematic	- Lack of communication with SOMINCOR due to SARS-Cov-2 pandemics - Development of mining activities - Groundwater contamination from agriculture fertilizers

3.2.5. References

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3.3. Requena-Utiel, Spain Case Study

3.3.1. Biophysical Attributes

The plain of Requena-Utiel is located in the western part of the Valencian region, in the southeast of Spain, as shown in Figure 40. In particular, it is located within the Júcar river basin district, in its central part.

Figure 40. Location map of the Requena-Utiel region, Valencia, Spain (Google Earth, November 2020)

The study site has an area of approximately 1,274.3 km2, it is located about 60-100 km from the Mediterranean coast and it has an altitude of 345-1,266 m above sea level. The northern area is the highest, there is a great descent in elevation in the southern part, as shown in Figure 43. These two characteristics cause the climate to be Mediterranean with continental features. In the hydrological year 2019/20, the average accumulated rainfall was 514 mm, the average potential evapotranspiration was 1,144.27 mm and regarding temperature, the mean was 15 °C, with a minimum of -3.8 °C in January and a maximum of 40.5 °C in August.

The groundwater mass 080.133 Requena-Utiel covers an area of 987.91 km2. Practically the entire area is situated in the province of Valencia, although in the north, a small area of approximately 21.5 km2 extends through the province of Cuenca, Castilla la Mancha. The groundwater mass 080.133 Requena-Utiel is jointly studied with the groundwater mass 080.139 Cabrillas-Malacara, which has an extension of 286.34 km2 situated entirely in the province of Valencia. Likewise, the majority of their surface is within the Júcar river exploitation system, while in the northeast, a small area of about 42.35 km2 is within the Turia river exploitation system. Figures 41 and 42 show the location of Requena-Utiel and Cabrillas-Malacara groundwater masses. For both masses, the major part of their surface is considered to be medium permeable [1].

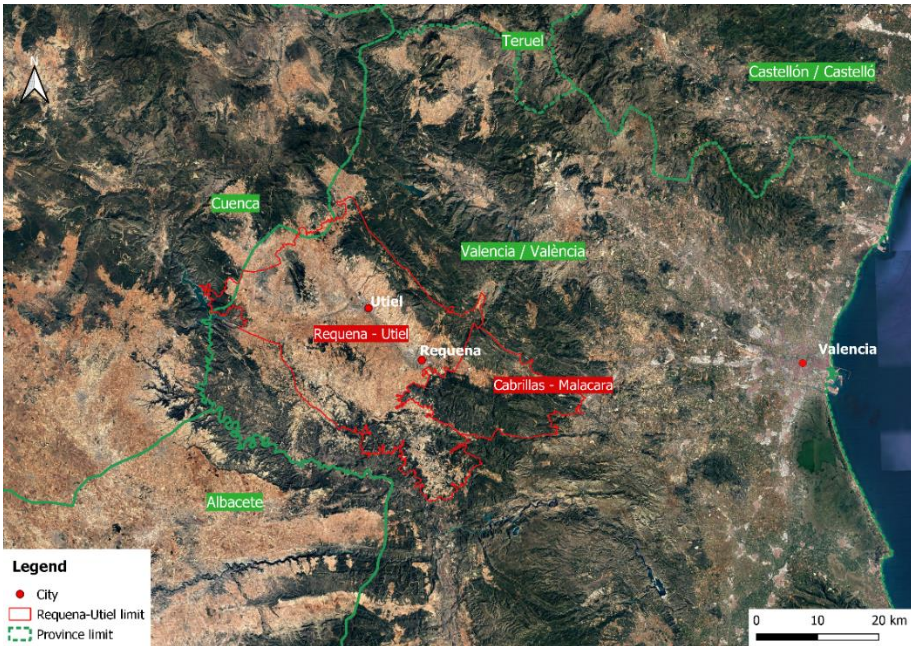

Figure 41. Location map of Requena-Utiel and Cabrillas-Malacara aquifers and the limit of provinces, Spain

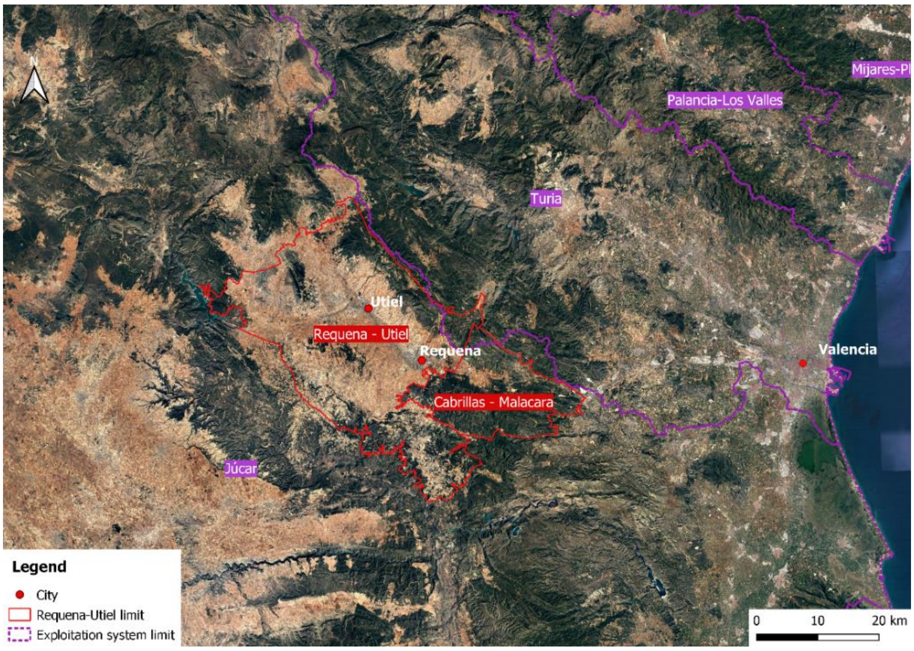

Figure 42. Location map of Requena-Utiel and Cabrillas-Malacara aquifers and the limit of exploitation system, Spain

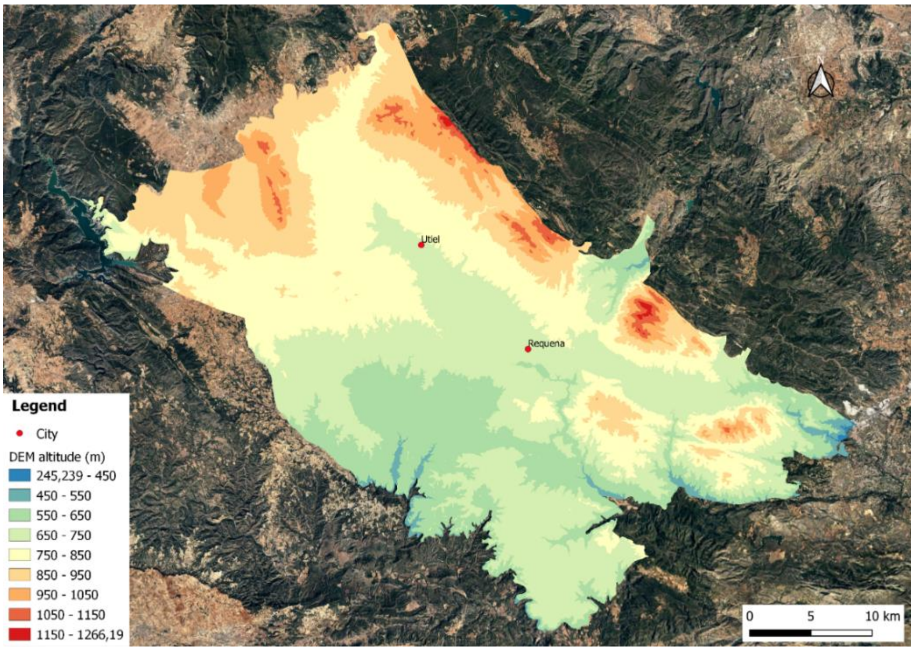

Figure 43. Elevation map of the study area of Requena-Utiel, Spain

3.3.1.1. Climate

Requena-Utiel has a Mediterranean climate with continental characteristics due to the altitude of some areas, which exceeds 1,200 m, and the distance from the sea.

The information collected by “Requena Cerrito” meteorological station from the SiAR (Sistema de información Agroclimática para el Regadío – Agroclimatic information System for Irrigation) [2] is used to characterize the temperature, precipitation and evapotranspiration in the study area. It is located in the municipality of Requena, at an altitude of 746 m. It was installed in July 1999 and it is still in operation.

Continental features of the climate can be acknowledged in the large variations in temperature that occur both between the summer and winter months and between day and night. The highest temperatures occur in summer (July and August), with mean temperatures of 23.8 °C and 23.2 °C, respectively in the period of hydrological years 2001/02-2019/20. The coldest month is January, with a mean temperature, for the same time period, of 5.1 °C. Followed by December and February, with a mean temperature of 5.8 °C and 6.1 °C, respectively. The Requena-Utiel area is characterized by a hot and dry short summer and a long winter, there are records exceeding 40 °C during the day in summer and records of temperatures below -10 °C in winter nights. Figure 44 shows the large daily thermal contrast of the study area, considering mean values. The mean value for the temperature in the recorded period is 13,7 °C, with a maximum of 37 °C and a minimum of -3 °C.

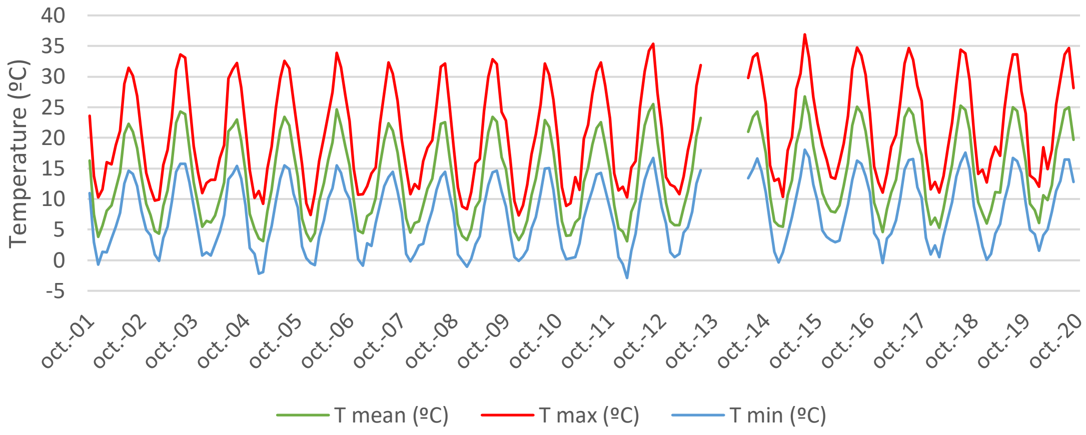

Figure 44. Average daily temperature at Requena Station, Spain [2]

Regarding the evolution of temperature from the hydrological year 1940/41 to the present, Figure 45 shows a slight increase of about a few tenths in the period 1980/81-2019/20.

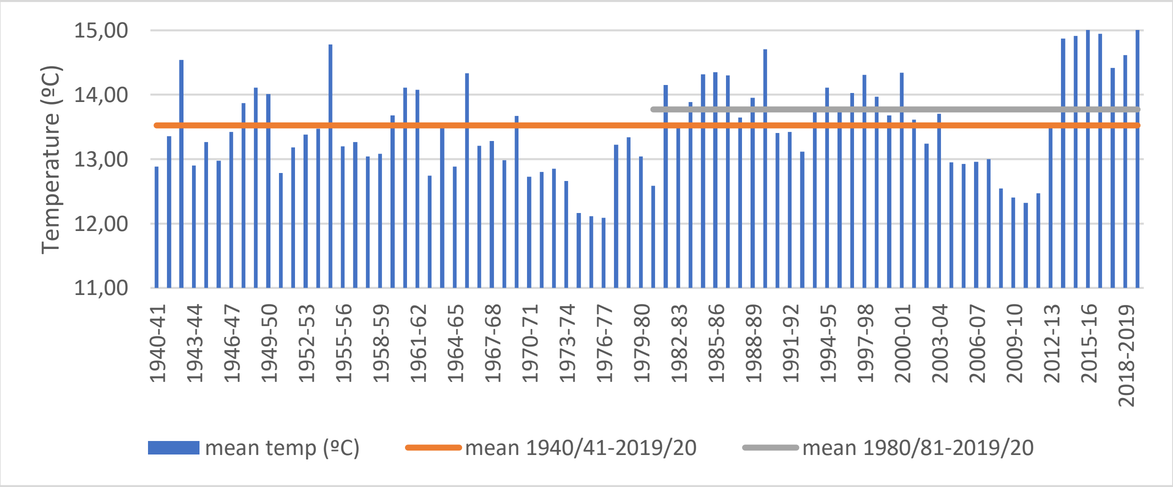

Figure 45. Average annual temperature at Requena Station, Spain [2]

Concerning the evolution of rainfall in the period 1940/41-2019/20, Figure 46 shows a great variability from one year to another and a very small decreases in the mean; the average annual accumulated precipitation for the period 1980/81-2019/20 is around 423 mm.

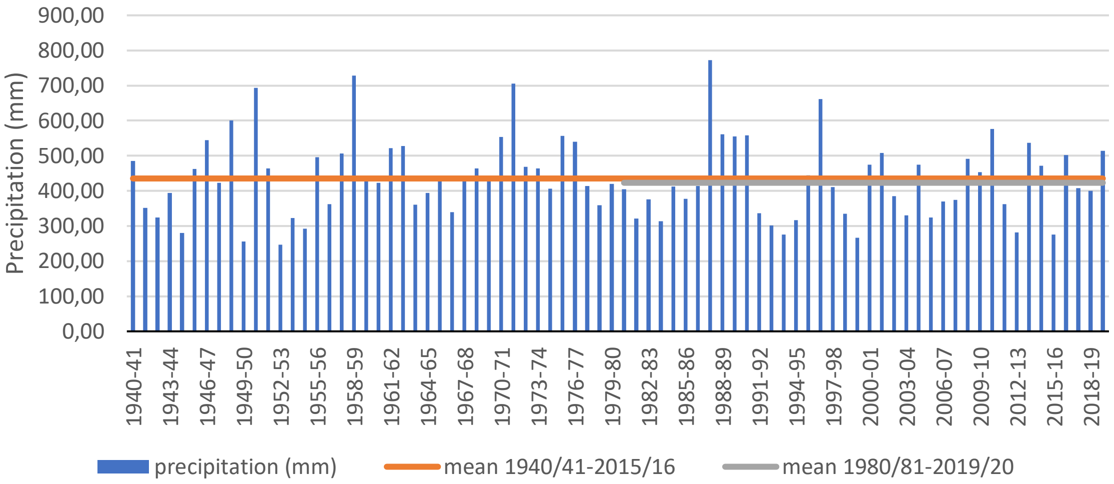

Figure 46. Accumulated annual precipitation at Requena Station, Spain [2]

There are two humid periods that coincide with the seasons of autumn (September, October and November) and spring (March, April and May). While summer, in addition to being warm, is the driest period. Rainfall at this time of the year is practically non-existent, except for possible convective storms. Due to the topography of this area, since it is surrounded by mountains, the phenomenon of thermal inversion occurs when very low temperatures are preserved in the valleys and warmer conditions are present on the slopes [3]. Figure 47 shows how the maximum accumulated precipitation takes place in spring, the mean value is around 50 mm/month. In autumn, the accumulated precipitation surpasses 40 mm/month and in summer, it falls below 20 mm/month.

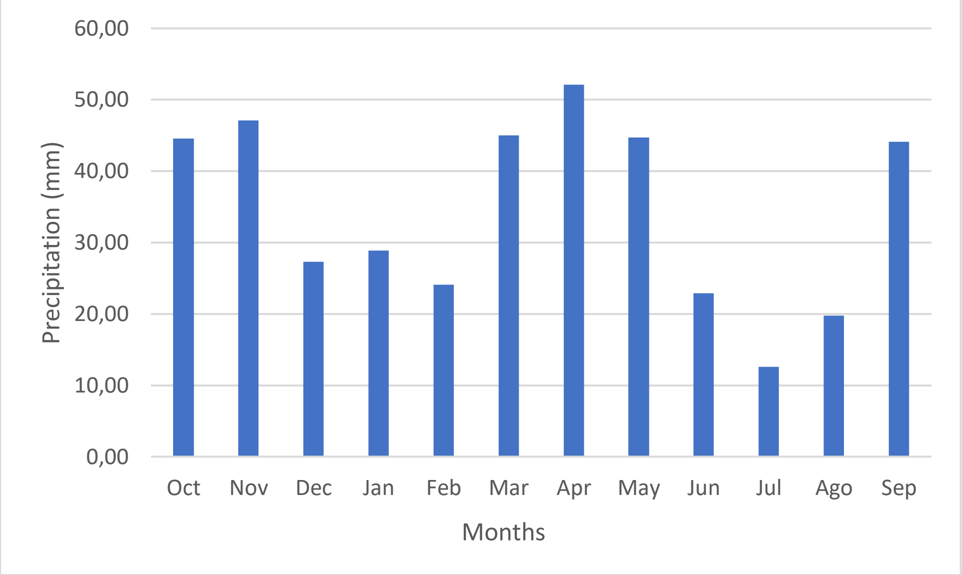

Figure 47. Mean monthly precipitation at Requena Station, Spain [2]

Lastly, the annual average potential evapotranspiration is 1,144.3 mm. Figure 48 shows the relationship between the precipitation, temperature and evapotranspiration.

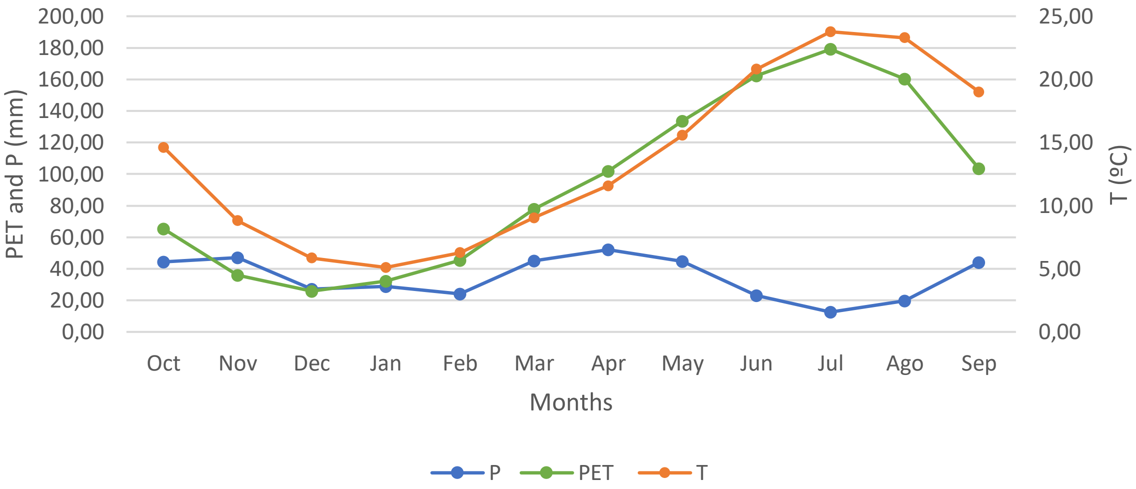

Figure 48. Average monthly rainfall, temperature and evapotranspiration at Requena Station, Spain [2]

3.3.1.2. Hydrological Context

Figure 49 displays the hydrological elements that can be found in the Requena-Utiel case study. Two springs are documented in this area, these are called Grande-Caudete and Mojón. Seven rivers represent the hydrographic network of the study area, these are the Magro river and its four tributaries, two of them rise from the Requena-Utiel aquifer, the Madre river and the

Torre ravine, and the other two rise s from the Cabrillas-Malacara aquifer, the Mijares and Buñol rivers, and the Romeroso and Reatillo rivers. There are no reservoirs within the study area, however, the Contreras reservoir defines the boundary conditions of the Requena-Utiel aquifer in its northwest border. Moreover, in the southeast, the rivers Magro and Mijares flow into the Forata reservoir.

