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Sustainable Water Storage and Distribution in The Mediterranean

Report on Demo Site Characterisation

VERSION 1.0

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Acronyms

DMP	Data Management Plan
WP	Work Package
CO	Consortium
PU	Public
R	Report
O	Other
DEM	Demonstrator
PT	Platform
NbS	Nature-based solution
MED	Mediterranean
UFZ	Helmholtz Centre for Environmental Research
RSS	Remote Sensing Solutions GmbH
UPV	Universitat Politècnica de València
IDRICA	Idrica
SEMIDE	Euro-Mediterranean Information System on know-how in the Water sector
TdV	La Tour du Valat
TUC	Technical University of Crete
UNIPR	Università di Parma
UNISS	University of Sassari
UNINA	University of Naples Federico II
RSCN	Royal Society for the Conservation of Nature
LPM	Living Planet Morocco
AGRI	AgroInsider
ESIM	Higher School of Engineering of Medjez El Bab
BU	Boğaziçi University
BMP	Best Management Practices

Executive summary

The overall objective of the "Sustainable Water Storage and Distribution in The Mediterranean" (OurMED) project is to design and explore innovative and sustainable storage and distribution systems tightly integrated into ecosystem management at the river basin scale. This is achieved by the combination of scientific and local knowledge, emerging from new and long-lasting spaces for social learning among interdependent stakeholders, society actors and scientific researchers in eight local and one regional MED demo sites. OurMED calls for a transition from a mono-sectoral water management approach based on trade-offs, to equitable multi-sectoral and integrative management that addresses all water bodies' capabilities and needs towards sustainability.

This Deliverable presents a comprehensive analysis of the challenges and opportunities in water management within the context of climate change in the Mediterranean region. Through a detailed examination of the hydrological and hydrogeological factors influencing water availability and demand, the report underscores the critical need for sustainable water development and management practices to ensure long-term water security and environmental sustainability. Drawing on insights from the OurMED project, funded by the PRIMA program, the deliverable highlights the importance of integrative approaches that enhance water storage and distribution systems while integrating local ecosystem management at the river basin scale. By analyzing demo sites that demonstrate the region's climatic patterns and water management practices, the report identifies key strengths, weaknesses, opportunities, and threats in current water management strategies. Through strategic recommendations and actionable insights, the report aims to guide stakeholders and policymakers towards more resilient and adaptive water management strategies that can effectively address the challenges posed by climate change in the Mediterranean region.

1.Introduction

The Mediterranean region, characterized by its diverse cultures and landscapes, is currently facing significant challenges in water management. These challenges are exacerbated by the region's climatic conditions, marked by hot, dry summers and mild, wet winters, which significantly influence water availability and distribution. The OurMED project, funded by the PRIMA program under the European Union's Horizon 2020 Research and Innovation Programme, aims to address these challenges by implementing integrative and sustainable water management practices across the Mediterranean region. The initiative focuses on enhancing water storage and distribution systems that are integrated with local ecosystem management at the river basin scale.

Key to the OurMED project are the demo sites, strategically chosen river basins that represent the common climatic and hydrological patterns of the Mediterranean. These demo sites are selected to reflect the typical conditions and challenges faced by the Mediterranean region. The selection of these sites is crucial for understanding and addressing the region's water management issues. These sites demonstrate the gentle balance between nature and human activity, a balance that is increasingly threatened by global climate variability.

The Mediterranean's historical and contemporary water management practices offer a variaty of solutions and challenges. From traditional irrigation systems, which have been used for centuries, to modern infrastructure that addresses current water use priorities influenced by agriculture and tourism, the region presents a unique case study in water management. These practices highlight the ongoing adaptations to water use priorities and the necessity for sustainable management strategies.

Biophysically, the varied geography of the Mediterranean provides each demo site with unique characteristics that contribute to their resilience and vulnerability. These geographical features not only shape the physical state of water systems but also support biodiversity and provide essential ecosystem services to both local and global communities. The OurMED project leverages these biophysical attributes to develop and implement sustainable water management practices.

A critical component of the OurMED project is the comprehensive characterization of each demo site. This characterization includes an analysis of climate, hydrological and hydrogeological contexts, water resource infrastructures, ecological and ecosystem footprints, soil and land use, and water development and management strategies. By understanding these elements, the project can develop targeted interventions that address the specific needs and challenges of each site.

The project also emphasizes the importance of stakeholder engagement and collaborative efforts. By promoting new and persistent spaces for social learning, the project encourages collaboration among various stakeholders, including local communities, researchers, and policymakers. This collaborative approach is essential for developing sustainable water management practices that are both effective and socially acceptable.

Furthermore, a SWOT analysis conducted at these sites reveals common strengths, such as robust ecosystems and well-established governance frameworks, and weaknesses, including rising water demand and pollution. These analyses also identify opportunities for sustainable development and ecological restoration, as well as significant threats like climate change and unsustainable practices. This analytical approach helps guide the strategic direction of the project and ensures that interventions are both effective and sustainable.

The OurMED project calls for a transition from a mono-sectoral water management approach, which often focuses on trade-offs, to an equitable multi-sectoral and integrative management approach. This new approach addresses all water bodies' capabilities and needs towards sustainability. By integrating scientific research with local knowledge and stakeholder engagement, the project aims to create a holistic and sustainable water management system that can be adapted and implemented across various locales in the Mediterranean region.

In summary, the OurMED project is a comprehensive initiative that seeks to address the Mediterranean region's water management challenges through innovative, sustainable, and integrative practices. By focusing on the unique characteristics of each demo site and fostering collaboration among stakeholders, the project aims to develop and implement effective water management strategies that ensure the long-term sustainability of water resources in the Mediterranean region.

1.1. Purpose

The purpose of the 'Demo Site Characterisation' work package within the broader OurMED project is to strongly understand and clarify the underlying similarities and unique characteristics of each demo site in their climatic, hydrological, and geographical contexts. This inquiry serves as the foundation upon which the mosaic of OurMED's strategic approach to water management is positioned. By analyzing climate phenomena, existing water management strategies, water usage practices, biophysical conditions, and comprehensive SWOT analyses, our efforts aim to uncover the complex patterns that bind these sites together.

Our provided site characterization will enable us to construct a holistic and integrated picture, facilitating targeted, effective interventions and the adoption of best practices that can be adapted and implemented across various locations. By merging scientific exploration, field measurements, living labs with practical knowledge, this work package not only explains current conditions but also plots a trajectory towards a future where harmonious coexistence with our aquatic lifelines is not only envisioned but actively pursued and realized. Thus, the 'Demo Site Characterisation' work package stands as a cornerstone, shaping the trajectory of sustainable water resource management in the Mediterranean for generations to come.

2.Demo site characterization

2.1. Case study Agia

The study area is situated from 35° 2450N to 35° 3000N, and 23° 4950E to 23° 5800E. It is located in the central part of Keritis river drainage basin, 3.5 km west of the city of Chania (Figure 1). The central study area is characterized by a rather gentle topography. The area is drained by the Keritis River which is considered to be the main river of the area. The demand for irrigation water is high, while at the same time only 31.0% of the available agricultural land is irrigated (Tsagarakis et al., 2004). The growing water demands make the water resources management extremely important for sustainable development. The area is 210 km^2.

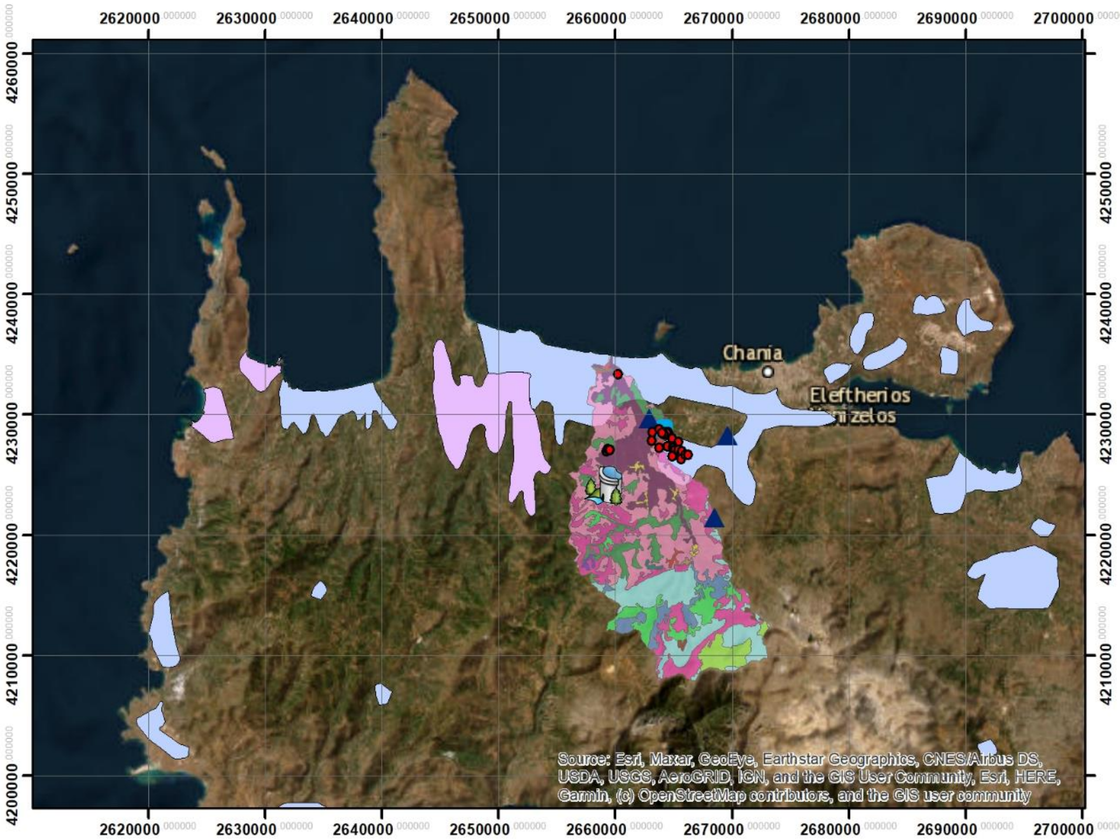

Figure 1 Agia demo site demonstration.

2.1.1. Biophysical attributes

The Keritis River in Crete has different biophysical attributes that are characterised by its hydrological properties, which are influenced by the prevailing sub-humid Mediterranean climate. The seasonal variations in precipitation, which are mainly concentrated in the winter months, have a significant impact on the river's discharge dynamics and water availability. The geological formations, especially the Trypali carbonate rocks, play a crucial role as they facilitate groundwater recharge and influence the hydrology of the river. In addition, the proposed water infrastructure projects in the catchment area aim to increase water storage capacity and reduce erosion, underlining efforts to sustainably manage water resources. In addition, the designation of protected areas in the river basin plays an important role in protecting biodiversity and maintaining the ecological integrity of the surrounding landscape. Taken together, these factors contribute to the complex interplay of environmental factors that shape the biophysical attribures of the Keritis River.

2.1.1.1. Climate

The climate of the study area is sub-humid Mediterranean with humid and relatively cold winters and dry and warm summers. During winter that starts in November, the weather is unstable due to frequent changes from low to high pressures. The annual rainfall for the broader Chania area has been estimated to be 665 mm (Chartzoulakis et al., 2001). The precipitation in Agya is estimated at 855 mm. About 65% of the annual precipitation is lost to evapotranspiration, 21% as runoff to sea and only 14% recharges the groundwater (Chartzoulakis et al., 2001). The rainfall is mainly concentrated in the winter months while the drought period extends to more than 6 months (May–October). The monthly evaporation ranges from 140 mm to more than 310 mm in the peak month. As a result, the water resources availability is limited due to the spatio-temporal variations of precipitation (Tsagarakis et al., 2004).

In the municipality of Platanias, to which the study area belongs, there are several meteorological stations from which data on the prevailing meteorological and data can be collected. Typically, the highest temperatures are reached in July, while the coldest temperatures occur between January and February, with rare instances of temperatures dropping below 0^{o}C. This seasonal pattern is evident in Figure 2, Figure 3 and Figure 4, which illustrate the variation of mean temperature over time in Agia and Alkianos. The data also shows that the highest levels of precipitation are generally recorded in January and February, as can be seen from the precipitation graphs for the two stations in question. This cyclical variation in weather patterns underlines the seasonal dynamics of the region, where temperature and precipitation fluctuations characterise the climate throughout the year.

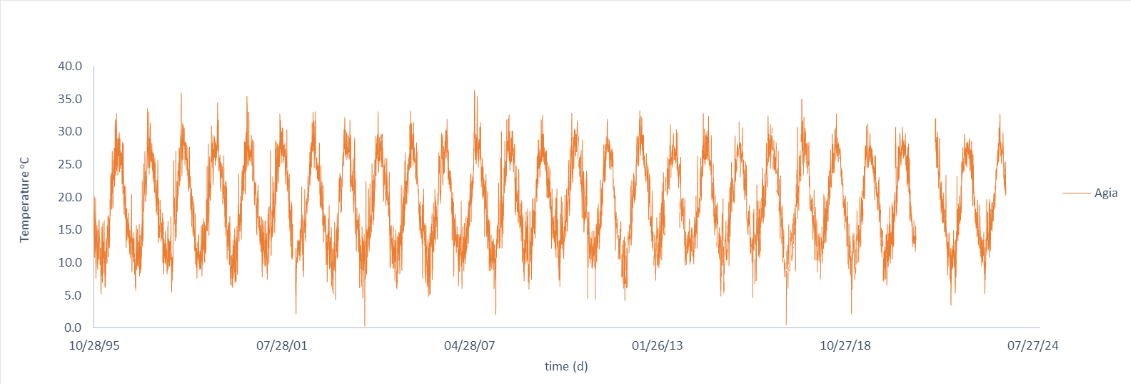

Figure 2 Mean Temperature flactuatios, Agia station.

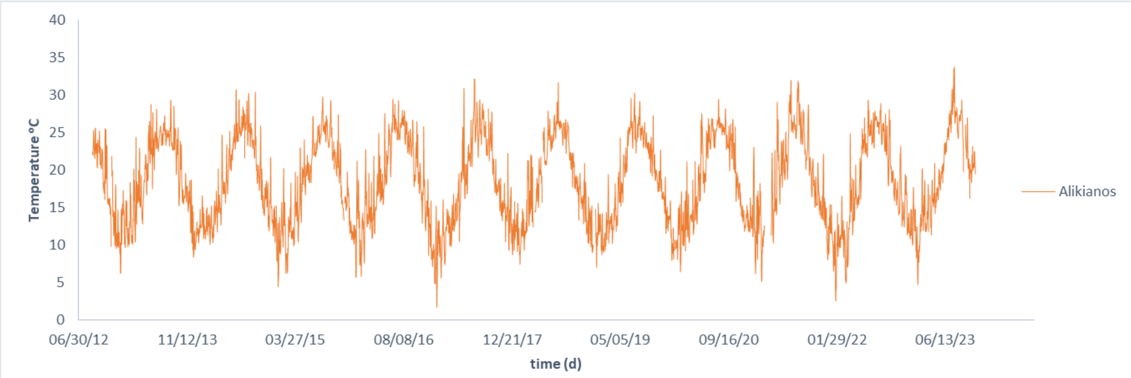

Figure 3 Mean Temperature flactuatios, Alikianos station.

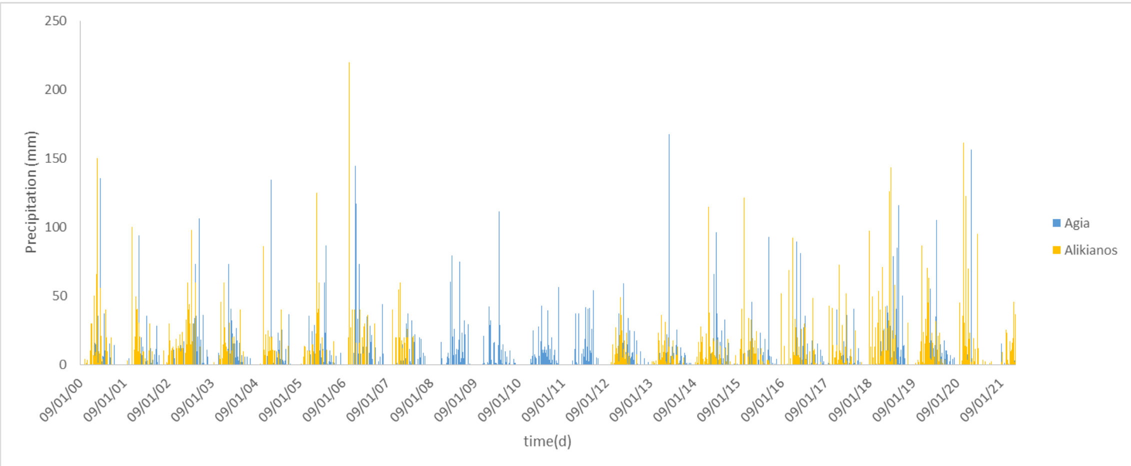

Figure 4 Precipitation fluctuations Agia & Alikianos stations.

2.1.1.2. Hydrological/hydrogeological context

Rainfall studies from 7 stations located in the area (period 2006 - 2018) have shown the relationship between rainfall and the altitude as shown in Eq. 1:

Eq. 1: $$P = 2.065\,h + 478.38$$

where, P is the precipitation in mm, and h the altitude in m. Based on the aforementioned relationship, the average annual precipitation in Agyia's catchment area is estimated at 260 Mm^3. Thirty seven percent (37%) of this quantity, which is equal to 96 Mm^3, infiltrates, and twenty percent (20%), namely 53 Mm^3, runs off. The mean annual evaporation ranges between 43–58% of total annual precipitation.

Plattenkalk formations are characterized by low permeability values (10^{-7} to 10^{-5} m/s), and where the geological conditions allow, they consist of the hydrogeological base layer of the overlying Trypali carbonate rocks. The highly fractured nature of the Trypali unit, in addition to the dissolution and the erosion process, have created a great variety of karst features, from simple rillenkarren up to dolines and karst cavities. The surface water tends to concentrate into the aforementioned features and then infiltrates, recharging the groundwater.

The hydraulic properties of this formation were estimated by pumping tests in the Myloniana well-field. The transmissivity of the carbonate unit ranges between 0.1 to 1 m^2/s, which is equivalent to a permeability between 10^{-3} and 10^{-2} m/s.

Pertinent studies show that 55% of the precipitation infiltrates, recharging the groundwater, while surface run off is very limited (about 5%), and surface drainage occurs only after strong rainfalls. Furthermore, the analysis of hydrographs of springs and wells within the karstic aquifer hosted in the Trypali unit presents a corresponding seasonal variation of the groundwater level that suggests a homogeneous karst.

Based on the aforementioned annotations, it is assumed that the Trypali unit forms a separate hydrogeological entity that discharges through the Agyia's springs while the Plattenkalk unit forms the accompanying base layer.

Phyllite-Quartzite formation is characterized as almost impermeable ($k < 10^{-8}$ m/s) due to its mineralogical composition and structure and selective circulation (10^{-8} to 10^{-7} m/s), with low to very low water permeability, when interferences of quartzite or crystalline limestones exhibit higher growth. The infiltration coefficient of this formation is estimated to be approximately 5%, and the runoff coefficient reaches an amount of 35%. The uppermost Quaternary sediments are of medium-low permeability (10^{-7} to 10^{-5} m/s) and they host phreatic aquifers of not significant yield compared to the karst aquifer hosted in the Trypali unit. The infiltration coefficient in the alluvial sediments is estimated to be about 20%, while the runoff coefficient is estimated to be about 20–30%.

The tectonic structure determines the area that contributes water to the karst aquifer (Figure 2). Specifically, the Phyllite-Quartzite unit in the west constitutes a regional aquiclude (no flow boundary); to the North, the stratigraphic (locally tectonic) limit between the Quaternary formations and the Phyllite-Quartzite unit determines an impermeable boundary that holds the aquifer and prevents the flow of the karst water towards the sea; in South the groundwater exchanges with the rest of the hydrogeological system of the Lefka Ori Mountains, while in the Eastern part of the area, data resulting from geological surveys and well drillings indicate that the Plattenkalk series (aquiclude) has a structural top at an altitude of +625 m.a.s.l. It acts as a local watershed (Figure 2) and divides the groundwater supplying the Agia's springs in the West, from the groundwater supplying the Chania basin in the East. Based on this conceptual model, Agyia's springs are fed by the groundwater flowing in the Eastern part of the catchment area.

The system is recharged mainly through the carbonate rocks exposed in the southeastern and southern part of the area (Lefka Ori Mountains), as well as through precipitation infiltrating from the ground surface to the groundwater table, across the entire area. The watertight horizons of chert and schists in the Plattenkalk series restrict the percolation of water and strongly influence its movement and concentration in the aquifer hosted in the Trypali unit.

The results of the systematic piezometric surveys confirm a regional groundwater flow direction from SE-S towards NW–N (Figure 2), with hydraulic gradients ranging from 3 to 8%. In the North margin of the study area, a fault zone running SW–NE approximately parallel to the coast, sinks the Phyllite-Quartzite nappe lower than the sea level and prevents the flow of the karst water to the sea. The direction of the fault identifies with the axis of occurrence of Agias's group of springs (Figure 5), which comprise the main discharge of the aquifer. They are contact-overflow springs with a mean outflow rate of 60 Mm^3 annually; they outflow at an altitude from +33.5 m a.s.l. (Kalamionas) to +40.6 m.a.s.l. (Varypetro).

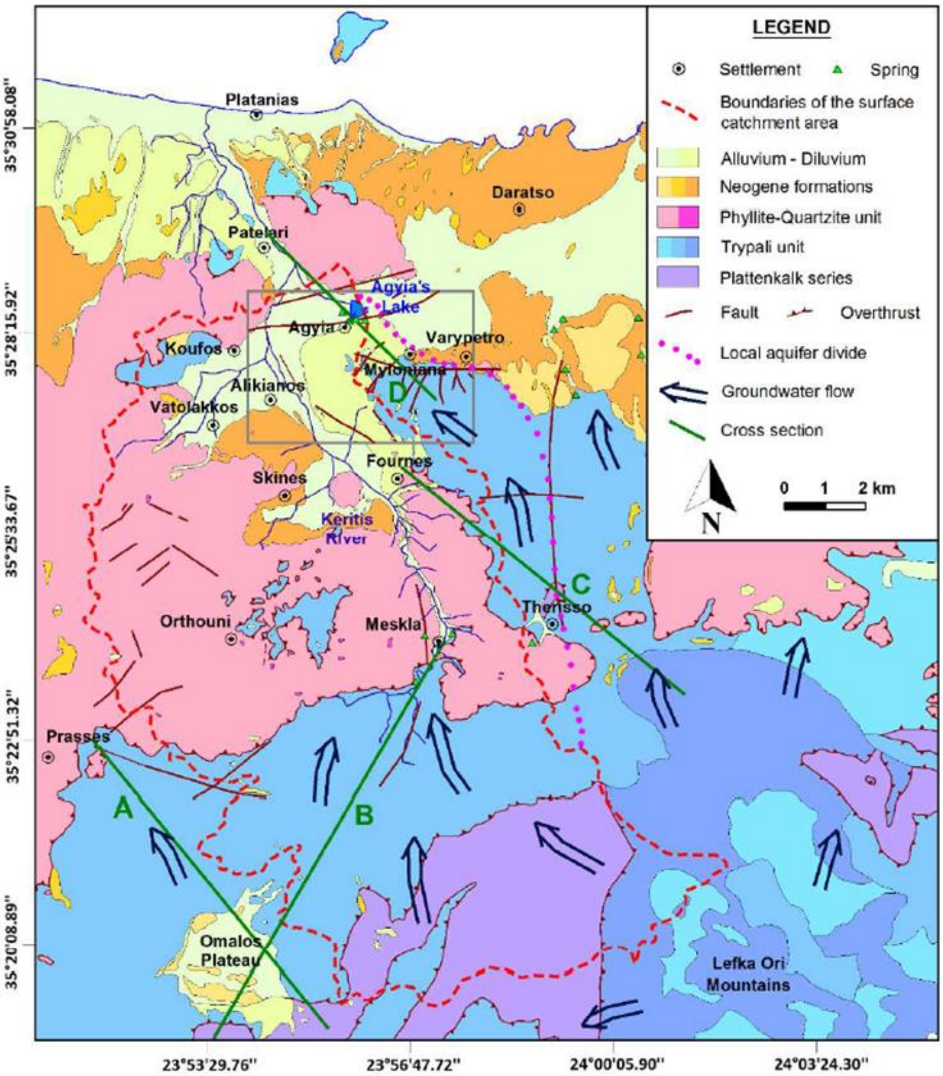

Figure 5 Geological map of the study area. The rectangle shows the area of the detailed flow model.