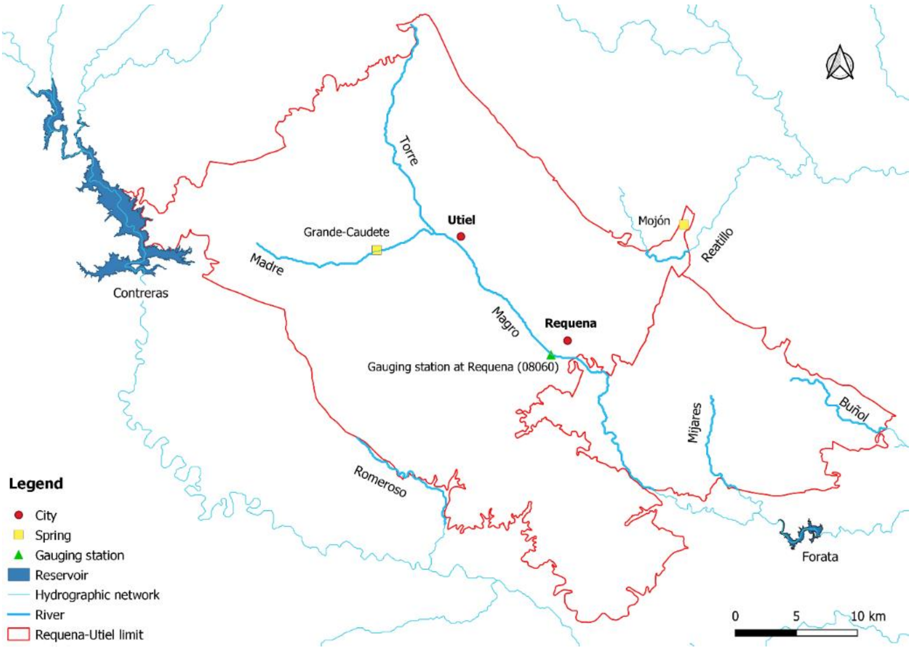

Figure 49. Location map of the springs, hydrographic network and reservoirs of the Requena-Utiel case site, Spain

In the north, the Torre ravine rises and in the northwest, the Madre river, where both meet, the Magro river originates. Magro river is one of the principal tributaries of the Júcar river, it flows into the Júcar river at the municipality of Algemesí. It has a length of 125.9 km and its basin has an extension of 1,544 km2. The descent in elevation in the study area is sharp, which characterizes this basin with a steep slope [4]. Between the rivers in the study area, the Magro river is the most relevant since it has the largest influence on the behaviour of the aquifer. The Magro river crosses the Requena-Utiel aquifer (080.133) through its central part from the northeast to the southeast, it also goes across the Cabrillas-Malacara aquifer (080.139). The two major municipalities of this area, Requena and Utiel are both located in the east Magro river basin. Outside the study, the Magro river crosses another three groundwater masses before its discharge into the Júcar river: Plana de Valencia Sur (080.142), La Contienda (080.143) and Sierra del Ave (080.144).

The only gauging station is situated in the Magro river, in the municipality of Requena, and it is part of the ROEA (Red Oficial de Estaciones de Aforo - Official Network of Gauging Stations) [5]. From this station a streamflow time series from 1914 to 2016 is obtained; however, there were no records in the period of 1980-2004. As can be seen in Figure 50, there has been a sharp drop in the flow in recent years compared to the first period recorded. In the period of 1914-1980, the average volumetric flow was 2.13 hm³/month, while, between 2004 and 2018, the average went down to 0.33 hm³/month, as shown in Figures 50 and 51.

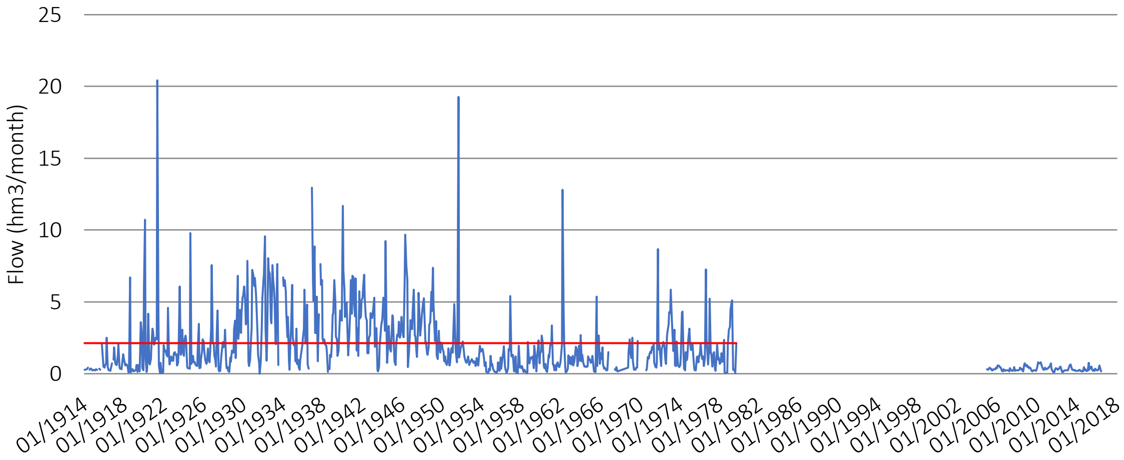

Figure 50. 1914-2016 streamflow time series at the gauging station at Requena, Spain [5]

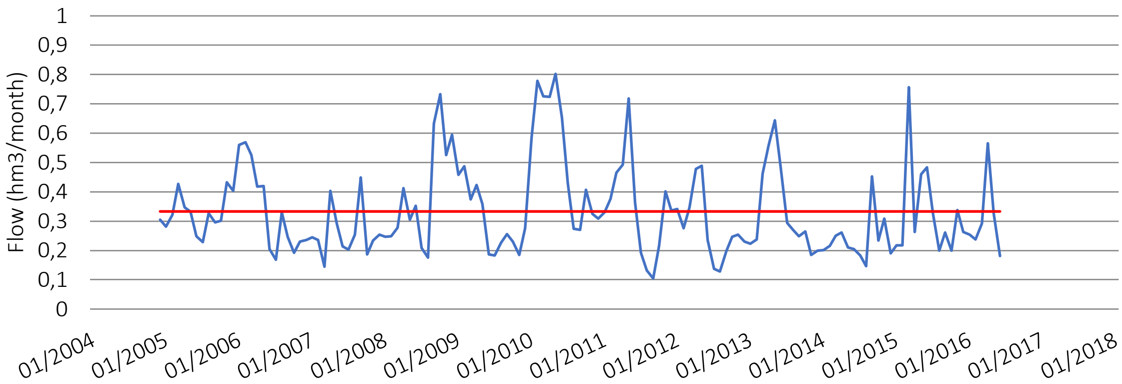

Figure 51. 2005-2016 streamflow time series at the gauging station at Requena, Spain [5]

The Mijares river does not usually carry any flow; therefore, it seems to be disconnected from the aquifer. Regarding the Buñol river, it is estimated that from November to February it has a minimum flow of 100 l/s (8,640 m3/day). These two rivers flow into the Magro river; the Mijares river meets the Magro river upstream of the Forata reservoir and the Buñol river meets it downstream. The Romeroso river, also known as Ruices ravine, flows along the west limit of the Requena-Utiel aquifer and it is a tributary of the Cabriel river. Despite being a sporadic stream that has not much flow, it may affect the groundwater system. The Reatillo river crosses the Requena-Utiel aquifer in the east and flows into the Turia river, the only data available about the flow of this stream are the entrances to the Buseo reservoir [6].

According to IGME-DGA [1] all the rivers in the study area are winners. Nonetheless, according to Martinez's [7] work, the Torre ravine, the Madre river and the Magro river are winners, but during the period of 1985-1990, when they became losers with the exception of the stretch where the first two converge to form the third.

The Contreras reservoir is located in the Cabriel river and it defines the boundary conditions of the Requena-Utiel aquifer in its northwest border. It has a storage capacity of 874 hm3 and it is exploited for water supply, irrigated agriculture, hydroelectric use and fishing. The Forata reservoir is situated outside the study area, in the southeast of Cabrillas-Malacara, it receives the flow from the Magro river. It has a storage capacity of 37 hm3 and it is exploited for irrigated agriculture and fishing. Figure 52 shows the inflow, outflow and the reservoir storage variation. Inflow, reservoir storage variation and, consequently, the outflow suffer a substantial decrease since year 1993, which coincides with the reduction in the circulating flow of the Magro River and the depletion of the piezometric level of the aquifers under study. In fact, the latter may be the cause of the decrease in flow [5].

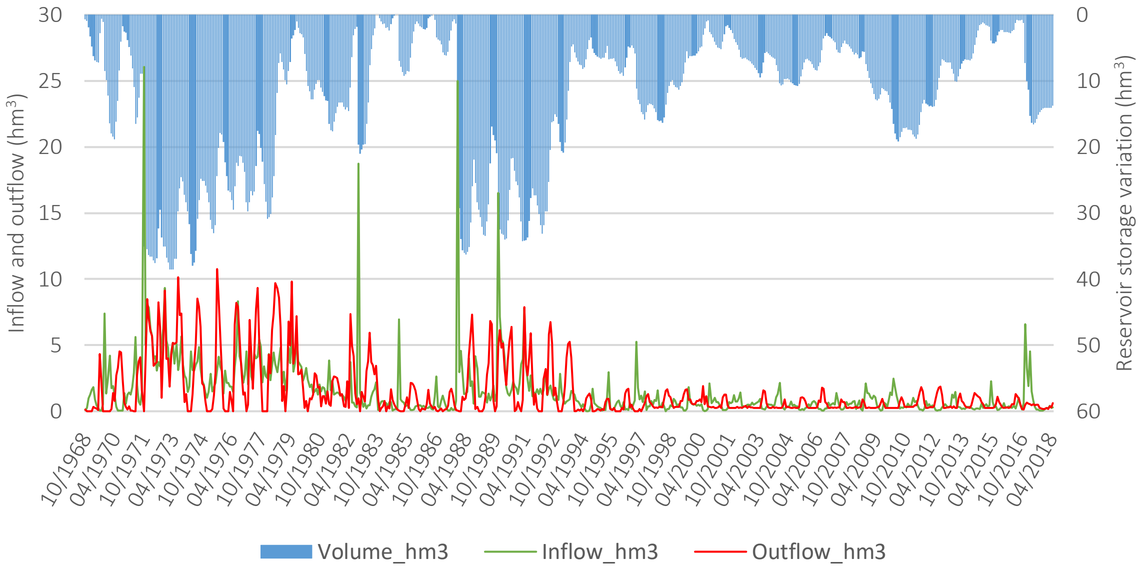

Figure 52. Inflow, outflow and reservoir storage variation series at Forata reservoir, Spain, monthly data from October 1968 to May 2018 [5]

The monthly average values of inflow, outflow and reservoir storage variation for the complete series are 1.51, 1.43 and 13.2 hm3, respectively. Nevertheless, considering two different periods within the time series, it is seen that, as of 1993, there has been a reduction of 75.72%, 78.15% and 53.44% in the value of these parameters, respectively. From October 1968 to September 1993, the monthly average value of inflow, outflow and reservoir storage variation is 2.43, 2.38 and 17.72 hm3.

From October 1993 to May 2018, these values fall to 0.59, 0.52 and 8.25 hm3. Regarding the average values for each month, there are not noteworthy variations. The lowest volume of inflow and the highest volume of outflow occurs in July, while the largest inflow and lowest outflow happen between October and March. The highest reservoir storage variation occurs between March and April, which coincide with the wet period, and the lowest, in September, which coincides with the dry periods and the irrigation season.

Regarding flood zones, the river valley of the Magro river has been an area subject to flood risk in the past; nevertheless, the Júcar Water Authority [4] states that the potential risk of suffering floods in the future as not relevant.

The Mediterranean area is one of the regions that will be most affected by the effects of climate change. Meteorological information is available from the hydrological year 1940/41 to the present, and it has been noted that since 1980 the average temperature has risen slightly, while precipitation has decreased.

Various studies [8, 9 10] have been performed to characterize the effects of climate change in the jurisdiction of the Júcar Water Authority, concluding that the anomaly in rainfall is defined by a great dispersion in its values according to the selected climate scenario. The Júcar Hydrological Plan [4], according to studies performed by CEDEX [11], establishes, for medium-term studies (up until 2027), the use of a global reduction coefficient of 12% on the average values of the system inflows with respect to those observed for the period 1980/81-2011/12.

One of the most detrimental consequences of climate change is the increase in the severity of meteorological and hydrological droughts, due to the reduction on rainfall and increase in evapotranspiration. In 2013, there was a great drought in the study area that lasted until 2016, producing a shortage of resources that forced the users of the Forata reservoir to make use of the resources from the Júcar-Turia canal, after signing the corresponding agreements for the transfer of rights to use the resource.

3.3.1.3. Aquifer Characteristics

In the western and central part of the 080.133 Requena-Utiel groundwater mass two aquifer systems can be differentiated that rest on an impermeable clay Keuper facies base. On the one hand, the upper level is an unconfined aquifer formed of permeable quaternary detritic materials from the Magro alluvial and glacis from the Utiel mountains with a thickness of 10-30 m. On the other hand, the lower level is a Miocene aquifer formed of limestone at the roof and conglomerates and sandstones at the base [1, 12].

The Miocene formation is divided into two permeable systems. The upper level is an unconfined aquifer composed of Pontian limestone, with a thickness of 80-100 m, which is drained by numerous springs. The lower level is associated with a low permeability multilayer aquifer, thus, it behaves as a confined or semi-confined aquifer, depending on the zone. It is composed of layers of conglomerates and sandstones that alternate with layers of clay and tertiary formation conglomerates [1, 12].

Moreover, the Miocene aquifer is also characterized by a piezometric divide located at the south of the Magro river. The wells located to the north of this line, at an altitude less than 700 m, they are usually artesian wells [1, 12]. There is a noticeable flow from north to south, primarily conditioned by the topography of the area, with head levels between 830 and 500 m.

The 080.139 Cabrillas-Malacara groundwater mass consists of two aquifer systems. First, the upper Cretaceous of Malacara mountains, which is composed of limestone, calcarenite, breccia, sandstone and Cretaceous marl. Secondly, the lower formation is made up of marls of Lías, Dogger and Palm [1].

Mostly, the permeability of the study area is considered to be medium, however, in some areas around the river, there are high permeability alluvial sediments, as can be seen in Figures 53 and 54.

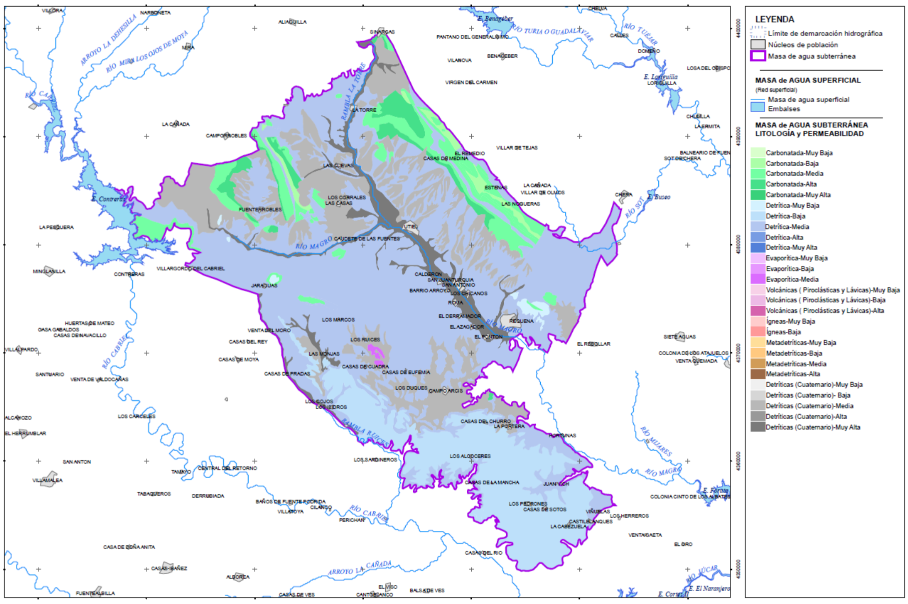

Figure 53. Lithology and permeability at 080.133 Requena-Utiel, Spain [13]

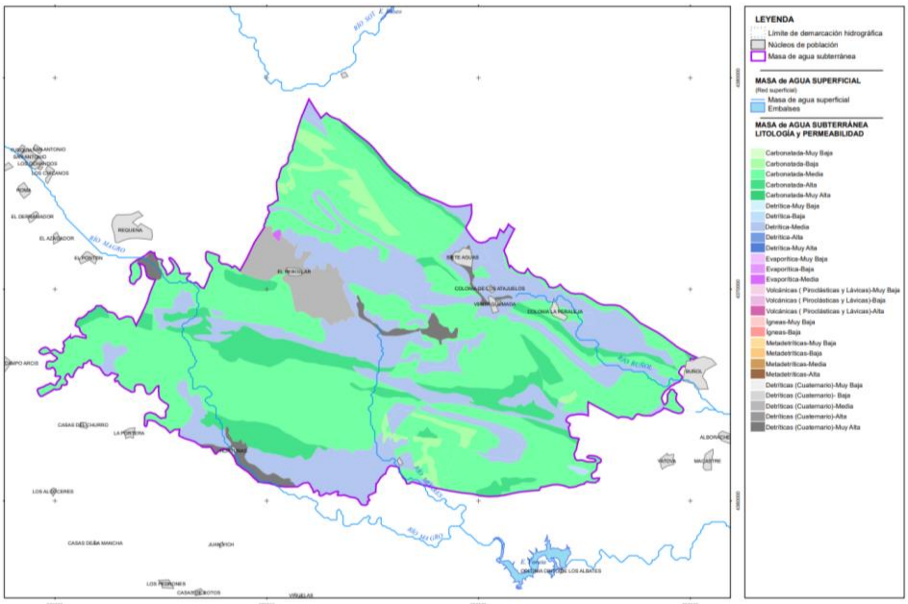

Figure 54. Lithology and permeability at 080.139 Cabrillas-Malacara, Spain [14]

Despite the geometric and hydrogeological definition described above, the Júcar Water Authority, in the initial documents of the third hydrological cycle planning, 2021-2027, [15] highlights that, currently, two different hydraulic behaviours have been detected in the Requena-Utiel groundwater mass. One located in the easternmost third and the other one that extends into the westernmost two thirds. Furthermore, they underline that the mass contributes to both the Magro river and the Cabriel basin. Nevertheless, the classical definition of the mass is still considered valid, due to the lack of more detailed hydrogeological information.

- The 080.133 Requena-Utiel and 080.139 Cabrillas-Malacara groundwater masses are surrounded by another five groundwater masses, as can be seen in Figure 55. The boundaries of the groundwater masses shown here were defined by the General Directorate for Water, DGA, of the Spanish Ministry of the Environment, [16]:

- To the east, the limit is determined by 080.132 Las Serranías groundwater mass: a carbonate and predominantly unconfined aquifer, following the thrust trace between the municipalities of Buñol and Sinarcas. The connection with the Requena-Utiel and Cabrillas-Malacara masses is variable, it depends on the piezometry of the area,

- To the southeast, 080.140 Buñol-Cheste groundwater mass is found: a detrital, alluvial, carbonate unconfined aquifer, which obtains recharge of 3 hm3/year by lateral transfer of the Cabrillas-Malacara groundwater mass,

- To the south, 080.144 Sierra del Ave groundwater mass: a detrital, carbonate predominantly unconfined aquifer, and an impermeable layer define this limit,

- To the west, the limit is determined by 080.135 Hoces del Cabriel groundwater mass: a carbonate and predominantly unconfined aquifer, following the course of the Romeroso river between the municipalities of Los Isidros and Jaraguas. It is separated from Requena-Utiel through a line that joins some small Keuper outcrops,

- To the north, 080.134 Mira groundwater mass defines the limit: a carbonate unconfined aquifer. There is a flow towards Requena-Utiel mass of 10 hm3/year,

- To the northwest and southeast, Requena-Utiel and Cabrillas-Malacara delimit with impermeable layers.

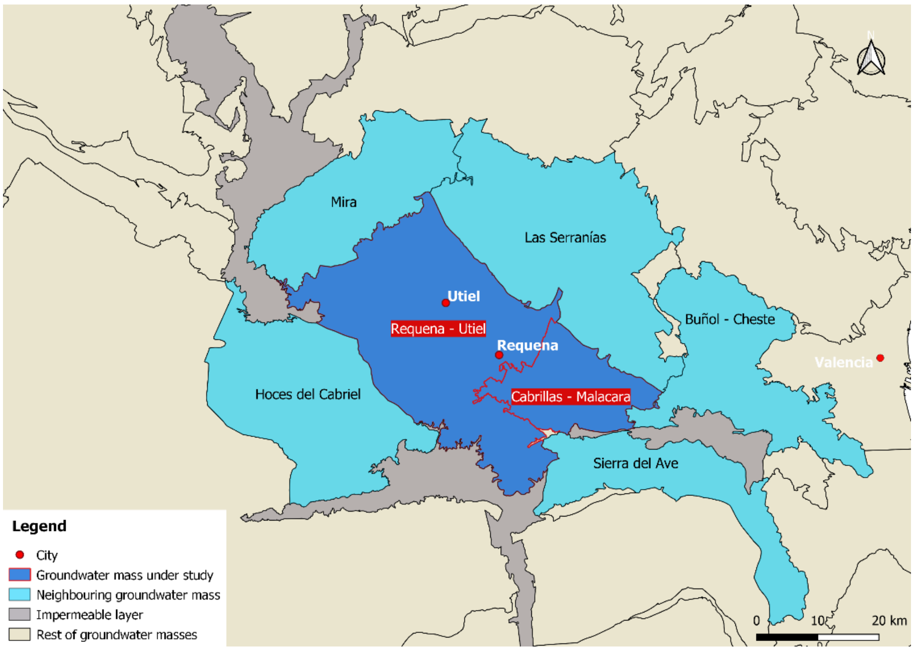

Figure 55. The Requena-Utiel study site and surrounding groundwater masses, Spain

Figure 56 shows three piezometric maps of the Spanish case study, in which the evolution of piezometry over the last decades can be appreciated. Júcar Water Authority has two wide piezometer networks, with monthly or bimonthly measurements. In Figure 57, the piezometers selected as relevant to our case study are shown, while the following Figures, 58, 59, 60, 61, 62, 63, 64 and 65 display the fluctuation of head level at these chosen locations.