2.1.1.3. Water resources infrasturctures

The Keriti-Therisou basin, known for its abundant water resources, serves as a vital water supply for a large part of the prefecture of Chania. The main source of these water resources is the karst aquifer of Agia, which is the most important water reservoir of the region. This water-rich aquifer feeds numerous wells and springs that are distributed throughout the area and are used for irrigation and general water supply. Among the most important water sources are the springs of Agia, consisting of the springs of Platanos and Kolymba. Furthermore, the spring of Kalamionas is another important part of this water network. In addition to the natural springs, the implementation of pumping wells has been undertaken in the watershed region, positioned above the aquifer's drainage zone. These pumping wells are an important part of the management of water resources in the region. An illustration of their location can be found in Figure 6.

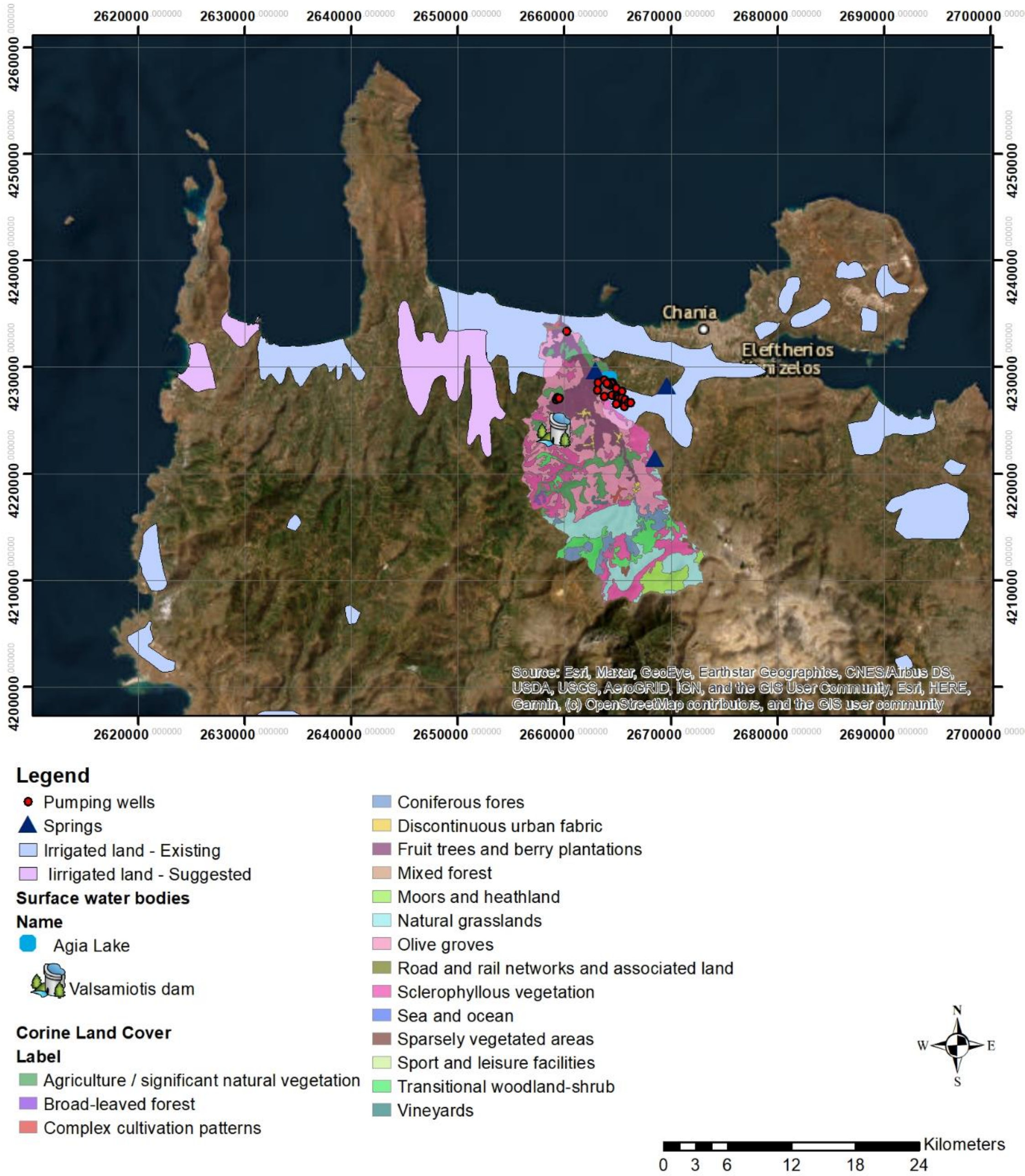

Figure 6 Water infrastuctures map of the study area.

The construction of the Deryanou and Sepranioti dams, with a capacity of 18 and 7 Mm^3 respectively, is a proposed solution that could have ensured an autonomous water supply for the area. These dams not only offer the possibility of solving the major problem of sediment transportation, but also promise to strengthen water resources. In the event that these larger projects cannot be realized, an alternative proposal suggests the construction of smaller retention dams, comprising between 8 and 12 per tributary and 30 small dams in total. These smaller structures would serve to mitigate the river's erosion potential while contributing to local water management and overall environmental sustainability

2.1.1.4. Ecological and ecosystems contet and footprint

In the study area, designated regions form part of the Natura 2000 Network, which serves as a comprehensive European Ecological Network. This network encompasses areas hosting natural habitat types and species of significant importance at the European level. Structurally, the Natura 2000 Network is organized into two distinct categories of areas:

- "Special Protection Areas (SPAs)" for birds, as defined in Directive 79/409/EEC "on the conservation of wild birds".
- "Sites of Community Importance (SCIs)" as defined in Directive 92/43/EEC. SCIs are designated considering habitat types and species listed in Annexes I and II of Directive 92/43/EEC as well as the criteria of Annex III of this Directive.

The regions forming part of the Natura 2000 Network, in the watershed, include Lake Agia with code GR4340020, Lake Agia - Platanias - Keritis River & Fasa Valley with code GR4340006 and Therisso Gorge with code GR4340007.These areas have been selected for protection due to the presence of significant natural habitat types and species crucial for the conservation of biodiversity at the European level. The protection of these areas is important for maintaining ecosystems and safeguarding species dependent on them. The National Park of Samaria with the code GR4340014 and the White Mountains & Coastal Zone with the code GR4340008 are also included in the Natura areas. Figure 7 shows the Natura areas in the watershed.

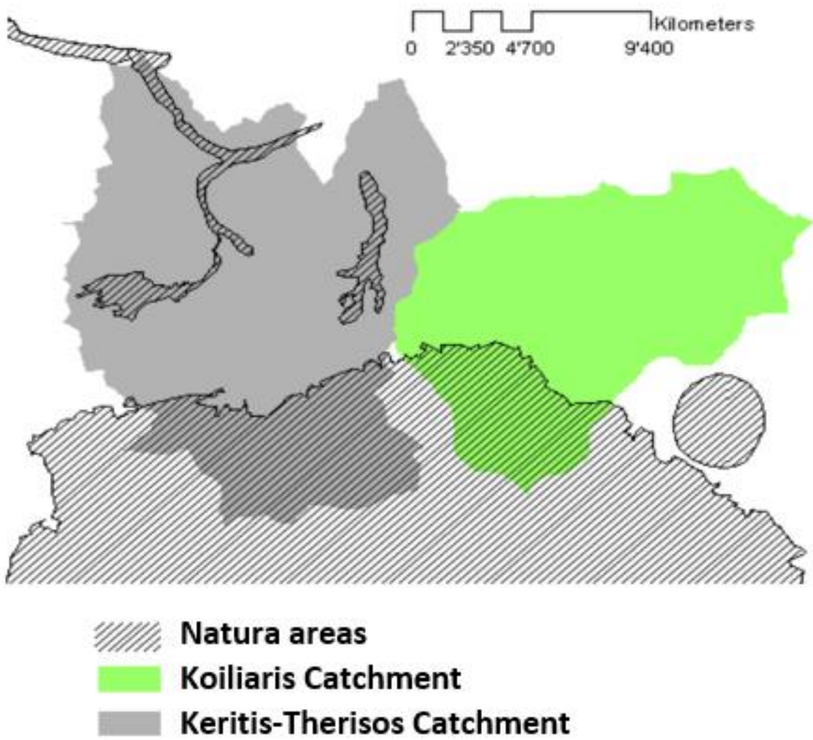

Figure 7 Natura areas in the catchment area.

Lake Agia, although not a natural lake, boasts a diverse array of aquatic communities, making it a significant habitat within the ecosystem. Notably, it serves as a crucial area for wetland bird species such as the little egret (Egretta garzetta) and the ferruginous duck (Aythya nyroca). However, this ecological balance faces threats from various sources including water abstraction, infrastructural developments and the impacts of intensive tourism activities.

In the Lake-Keritis ecosystem, several notable species contribute to its ecological richness. These include:

- The leopard snake (Elaphe situla)
- Balkan pond turtle (Mauremys rivulata)
- Greater horseshoe bat (Rhinolophus ferrumequinum)
- Lesser horseshoe bat (Rhinolophus hipposideros)
- Woodwardia radicans.

Each of these species plays a distinct role within the ecosystem, contributing to its biodiversity and ecological stability.

2.1.1.5. Soil and Land use

The provided data in the Figure 8 elucidates the distribution of diverse land types within the surveyed region, furnishing valuable insights into its overall land cover composition. Among the notable findings, natural grassland emerges as the dominant feature, encompassing 29.23% of the terrain and indicative of extensive open grassy areas. Additionally, olive groves occupy a significant portion, covering 21.13% of the land, reflecting substantial agricultural activity centered around olive cultivation. Sclerophyllous vegetation, accounting for 19.21% of the area, denotes the prevalence of hard-leaved plant species, characteristic of Mediterranean climates. Fruit trees and berry plantations, occupying 9.65% of the landscape, contribute to agricultural diversity, while forest areas, spanning 6.90% of the total hectares, serve as habitats for diverse flora and fauna populations. Moreover, agricultural lands, discontinuous urban fabric, moors and heathland, complex cultivation patterns, sparsely vegetated areas, and vineyards represent distinct land cover features, each contributing uniquely to the surveyed region's ecological profile and land use dynamics. This comprehensive portrayal underscores the heterogeneous nature of the landscape.

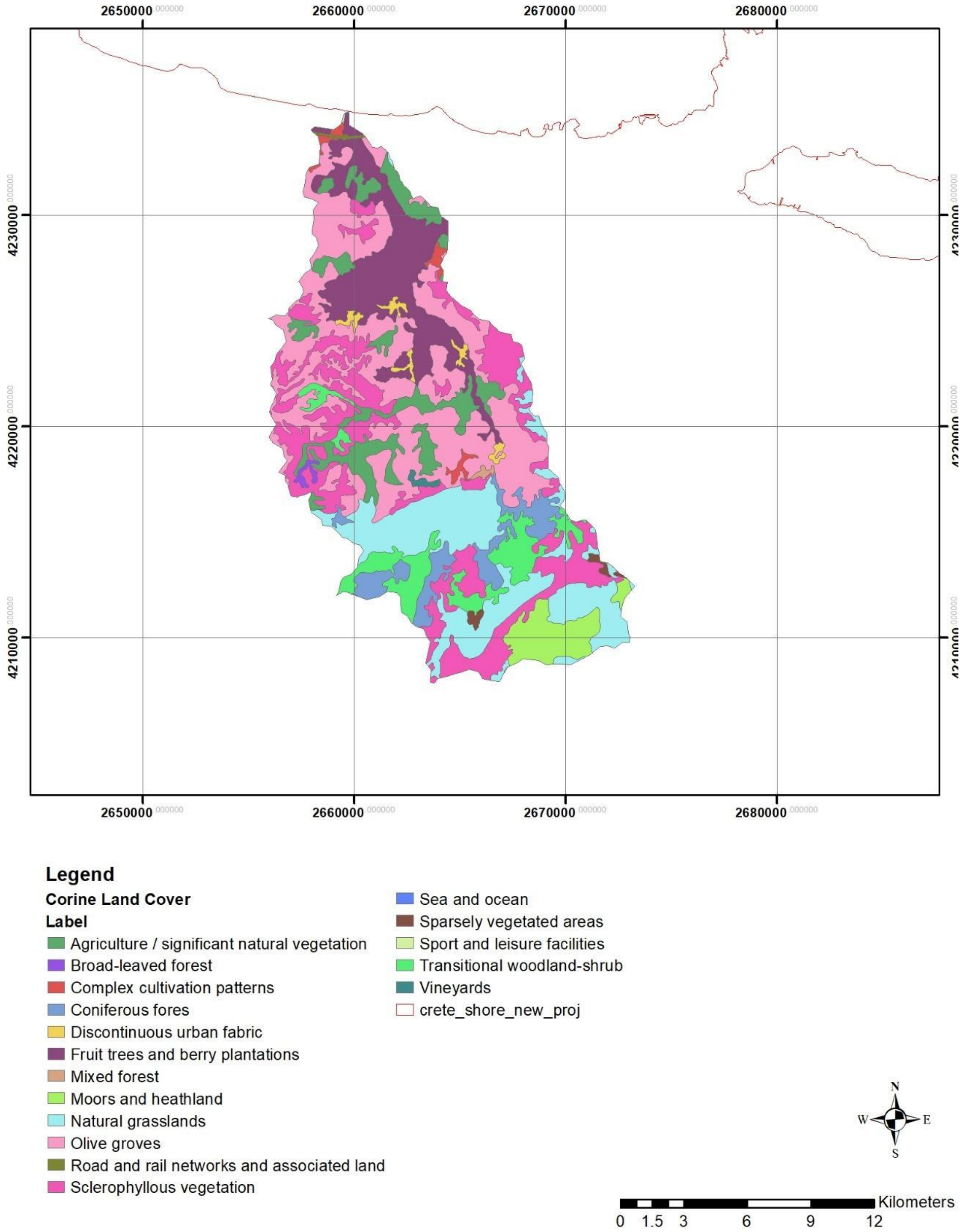

Figure 8 Land Cover in the Keritis River catchment area (Corine, 2000).

The Keritis River basin's primary geological formations—limestone, alluvium, marl, and schists—play a crucial role in determining the region's soil composition. These formations significantly influence the catchment area's terrestrial environment. The surface soils within the Keritis catchment are characterized by loam, sandy loam, and clayey loam textures, directly reflecting the impact of the underlying geological formations on soil structure. Additionally, the soil composition in the Keritis watershed shows notable levels of heavy metals, primarily attributed to the region's predominant agricultural activities. The primary heavy metals identified in the soil include copper, zinc, lead, and chromium, which provide valuable insights into the extent of soil contamination. The pH levels in the Keritis watershed vary from acidic to slightly alkaline, reflecting the diverse soil conditions present. The calcium carbonate content is generally low, indicating the influence of the region's geology on soil mineralogy. Moreover, the organic matter content shows considerable variation, emphasizing the dynamics of organic input and soil fertility within the basin (Papafilippaki et al., 2007).

2.1.2. Water development and management

During the last decades, the incremental need of accurate global groundwater resource assessment has led to a rapidly growing awareness in the field of groundwater management. Therefore, quantitative description of aquifers has become vital in order to address several hydrological and hydrogeological problems.

2.1.2.1. Water supply, water storage and distribution

The Keriti-Therissos basin plays a pivotal role in meeting the irrigation and watering requirements of a substantial area within the Chania Prefecture. Most of the water resources come from the karst aquifer of Agia, which is also the main source of water in the area. The maximum surface area of Lake Agya is 120,325 m^2 at a water level of 38 m above sea level and the volume is 215,138 m^3. At an elevation of +37 m, the surface area is reduced to 87,775 m^2, while the volume is 104,050 m^3.

Ongoing initiatives in the region include the management of water extraction from the Platanos, Kolympa and Kalamionas springs, as well as pumping wells supervised by the Municipal Water Supply and Sewerage Company of the Municipality of Chania (DEYACH), the Organization for the Development of Crete (OAK) and the Local Land Reclamation Organizations (TOEB).

The Chania Water Supply and Sewerage Company (DEYACH) retrieves water mainly from the Platanos spring, which is then conveyed to the central reservoir in Chania for urban distribution. In addition, water is extracted from several pumping wells to meet the water demand of approximately 9 Mm^3 in Chania. Prior to 2018, DEYACH drew additional water from pumping well belonging the Organization for the Development of Crete OAK.

In the Myloniana region, the Organization for the Development of Crete (OAK) manages a network of pumping wells. Together these wells have an impressive capacity of 4750 m^3/hour. These wells are among the largest in Greece with a hydraulic gradient of less than 1 meter. They are located 2 km south of the Agyia springs and draw their water from the same karst aquifer. The pumping wells are mainly operated from May to November each year. During this period, an estimated 14 Mm^3 of water is extracted. Most of this water is used for irrigation purposes, while some is used to meet water needs during the summer months.

An OAK-owned pumping station near Patelari draws water from Lake Agyia and the Kalamionas spring, mainly from April to November, with an annual withdrawal of 6.3 Mm^3. This water is used for irrigation and water supply in the Kolymvari region.

The Local Land Reclamation Organization (TOEB) extracts water exclusively from the Kolymba spring for the irrigation of 12,000 hectares. It operates two wells, mainly from April to September, with an estimated annual abstraction of 4 Mm^3.

2.1.2.2. Water uses

The Keriti-Therisou basin, renowned for its copious water reserves, serves as a vital source of water for irrigation and domestic needs spanning a significant area of Chania Prefecture. Water allocation in Chania is crucially distributed across various sectors:

1. Agriculture: This sector stands as the primary consumer, heavily reliant on irrigation methods to sustain crop growth and productivity.
2. Domestic consumption: Catering to the essential water requirements of households and local communities, this sector follows closely behind agriculture in terms of water usage.
3. Industrial operations: Notably, industries such as olive processing make substantial contributions to the region's water consumption, utilizing water in various production processes.
4. Tourism sector: With its expanding influence, both domestically and internationally, tourism significantly impacts water demand in the region.

Taken together, these sectors describe the multiple dimensions of water use in Chania and characterise the patterns of resource allocation and management in the region.

2.1.2.3. Water management strategies

The water management strategy initiative includes the management of Lake Agia, a small body of water with an area of approximately 0.2 km^2 and an average depth of 4 meters. Originally a marshland, it was converted into a reservoir as part of the Comprehensive Water Management Plan for Crete (GR13), which was started in 1927 under the auspices of the Public Power Corporation of Greece (DEH) to enable the construction of a hydroelectric power plant. Although the operation of the power plant was later discontinued, the lake has evolved into a natural reservoir characterized by a remarkable bird population, diverse ecosystems and its designation as a Natura 2000 site.

Significant human intervention, in particular the excessive abstraction of irrigation water below the ecological regeneration threshold, has led to eutrophication problems in Lake Agia. Combined with the accumulation of sediments in certain regions of the lake, these interventions have exacerbated the environmental problems of this ecosystem. The excessive abstraction of water for irrigation purposes during periods of low rainfall has not only disturbed the natural balance of nutrients in the lake, but has also contributed to the lake becoming increasingly shallow due to sedimentation. Consequently, the cumulative effect of these human activities has led to a deterioration in the water quality of Lake Agia.

The management of Lake Agia must comply with the environmental conditions approved by the Ministerial Decision EPO 125585/24.1.2007. This legal framework provides for a number of measures that are essential for the management of the lake.

- **Monitoring drinking water quality**: Ensuring the safety and cleanliness of the water supply remains a top priority, necessitating continuous monitoring efforts.
- **Conducting dam integrity studies**: Comprehensive assessments are crucial to evaluate the structural integrity of the dams, particularly in relation to potential flood risks.
- **Issuing water use permits**: Regulatory oversight and management of water usage are essential for maintaining sustainable water resource utilization.
- **Addressing ecological concerns**: Strategies aimed at preserving the ecological balance of the lake, including restricting dam discharge and managing aquatic vegetation, are paramount for ecosystem health.
- **Evaluating lake hydrochemical and biological states**: Scientific assessments provide critical insights into the overall health and functioning of the lake ecosystem.

The overarching objective is to ensure the preservation of Lake Agia's ecological integrity and the sustainable utilization of its resources.

2.1.2.4. Main issues

In order to prevent groundwater pollution phenomena and to preserve water resources for human consumption, protection zones around the water abstraction points are established. By placing some form of regulatory control on activities taking place in these zones, the anthropogenic impact on the quality of the abstracted water can be minimized. According to Cost Action 65, source protection zones should be defined around individual groundwater sources of supply, which ideally encompass the total catchment area, while the groundwater resources should be protected with a more extensive zoning that may cover the entire land surface of the aquifer (resource protection zones).

The produced map (Figure 9) divides the area into a number of groundwater protection zones according to the degree of protection required. Within these protection zones, a code of practice describes the recommended controls for both existing and new activities. The results from the vulnerability estimation and the groundwater flow simulation were merged into an integrated assessment in order to delimit the protection zones for the groundwater abstraction points located in the discharge zone of the aquifer. In detail, the following protection zones were designed:

Protection Zone I: This represents an immediate protection zone against the direct introduction of contaminants to the groundwater. It should be excluded from any anthropogenic activity.

Protection Zone II: This is known as a controlled zone or a microbiological protection zone. It spans in the area around Zone I and it should be protected against pollution from any anthropogenic activity, such as crafts, oil mills, cesspools, cemeteries, etc. It is a sensitive area that is necessary to be protected.

Protection Zone III: This refers to the area of the unsaturated zone of the karstic system that can transport the pollution or the chemical contaminant to the downstream area where the springs and pumping wells are located (Figure 9). This zone extends outside Zone I and Zone II. It includes the entire capture zone (i.e., the surface and underground catchment area) that feeds the water abstraction points.