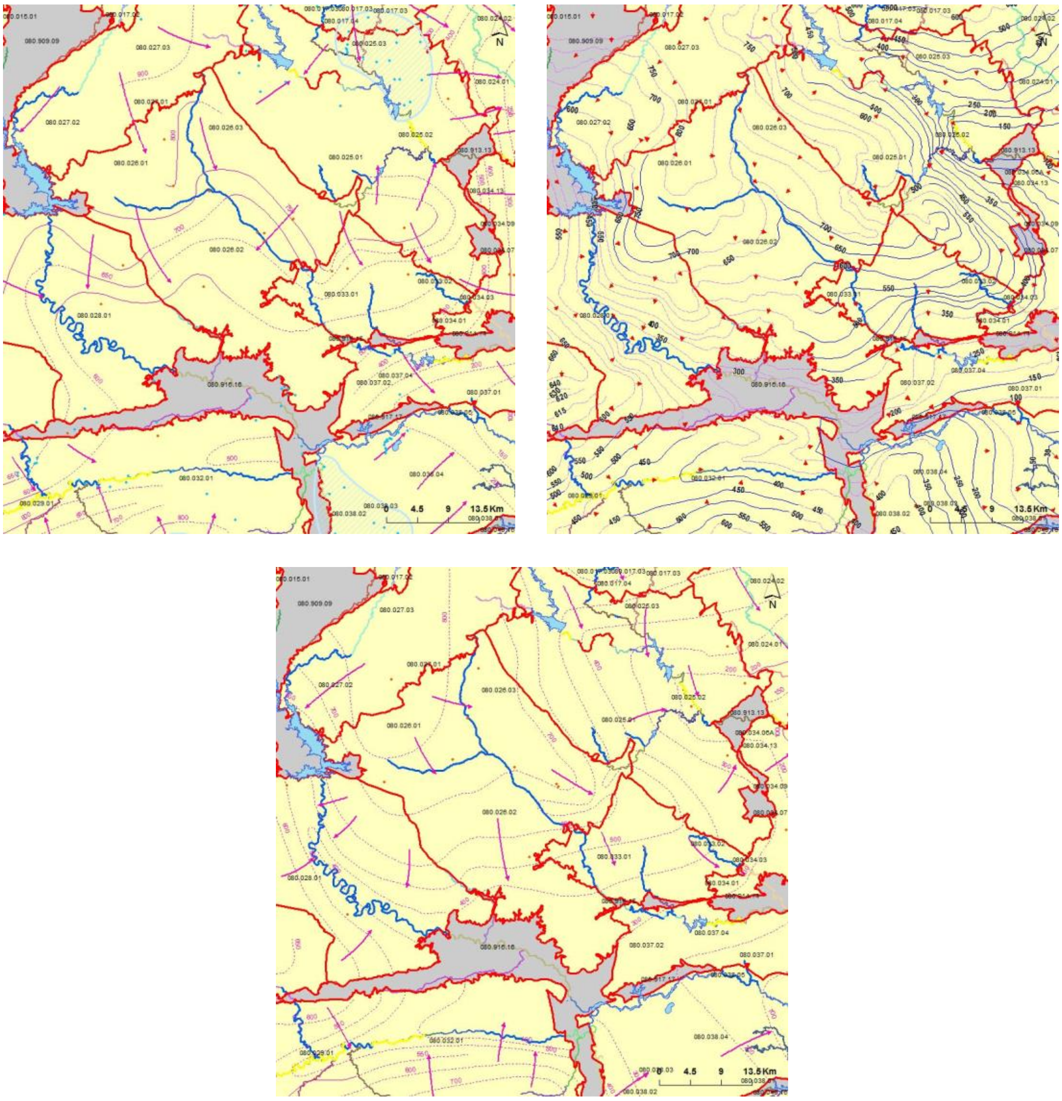

Figure 56. Piezometric maps of the Spanish case study, years 1970/74, 2005 and 2008 (CHJ)

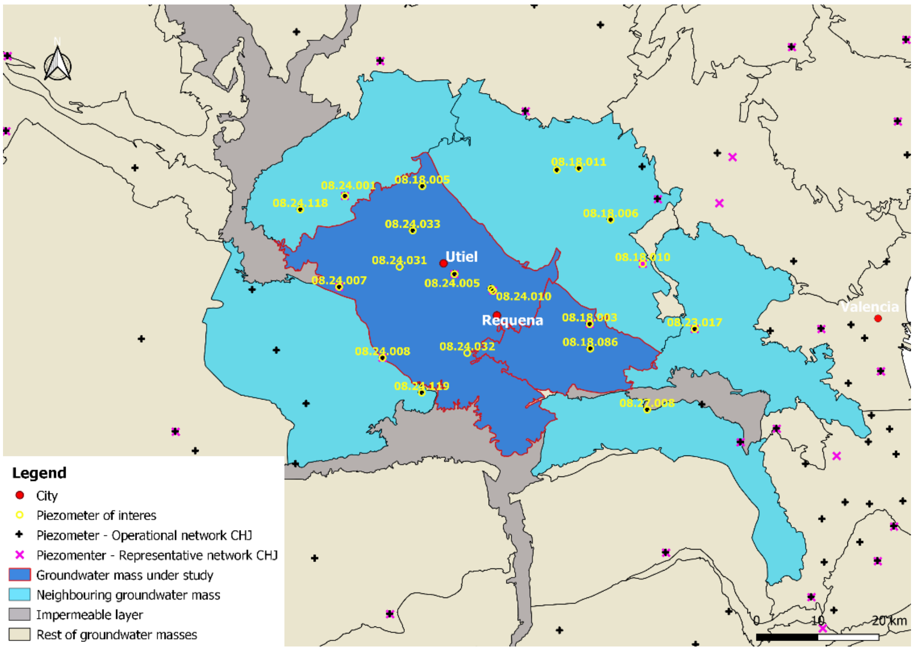

Figure 57. Piezometer location at Requena-Utiel study site, Spain

By analysing these graphs, a straightforward conclusion can be drawn, a sustained decline in head levels has been occurring throughout the series of 080.133 Requena-Utiel groundwater mass and the water balance is negative, which indicates the emptying of the aquifer. In the hydrological year 2016/2017 an improvement was noted, due to heavy rainfall. Nevertheless, years later, the downward trend remains. Regarding the series of 080.139 Cabrillas-Malacara groundwater mass, they show that the quantitative state is good.

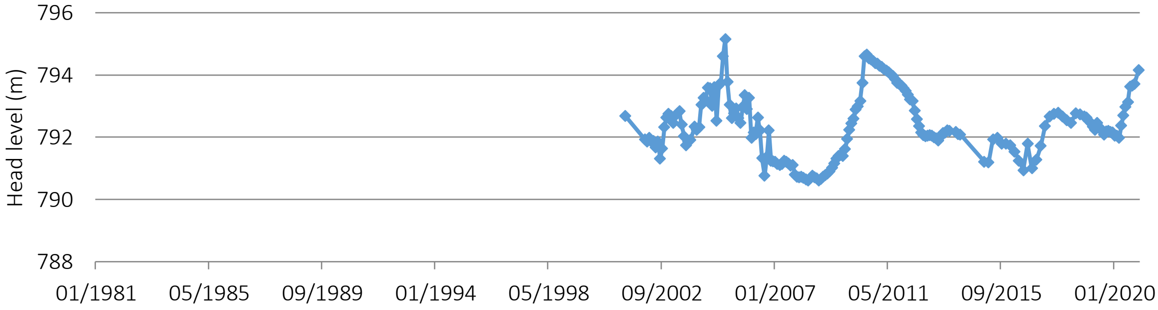

Figure 58. Head level series at 08.24.007, Requena-Utiel, Spain [17]

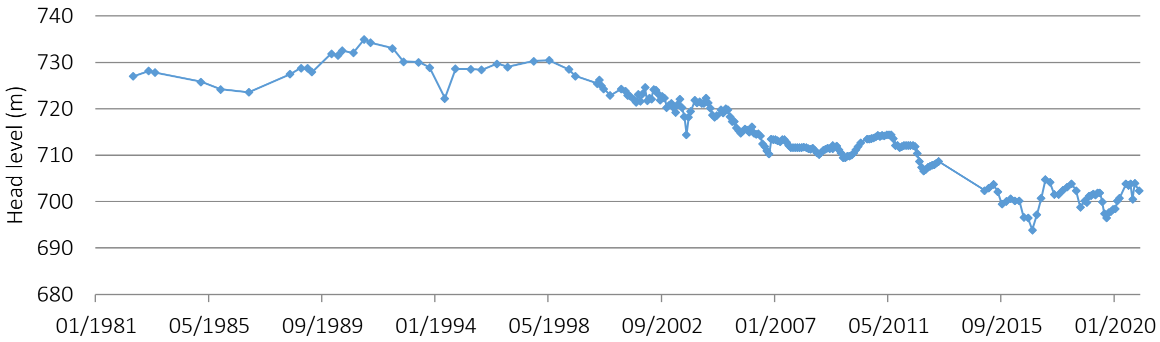

Figure 59. Head level series at 08.24.010, Requena-Utiel, Spain [17]

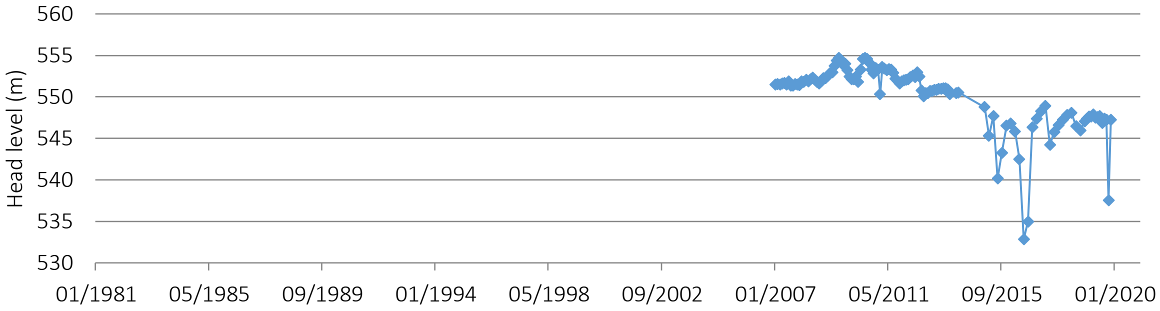

Figure 60. Head level series at 08.24.032, Requena-Utiel, Spain [17]

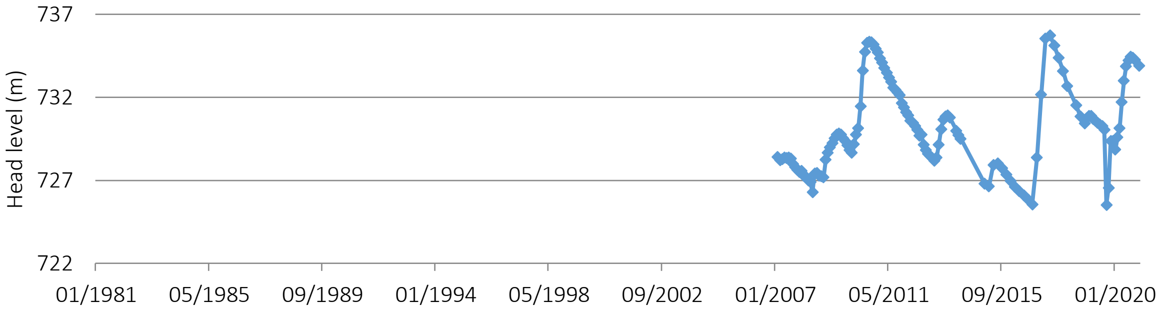

Figure 61. Head level series at 08.24.005, Requena-Utiel, Spain [17]

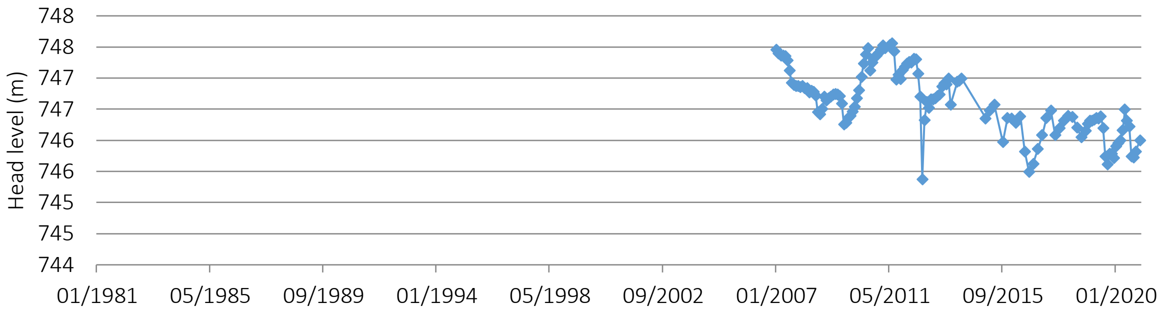

Figure 62. Head level series at 08.24.033, Requena-Utiel, Spain [17]

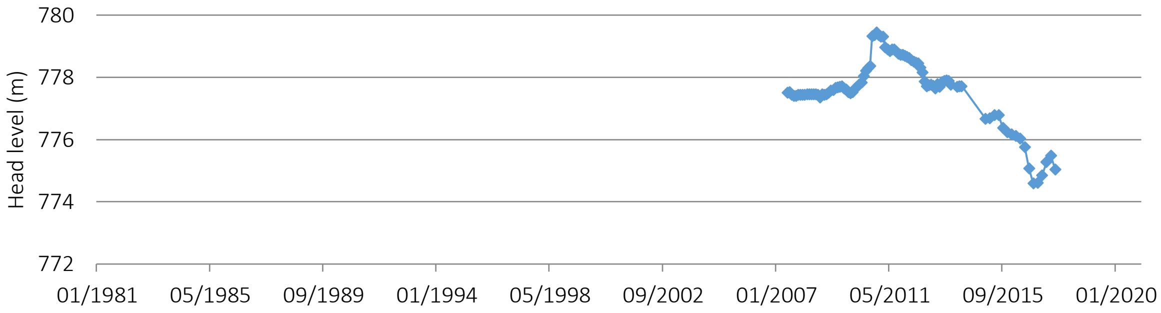

Figure 63. Head level series at 08.24.031, Requena-Utiel, Spain [17]

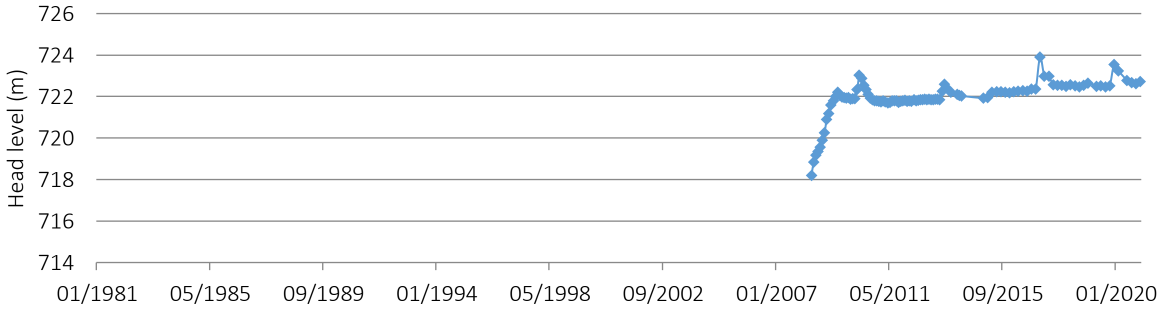

Figure 64. Head level series at 08.18.003, Cabrillas-Malacara, Spain [17]

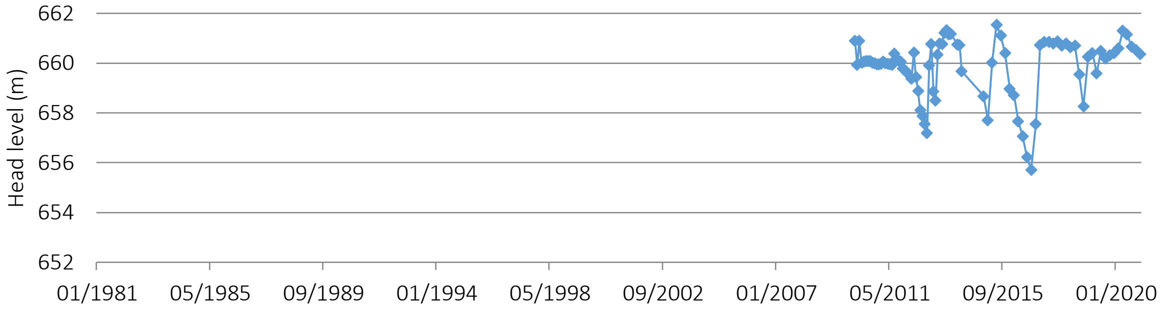

Figure 65. Head level series at 08.18.086, Cabrillas-Malacara, Spain [17]

Figure 66 displays the location of the points that monitor the Requena-Utiel and Cabrillas-Malacara masses.

Royal Decree 1514/2009 [18] establishes a threshold value of 50 mg/l for nitrates and for pesticides, a value of 0.1 µg/l per substance or 0.5 µg/l to the sum of all the pesticides detected. The threshold value of the rest of pollutants contained in the Royal Decree 1514/2009 must be stipulated by the competent Water Authority, in Annex II, the criteria to be followed are indicated. In the case of The Júcar Authority, these threshold values only apply to groundwater masses at risk of marine intrusion. Thereby, for the case study in Spain, solely nitrates and pesticides are analysed.

Figure 67 shows the nitrate values measured throughout 2008 and 2020 for the Requena-Utiel groundwater mass. In 2008, the control point 08.133.CA001 registers values much higher than the threshold, which may be due to the area it samples, it is located near the city of Utiel and in an area of great agricultural activity. A decrease can be noted in 2009, however, up-to-date data for that particular site are not available to define its current status. The values of the rest of the control points indicate a good chemical state, although as of 2020, values close to the threshold appear. Figure 68 shows the nitrate values for the Cabrillas-Malacara groundwater mass, indicating a good chemical state. Regarding pesticides, they were only detected in 2009 at control point 08.139.CA002, with a value of 0.00247 µg/l, much lower that the threshold, not posing any risk.

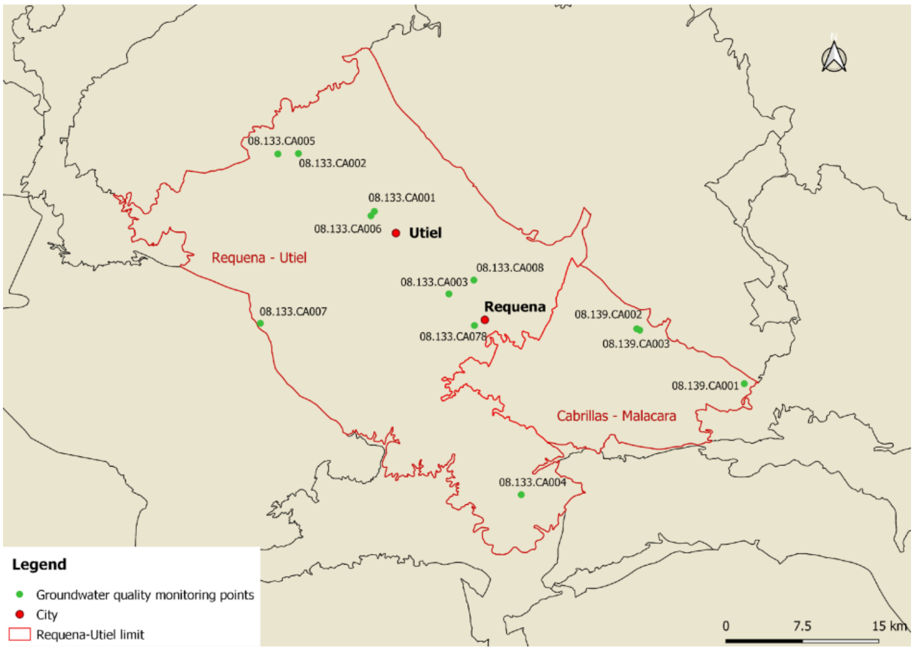

Figure 66. Groundwater quality monitoring points location in Requena-Utiel, Spain

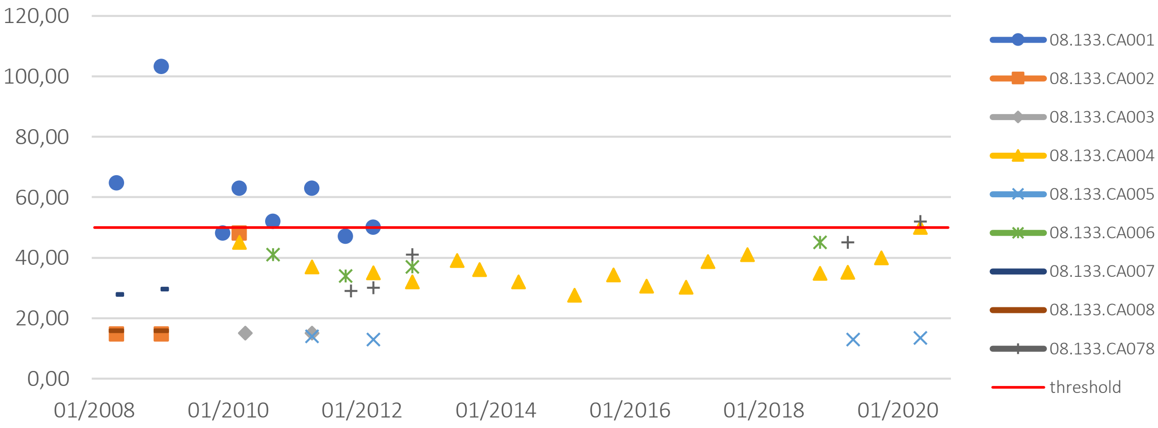

Figure 67. Nitrate observations at Requena-Utiel, Spain

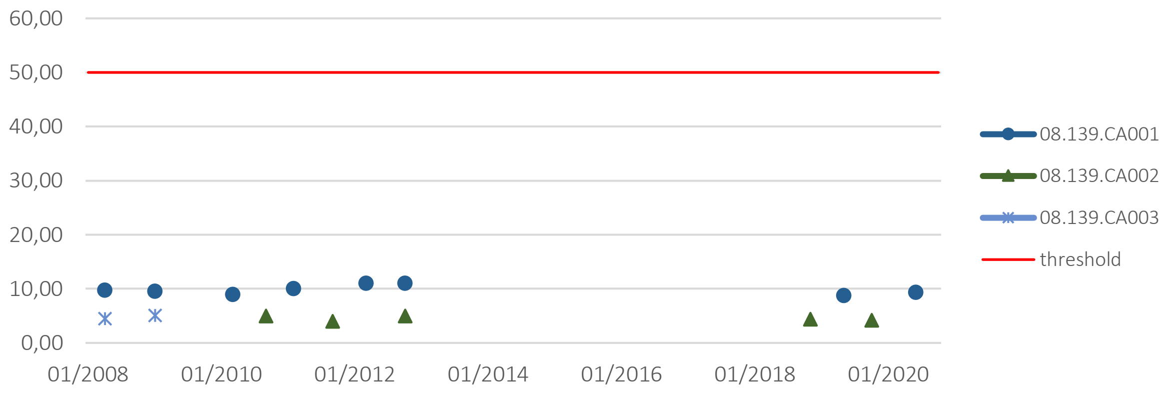

Figure 68. Nitrate observations at Cabrillas-Malacara, Spain

3.3.1.4. Land Use

More than half of the surface corresponds to agricultural areas, approximately 52.5 %. Essentially, the other half of the surface pertain to forest and semi natural areas, approximately 46.3 %. The remaining 1.2 % corresponds to artificial areas such as urban fabric and roads. The Figure 28 shows the distribution of these land use categories in the Requena-Utiel territory. A more thorough classification of land use and the area that each element of this classification occupies and its percentage by category is shown in Table 13.