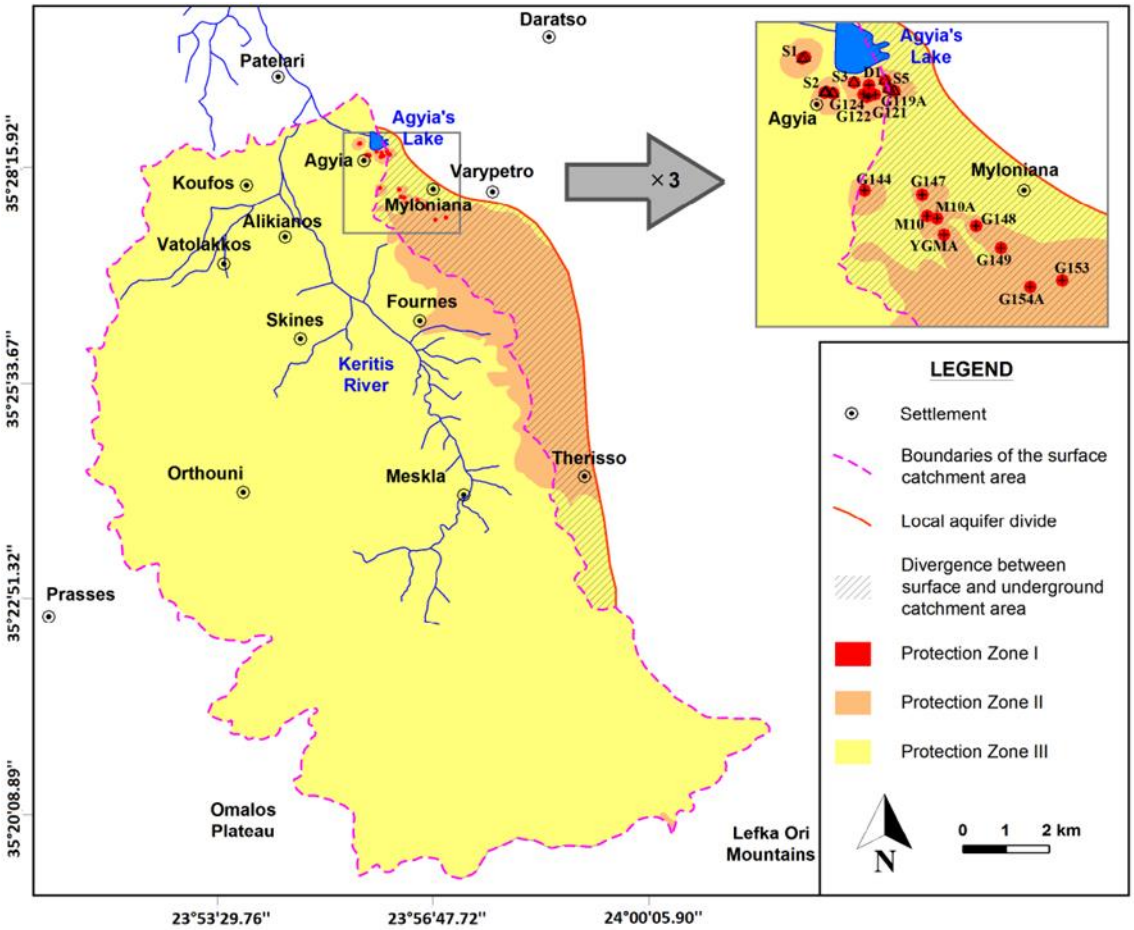

Figure 9 Protection zones in the discharge area of Agia's karstic system.

2.1.3. Water resources governance

Various organizations have the task of distributing water resources according to the specific contexts of use. This distribution network ensures that water is allocated efficiently to meet the different needs of the various sectors. One of these organizations responsible for monitoring water supply and irrigation in the Hydrographic Basin is the Organization for the Development of Crete (OAK).

The Organization for the Development of Crete S.A. assumes the role of the supervisory authority for essential water supply and irrigation within the Hydrographic Basin. It extends services encompassing water supply, irrigation, livestock, and industrial provisions to entities such as Water Supply and Sewerage Companies (DEYAs), Municipalities, Local Water Management Organizations (TOEB), Industries, and notable consumers like the Technical University of Crete. Moreover, it facilitates irrigation water services to private consumers.

DEYAs, operating within their designated areas, administer water supply and sewerage facilities to households, private enterprises, and commercial ventures (for water supply, livestock, and industrial purposes). Municipalities outside of the authority of DEYA's operational boundaries function as autonomous providers of water supply and sewerage services (pertaining to water supply, livestock, and industry).

Furthermore, the local land reclamation organizations (TOEB) attend to the irrigation needs of individual users

2.1.3.1. Water policy and current instruments of water regulation

The protection of wild birds, as laid down in Directive 79/409/EEC, together with the conservation of Natura 2000 sites under Directives 92/43/EEC and 2009/147/EC, is a major environmental project. Under GR13BM02, efforts are focused on the development and implementation of management plans specifically designed for Natura 2000 sites related to aquatic ecosystems. This initiative is overseen by the Ministry of Environment and Energy to ensure that the management strategies effectively address the challenges related to aquatic ecosystems. At the same time, the Water Directorate of the Decentralized Administration of Crete is responsible for the important task of monitoring and assessing the conservation status of water-dependent habitats and species within these Natura 2000 sites. In addition, proactive initiatives are formulated to introduce new measures based on the assessment results, taking into account the complex dynamics of the water systems. The most important measures include:

1. Development and establishment of management plans for Natura 2000 sites influenced by aquatic ecosystems.
2. The monitoring and assessment of the conservation status of water-dependent habitats and species.
3. The development of new measures in response to assessment outcomes and the pressures on water systems.

Furthermore, in order to ensure public health, water supply and wastewater treatment companies (DEYA) shall implement water safety plans in accordance with Directives 80/778/EEC and 98/83/EC. These plans include the introduction and implementation of best practices in the drinking water distribution network with the aim of maintaining high standards of water quality and safety.

2.1.4.SWOT analysis of project actions

The analyzed area exhibits notable strengths in its water resources, characterized by good-quality groundwater, surface water, and wastewater suitable for re-use. Community-managed irrigation, stable water infrastructure, and a high level of financial sustainability further contribute to effective water management. Active community engagement, government support, and widespread water network accessibility enhance the region's resilience. However, the area faces challenges, including dependence on seasonal rainfall, significant urbanization pressure, and high water consumption in farmland. These weaknesses, coupled with issues like low wastewater reuse, flood risks, and biodiversity loss, underscore the need for comprehensive water management strategies. Opportunities arise from an appropriate legislative framework, implementation of directives, and agricultural policies promoting biodiversity-friendly practices. Nevertheless, threats such as climate change impacts, lack of infrastructure investment, and potential elimination of Common Agricultural Policy (CAP) aid pose risks to the region's water security and sustainability. A balanced approach addressing weaknesses and capitalizing on opportunities is crucial for effective and resilient water resource management in the analyzed area. A SWOT analysis helps organizations and individuals systematically evaluate the internal Strengths and Weaknesses and external Opportunities and Threats related to a specific area, project, or situation.

Strengths	Weaknesses
Good quality of groundwater, surface water and waste water for re-use. High irrigated area belonging to irrigation communities. Most of the 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 Quality
Opportunities	**Threats**
Appropriate legislative framework for proper water management. Implementation of the measures defined in the Water Framework Directive. Compliance with environmental objectives. Promoting active participation of all stakeholders in the implementation of this Directive. Monitoring of surface water and groundwater. Cost recovery of water-related services. Common Agricultural Policy (CAP) associated with good practice for the maintenance of biodiversity, landscape, soil protection and water resources. Specific measures include: Recovery of local varieties with lower water consumption. Adaptation measures to climate change. Improving irrigation efficiency.	Reduced flows resulting by processes associated with climate change. Major drought periods during the summer months by processes associated with climate change. Increased water demands due to rising temperatures associated with climate change. Increased water temperatures due to rising temperatures from 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. Subvention, by the CMO (Common Market Organisation), of crop production highly water consumers or to facilitate the transformation in irrigation (example: olive irrigation in the basin).

Ensure compliance with Water Framework Directive. Avoid use changes and increase agriculture in protected areas. Rural Development Programme Ensure the efficient management and sustainable of ecological farming. Aid for exports of high environmental interest located in Natura 2000. Subvention of Marginal rainfed crop with constrained profitability, with impact on soil, water, landscape or biodiversity.	

2.2. Case study Bode

The Bode catchment area is 3300 km^2 and is located in the transition zones of Germany's central uplands and northern lowlands. The Bode catchment is surrounded by the Harz Mountains in the southwest and lowland plains in the northeast. The catchment's elevation ranges from 1142 metres above sea level at the Brocken (the highest point in the Harz Mountains) to 70 metres above sea level in the lowland region (Figure 10). The watershed features considerable variations of climatic, land use, soil type, and geological properties along the elevation gradient (Zhou et al., 2022). Anthropogenic influences have a substantial impact on the region, with agriculture being the primary land use (Wollschläger et al., 2017). The Bode River basin has diversified land-use properties, with upper alpine parts dominated by forests and lowland sections dominated by agricultural land. The Bode River basin has recently experienced severe drought conditions, impacting heavily its land use and biogeochemical properties (Zhou et al., 2022).

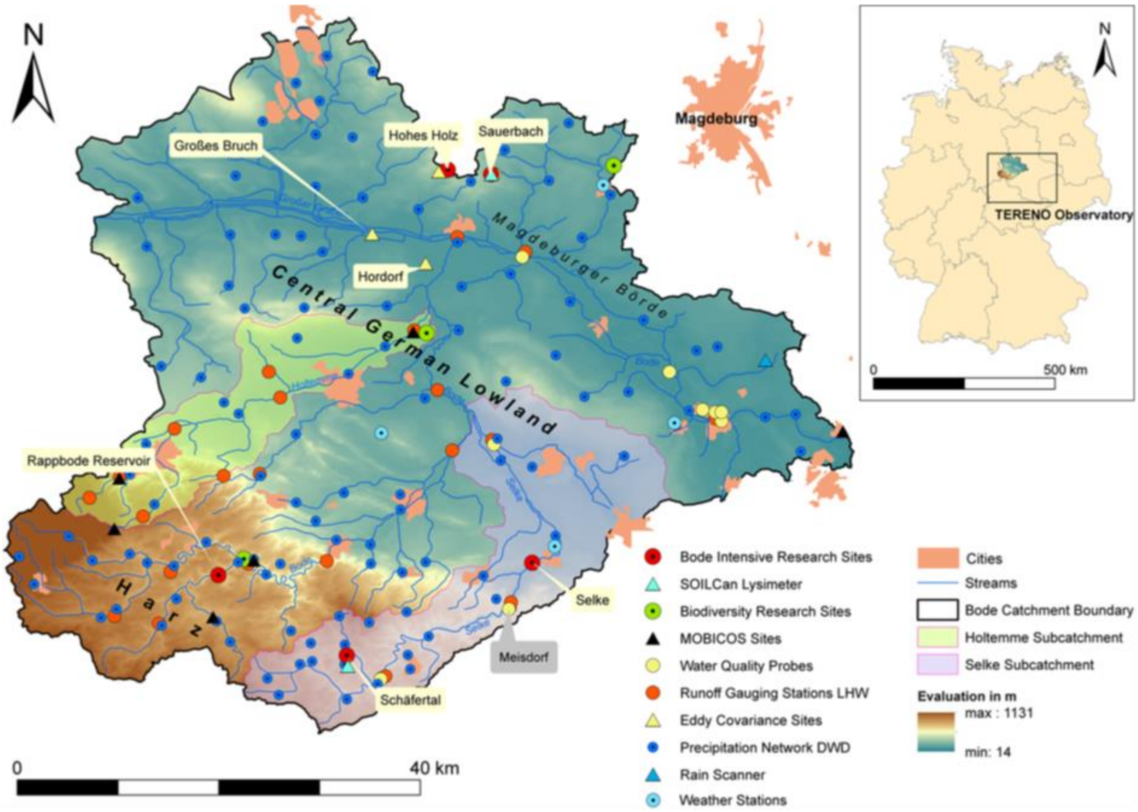

Figure 10 Bode catchment map as part of the Central German Lowland Observatory (TERENO Harz) taken from Wollschläger et al., (2017).

2.2.1. Biophysical attributes

The Bode River basin, situated within the Harz Mountains and extending into the Central German Lowlands, presents a complex biophysical landscape characterized by diverse topographical and hydrological features. This catchment area serves as a critical hydro-ecological observatory, where the interplay of high-altitude river headwaters and extensive agricultural lowlands significantly influences the regional water cycle and ecological dynamics. The area experiences a range of precipitation levels and varying temperatures, that contribute to distinct microclimates across the basin. The geological diversity, including fault-block mountains and sedimentary layers, forms unique aquifers that affect water movement and storage, while land use patterns, predominantly agricultural, impact the hydrological and biological characteristics of the region. This integration of natural and anthropogenic elements underscores the Bode basin's role in multidisciplinary environmental research and sustainable water resource management. The following subsections will provide detailed data on the biophysical attributes of the Bode River basin.

2.2.1.1. Climate

The annual mean precipitation ranges from around 1500 mm in the Brocken to around 500 mm in the lowland (Wollschläger et al., 2017). The mean annual potential evapotranspiration in the mountain area is around 710 mm, whereas it is approximately 810 mm in the lowland area (Figure 11). The mean annual temperature ranges from 5 °C on the Brocken to 9.5 °C in the lowland, with a minimum of -0.6 °C (1.2 °C) in January and a maximum of 16.8 °C (19.1 °C) in July in the mountain and lowland areas, respectively (Zhou et al., 2022).

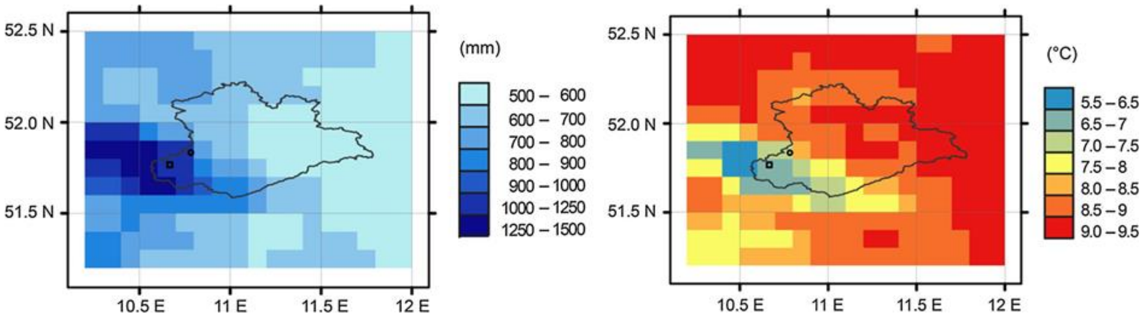

Figure 11 Mean annual precipitation and air temperature maps for the Bode catchment from 1951-2011 (left and right, respectively) taken from Wollschläger et al., (2017).

Extreme weather events, such as droughts and floods, have a substantial influence on the basin. The period 2015-2019 experienced a 10% decline in mean annual precipitation and a 1.46°C increase in mean temperature when compared to the period 1969-2014 (Jomaa, et al., 2020).

2.2.1.2. Hydrological/hydrogeological context

The catchment's topography has a significant impact on hydrological processes, ranging from high-altitude regions with intricate river headwaters to expansive lowlands with agricultural land. In the upper reaches, the mountainous river headwaters play an important role in total flow, with streams such as Kalte Bode, Warme Bode, Rappbode, and Luppbode combining to form a significant portion of the river's discharge. Transfer streams, such as Hassel, Selke, and Holtemme, account for a significant portion of total discharge because they flow between protected forested areas and agriculturally intensive zones (Figures 10 and 12). Major tributaries can be divided into four categories. First, the mountainous river headwaters, which include the Kalte Bode, Warme Bode, Rappbode, and Luppbode streams, account for approximately 28% of the total flow that enters the Rappbode drinking water reservoir. Second, transfer streams (Hassel, Selke, and Holtemme) account for 27% of total discharge and connect protected forest areas with agricultural land. Of the transfer streams, 21 subcatchments near the headwater catchments are entirely covered by forest. Nine subcatchments downstream have a mix of forest and agricultural land use, with agricultural land use covering 50% ± 10% of the total area. Agricultural land use dominates the tributaries, with arable land covering more than 60% of 13 subcatchments. Third, the northern agricultural lowlands primarily consist of arable land, with Großer Graben accounting for 21% of total discharge. Forth, Minor tributaries, including groundwater, contribute 22% of total discharge despite not being included in the sampling network or use inflow (Figure 12).

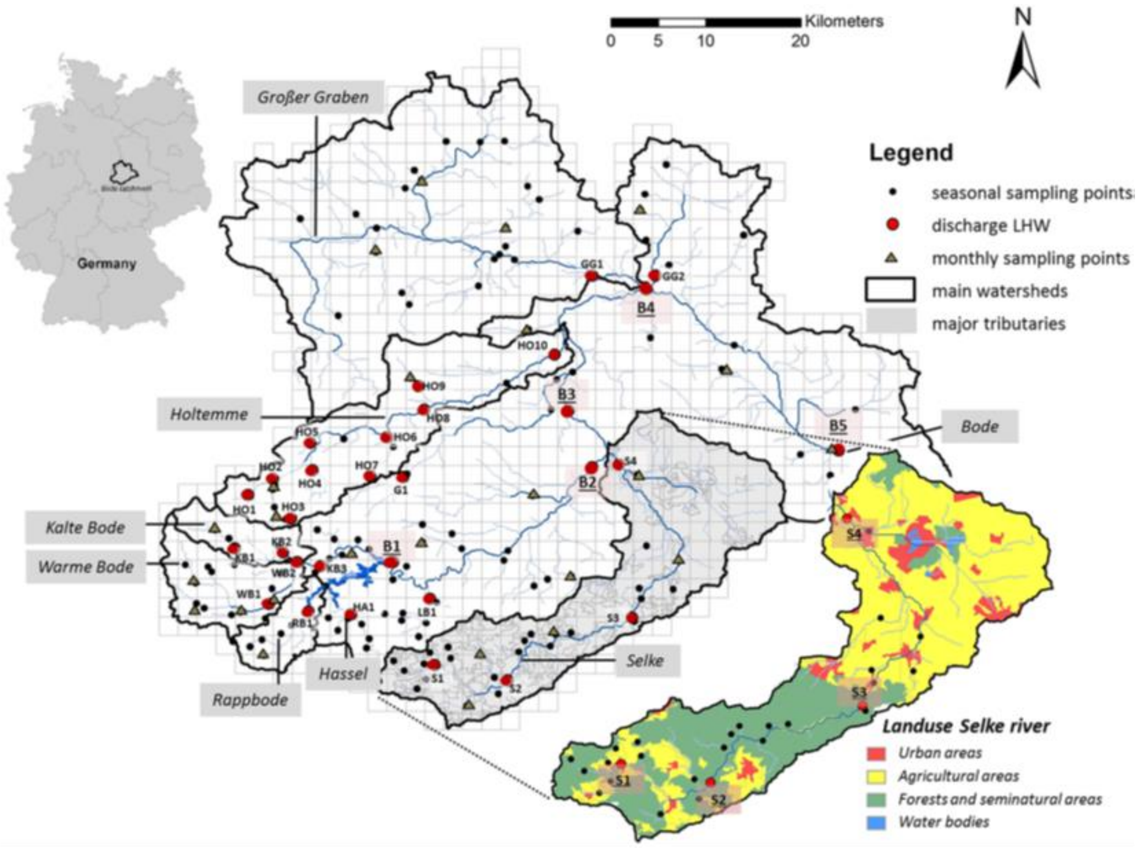

Figure 12 Location of the Bode catchment, including major subcatchments, and the spatial distribution of stream discharge gauges (Mueller, Christin et al., 2016).

As these tributaries flow downstream, the impact of agricultural activities becomes more apparent, highlighting the various effects of land use on hydrological characteristics. The hydrogeological complexity of the Bode catchment is closely related to its geological composition, which includes fault-block mountains, uplifted Paleozoic rocks in the Harz Mountains, and sedimentary layers in the lowlands. These geological factors help to form distinct aquifers and influence water movement throughout the catchment (Figure 13).

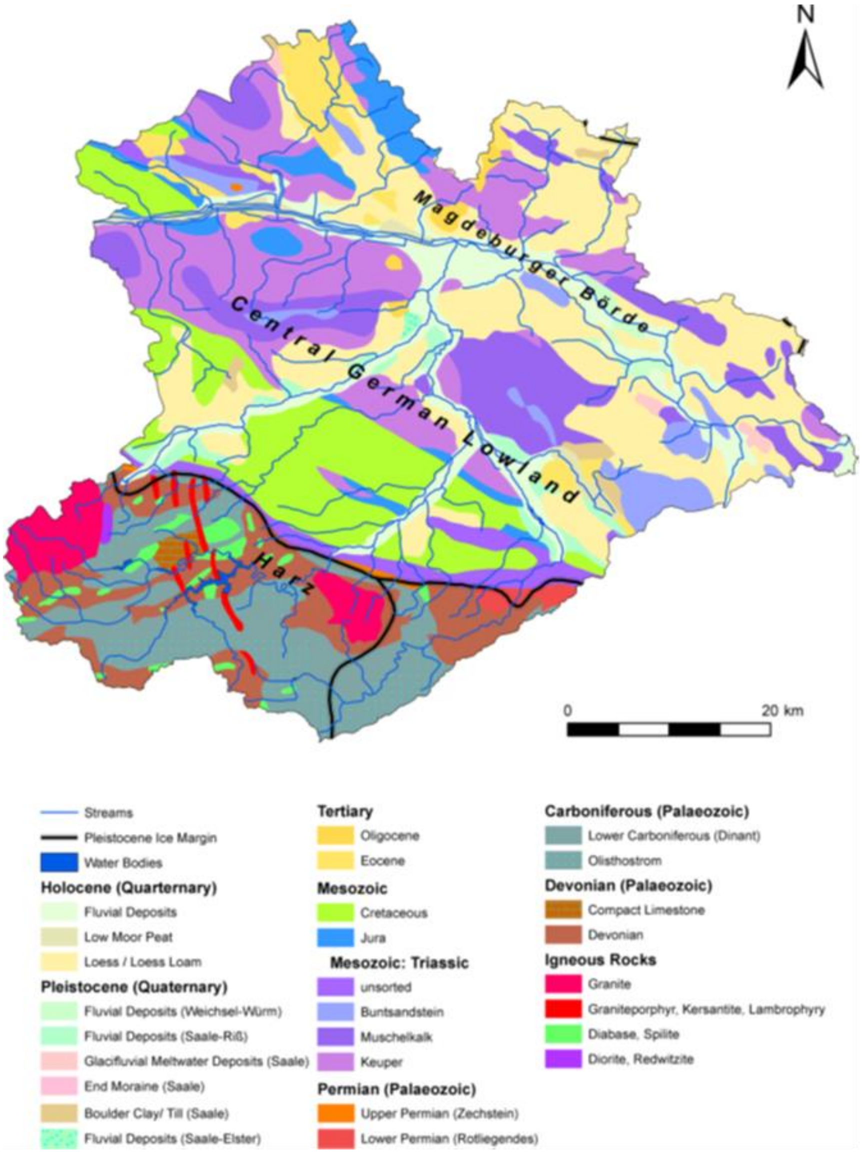

Figure 13 Geology of the Bode catchment. The Harz Mountains' geology is simplified from the Geological Map 1:1,000,000 (GK 1000), sourced from BGR and Wollschläger et al., (2017).