Table 13. Land use in Requena-Utiel site [18]

Land use category	Land use feature	Area (km^2)	Area (%)
Agricultural areas	Non-irrigated arable land	22.97	3.4
	Permanently irrigated land	0.94	0.1
	Vineyards	472.63	70.6
	Fruit trees and berry plantations	85.10	12.7
	Olive groves	4.01	0.6
	Pastures	3.41	0.5

	Annual crops associated with permanent crops	0.52	0.1
	Complex cultivation patterns	37.19	5.6
	Land principally occupied by agriculture, with significant areas of natural vegetation	42.25	6.3
Forest and semi natural areas	Coniferous forest	287.77	48.8
	Mixed forest	0.98	0.2
	Natural grasslands	103.67	17.6
	Sclerophyllous vegetation	145.36	24.7
	Transitional woodland-shrub	51.15	8.7
Artificial surfaces	Continuous urban fabric	2.96	18.8
	Discontinuous urban fabric	5.39	34.1
	Industrial or commercial units	4.40	27.8
	Road and rail networks and associated land	1.34	8.5
	Mineral extraction sites	1.29	8.2
	Construction sites	0.42	2.6

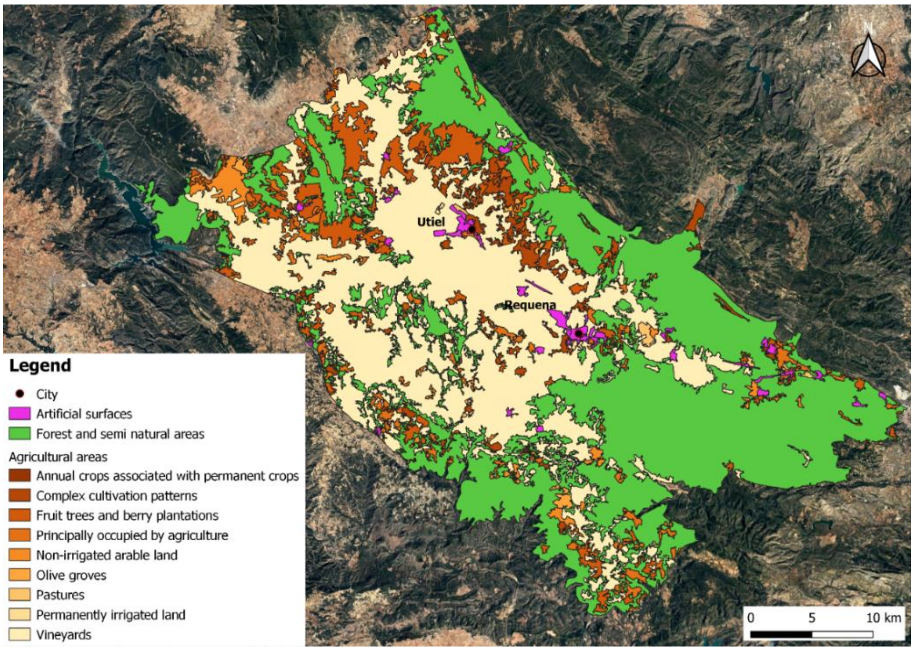

Figure 69. Land use map of Requena-Utiel site, Spain [19]

3.3.2. Water Development and Management

3.3.2.1. Water Supply and Water Uses

Agriculture is the most prominent sector in water and land use in the system; in 2017 it entails around 88% of the total groundwater use. The main cultivation in the area is vine for winemaking, woody crops such as fruit trees, almond trees and olive groves, as well as herbaceous crops [4].

The main irrigation users are grouped into three agricultural demand units (ADU), which are presented in Table 14. Among these three ADU, there are 1,001 registered wells in 080.133 Requena-Utiel groundwater mass and 55 wells in 080.139 Cabrillas-Malacara, their location is displayed in Figure 70. Riegos de Alto Magro has the highest pumping.

Table 14. Agricultural Demand Units (ADU) and irrigation users at Requena-Utiel case study [4]

ADU code	ADU mame	Irrigation user
082033A	Hoya de Buñol y Chiva	C.G.U. Godelleta, Aguas de Cheste-Chiva IC, Buñol IC, Chica IC, La Redonda de Yátova IC, San Jaime de Alborache IC and Santa Bárbara de Macastre IC
082044A	Alto Magro irrigations	Fuencaliente Irrigation Community (IC), Fuente de las Reinas IC, Fuente del Pino IC, Gollizno IC, Las Casas-Los Corrales de Utiel IC, Regajo IC, Riegos Las Cuevas de Utiel S. COOP., Riegos La Mina IC, Regantes de La Vega de San Antonio IC and Central Union of the Irrigation Communities of Requena
082044B	Mixed irrigations of the Utiel plain	Riegos los Ruices IC

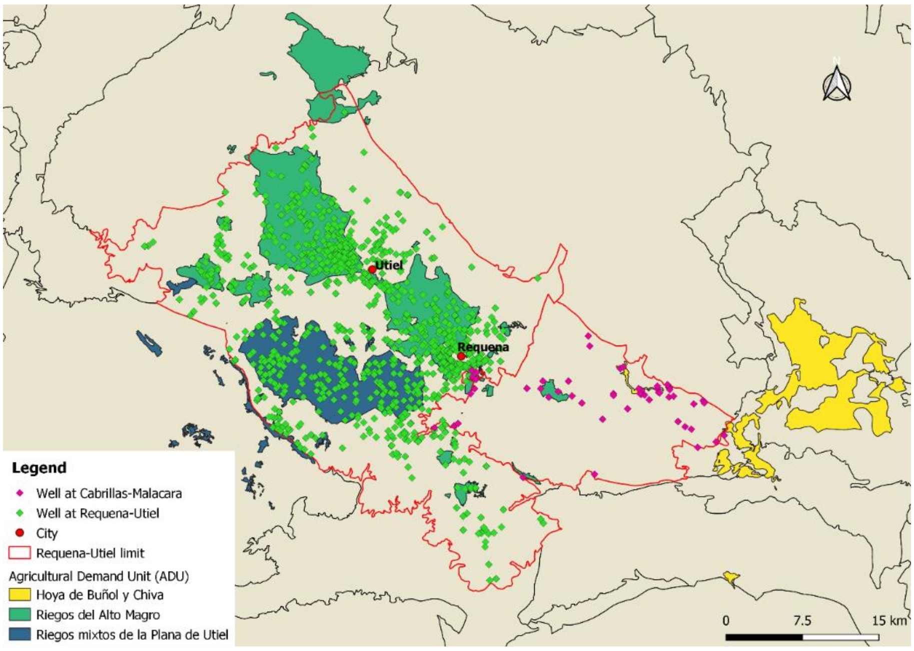

Figure 70. Agricultural demand units and their corresponding wells at Requena-Utiel case study, Spain

Afterwards, the second largest use of the water resources of the system is urban supply, representing approximately 17% of the groundwater resources. The supply users, also known as urban demand units (UDU), which are supplied by groundwater are shown in Figure 30 and Table 15. There are 38 registered wells in 080.133 Requena-Utiel groundwater mass and 6 wells in 080.139 Cabrillas-Malacara, their location is displayed in Figure 71. In this case, the greatest pumping takes place in the wells near the towns of Utiel and Requena, since they have a bigger number of inhabitants.

Table 15. Urban Demand Units (UDU) and municipalities at Requena-Utiel case study [4]

UDU code	UDU mame	Municipality
246213	Subterráneo de Requena	Requena
300014	Superficiales del Macizo del Caroche y Hoya de Buñol	Albarache, Ayora, Bicorp, Buñol, Cofrentes, Cortes de
400133	Subterráneos de Requena-Utiel	Caudete de las Fuentes, Fuenterrobles and Utiel
400135	Subterráneos de Hoces del Cabriel	Venta del Moro
400140B	Subterráneos de Buñol-Cheste sur	Siete Aguas

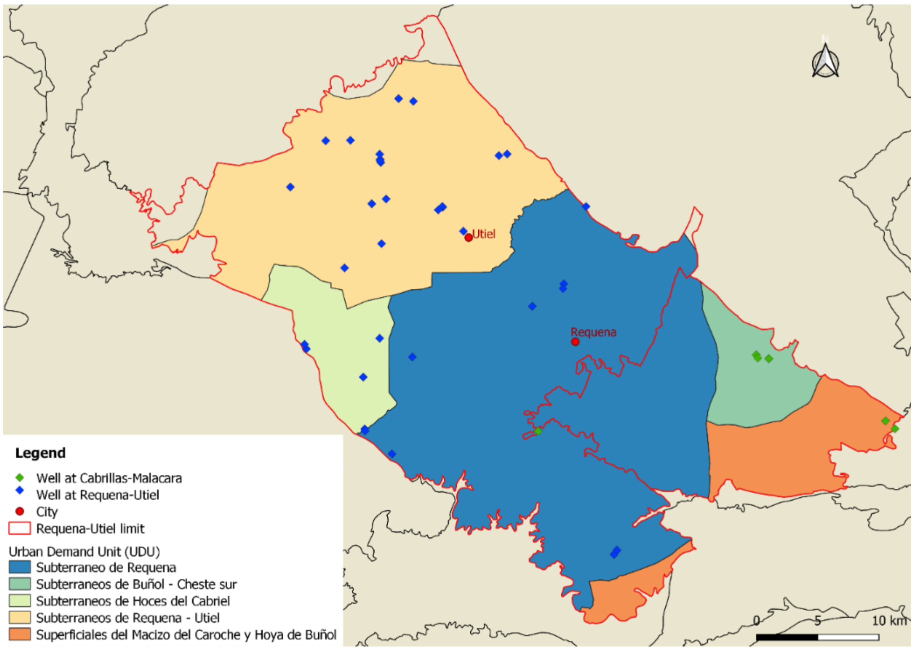

Figure 71. Urban demand units and their corresponding wells at Requena-Utiel case study, Spain

Finally, industrial production is the third water demand, assuming approximately 12% of the groundwater resources. Among the industries that can be found in the study area, it can be highlighted the tanning, food and furniture industries. There are 63 registered wells in 080.133 Requena-Utiel groundwater mass and 7 wells in 080.139 Cabrillas-Malacara, their location is shown in Figure 72.

Figure 73 shows the evolution of pumping in the study area from 1980 to 2017. It is noted how the groundwater supply for irrigation maintains a progressive growth throughout the series. However, it began to be really relevant from year 2001. When it started to account for more than 30 % of the demand, the pumping rate for the Requena-Utiel mass was 2.6 hm3 and 0.3 hm3, for Cabrillas-Malacara. The most current data, from 2017, shows that agricultural supply has risen to 15.3 hm3 in Requena-Utiel and 1.1 hm3 in Cabrillas-Malacara. In the case of urban supply, it remains constant throughout the series and despite being a smaller number of wells, the extracted volume is considerable.

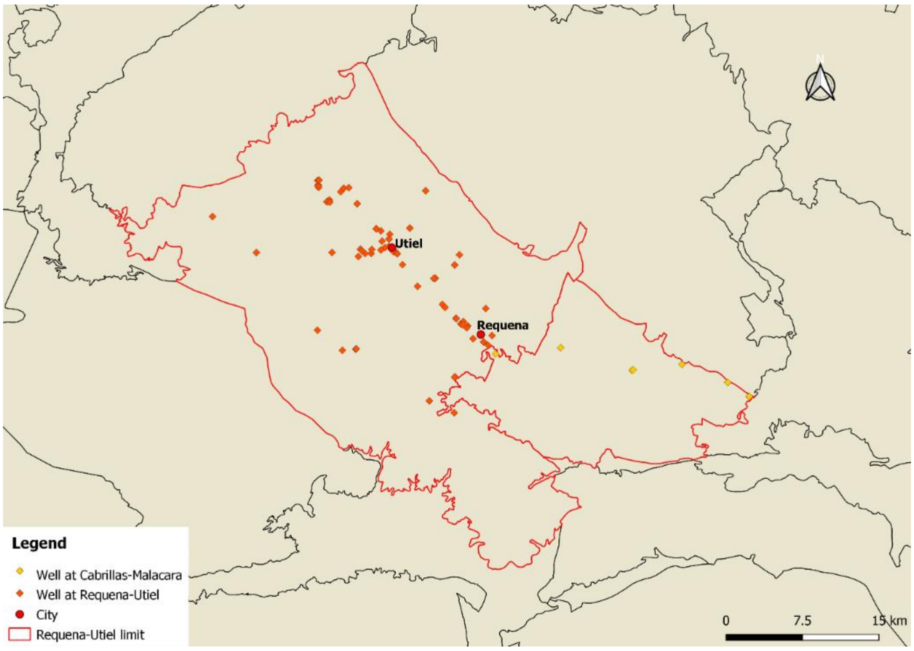

Figure 72. Wells for industrial demand at Requena-Utiel case study, Spain

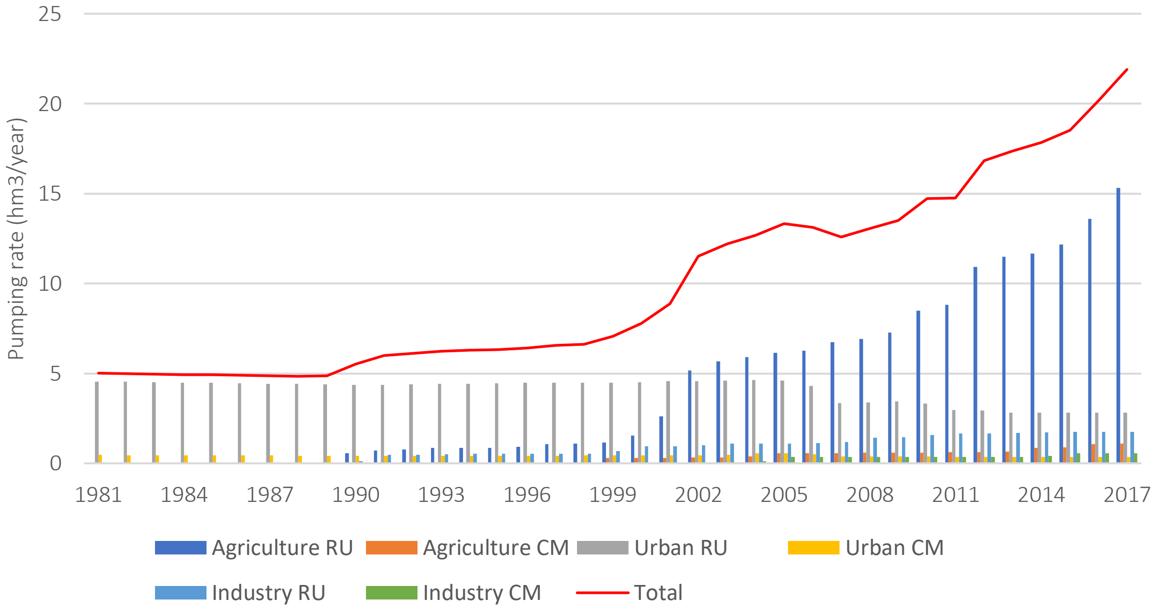

Figure 73. Pumping in Requena-Utiel and Cabrillas-Malacara groundwater masses, Spain

3.3.2.2. Main Issues

080.133 Requena-Utiel and 080.139 Cabrillas-Malacara groundwater masses are characterized by being heavily exploited aquifers, thus, the main issue would be described as unsustainable use of groundwater resources caused by irrigated agriculture. Numerous pumping began in the 1980s and they have been increasing since 2001, due to farmers moving from vine crops to vines growing in trellises. The latter is more productive but requires irrigation to adequately control the stress at which the plant grows. The water level series show a progressive decrease and the aquifer storage balance is negative, which indicates the emptying of the aquifer. If this situation continues in the future, system recovery could be jeopardized.

This consistent drop in the water table may have caused other issues in surface water resources that depend on groundwater. The river-aquifer flow exchange between the Magro river and the aquifer system has diminished, which may be due to the loss of aquifer storage. Furthermore, a streamflow depletion in the Magro river has been noted, which may be owning to the decrease in rainfall that has been experienced in recent decades. Consequently, the inflows to the Forata reservoir have been lower, which has led to supply problems to its users (irrigation purposes).

3.3.3. Groundwater Governance System

Spanish water governance system unites common efforts of Public Administrations and private enterprises. Moreover, this system relies on strong public participation by civil society dating back centuries. The user communities are involved in the process of preparing the different plans and laws in relation to water management.

3.3.3.1. Actors and Institutions Involved in Water Management

The Spanish water governance system is based on integrated management of water resources on river basin scale alongside national scale.

On a national scale, the Ministry for Ecological Transition and Demographic Challenge (Ministerio para la Transición Ecológica y el Reto Demográfico, MITECO) of the Spanish

Government has the authority over water governance. Its office is located in Madrid, the capital of the country.

On a river basin scale, Water Authorities manage the water resources of the hydrographic demarcations, which refers to terrestrial and marine area composed of one or more nearby hydrographic basins and the transitional, groundwater and coastal water associated to these basins. These basin organizations are autonomous public bodies attached to the Ministry for Ecological Transition and Demographic Challenge (Ministerio para la Transición Ecológica y el Reto Demográfico, MITECO) of the Spanish Government, through the General Directorate for Water (Dirección General del Agua), under the superior direction of the Secretary of State for the Environment (Secretaría de Estado de Medio Ambiente). The organization chart of the authorities in relation to water governance in Spain is displayed in Figure 74. The Júcar Water Authority is the body responsible for the management of 080.133 Requena-Utiel and 080.139 Cabrillas-Malacara groundwater masses. It has several offices distributed throughout the territory it governs, in Teruel, Albacete, Alicante and Valencia, the latter being its head office.

Figure 74. Organization chart of the authorities in relation to water governance in Spain, case study of Requena-Utiel

Additionally, the Spanish water governance system relies on public participation from user communities. Irrigation communities are governed by the legal framework of the Water Law in force, they have the right to attend and intervene in matters that are submitted for debate, as well as the right to vote. They are involved in the process of preparing the different plans and laws in relation to water management.

Thanks to the collaboration with the Irrigation Communities, we can benefit from their experience and knowledge. Likewise, several wine companies (Vegalfaro, Vereda Real and Coviñas) are interested in sharing their experience in water use. It is necessary to establish a close connection with these stakeholders, since the trend to install irrigation systems in vineyards is an increasingly widespread method.

3.3.3.2. Water Policy and Current Instruments of Water Regulation

National Hydrological Plan [20] in effect was approved by the Spanish Congress through Law 10/2001, of July 5, National Hydrographic Plan [21], and it was modified by Law 53/2002, of December 30 [21], Law 62/2003, of December 30 [23], Royal Decree-Law 2/2004, of June 18 [24] and Law 11/2005, of June 22 [25]. It contemplates measures to satisfy the water resources planning objectives for the different Spanish river basin districts in a balanced manner.

Basin Hydrological Plans are adapted to the strategies defined in the National Hydrological Plan [20]. Likewise, the composition of these documents is executed considering the principles of the Directive 2000/60/EC of the European Parliament and of the Council, of 23 October 2000 [26], which establishes a framework for Community action in the field of water policy, also known as the EU Water Framework Directive, and the principles of the consolidated Law of Water (texto refundido de la Ley de Aguas, TRLA), approved by Royal Legislative Decree 1/2001, of July 20 [27]. As described in the article 40.2 of the consolidated Law of Water (TRLA), the territorial scope of each Basin Hydrological Plan must conform to the limits of the corresponding river basin district. Additionally, the article 40.1 of the same law states that these documents will be developed by the corresponding basin organization or by the competent hydraulic Administration. These Plans determine the specific guidelines to be followed in order to execute an optimal water management in each basin district.