2.2.1.3. Water resources infrasturctures

Within the TERrestrial ENvironmental Observatories Harz/Central German Lowland Observatory, the Bode River basin serves as a hydrological observatory and a main site for hydro-ecological research. It is a platform for multidisciplinary, integrated hydro-ecological research that provides information on general features, water quality, and aquatic ecology (Wollschläger et al., 2016).

Notable water bodies, such as the Rappbode reservoir, serve a dual purpose of storage and regulation, influencing downstream flow patterns. Wastewater treatment plants strategically located along the Bode River play an important role in water quality management, addressing the challenges posed by human activities. The interplay between these infrastructural components highlights the catchment's commitment to sustainable water resource management and emphasizes the importance of incorporating technological advancements for effective environmental stewardship.

2.2.1.4. Ecological and ecosystmes context and footrnt

The biological background and footprint of the watershed are impacted by agricultural land use, which accounts for around 70% of the catchment's entire area. The interplay between hydrological parameters and microbiological activities influences the isotopic composition of dissolved nitrate in surface water, reflecting the impact of agricultural operations on the ecosystems of the watershed (Mueller et al., 2016). Different biological activities and ecosystem services became fragile during the extended drought periods and its associated very low-flow conditions, especially in the downstream part of the Bode basin.

2.2.1.5. Soil and Land use

The mountain area's land use is dominated by forest, with 10% pasture, 8% agricultural, and 7% urban areas and lakes. Cambisols dominate the soil type in the Harz Mountains. Agriculture accounts for 81% of land use in the lowland area, with the major crops being winter wheat, winter barley, rapeseed and sugar beet; forest and pasture account for 7% and 3%, respectively; and urban areas and small lakes account for the remaining 9% (Figure 14 (b)). Chernozems are the most common soil type in the lowlands. By integrating soil attributes and land-use patterns, five prominent soil groups were determined using the United States Department of Agriculture classification: 1) sandy, 2) sandy loam, 3) loam, 4) silt loam and 5) silty clay loam as given in Figure 14 (c) (Zhou et al., 2022).

The basin is heavily impacted by agricultural land use, with distinct nitrate isotopic discrepancies between nitrogen sources like as ammonia (NH4) fertiliser, soil nitrogen, and organic fertiliser. As restricted by stable isotope trends, the catchment's soil and land use play an important influence in regional nitrogen dynamics (Mueller et al., 2016).

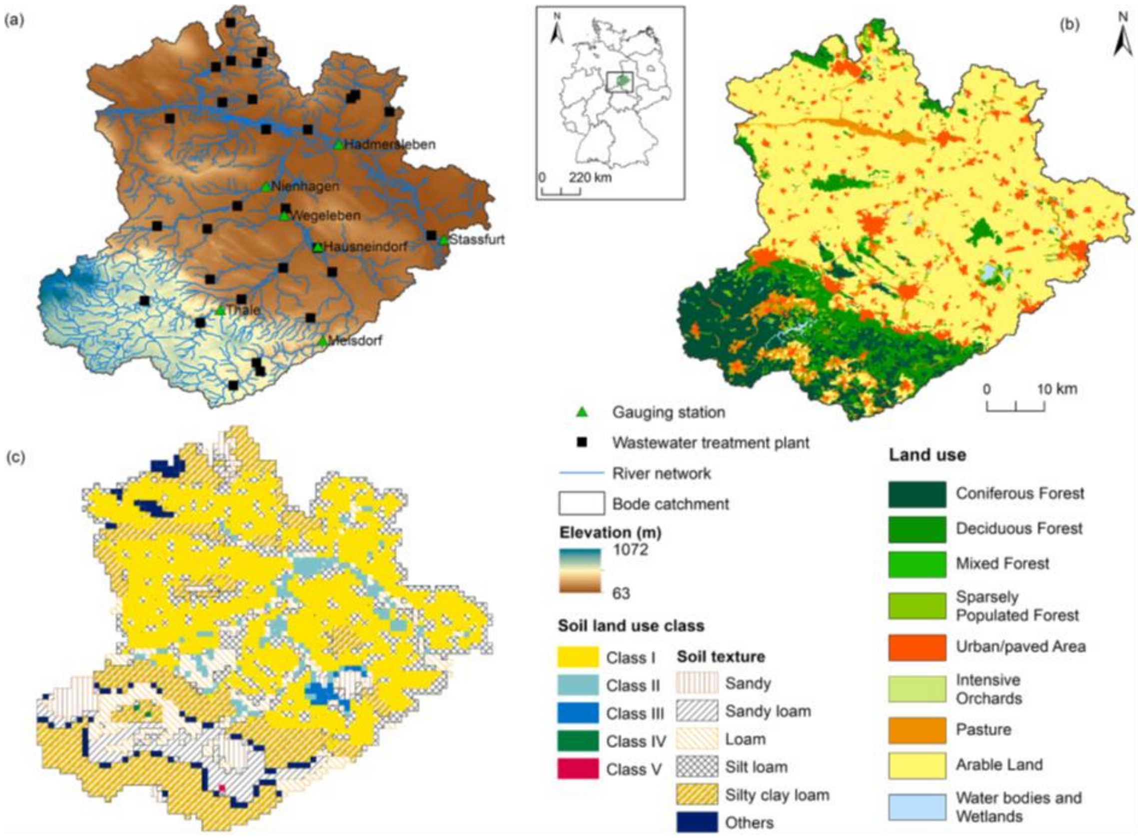

Figure 14 The Bode catchment: (a) geographical location of the gauging stations and wastewater treatment plants, (b) land use types and (c) five dominant soil-landuse (Zhou et al., 2022).

2.2.2. Water development and management

Water development and management in the catchment are supported by a network of monitoring infrastructure, including government-regulated discharge stations overseen by the Landesbetrieb für Hochwasserschutz und Wasserwirtschaft (LHW) in Saxony-Anhalt. The Bode River, as the primary watercourse, facilitates these monitoring efforts by providing real-time data on river flow and water quality through TERENO Observatory. Major tributaries such as Kalte and Warme Bode contribute to the complex hydrological network, influencing overall water dynamics in the catchment.

2.2.2.1. Water supply, water storage and distribution

The Rappbode Reservoir serving as Germany's largest drinking water reservoir provides approximately 100 Mm^3 drinking water for over one million people in central Eastern Germany. The Rappbode Reservoir receives water directly from the tributaries Hassel and Rappbode. Pre-reservoirs have been built to trap sediment and remove nutrients (Rinke et al., 2013).

The provision of freshwater in sufficient quantity and quality to meet diverse sectoral needs such as domestic use, food production, and ecosystem needs presents a growing challenge in the Bode catchment, particularly in light of the recent drought. The region's climate patterns are shifting, resulting in extreme weather events such as prolonged droughts, which have a significant impact on water availability.

Droughts in recent years have resulted in a decline in mean annual precipitation, affecting water source replenishment. As temperatures rise, evapotranspiration increases, putting additional strain on available water resources. To address these challenges, a comprehensive water supply strategy must take into account changing climate conditions, population growth, and competing demands from various sectors.

2.2.2.2. Water uses

The main water uses in the Bode catchment are:

1. Drinking water (more than 1 Million people rely on Rappbode reservoir for drinking water supply with an amount of about 100 Mm^3),
2. Irrigation: about 10% of farming land in the downstream part of the Bode relies on irrigation from surface water during the summer seasons.
3. Different ecosystem services and sports activities (such as canoeing) in the downstream part of the catchment depend on minimum flow (ecological flow).

2.2.2.3. Water management strategies

Effective water management involves enhancing storage and distribution infrastructure to meet current and future demand. The Bode catchment, with its extensive network of rivers and streams, relies on reservoirs and groundwater storage to protect against precipitation fluctuations. However, the effects of climate change, such as altered precipitation patterns and increased frequency of extreme events, necessitate a rethinking of current storage capacity. Furthermore, equitable distribution requires taking into account the multisectoral needs of agriculture, cities, and ecosystems.

2.2.2.4. Main issues

The main water-related issues in the Bode River basin are listed below:

- The prolonged drought and its associated effects have affected the Bode catchment in recent years, resulting in severe deforestation and a negative impact on both water quantity and quality. This situation necessitates an urgent shift in water management from a mono-sectoral approach based on trade-offs to a more balanced multisectoral management that takes into account the needs of all stakeholders.
- The drought conditions have increased nutrient leaching to the drinking water reservoir and the downstream part of the river network due to reduced forest uptake, dilution capability and increased risk of soil erosion.
- Farmers will probably shift to more irrigated crops using surface water and groundwater, putting additional pressure on water resources.

2.2.3. Water resources governance system

In the Bode River basin of Saxony-Anhalt, water resource governance is based on a comprehensive approach that includes climate change adaptation, sustainable water management, and stakeholder participation. The "Strategie des Landes zur Anpassung a den Klimawandel"[1] outlines the state's climate change adaptation strategy, which includes water management-specific measures. This strategy is consistent with broader EU policies, such as the Green Deal, and focuses on adapting water management practices to mitigate the effects of climate change while ensuring the sustainable use of water resources.

The Landesbetrieb für Hochwasserschutz und Wasserwirtschaft Sachsen-Anhalt (LHW)[2] contributes significantly to the Bode River basin's governance system by implementing water management and flood protection measures. The LHW is in charge of developing and implementing Gewässerentwicklungskonzepte (River Development Concepts), such as the one for the Obere Bode, which seek to restore natural river dynamics, improve water quality, and increase biodiversity. These concepts are part of a larger effort to manage water resources in a way that balances ecological needs with human use, as outlined in the EU Water Framework Directive.

Furthermore, the governance system emphasizes the importance of local water authorities, also known as Untere Wasserbehörden[3], who are in charge of water management at the local level. These authorities collaborate closely with the LHW and other state-level agencies to implement water policies and projects. Their responsibilities include monitoring water use, managing water protection areas, and ensuring compliance with water quality standards. This multi-level governance structure ensures that water management in the Bode River basin meets both local needs and larger environmental goals.

The water governance in the Bode River basin is part of the umbrella of the Water Framework Directive implementation in the larger Elbe River basin. Since the end of 2000, the Water Framework Directive has established a regulatory framework for the measures of the European Community in the field of water policy. The Water Framework Directive aims at reaching a good status of the surface and groundwater bodies. Procedures and instruments have been set up, which need to be implemented by the member states.