InTheMED Spanish case study is regulated by the Hydrological Plan of the Júcar Hydrographic Demarcation for the 2015-2021 term [4], approved by Royal Decree 1/2016, of January 8 [28], and it was written by the Júcar Water Authority. The territorial scope of the Júcar Water

Authority is defined by the article 2.3 of Royal Decree 125/2007, of February 2 [29]. Currently, the Júcar Water Authority is immersed in the preparation of the future Hydrological Plan for the 2021-2027 term [15].

The Hydrological Plan of the Júcar Water Authority for the 2015-2021 term [4] declares the 080.133 Requena-Utiel groundwater mass in bad quantitative state. Consequently, and with the purpose of accomplishing efficient management and planning to ensure a reliable service to users and to restore the good quantitative status of the groundwater mass, the Exploitation Plan for the Requena-Utiel groundwater mass [30] was created in December 2016. The implementation of this Exploitation Plan was for a period of three years from the beginning of the hydrological year 2016/2017, with annual follow ups of the evolution of surface and groundwater resources. In December 2020, the Exploitation Plan for the Requena-Utiel groundwater mass was reviewed and updated. Nevertheless, once the Hydrological Plan of the Júcar Hydrographic Demarcation for the 2021-2027 term comes into force, this Exploitation Plan must be reviewed again within a maximum period of six months [31].

In this Exploitation Plan, the vegetative cycle of the main crops presents in the area of Requena-Utiel and the evaluation of the rainfall recorded in the area in two different periods: a winter period (from December to March) and another period that only considers the month of April, are considered so as to characterize each year as a dry, normal or wet year and, thereafter, establish the average gross irrigation water requirements for each year. The Júcar Water Authority applies the following criteria:

Dry year, when the precipitation in April is equal or less than 30 mm. Likewise, when the precipitation in April is between 30 mm and 50 mm and the accumulated precipitation in the winter period is equal or less than 100 mm. The average gross irrigation water requirements for the cultivation of vine, olive grove and dried fruit trees will be 600 m3/ha/year, which can be increased up to 900 m3/ha/year as maximum.

Normal year, when the precipitation in April is between 30 mm and 50 mm and the accumulated precipitation in the winter period exceeds 100 mm. Likewise, when the precipitation in April exceeds 50 mm and the accumulated precipitation is the winter period is equal or less than 100 mm. The average gross irrigation water requirements for the cultivation of vine, olive grove and dried fruit trees will be 600 m3/ha/year, without exceeding this value.

Wet year, when the precipitation in April exceeds 50 mm and the accumulated precipitation in the winter period exceeds 100 mm. The average gross irrigation water requirements for the cultivation of vine, olive grove and dried fruit trees will be 600 m3/ha/year, which can be reduced to 450 m3/ha/year as maximum.

To date, only precipitation and plant water needs has been analysed to establish agricultural supply rules. InTheMED aspires to elaborate rules using more sophisticated techniques, which consider a greater number of variables.

The effective control of the water volumes employed along with the conditions under which measurements and records must be executed are established in Order ARM/1312/2009, of May 20 [32]. User communities and private users are obliged to provide the Júcar Water Authority their consumption data in each catchment every six months, also including the irrigated area and the type of crop.

Furthermore, in 2018 the Special Drought Plan for the Júcar Hydrographic Demarcation [33] was approved through Order TEC/1399/2018, of November 28 [34], which aims to minimize environmental, social and economic impacts of droughts, differentiating situations of prolonged drought (meteorological and hydrological droughts), associated with the decrease in rainfall and water resources in natural regime, and temporary shortages, related to temporary issues of lack of resources to meet the various socioeconomic water uses. Structural scarcity, produced when the water resources scarcity issues in a given area are permanent, is managed within the scope of general planning.

To combat groundwater contamination, Europe count on Directive 2006/118/EC of the European Parliament and of the Council, of 12 December 2006, on the protection of groundwater against contamination and deterioration [35], whereby the criteria for evaluating the chemical status of groundwater are defined. In Spain, Directive 2006/118/EC was transposed by Royal Decree 1514/2009, of October 2, which regulates the protection of groundwater against contamination and deterioration [18].

Spain has a proper policy framework on the treatment and discharge of wastewater. The regulations to consider with regard to urban wastewater rejects are Royal Decree-Law 11/1995, of December 28 [36], and the Royal Decree 509/1996, of March 15 [37], which establish the rules applicable to the treatment of urban wastewater. In order to request a discharge authorization, the Regulation of the Public Hydraulic Domain [38] must be considered, which develops the preliminary, I, IV, V, VI, VII and VIII tittles of the consolidated text of the Water Law, approved by Royal Legislative Decree 1/2001, of July 20 and also, Order AAA/2056/2014, of October 27, by which the official models of application for authorization and declaration of discharge are approved [39]. Moreover, since 2007, Spain has its own legislation on wastewater reuse by Royal Decree 1620/2007, of December 7, which establishes the legal regime for the reuse of reclaimed wastewater [40].

3.3.3.3. Water Remediation Strategies in Practice

The Júcar Water Authority has analysed the data of the chemical parameters exposed in section 3.3.1.3. Aquifer Characteristics, and the Hydrological Plan for the 2015-2021 term stated that the masses under study present a good overall qualitative state. Nonetheless, there are some point sources that can harm the aquifer, associated with urban, storm water and industrial discharges, and waste disposal facilities, and some diffuse sources related to agricultural and livestock activities and urban and industrial discharges without a sewage system, which can imperil the good chemical status of the masses. Therefore, in the initial documents of the forthcoming Hydrological Plan for the 2021-2027 term [15], the Júcar Water Authority contemplates the Requena-Utiel groundwater mass at risk of suffering nitrate pollution.

Currently, there are no groundwater remediation strategies in practice, but given the deterioration of the water quality of Requena-Utiel mass, a more exhaustive study should be performed to determine if it is necessary to take prevention or remediation measures.

In the Spanish case site, there are six wastewater treatment plants, their location is shown in Figure 75, they serve the main urban areas and currently, their operation is adequate. EPSAR [41] is the public entity created by the Government of Valencia (Generalitat Valenciana) that manages water sanitation in the autonomous community of Valencia. All WWTPs have a water line with pre-treatment and secondary treatment. None have tertiary treatment, although Requena and Siete Aguas WWTPs have ultraviolet disinfection and San Antonio and Aldeas Vega and Utiel WWTP have disinfection by chlorination. Likewise, the 6 WWTPs have a sludge line with sludge thickening and dewatering. Utiel WWTP also has sludge stabilization and electricity generation through cogeneration.

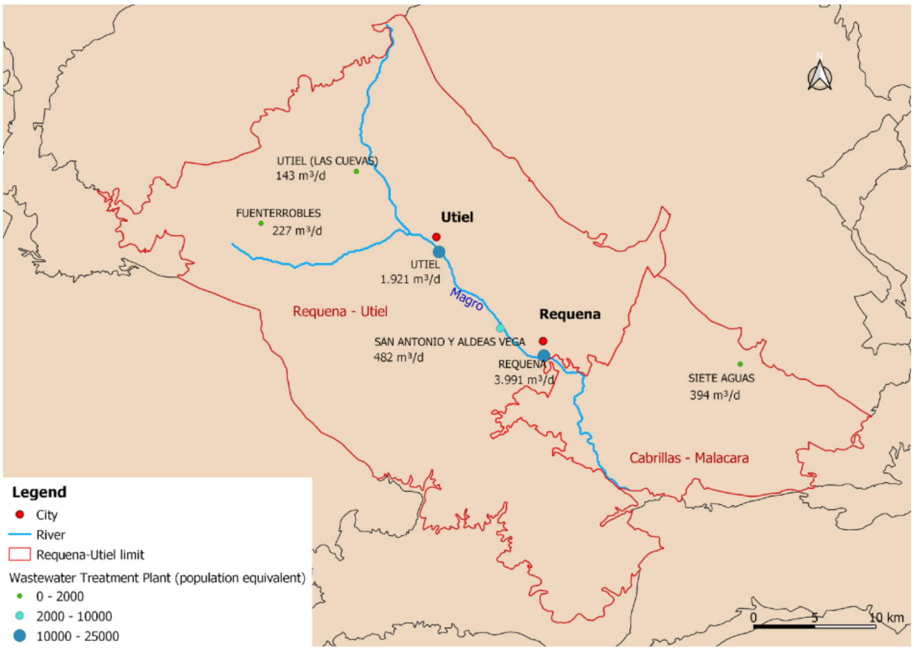

Figure 75. WWTPs location, population equivalent and influent at Requena-Utiel, Spain

3.3.4 . SWOT Analysis of Project Actions

SWOT analysis is a resourceful tool for decision making that helps identify the possibilities and limitations of a sustainable environmental and water resource management incorporating interdisciplinary perspectives, such as environmental, engineering, scientific, legal, economic and social outlooks. Strengths and weaknesses are considered internal factors, while opportunities and threats are external factors. On the one hand, weaknesses and threats must be avoided, minimized or they should be converted into strengths and opportunities. On the other hand, strengths and opportunities should be jointly examined for optimal management.

The SWOT analysis for the Requena-Utiel groundwater mass has been based on the exhaustive study of the biophysical conditions, the water management and the groundwater governance system, which is included in the previous sections. Table 16 shows the framework of SWOT analysis for Requena-Utiel groundwater mass.

As strengths, the close relationship that the UPV maintains with the Júcar Water Authority is identified, which has been strengthened over years of working together, as well as with the Irrigation Communities. Both show a high engagement in the participation and discussion of proposals concerning them. Furthermore, the UPV has a groundwater model for Requena-Utiel and Cabrillas-Malacara groundwater masses that works properly and despite not having a large amount of data on piezometric measurements, there are several complete time series since 1980.

On the side of weaknesses, the lack of exhaustive knowledge of groundwater contamination and the need for a better characterization of the relationship between the Magro river and the aquifer are noted. Moreover, the Requena-Utiel groundwater model is outdated and it should be optimized. Additionally, it is noteworthy the absence of thorough geological studies in the Spanish study site, which leads to a great uncertainty in the hydrogeological characterization of the aquifers.

As opportunities, the development of a complex exploitation strategy, which considers several factors at the same time (climatic conditions, state of the aquifer resources, variety and type of crop, etc.) and the development of a contamination prevention strategy can be underlined. Furthermore, the installation of new sensors for the continuous measurement of piezometric heads and contaminants, to help better monitoring and forecasting.

There are three main threats for the Spanish case study, firstly, meetings with stakeholders and the Júcar Water Authority are being affected by the SARS-CoV-2 pandemics, as well as field trips to collect data. Secondly, the Requena-Utiel groundwater mass is at risk of contamination by nitrates from agricultural activities. And finally, the aquifer is already identified as overpumped, there are risks of affecting not only the local economy, but also the economy in the area that is downgradient, because of reduction of surface water transfers, if no coordinated actions are taken.

Table 16. SWOT analysis for Requena-Utiel groundwater mass

Strengths	Weakness
● Close cooperation with the Júcar Water Authority and Irrigation Communities, ● Requena-Utiel groundwater model available and working properly, ● Global good knowledge of aquifer resources.	● Little data on groundwater contamination, ● Poorly defined river-aquifer connection, ● Need to update and optimize the Requena-Utiel groundwater model, ● Poor hydrogeological characterization of the aquifer.
Opportunities	**Threats**
● Development of a complex exploitation strategy, ● Development of a contamination prevention strategy, ● Installation of new sensors in the aquifer.	● Delays due to the SARS-CoV-2 pandemics, ● Contamination by nitrates from agricultural activities, ● Detriment to the economy in the local and downgradient areas.

3.3.5. References

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3.4. Tympaki, Greece Case Study

3.4.1. Biophysical Attributes

The Tympaki basin (Heraklion, Greece) is located in the southwestern tip of the Heraklion prefecture in Central Crete and covers a surface of about 55 km². With more than 5.000 inhabitants, the Tympaki region density is around 90 hab/km2 (Figure 76). The basin was morphologically differentiated into a coastal plain to the west and a hilly area to the east. Its average annual rainfall is 500 mm/year, with an average temperature about 15°C. The resultant moisture index Ih of 0.532, is in turn very low, bordering semi –arid conditions. Despite these unfavourable climatic conditions, the basin is the centre of intense agricultural activity. More than 4,000 hectares are cultivated, predominantly with olive growths and greenhouse vegetables, and most of them are irrigated. Irrigation is performed exclusively by groundwater extraction, amounting to 7,000,000 m3 per year. Due to over pumping the groundwater level has decreased more than 20m in the last two decades resulting in a major problem in the area: the seawater intrusion of the Tympaki aquifer. According to recent studies the toe of the saltwater intrusion front lies 550 to 600 m from the coastline, while at the northern end of the coast, the toe of the saltwater intrusion front is located 1500 m from the coastline. This apparent differential behaviour of seawater intrusion between the southern and northern part of the coast, is attributed to the complex hydrogeology of the northern part and effects of the Geropotamos river infiltration recharge which represents 36% of the total recharge of the basin. Recently, after the construction and full operation of the Faneromeni dam in the area, irrigation water is also supplied from surface resources (Special water secretariat of Greece, 2017).

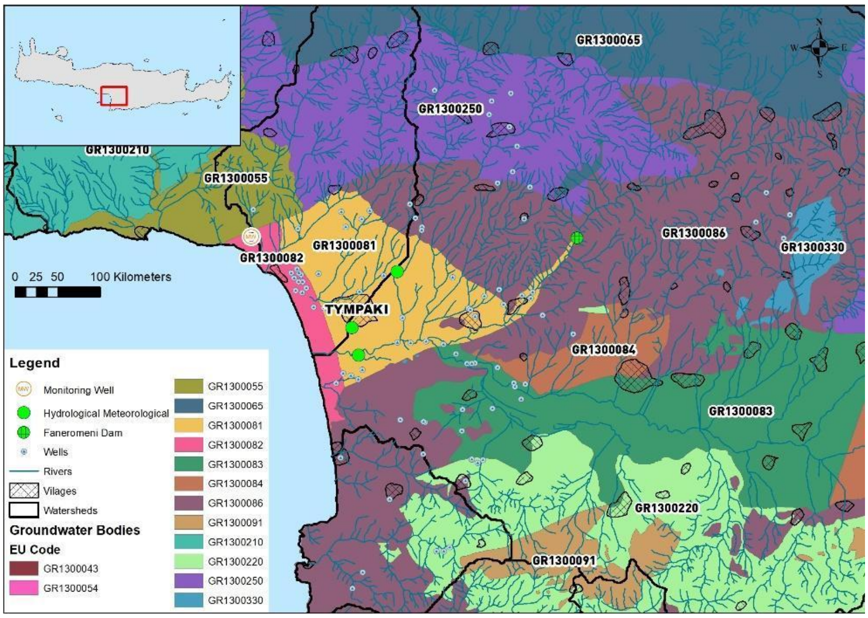

Figure 76. Location map of the Tympaki basin study area, Herakleio Greece

3.4.1.1. Climate

Tympaki basin belongs to the Messara Valley and the climate is classified as dry sub-humid according to UNCED definitions and its hydrological year can be divided into a wet and dry season. Figure 77 below presents interannual and mean monthly precipitation for Timpaki using measurement from the local meteorological stations. For the available record, precipitation shows no significant trend and remains stable at an annual rate of 500 mm. The climate ranges between sub-humid Mediterranean and semi-arid with mild moist winters and dry hot summers. The average winter temperature is 12°C while in the summer it is estimated at 23°C (Donta et al., 2006; Tsanis and Daliakopoulos, 2018; Vozinaki et al., 2018).

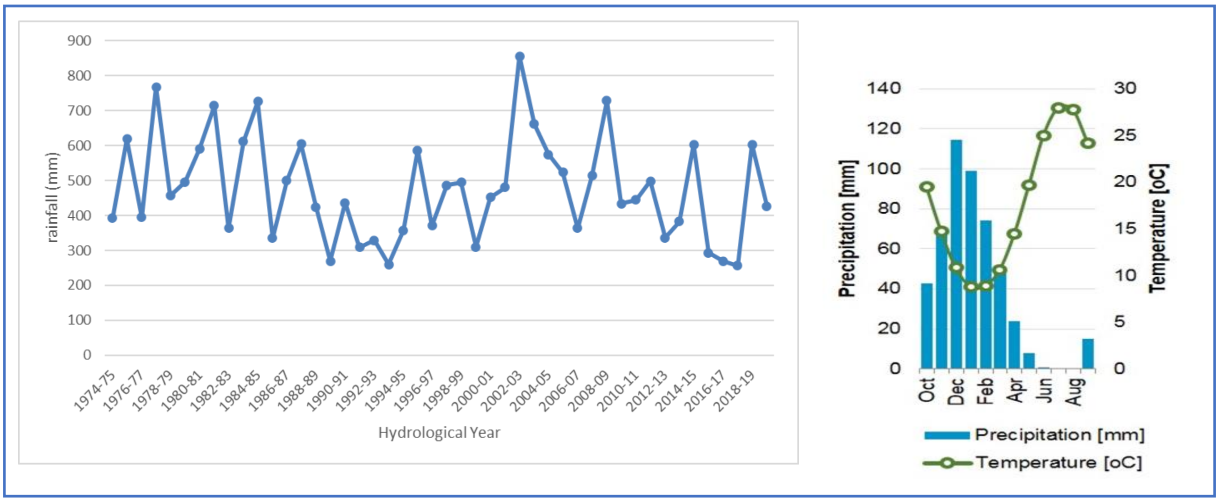

Figure 77. Precipitation and temperature variations in the basin

3.4.1.2. Hydrological Context

The Timpaki basin comprises five hydrological units. The major one is the Koutsoulidis unit. All the five hydrological units contribute to surface water flow of the study area. On average, 65% of the precipitation is lost due to evapotranspiration, 25% infiltrates towards ground water recharge and 10% is lost as runoff to the sea. Since evaporation increases with temperature, the recharge due to precipitation is negligible during the summer, coinciding with peak pumping rates. The average monthly evaporation (PAN) has been calculated 181.3 mm and the average annual evaporation 1894 mm. The average annual surface water flow in the Koutsoulidis Stream is 11.4 Mm3/year whilst the historical average annual surface water flow in Geropotamos is 15.8 (around 5 Mm3/year the last decade), value that appears low due to surface water infiltration into the aquifer and the high groundwater abstraction rates that occur in the Messara valley. A general fact in the area is that surface water features are losing water to the aquifer. This interaction is also induced at the smaller streams such as Mageiros, Klimatianos and Grias by locating the groundwater abstractions close to these surface water features. Surface flows contribute approximately 57% of the total inflows into the aquifer. A recent study estimated that the recharge rate in Timpaki sub basin is 22.5 % (75% of the effective precipitation) and 24% of the total areal rainfall (25% of the effective precipitation) in the basin for the Pleio-Pleistocene and the Pleiocene respectively (Dokou et al., 2016; Paritsis, 2005; Varouchakis, 2016; Vozinaki et al., 2018).

3.4.1.3. Aquifer Characteristics

The basin is filled with Pleistocene to Holocene alluvial deposits and is fault bound to the north and south by Neogene aquitards and to the east by Mesozoic aquifuge flysch. The alluvial sediments are underlain by Neogene sediments and at the eastern tip of the basin, by the Mesozoic flysch. The alluvial deposits fill erosion troughs within the Lower Pleistocene and comprise upper Pleistocene reddish and brown clay, silt, and gravel beds and grey Holocene deposits of gravel, sand, silt and clay, often with organic matter. At the Geropotamos river, the alluvial deposits extend from a few hundred metres in the east to about 1.5 km in the west and their corresponding thickness increases from about 60 m in the east to around 100 m in the west. The Koutsoulidis, Mageiros and Klematianos alluvial fans do not attain significant thicknesses and their importance is restricted to their contribution to infiltration recharge. Groundwater level maxima are observed around May and minima during October - November. There is usually a 5-month time lag between maximum rainfall and the maximum ground water level. Water table levels are not affected by the hydrogeological differences between the Geropotamos Alluvium and Lower Pleistocene deposits. Furthermore, the Pleistocene deposits despite their lateral and vertical inhomogeneities exhibit very uniform ground water levels. Hydraulic gradients in the basin are of the order of 2.5 to 3.5%. On the other hand, the hydraulic conductivity has been found as follows: alluvium deposits: 20-100 m/day, gravely layers up to 200m/day, Pleiocene: 10m/day, Neogene (Tibaki Hills according to FAO): 0.68 m/day, Stream fans: 10 m/day. The table 17 below presents basic hydrogeological characteristics of the aquifer. In terms of a hydrogeological point of view Figure 78 presents the hydrogeological units of the aquifer (Kritsotakis and Tsanis, 2009; Paritsis, 2005; Varouchakis and Hristopulos, 2013).

Table 17. Aquifer parameters

PARAMETER	TYMBAKI PLAIN		TYMBAKI HILLS
	ALLUVIUM	PLEISTOCENE	LOWER PLEISTOCENE
HYDRAULIC GRADIENT	2.5 – 3.5 $^{0}/_{00}$	2.5 – 3.5 $^{0}/_{00}$	40 $^{0}/_{00}$
ANNUAL WATER LEVEL VARIATION	1-2 m	1-2 m	>2 m
AVERAGE TRANSMISSIVITY	1X10^{-1} m^2/s	1X10^{-2} m^2/s	2X10^{-3} m^2/s
AVERAGE STORAGE COEFF.	10 %	6 %	6 %
WELL YIELD	>300 m^3/h	50 - 200 m^3/h	20 - 100 m^3/h
SPECIFIC CAPACITIES	>100 m^3/h/m	ca 10 m^3/h/m	ca 3 m^3/h/m
WATER LEVEL AT FAULT		5 – 14 m	35 – 50 m
MAX. PUMPING DEPTH	>10 m	av. 40 m	>60 m

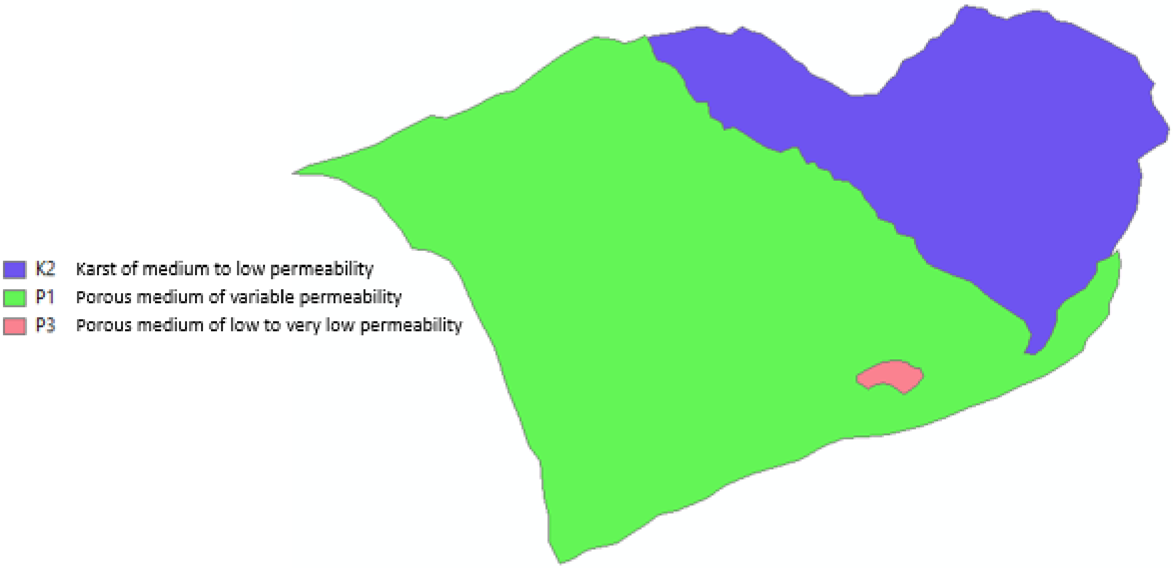

Figure 78. Hydrogeological units in Tympaki basin

There are numerous groundwater wells and abstractions in the basin. The majority of the groundwater abstractions take place in the centre of the basin. A significant number of private shallow wells are located mainly in the coastal area also abstracting groundwater. The average pumping rates range between 10-200 m^3/h. Groundwater levels in the alluvium part range between 3 and 7 m a.s.l. close to the coast and around 25 m a.s.l towards the inland part of the basin. Two characteristics examples are presented in figures 79 and 80. On the other hand, in the Pleistocene range between 20 and 40 m below sea level. The Tympaki and Messara basins have a hydraulic connection through a narrow fault bound corridor, the Faestos corridor, filled with alluvium deposits. The corridor extends down to the top of a Neogene horst block, the Faestos block, 30 m.b.s.l. The only groundwater inflow into the Tympaki basin occurs via the Faestos corridor. The amount of inflows (or outflows) therefore, depends on the exploitation conditions of the adjacent basins. An annual groundwater inflow of 1.5 Mm^3 was considered as an average value, would decrease to about 0.5 Mm^3/year for a drawdown of 20 m and to about 1 Mm^3/year, for a 10 m drawdown. Due to the over-pumping of the aquifer the whole front of the aquifer suffers from salt water intrusion on average up to 1 Km length towards the inland of the basin. The groundwater level monitoring at the area has shown the significant drop of the aquifer level at the coastal part that usually falls below the sea level during the summer period. In addition, the electrical conductivity measurements present a rising trend, which may occasionally reach 1800-2250 μS/cm, showing the degradation of the aquifer water (Papadaki, 2014; Paritsis, 2005; Pipatpan and Blindow, 2005; Special water secretariat of Greece, 2020).

Figure 79. Groundwater level variations; well A3(inland)

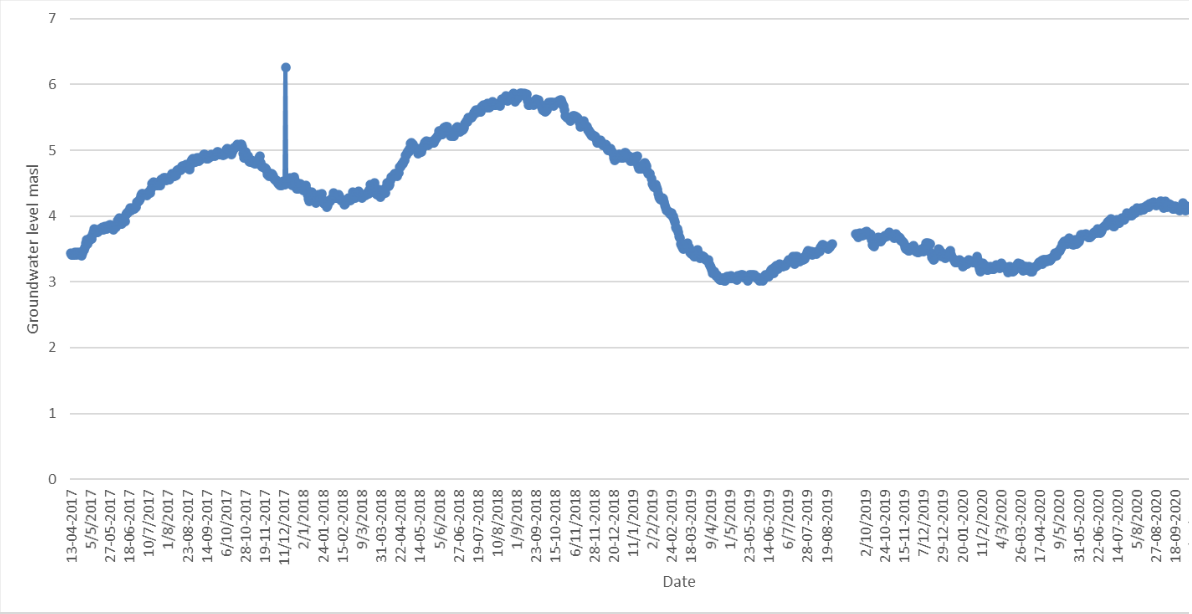

Figure 80. Groundwater level variations; well Airport (coast)

3.4.1.4. Land Use

Timpaki area is covered by enormous greenhouse cultivations because of the favourable climatic conditions year-round. Olive trees (43%), arable crops (39%), vineyards and citrus<2% and horticulture (16%) comprise the main crops types with greenhouses playing a major role for the latter (Figure 81). Hellenic Statistic Authority has identified about 2,500 ha of cultivated land in Timpaki, while others estimate more than 4,000. The irrigation is almost exclusively by groundwater extraction (Donta et al., 2006; LEDDRA and Project, 2013; Tsanis and Daliakopoulos, 2018).

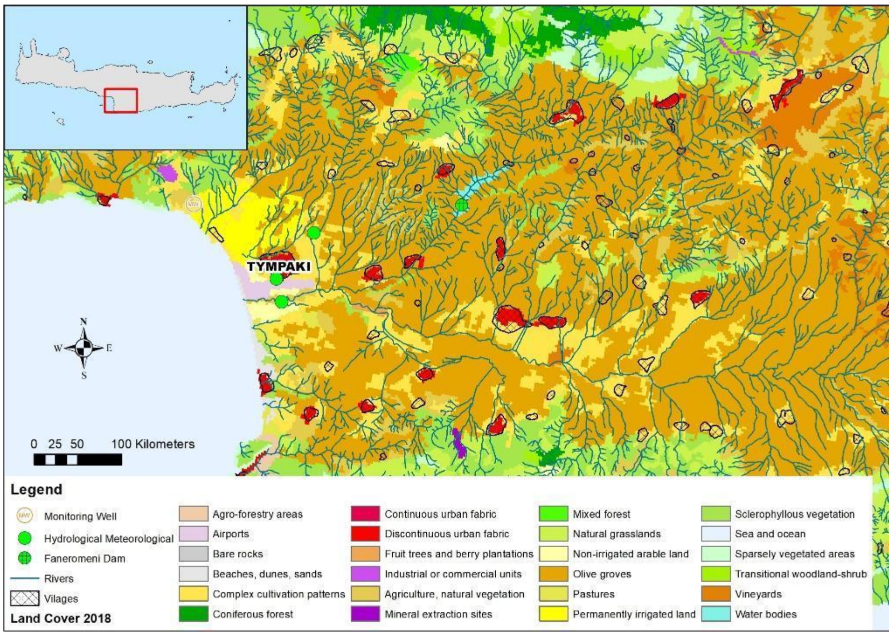

Figure 81. Land use information for Tympaki basin

3.4.2. Water Development and Management

Drip irrigation is widely used for olive orchards and tree crops, micro-sprinklers for potatoes and drip irrigation for the rest of the vegetables. Modern type irrigation systems have been used in the last decade, increasing the water use efficiency. The amount of the water applied is usually empirically defined and it comes from boreholes. However, Local Organizations of Land Reclamation (LOLR) has issued in association with the local authorities suggested crop water requirements (Table 18). The water price varies from 0.10-0.13 euro/m3. The irrigation requirements amounting to 7,000,000 m^3 per year. The local board of water management has set limitations in water use for each crop and any exceeding of this limit has a financial penalty for the farmer.

Table 18. Crop water requirements (m^3 x 10^2/ha)

Crop	J	F	M	A	M	J	J	A	S	O	N	D	SUM
Olives	-	-	-	-	3.5	6.0	7.5	7.0	4.0	1	-	-	29
Citrus	-	-	-	-	7.5	11.0	14.0	12.5	8.0	4.0	-	-	57
Table wines	-	-	-	-	-	9.0	11.5	10.0	6.5	-	-	-	37
Vines for wine	-	-	-	-	-	9.0	11.5	-	-	-	-	-	20.5
Greenhouse tomato	2.0	2.0	3.5	5.5	11.0	-	-	-	-	3.5	2.5	2.0	32
Greenhouse cucumber (Aug-Nov	-	-	-	-	-	-	-	4.5	10.0	9.0	6.0	-	29.5
Greenhouse cucumber (Mar-Jun	-	-	3.5	7.0	9.5	10.0	-	-	-	-	-	-	30
Waterlemon (Mar-Jun)	-	-	1.5	5.0	10.0	14.0	18	-	-	-	-	-	48.5
Waterlemon (May-Aug)	-	-		-	7.0	12.0	18.0	15.0	-	-	-	-	52
Melon	-	-	1.5	5.0	9.5	13.0	-	-	-	-	-	-	29
Potatoes (spring)	-	-	2.0	5.5	9.0	13.0	-	-	-	-	-	-	29.5
Tomatoes open (Jun-Oct)	-	-	-	-	-	8.0	12.5	14.5	10.0	5.0	-	-	50
Tomatoes open (Aug-Nov)	-	-	-	-	-	-	-	9.0	7.5	5.0	1.5	-	23

The main water policy actions are water monitoring programmes, water use and water works license, reservoir construction and seasonal restrictive measures. Regular quantitative and qualitative sampling is implemented by the National Institute of Mineral Resources Exploration and land reclamation organizations to monitor groundwater level and to prevent nitrate pollution according to the approved water management plan for the island of Crete (ADAPT2CLIMA, 2017; Special water secretariat of Greece, 2017).

3.4.2.1. Water supply

Groundwater is the main source of the water in the basin. In 2013 a reservoir was constructed to provide irrigation water. Thus, the surface water use has been increased to around 25% (Special water secretariat of Greece, 2017; Special water secretariat of Greece, 2020).

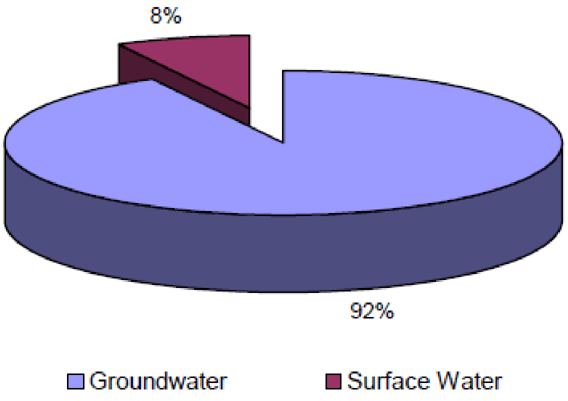

Figure 82. Origin of irrigation water

3.4.2.2. Water Uses

The major water use is for irrigation in agriculture while domestic use includes tourism and industry. The water used for industry includes mainly olive oil extraction plants, packaging units and livestock (Special water secretariat of Greece, 2017).

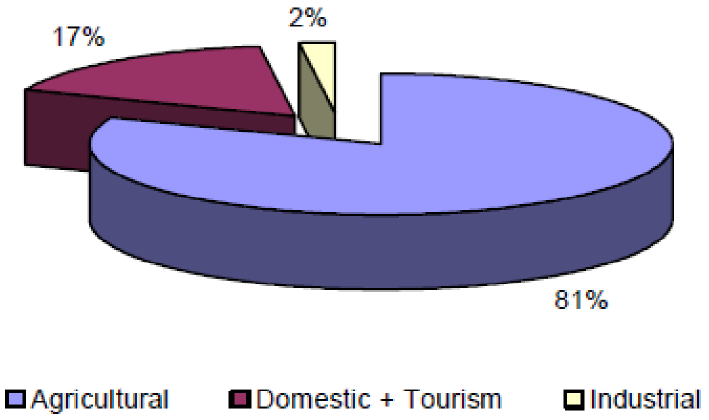

Figure 83. Water uses in the basin

3.4.2.3. Main Issues

Groundwater is the key resource controlling the economic development of the region, and it comprises a component of the environment under siege as water demand is increasing with time. The increased demand of water mainly for agricultural use, cannot always be met, despite adequate average precipitation amounts. Water imbalance is often experienced, due to temporal and spatial variations of precipitation, increased water demand during summer months and the difficulty of transporting water due to the mountainous areas. Insufficient pumping schemes and under prolonged dry climatic conditions, resulted in a negative water balance. The sequential occurrence of dry years in the 1990s, the intensive agriculture and the increased irrigation demands has led to more intensive pumping. As a result, more than 20m decline of groundwater level was monitored in the basin and negative or close to zero values are constantly met along the coast. A salt water intrusion front exists in the coastal basin leading to depletion and deterioration of the groundwater quality. Furthermore, the reduced runoff of Koutsoulidis and Klematianos streams as well as of Geropotamos River the last decade has growing concerns over the long-term sustainability of the groundwater quantity and quality in the basin due to intensive pumping and increased irrigation needs. The effect of long-term saline irrigation water has caused significant soil degradation in the area. With regard to nitrate pollution Tympaki area is not in the List of Vulnerable Zones and no special water pollution prevention and control programmes are in place, despite extensive application of nitrogen fertilizers and increased seasonal concentrations (Daliakopoulos et al., 2016; Dokou et al., 2016; Special water secretariat of Greece, 2017; Tsanis and Daliakopoulos, 2018).

3.4.3. Groundwater Governance System

The river basin management report for the water district of the island of Crete incorporates the European and national law regarding water resources management. In addition, an integrated water resources planning system adapted to the characteristics of each basin is described in detail. In Greece, groundwater governance is primary supervised by the Special Secretariat for Water then, by the regional directorates of water such as the Water Resources Department of the Prefecture of Crete and locally by the local organizations of land reclamation and local municipalities. In the study basin there are numerous groundwater wells, mainly private (92% in total). The majority of the groundwater abstractions in the centre of the basin belong to the Local Organizations of Land Reclamation (LOLR) and the Municipality. The volume of the abstracted groundwater from the private abstractions is considered significant because it covers systematic agriculture which is very high in the region. The distribution network losses are estimated to a 10 %, and the total annual volume of groundwater that is abstracted from the basin is estimated to 6,55 – 7 Mm^3 (Kritsotakis and Tsanis, 2009; Special water secretariat of Greece, 2017).

3.4.3.1. Actors and Institutions Involved in Water Management

The Water Resources Department of the Prefecture of Crete (WRDPC) is the main managing authority in-charge of the water resources within the Tympaki basin and throughout Crete. Also, the Local Organizations of Land Reclamation (LOLR) has certain administrative authority in agreement with the decisions of the WRDPC. The EU WFD is a management directive that defines specific objectives, which have to be achieved by river basin management planners, mainly the WRDPC. The wells in the area are also controlled by the LOLR which regulates water use, e.g. pumping and irrigation rates and monitors water resources. The organization has extensive rights to establish rules and thresholds and as members, the farmers are entitled to vote and involve themselves in the LOLR's decisions (Special water secretariat of Greece, 2017).

3.4.3.2. Water Policy and Current Instruments of Water Regulation

Pumping schedule and regulations have been designed and applied in the basin by the Water Resources Department of the Prefecture of Crete (WRDPC) to control salt water intrusion and to employ effective groundwater resources management. If the estimated reduction of pumping rates is not achieved despite imposed measures, the water table will continue to decline and consequently, the yield of wells will be gradually reduced from the margins of the aquifer towards the centre. In the case of a dry year's sequence, the deficiency of water in the region has been estimated at the order of 50%. If this deficiency is not covered by alternative freshwater resources or reduction of the consumption it is almost certain that more seawater will be abstracted leading to acute water and soil salinity problems. The operation of the Fanerwmwni reservoir has provided a long-term solution to the increased irrigation demands and consist of the major tool for the recovery of the Tympaki aquifer (Special water secretariat of Greece, 2017).

3.4.3.3. Water Remediation Strategies in Practice

The Water Resources Department of the Prefecture of Crete (WRDPC) in collaboration with the local authorities and under the water resources management plan for the district of Crete have set targets to succeed water remediation and aquifer recovery for the area of Tympaki (Special water secretariat of Greece, 2017):

- Improvement of regular monitoring and sampling
- Available water resources infrastructure can guarantee groundwater improvement (Fanerwmwni reservoir) through surface water allocation and reduced groundwater extractions
- Successful implementation of groundwater management under climate change
- Governance and policy initiatives through consumption regulations, pumping control and management under a central scheme involving stakeholders to reverse current conditions
- Planning of water reuse and aquifer recharge

3.4.4. SWOT Analysis of Project Actions Related to Remediation Strategies

Strengths	Weakness
• Water collection and allocation infrastructure (reservoir-networks) • Good quality of wastewater for reuse. • High irrigated area belonging to irrigation communities. • Most of the irrigation channels have minor morphological pressures. • Cost recovery derived from the water use, higher than 80%. • Existence of adequate statistics to monitor the parameters involved in the threats. • Existence of associations concerned and involved in the conservation of water resources. • Local, Regional and National Governments involvement in the conservation and good management of water resources. • Connecting the majority of the population to a water network.	• Strong seasonality in the annual rainfall volume can lead to complications of supply. • Significant increase in built-up areas. • High surface area occupied by farmland. • Negligible percentage of wastewater reused. • Flood risk caused by episodes of heavy rain. • Loss of aquatic biodiversity due to the presence of biocides, herbicides and pesticides. • Poor state of water transport infrastructure. • High consumption of water for irrigation. • Weak appreciation of associated river spaces. • High degree of erosion in the study area. • Poor quality of riparian vegetation. • Poor Groundwater and soil quality • Poor groundwater monitoring.
Opportunities	**Threats**
• Appropriate legislative framework for proper water management. • Implementation of the measures defined in the Water Framework Directive. • Common Agricultural Policy (CAP) associated with good practice for the maintenance of biodiversity, landscape, soil protection and water resources. • Rural Development Program	• Climate change effects • Increased water demand due to rising temperatures associated with climate change. • Lack of investment in infrastructure due to the economic crisis (wastewater treatment plants, pipelines, saving measures, etc). • Elimination of aid from the Common Agricultural Policy (CAP) in Europe

3.4.5. References

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3.5. Konya, Turkey Case Study

3.5.1. Biophysical Attributes

The Konya closed basin is located in the central part of Anatolia, Turkey (Figure 84). It is the 5th largest basin in Turkey among a total of 26 basins. The basin is classified as closed because no water naturally flows into or out of the basin. The Konya basın is characterized by limited water resources but intense demand, primarily due to agriculture. Surface water resources are primarily for urban areas with agricultural areas relying predominantly on groundwater resources.

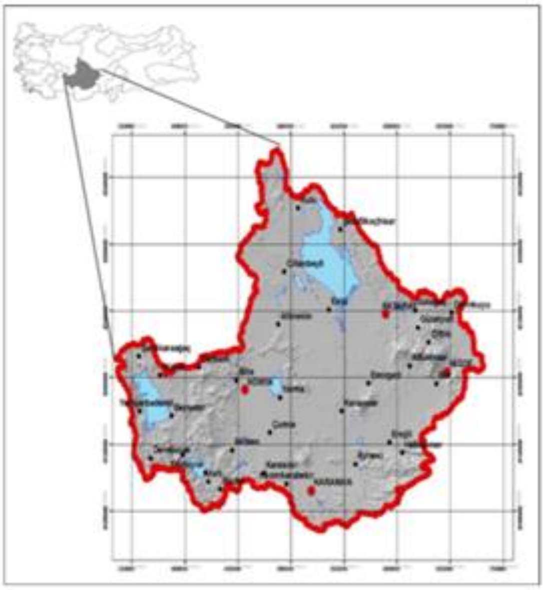


Figure 84. Location map of the Konya closed basin, Turkey (SUİŞ Proje Müh. ve Müş. LTD. ŞTİ., n.d.-e)

Based on the drainage boundaries of groundwater bodies, the Konya closed basin is divided into 9 sub-basins. The location and the areas of sub-basins are shown in Figure 85 and Table

19, respectively. The total area of the Konya closed basin is more than 50,000 km^2, covering about 7% of the total land area of Turkey.

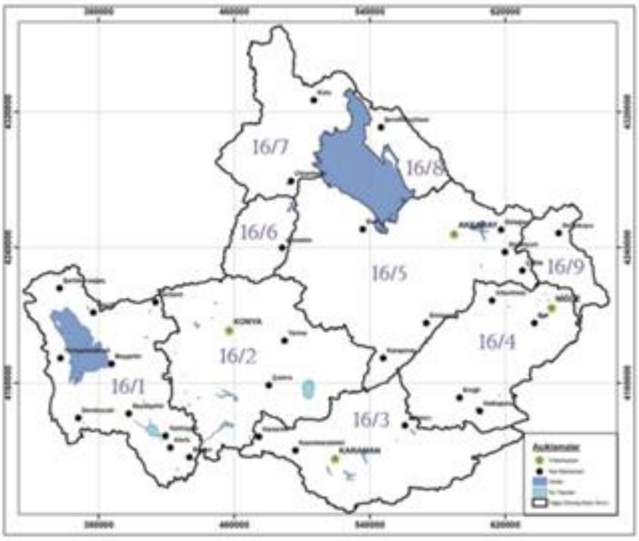


Figure 85. The location of the sub-basins (SUİŞ Proje Müh. ve Müş. LTD. ŞTİ., n.d.-d)

Table 19. Sub-basins of the Konya Plain (SUİŞ Proje Müh. ve Müş. LTD. ŞTİ., n.d.-f)

Sub-basin no	Name of the sub-basin	Area(km^2)
16-1	Beyşehir-Kaşaklı	7341
16-2	Konya-Çumra-Karapınar	8742
16-3	Karaman-Ayrancı-Akçaşehir	6263
16-4	Ereğli-Bor	6057
16-5	Aksaray	10560

16-6	Altınekin	1606
16-7	Cihanbeyli-Yeniceoba-Kulu	4276
16-8	Şereflikoçhisar	1442
16-9	Misli	1673
TOTAL		47960

The Konya closed basin consists of a central valley surrounded by mountains especially along the south-east, south-west and north-west boundaries of the area. The highest mountain in the region is located at the south-west of the area, with elevation reaching up to 3000 meters. The central-south part of the region has many low plains that are used for agricultural practices. Figure 86 shows the elevation map of the basin with darker colors representing higher altitudes.

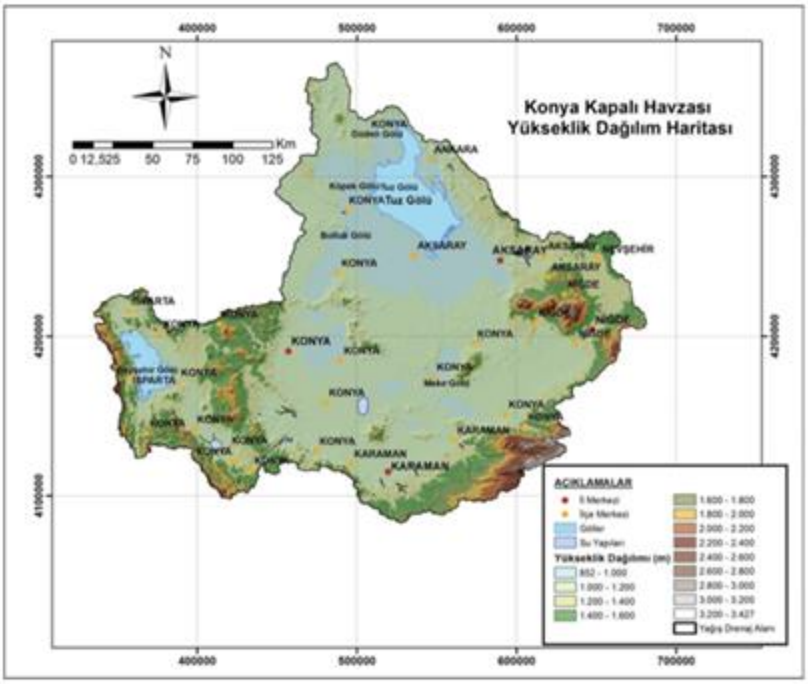


Figure 86. Elevation map of the Konya closed basin (SUİŞ Proje Müh. ve Müş. LTD. ŞTİ., n.d.-g)

3.5.1.1. Climate

The climate of the Konya closed basin is classified as continental climate with a cold winter season and frequent snowfall, a short and relatively humid spring, a long, hot and dry summer season and a dry and mild fall. The highest temperatures occur in July and August, whereas the lowest temperatures are observed in January and February. The lowest temperature observed in February is around -25 ^{o}C, and the highest temperature observed in August is 39.6 ^{o}C. The yearly average temperature is around 10-12 °C.

Precipitation is mainly during the winter and spring seasons, distributed unevenly within the basin. The south receives more rain (~ 755 mm), compared to the north (~255 mm). The average rainfall received in the basin is 300 – 350 mm (Dolsar Mühendislik, 2015c), which is around half of Turkey's average. Table 20 gives information about the temperature and precipitation measured at the central part of the Konya closed basin in 2009.

Table 20. Temperature and precipitation data measured at the central region of the Konya basin (SUİŞ Proje Müh. ve Müş. LTD. ŞTİ., n.d.-f)

Month	1	2	3	4	5	6	7	8	9	10	11	12	Total
Average temperature (°C)	-0.3	1.35	5.5	11	15.8	20.1	23.4	23.1	18.4	12.5	6.3	1.9	11.6
Max temperature (°C)	19	23.8	28.9	31.5	34.4	37.2	40.6	40	36.1	31.6	25.4	21.8	
Min temperature (°C)	-28.2	-26.5	-16.4	-8.6	-1.2	1.8	6.7	5.3	-3	-8.4	-20	-26	
Average number of days with precipitation	9.7	8.8	8.7	9.6	10.6	6.5	2.8	2.4	3.5	6.7	7	10	86.3
Monthly average precipitation (mm)	37.1	29.3	28.1	33.9	43.1	24.3	6.6	4.8	11.7	29.7	33.1	42	323.8

3.5.1.2. Hydrological Context

The long term annual precipitation and evapotranspiration of the Konya basin are estimated as 307 mm and 289 mm, respectively (Bozdağ, 2015). Infiltration consists of about only 6.3% of total precipitation. The extensive reliance on groundwater resources along with the low precipitation and high evapotranspiration has led to a drastic drop in groundwater levels by about 10 m in the last 30 years. The overreliance on groundwater has also contributed to groundwater contamination.

The annual amount of groundwater available and groundwater used in each sub-basin is given in Table 21 for 2009. The data exemplify the scarcity of the water resources in the region with a total consumption 1.77 times the total available water. The reduction in the reservoir is the highest in the sub-basins 16-2 (Konya-Çumra-Karapınar) and 16-5 (Aksaray) where the consumption is 2 times the water recharge. Groundwater sources are mostly utilized for agricultural practices, especially in sub-basins 16-2 and 16-5.

Table 21. Groundwater balance for the Konya closed basin and its sub-basins (SUİŞ Proje Müh. ve Müş. LTD. ŞTİ., n.d.-f)

Konya sub-basins	Groundwater recharge (hm^3/year)	Total consumption (hm^3/year)	Change in reservoir (hm^3/year)
16-1	130	52.89	77.11
16-2	456	1057.05	-601.05
16-3	244	430.72	-186.72
16-4	435	371.12	63.88
16-5	440	1066.77	-626.77
16-6	71	158.44	-87.44
16-7	68	136.74	-68.74
16-8	32	3.65	28.35

16-9	147	309.89	-162.89
Total basin	2023	3587.27	-1564.27

The average decrease in the water level for the 7 sub-basins is being monitored by government authorities (Table 4). For the past 2-3 decades water table levels have been dramatically decreasing throughout the basin with drawdowns as high as several meters per year in some locations. Drawdowns are associated with higher electrical costs for groundwater extraction and increase in salinity in many locations.

The drawdown-time graphs obtained from two sub-basins (16-2 and 16-5) are given in Figure 87 and Figure 88, demonstrating the rapid decrease in the water table in recent years.

Table 22. Total and average groundwater drawdown for Konya sub-basins (SUİŞ Proje Müh. ve Müş. LTD. ŞTİ., n.d.-f)

Konya sub-basin	Well Number	Measurement interval (year)	Drawdown	
			Total (m)	Average (m/year)
16-1	1	3	5.2	1.73
	2	3	1.8	0.60
16-2	3	34	39.0	1.15
	4	19	16.5	0.87
	5	19	22.0	1.16

	6	28	14.1	0.50
	7	31	37.4	1.21
	8	39	31.6	0.81
16-3	9	15	13.0	0.87
	10	15	23.3	1.55
	11	16	39.0	2.44
	12	12	17.0	1.42
	13	29	31.0	1.07
16-4	14	13	14.0	1.08
	15	13	2.0	0.15
16-5	16	16	17.2	1.08
16-6	17	40	22.2	0.56
	18	13	17.6	1.35
16-7	19	8	4.6	0.57
	20	8	2.0	0.25

	21	5	5.0	1.00

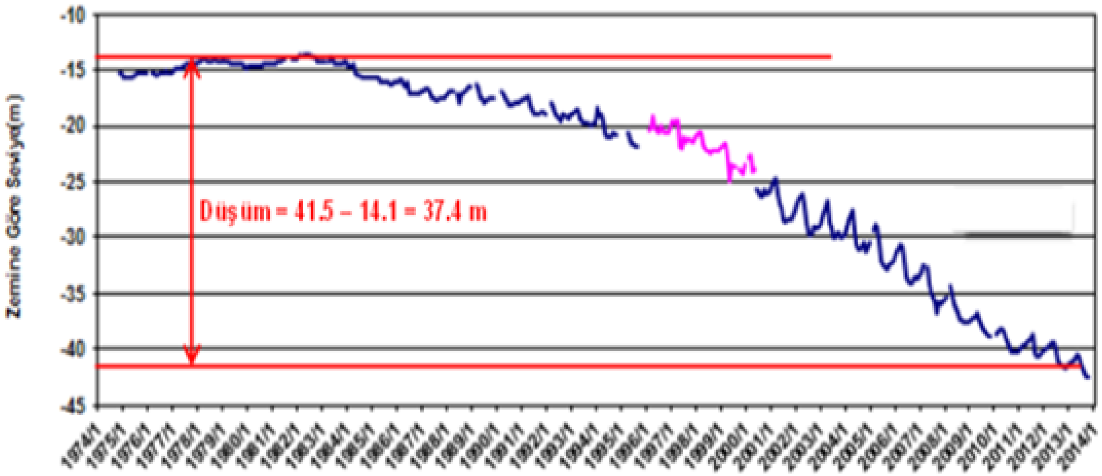


Figure 87. Drop in water level data at a monitoring well located at the sub-basin 16-2 (Dolsar Mühendislik, 2015a)

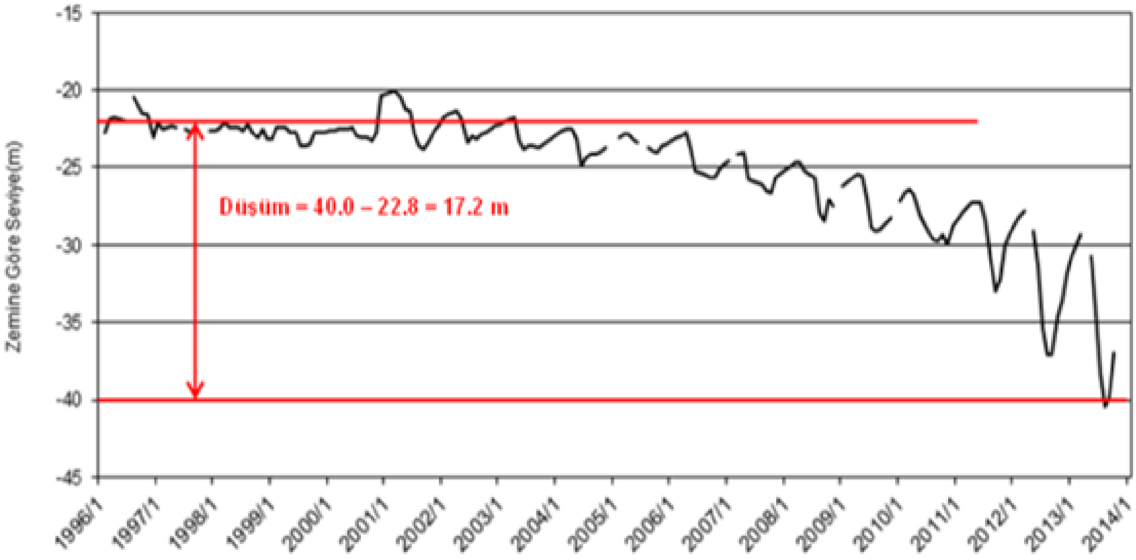


Figure 88. Drop in water level data at a monitoring well located at the sub-basin 16-5 (Dolsar Mühendislik, 2015d)

3.5.1.3. Aquifer Characteristics

The geologic characteristics of the study area are presented in Figure 89. Three general geologic units exist in the Konya region (Bozdağ and Göçmez, 2013; Bozdağ, 2015). The uppermost is the Quaternary units composed of conglomerate, sandstone, mudstone, gravel, gravelly-sandy mud, sand, and clay. The thickness of the Quaternary deposits is variable, reaching up to 100 m towards the north–northeast and east (DSI, 1975). Underneath the Quaternary deposits is the Neocene unit which is the most important aquifer within the Konya Closed basin. The Neocene unit is composed of fractured limestone with karst forms ranging from 1 to 2 mm to over a few meters (Bozdağ, 2015). The thickness of the Neocene unit ranges from several meters to more than 250 m. The hydraulic conductivity of the Neocene limestone ranges from about 1-3.5 x 10^{-3} m/s and the storage capacity ranges from 10^{-3}-10^{-1} (DSI 1975). The Mesozoic basement rocks consist of limestone, crystalline limestone, and dolomite.

Figure 90 shows a conceptual hydrogeological model of the basin along the southeast-northwest direction. Groundwater generally flows from the mountainous region towards the central plain where the water consumption is highest and to Salt Lake (Tuz Gölü) in the north-western part of the basin. Salt Lake is the largest surface water body located within the region. It is a wide but shallow lake with a density of 1.22 g/cm^3 and 32% salinity. The ion concentrations in the lake are reported as 10.4 g/l Na, 3.9 g/l K, 0.3 g/l Ca, 120 g/l Mg, 200 g/l SO_4 and 188 g/l Cl (Konya close basin Hydrogeology Report, 2009).

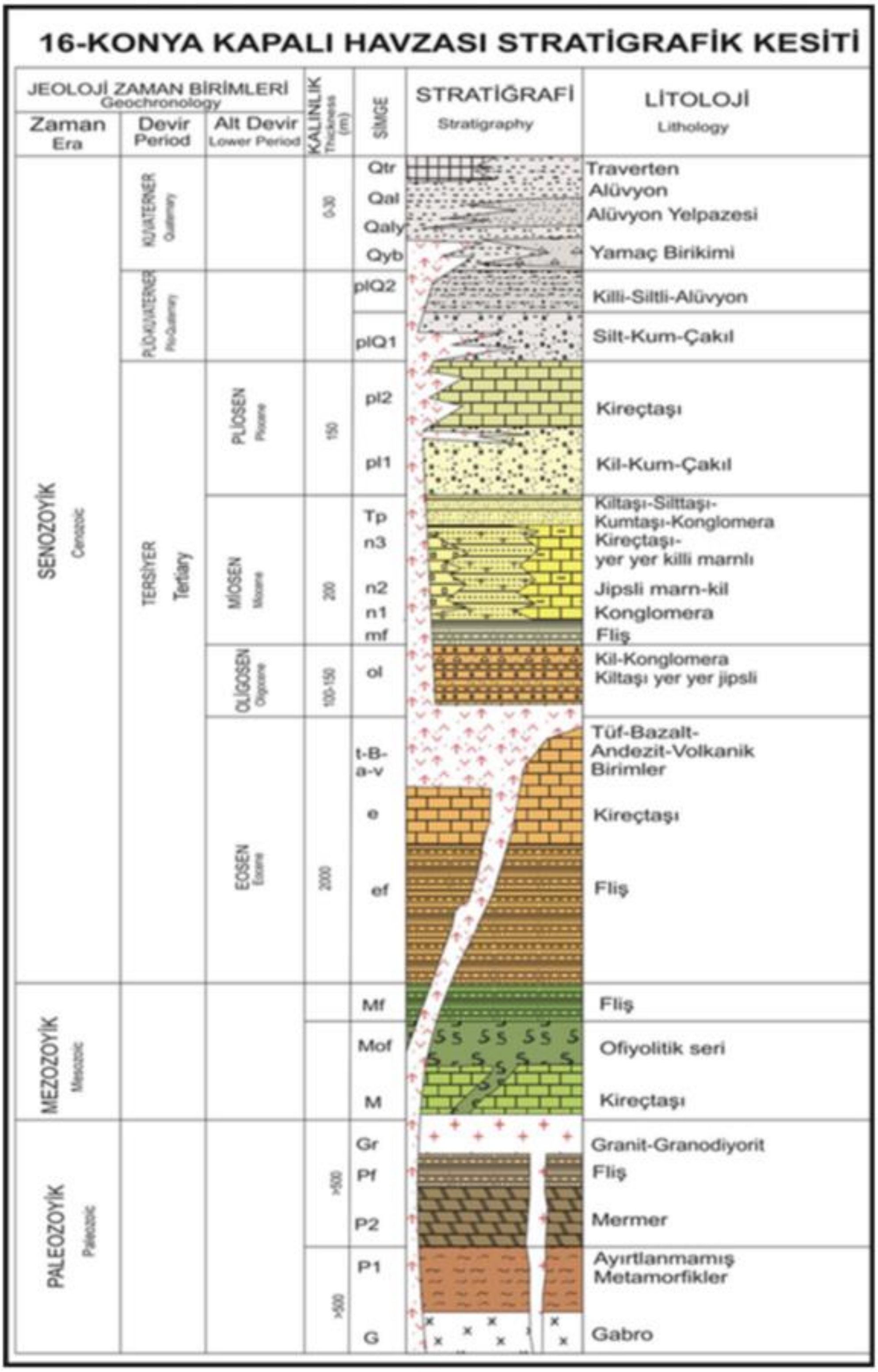


Figure 89. Main Geologic Units (SUİŞ Proje Müh. ve Müş. LTD. ŞTİ., n.d.-c)

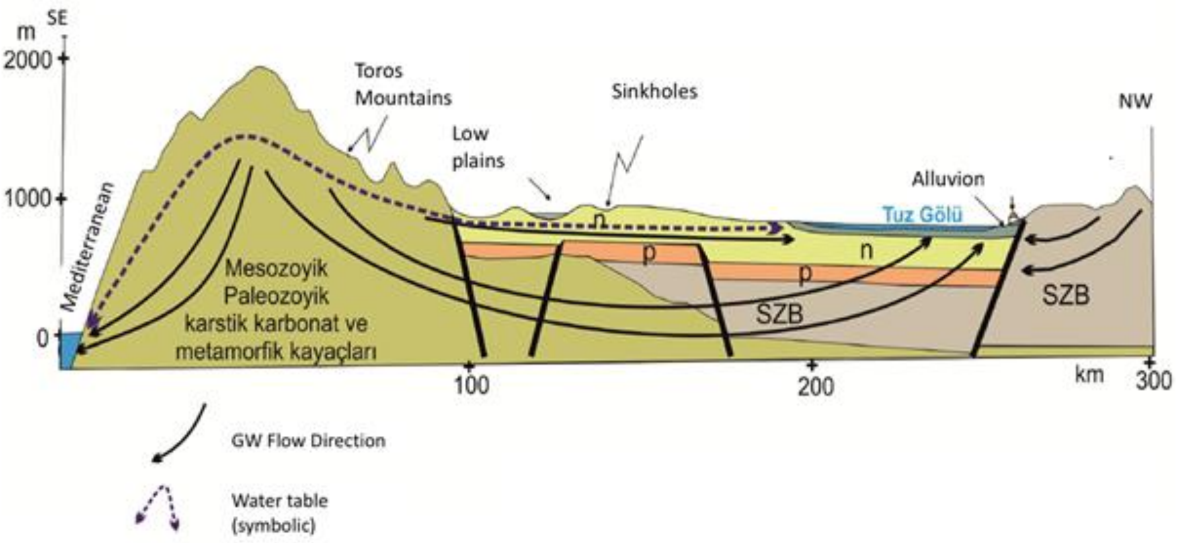


Figure 90. Conceptual hydrogeological model of the Konya closed basin (SUİŞ Proje Müh. ve Müş. LTD. ŞTİ., n.d.-b)

About 5 decades ago, the groundwater discharge from the neighboring basins was through the Salt Lake. However, due to the overutilization of the groundwater bodies in the region, the discharge to Salt Lake from the neighbor basins either decreased significantly or stopped completely. If the overutilization continues at this rate, the groundwater flow direction can be reversed, causing a further increase in water salinity in the long run.

In addition to the drop in water table levels, sinkholes are occurring more frequently, especially in the Karapınar region. Sinkholes form when CO_2 rich groundwater comes in contact with limestone structures as a result of excessive extraction of groundwater, resulting in the collapse of limestone structures. Sinkholes can lead to loss of agricultural lands, and risk to infrastructure and human lives. Figure 91 shows one example of a sinkhole located in sub-basin 16-2.

Figure 91. Çıralı Sinkhole with a diameter of 150 meters. (SUİŞ Proje Müh. ve Müş. LTD. ŞTİ., n.d.-a

3.5.1.4. Land Use

Land use in Konya Closed Basin is distributed as follows: 56% agricultural land, 37% forests and semi-natural areas, 4% surface water, 2% constructed land, 1% wetland (TRAGSATEC et al., 2018). It is estimated that about 1/3 of the agricultural lands are irrigated and 2/3 are used for dry farming.

The main agricultural products grown in the area are wheat, sunflower, sugar beet, maize, potato, barley, and some fruits. Figure 92 indicates the distribution of the agricultural land within the basin and the portions irrigated with groundwater. Based on 2018 data, irrigated farming is practiced in an area of 890,000 ha. The state institutions plan to increase irrigated farming areas to 969,000 ha by the end of 2025 (T.C. Tarım ve Orman Bakanlığı Su Yönetimi Genel Müdürlüğü, 2018).

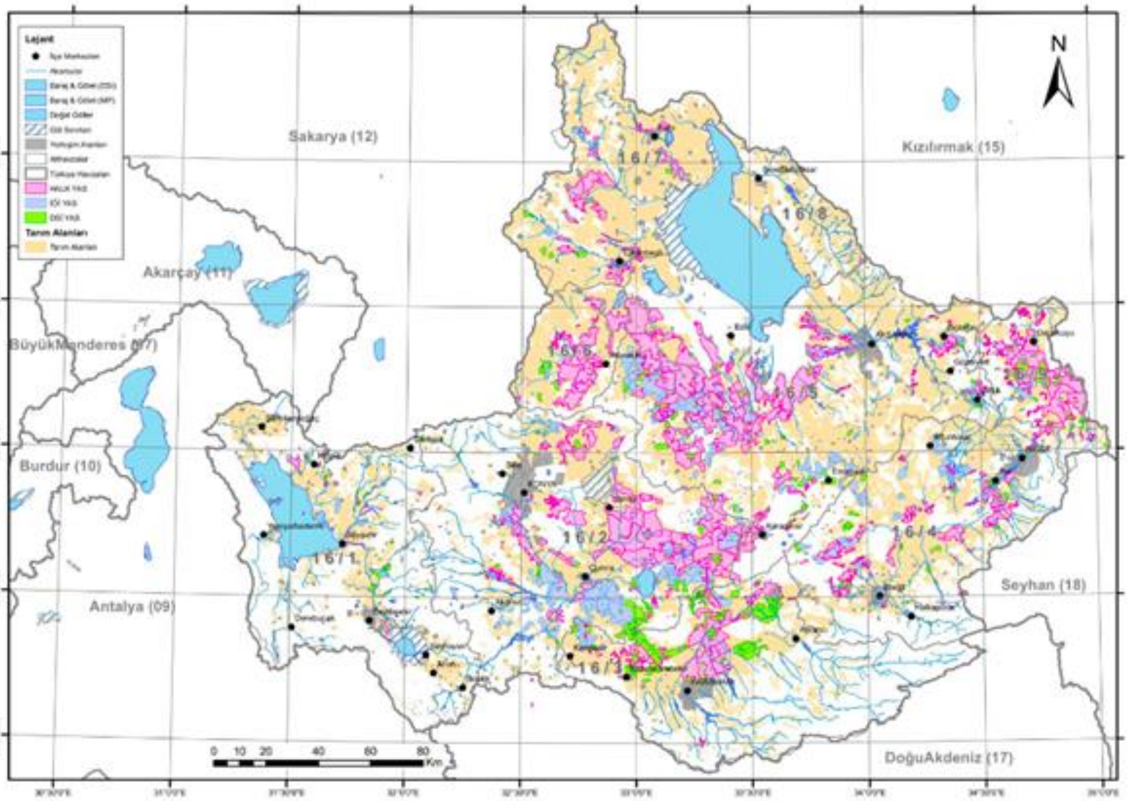


Figure 92. Map of land use and water bodies (Dolsar Mühendislik, 2015b)

3.5.2. Water Development and Management

In the Konya Closed Basin Management Plan, development of water resources is prioritized as an environmental objective and stated as a duty of the state (TRAGSATEC et al., 2018).

3.5.2.1. Water Supply

In an inventory study carried out by DSİ 4. District Office in 2007, 94.000 groundwater wells were identified in the basin, of which 66.8 % were drilled illegally. The total number of wells are estimated to have exceeded 100.000 by the end of 2012 (WWF, 2014), however the exact number of wells (both licensed and unlicensed) is unknown.

WWF (2014) estimates the total water use as nearly 6.5 billion m^3, of which 4 – 4.5 billion m^3 is from groundwater resources. Since the yearly utilizable amount of groundwater is estimated to be 2435 billion m^3 it is estimated that the annual water deficit is about 2 – 2.5 billion m^3 per year.

The limited surface water resources are almost completely utilized in the basin. There is local demand for inter-basin water transfer projects to fulfill the increasing water demand. Currently, the only active inter-basin transfer to Konya Closed Basin is from Göksu River, via the so-called 'Blue Tunnel'. Figure 93 shows the map of the project including the dams, tunnels and regulators. The 17 km tunnel was built as part of the Konya Plains Project by the State Water Works (Devlet Su İşleri, DSI).

İlk etapta **3 bin 200 hektar** alan suyla buluşacak

Bağbaşı, Bozkır ve Afşar barajlarında toplanan suyu Konya Ovası'na aktaracak Apa Hotamış İletim Kanalı (AHİ) tamamlandı

Konya İçme Suyu Şantiyesi de bitirildi

Yıllık 100 milyon metreküp su ile Konya'nın 2065'e kadar içme suyu ihtiyacı karşılanacak

Figure 93. Map of the Blue Tunnel Project (2017)

The completed section of the previous project is one component of a broader plan to bring more water resources to the Konya plain. In the official reports of Grand National Assembly of Turkey (TBMM), Konya-Çumra Phase Projects (I, II and III) are summarized as follows:

Phase I includes Beyşehir Lake, Apa, Altınapa, Sille and May Dams, and the irrigation and discharge facilities in Çumra Plain.

Phase II includes transferring Gembos River flows from Derebaşı Dam to Beyşehir Lake via Gembos Plains with derivation tunnel, reclamation of Beyşehir-Seydişehir-Apa channel, and gravity and pumping irrigation of Beyşehir and Seydişehir surface water obtained from Beyşehir Lake and Suğla Water Storage (TBMM, n.d.-a).

Phase III consists of Göksu Water Transfer mostly, and involves Bağbaşı, Bozkır, Afşar Dams, Blue Tunnel and Hadimi Tunnel, Hotamış Water Storage and Apa-Hotamış Channel. The overall goal is to transfer 414 million m^3 of water (amounts to nearly 0.095% of the yearly water budget of the basin and could be used to irrigate 1/40 of the total agricultural land (WWF, 2014) yearly from Göksu River. Bağbaşı Dam and the Blue Tunnel first started transferring water in 2015. Hadimi Tunnel, which is currently under construction, is planned to be 18 km long, transferring water from Afşar Dam to Bağbaşı Dam (TBMM, n.d.-b; KOP'un 2. Tüneli'nde 7/24 Çalışma, 2020).

3.5.2.2. Water Uses

The dominant economic activity of the region is agricultural production. Nearly 90% of water (both surface water and groundwater) is used for irrigation purposes (T.C. Tarım ve Orman Bakanlığı Su Yönetimi Genel Müdürlüğü, 2018). Currently available water reserves in the basin can satisfy the demand of existing sectors and purposes of use (drinking and utility water, industry - production, energy, mining etc.-, environmental water demand) excluding agricultural demand, under normal to extreme drought conditions (T.C. Tarım ve Orman Bakanlığı Su Yönetimi Genel Müdürlüğü, 2018). This implies that the groundwater stress is mostly related to high irrigation demand in the area.

The amount of groundwater utilized per year is not exactly known, because there is no standard measurement system to keep track of the amount of groundwater pumped from the existing wells. Both farmers and relevant state institutions estimate the water use from the electricity bills (given the depth of the well and energy consumption per unit of time).

3.5.2.3. Main Issues

Konya closed basin has the highest groundwater use in Turkey (WWF, 2014) leading to water stress in the basin due to a number of pressing issues. The ever-increasing water demand of various sectors is one of the key factors. The General Directorate of State Hydraulic Works (DSİ) reports a 28m average decline in groundwater levels from 1980 to 2010s. The Chamber of Geological Engineers (JMO) estimates that the groundwater sources will be available for use for only another 20-30 years given the current state of the aquifers (WWF, 2014). Overexploitation of the groundwater causes a yearly average of as high as 3 m decrease in the water table in some areas. (T.C. Kalkınma Bakanlığı Konya Ovası Projesi Bölge Kalkınma İdaresi Başkanlığı, 2014).

Some agricultural products like sugar beet have played an important role in increasing economic welfare in the basin. Since the mid-20th century, the state has incentivized production of fruits, potato, corn, and trefoil in the region, and, in the last few years, sunflower production has been supported via financial schemes. All those products have a high-water demand, compared to grains like wheat and barley.

Measurement and monitoring methods for water resources lack standardization and consistency. The difference in the methods adopted and equipment used by various institutions leads to high variation in the outputs. Different sources estimate inconsistent depletion rates. It could be argued that the past and seemingly ongoing practices (and perhaps a lack of sufficient monitoring and appropriate sanction enforcement) has transformed groundwater governance to a de facto open access regime, which created a sense of exemption from laws for local users.

3.5.3. Groundwater Governance System

Water is recognized as a public good. All use rights (access, withdrawal, management, exclusion, alienation (Schlager & Ostrom, 1992)) are held by the state, which is clearly stated in the Constitution of 1982, Article 168.

State Hydraulic Works (DSİ) is the main institution responsible for the extraction, allocation, monitoring, protection of groundwater and the sole decision-making authority.

In 2019, Basin Management Committees were introduced into the governance system, to improve participation in local decision making. However, their effectiveness in achieving those goals is contested among the rest of the stakeholders.

3.5.3.1. Actors and Institutions Involved in Water Management

The prominent actors and institutions are classified in Table 23. Brief information about the most relevant actors is presented below.

- State Hydraulic Works (DSI) & 4th District Office

DSI can be considered as the main enforcing institution in water governance and the sole authorized enforcing entity in groundwater governance. Its main duties include drilling wells for groundwater monitoring, research, distribution, protection of groundwater, registry of groundwater use, gathering and evaluation of data, dissemination of irrigated farming (Muluk et al., 2014) and land consolidation (*Cennet Topraklar Konya | Konya Sulama Kooperatifleri Birliği Başkanı - Şaban Güven*, 2020).

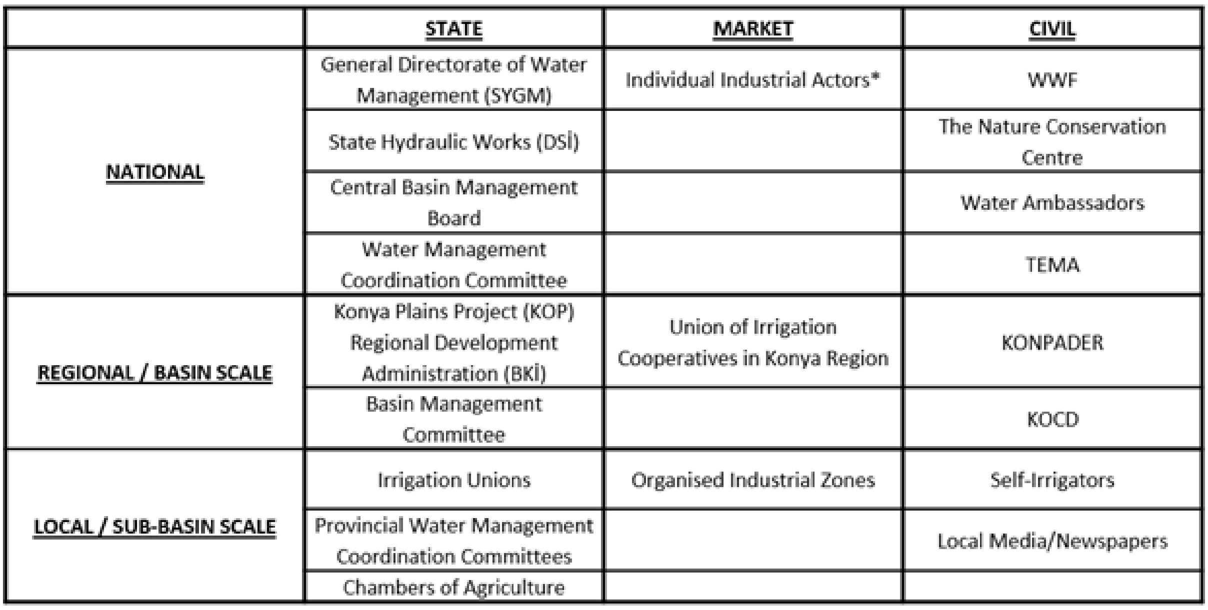
- Irrigation Cooperatives

Irrigation cooperatives have been active in Turkey since 1966. Their duties are: land development, informative and educational campaigns on irrigation and on-field activities, financial loans to their shareholders for irrigation facilities and operation, technical support by cooperating with other public and private institutions, and environmental protection activities (T.C. Tarım ve Orman Bakanlığı, n.d.).

- Konya Leader Farmer Association (KOCD)

KOCD was founded in 2009 by a former governor of Konya. The main purpose of the association is to provide information flow among farmers of Konya. The association aims to bring together leader farmers keen on adopting new technologies and techniques in farming. Under the roof of KOCD, these farmers are both supported (consultancy) and are expected to pass on their experiences to their networks to contribute to the development of the region. The association believes that the existence of pioneers is crucial to the success of agricultural extension (Konya Önder Çiftçi Derneği, n.d.).

Table 23. Classification of stakeholders



	STATE	**MARKET**	**CIVIL**
NATIONAL	General Directorate of Water Management (SYGM)	Individual Industrial Actors*	WWF
	State Hydraulic Works (DSİ)		The Nature Conservation Centre
	Central Basin Management Board		Water Ambassadors
	Water Management Coordination Committee		TEMA
REGIONAL / BASIN SCALE	Konya Plains Project (KOP) Regional Development Administration (BKİ)	Union of Irrigation Cooperatives in Konya Region	KONPADER
	Basin Management Committee		KOCD
LOCAL / SUB-BASIN SCALE	Irrigation Unions	Organised Industrial Zones	Self-Irrigators
	Provincial Water Management Coordination Committees		Local Media/Newspapers
	Chambers of Agriculture		

3.5.3.2. Water Policy and Current Instruments of Water Regulation

Turkey has a "Water Code", which was adopted in 1926 and has not yet been fully updated for today's necessities. Considering the change in demand, technology, priorities, purposes of use, and environmental conditions, it is obvious that an overarching and holistic legal framework is required for effective governance of both surface and groundwater resources. The adoption of such a water code has been on the agenda of the government for several years now.

- Law No- 167, The Groundwater Code (Yeraltı Suları Hakkında Kanun, N.D.)

The code was adopted in 1960. The important articles of this code could be summarized as the following:

- Groundwater resources are public property and research, use, protection, and registration are bounded by the articles of this code.
- DSİ is the main state institution that has the right to control and coordinate groundwater operational sites. It provides necessary permits to search for groundwater and groundwater utilization permits as well as reclamation and modification permits, determines the location, number, depth of wells and amount of water to be used, and has the right to drill wells for groundwater studies.

- DSİ, along with the relevant ministry (currently Ministry of Agriculture and Forestry) identifies the minimum depth above which a permit is required for any drilling and digging activities.
- Landowners, if their land is not a part of declared groundwater operational sites, have the right to search for groundwater within their land, and use as much as their 'adequate need', which is determined by DSİ. A utilization permit is still required.
- If the demanded amount of groundwater in concurrent applications to DSİ is close to the total allowable amount, the final decision on accepting or rejecting the applications is the responsibility of a board with delegates from relevant ministries.
- An additional paragraph added to the code in 2011 stating that all groundwater wells and tunnels must be equipped with measurement systems. Without the measurement system, a utilization permit cannot be provided. However, as noted above about two-thirds of all wells are installed illegally.
- A provisional clause added to the code in 2011 states that for both industrial and agricultural wells with permits that were given prior to the addition of the clause, are obligated to set up measurement systems.
- Regulation for Groundwater (Yeraltı Suları Tüzüğü, N.D.)

The regulation was adopted in 1961, along with its publication in the official gazette (No: 10875), to define the practical provisions of the Groundwater Code (167). Most articles are structured to clarify and guide stakeholders about the Groundwater Code. Some points are worth mentioning here:

- Even with utilization permits, well depths are determined by DSİ.
- The amount of water to be pumped from each well is the sustainable amount and the 'adequate need' determined by DSİ. In another article, it is also stated that the portion of groundwater reserved for adequate need can never exceed the safe extraction amount.
- DSİ has the right to control the technical legitimacy of the groundwater search, utilization, reclamation, and modification works instantaneously.

- Regulation for the Protection of Groundwater Against Pollution and Deterioration (Yeraltı Sularının Kirlenmeye Ve Bozulmaya Karşı Korunması Hakkında Yönetmelik, 2012)

The regulation was published in the official gazette with number 28257, on April 7, 2012. The purpose is to identify the methods to protect the current quality of groundwater aquifers that are in 'good' condition (specified in the regulation), to prevent pollution and deterioration of groundwater resources, and to enhance the overall quality of the aquifers. The prominent articles state the following:

- Direct discharge of wastewater, no matter what quality, is strictly prohibited. In some cases, specified in the regulation, direct or indirect discharge of wastewater, even after treatment, is also prohibited.
- DSİ is assigned to mapping and monitoring (and setting up a monitoring network) of groundwater resources, holding inventory for groundwater protection areas, and notifying SYGM.
- SYGM is assigned to determine the quality standards and threshold values. Viable threshold values must be set to protect the groundwater resource. SYGM is also responsible for (with DSİ being the consultee in the process) publishing groundwater quality reports periodically.
- In resource allocation, protecting the balance between the input (feeding) of the resource and extraction is essential. Requirement of water budgeting and any other factors that might endanger the quality or the quantity of the resource is highlighted.
- A general 'precautions program' is described, identifying measures to be taken and responsible institutions.
- The quality of groundwater is to be monitored by the Ministry of Environment and Urbanisation, and the quantity is to be monitored by DSİ.
- Other legislation relevant to groundwater extraction, allocation, and distribution are listed below.

- Law No: 831, The Water Code
- Regulation for the DSİ Groundwater Measurement Systems
- Law No: 6200, The Code for Services Provided by DSİ General Directorate

- Regulation for Water Allocation
- Regulation for Planning, Implementing and Follow-Up of Basin Management Plans
- Declaration of the Formation, Duties and Rules of Procedure of Central Basin Management Board, Basin Management Committees and Provincial Water Management Coordination Committees
- Law No: 6172, The Code for Irrigation Unions

3.5.3.3. Water Remediation Strategies in Practice

The remediation strategies in the agenda related to the quality of groundwater resources include,

- Enhancing wastewater treatment,
- Defining chemical pollutant concentration limits for industrial discharge waters
- Reducing the use of pesticides

(TRAGSATEC et al., 2018).

In Konya Closed Basin, issues regarding quality are not highlighted, either in the state plans or by local stakeholders; the main emphasis is on water quantity, rather than quality. The existing legal framework also focuses on quantity conservation and precautionary measures (as in the Regulation for the Protection of Groundwater Against Pollution and Deterioration) rather than quality remediation strategies. Nonetheless, data shows that the groundwater in the Konya plain is high in salinity, total dissolved solids (TDS), chloride, boron and nitrates concentrations (Bozdağ, 2013)

3.5.4. SWOT Analysis of Project Actions Related to Remediation Strategies

Strengths	Weakness
• Strong awareness of groundwater depletion and potential effects of climate change among stakeholders • Existence of a legal framework for allocation, monitoring and protection of groundwater resources • Researcher's through understanding of the site situation • High resolution monitoring of the groundwater resources	• Rooted conflicts among state and civil stakeholders • Lack of technical capacity to adopt smart agriculture structure technologies • Lack of sufficient past hydrological data • Lack of coordination in the implementation of decisions • Complexity in authority between state institutions • Lack of enforcement of the existing legal framework

Opportunities	Threats
• Social learning environment in the MED project • Decrease in the gap between scientific committee and local knowledge systems • Willingness of most stakeholders to act upon the problems and collaborate with the researchers • Use of technological tools to assist the decision-making process	• Being unable to execute the stakeholder meetings due to the Covid-19 pandemic • Failure in resolving the existing conflicts between the stakeholders • Inaction due to fatalism and the belief that there is nothing to do • Disconnection between local and national stakeholders • Increasing water security risk due to climate change

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