2.2.3.1. Water policy and current instruments of water regulation

The Gewässerrahmenkonzept (Water Framework Concept) for Sachsen-Anhalt 2022-2027[4] defines a comprehensive approach to water management in the region, including the Bode River catchment. This concept is consistent with the European Union's Water Framework Directive (WFD), which seeks to achieve good ecological and chemical status for all water bodies by 2027.The water policy for the Bode River catchment focuses on restoring natural water body structures and improving water quality. Measures include reversing previous modifications such as river straightening, removing meanders and old arms, and building on riverbanks. These restoration efforts are part of a larger effort, with

[1] https://mwu.sachsen-anhalt.de/fileadmin/Bibliothek/Politik_und_Verwaltung/MWU/Klimaschutz/00_Startseite_Klimawandel/220330_Dritter_Umsetzungsbericht_bf.pdf
[2] https://lhw.sachsen-anhalt.de/untersuchen-bewerten/gewaesserentwicklungskonzepte/gek-obere-bode
[3] https://www.geodaten.lagb.sachsen-anhalt.de/wilma.aspx?pgId=36
[4] https://lvwa.sachsen-anhalt.de/fileadmin/Bibliothek/Politik_und_Verwaltung/LVWA/LVwA/Dokumente/4_landwirtschaftumwelt/404/wasserrahmrichtlinie/entwurf_gwk_2022_2027/Gwk_broschuere.pdf

at least 90 million euros invested in improving water structures in Sachsen-Anhalt since 2000. Furthermore, a sediment management concept has been in place since September 2009 to address pollutant accumulation in sediments, as part of a larger Elbe-wide sediment management plan. The framework also emphasizes the importance of collaboration across government levels and stakeholders in order to achieve the WFD's ambitious goals. The implementation process requires public participation as well as the use of economic instruments. The Gewässerrahmenkonzept for Sachsen-Anhalt outlines the specific measures and strategies to be implemented within the Bode River catchment to improve water quality and achieve the WFD's objectives.

2.2.4.SWOT analysis of project actions

Strengths:	Weaknesses:
Engagement with stakeholders: The UFZ has established strong connections with key stakeholders, which is crucial for environmental sustainability. This engagement has led to continuous dialogue and collaboration on improving water quality and ecological monitoring. **Expertise in water resources management**: UFZ's strong expertise in water resources management and real-time water quantity and quality monitoring is a significant strength. This expertise is backed by EU and German-funded research and innovation projects. **Water resources well characterized and monitored**: The Bode Basin demo site has well-characterized and monitored water resources, which is essential for effective environmental management. **Presence of huge amounts of wastewater that could be reused**: The site has a large amount of treated wastewater that can potentially be reused in water resources management, contributing to a circular economy and reducing environmental impact.	**Lack of benefits from the improved resolution of EO products and digital twins**: The site does not fully utilize the potential of Earth Observation (EO) products and digital twins, which could provide valuable data for environmental management. **Lack of multi-sectoral management considering artificial infrastructure:** The absence of a multi-sectoral approach that includes artificial infrastructure could lead to uncoordinated and potentially harmful environmental impacts. **Lack of long-lasting social learning and conflict mediation for stakeholders**: This could hinder the development of sustainable environmental management strategies and lead to conflicts that negatively impact the environment.
Opportunities:	**Threats:**
Water resources and water-related ecosystems management is a priority at the national levels: This provides an opportunity to implement effective environmental management strategies and secure funding. **Existence of national and international initiatives for supporting proper management and governance:** These initiatives could provide additional resources and support for environmental management at the Bode Basin demo site. **Easy accessibility of social media that could raise public awareness:** Social media could be used to educate the public about the importance of environmental sustainability and gain support for environmental initiatives.	**Increase of water pollution and biodiversity loss hotspots**: This could harm the local ecosystem and reduce the quality of water resources. **Increased conflicts and fragmentation of the water institutional framework:** This could hinder effective environmental management and lead to negative environmental outcomes. **Increase occurrence of heatwaves, droughts, wildfire, migration and extreme storms:** These climate-related threats could severely impact the local environment and the sustainability of water resources.

2.3. Case study Jucar

The Albufera of Valencia, henceforth referred to simply as the Albufera or Albufera Lake, is the Spanish demo site of the OurMED project. Situated along the Mediterranean coast of Spain, about 15 kilometres from the southern end of Valencia, between the Túria River to the north and the Júcar River to the south, it is the largest natural lake on the Iberian Peninsula, covering a surface area of 24 km^2 with an average depth of 1.0 m. To the north and west of the lake area, there is a string of towns and several thousand small, medium, and large industries. Also, it is surrounded by rice fields, fruit orchards (mainly citrus), mixed crop areas, and a sandbar (around 30 kilometres long and 1 kilometre wide) (Soria & Vicente, 2002). Figure 15 shows the localisation of the Albufera of Valencia.

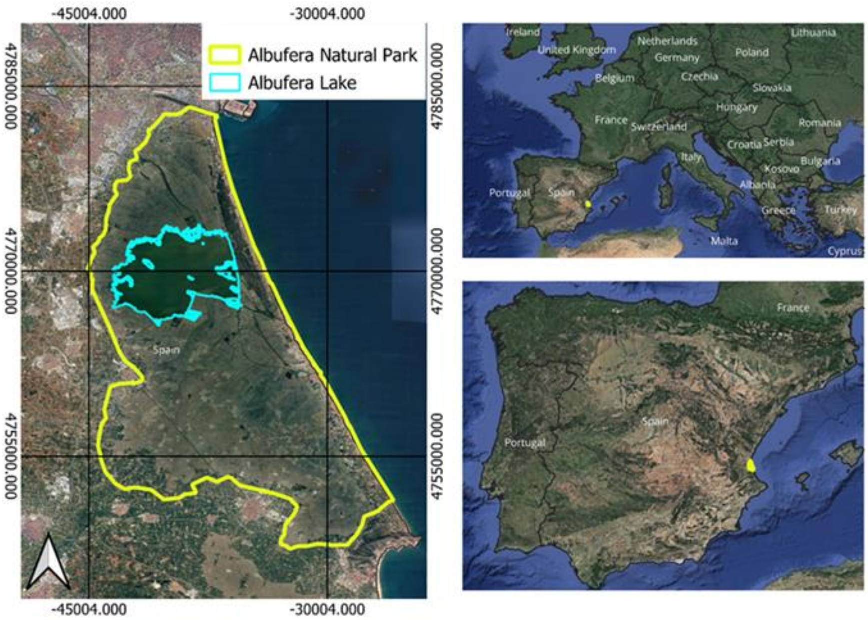

Figure 15 Localisation of the Albufera of Valencia.

Over the course of history, both natural forces and human activities have significantly influenced the configuration of the lake as it is recognised today. Originally a brackish lagoon, the lake has transformed into a freshwater ecosystem due primarily to centuries of extensive irrigation agriculture in its surrounding area. This shift has seen a notable reduction in the open water surface, which has dwindled from an estimated expanse of over 30,000 hectares during the Roman era to a mere 2433 hectares presently. This alteration can be attributed to a combination of natural sedimentation processes and human interventions, such as the conversion of waterlogged regions into rice paddies in the XIX-XX centuries (Martín et al., 2020).

In the mid-1970s, the Albufera lake experienced a decline in water quality due to the influx of untreated sewage and agrochemicals, stemming from inadequate sanitation facilities. Over the subsequent four decades, urban development led the lake to function as a de facto wastewater treatment site.

Despite of this and acknowledging its ecological significance, the lake and its surrounding areas (approximately 216 km^2) gained recognition as a Natural Park in 1986 by the Valencian Community (see Figure 15). In addition, the Albufera holds special protection status at both the community and international levels. Designated a Special Protection Area for Birds (SPA) in April 1991 under the Birds Directive (79/409/EEC)[5] , it was listed in the RAMSAR Convention's Wetlands of International Importance in 1989 [6]. The Albufera also features habitats and species protected by the Habitats Directive (92/43/EEC)[7]. Furthermore, it is part of the Natura 2000 Network[8].

Nowadays, enhancing water quality and ecological status remains a challenging task and a primary goal for managing its unique water system, developed over centuries (Martín et al., 2020).

2.3.1. Biophysical attributes

The Albufera Natural Park, nestled in the heart of Valencia, showcases the classic Mediterranean climate. The park receives water from various sources like irrigation ditches, springs, and treated wastewater. This flow is carefully managed by gates, which is especially important for balancing needs like rice growing. Despite challenges from urban growth, farming, and pollution, the Albufera remains a haven for wildlife. Its mix of habitats, from wetlands to woods, provides homes for various plants and animals, making it a popular spot for locals and migrating species. The park's landscape is mostly farmland, blending old traditions and modern conservation efforts. The following subsections will provide detailed data on the biophysical attributes of the Albufera of Valencia.

2.3.1.1. Climate

The Albufera Natural Park in Valencia experiences a Mediterranean climate. This type of climate is characterised by hot, dry summers and mild, wet autumn and winters. The Valencia, in general, has warm temperatures, with average highs ranging from around 10°C in winter to 30°C or more in summer. The mean annual precipitation in the natural park is 457 mm, and the region typically receives most of its precipitation during the autumn and winter months. The average evapotranspiration is high, reaching over 409 mm/year for the entire park. Figure 16 shows as the temperature in the park has varied since 2016, which is when the sensor was installed in the Tancat de la Pipa, the constructed wetland of interest for this project. Table 1 summarises the monthly total precipitation (mm) since 2016. These data were retrieved from AVAMET[9] in 2024.

The trajectory of the agroecosystem in the Albufera region is intricately intertwined with the challenge of climate change. Within coastal lake ecosystems such as this, the anticipated rise in sea levels coupled with elevated temperatures is poised to elevate salinity levels. The magnitude of this phenomenon hinges upon forthcoming shifts in temperature. However, managers and stakeholders in the area must acknowledge this

[5] https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=celex%3A31979L0409
[6] https://www.ramsar.org/
[7] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A31992L0043
[8] https://www.eea.europa.eu/themes/biodiversity/natura-2000
[9] https://www.avamet.org/

potentiality and accordingly tailor restoration efforts to accommodate these impending changes.

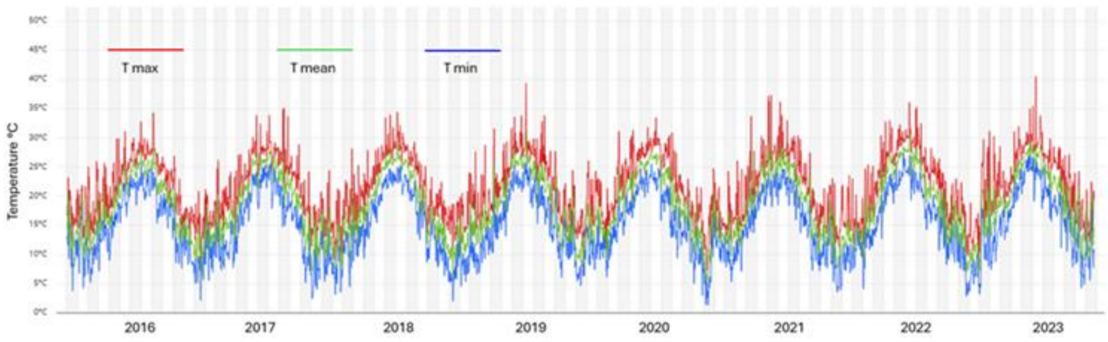

Figure 16 Evolution of the temperature in the park since 2016.

Table 1 Details on the agricultural demand units.

Year	Jan	Feb	Mar	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2016				5.8	18.6	0.4	0.6	21.2	46.2	14.8	120.6
2017	110.4	16	41.2	29.4	3.6	28.4	2.4	24.6	20.4	17.4	8
2018	24.4	50.6	14	11.6	19	95.8	1.4	14.6	159	287.6	114.4
2019	0.6	0	15.8	47.6	8.2	0	3.4	2	70	23.4	6
2020	147.6	1.2	47.4	33.4	8.6	3	7.4	0.6	49	3	
2021	34.6	2.6	43.2	64.8	26.4	33.4	20.6	11.8	72.6	65.4	78.2
2022	11.6	2	213.2	108.2	89.6	5.6	1.2	32	46.2	51	47.2
2023	3	47.4	1.2	0.2	65.2	27.4	21.6	11.2	122.6	4.8	0.4

2.3.1.2. Hydrological/hydrogeologial context

The Albufera Natural Park lies between the Túria River to the north and the Júcar River to the south, with water flowing into the lake primarily through ravines such as the Massanassa (Torrent) and Picassent (Beniparrell) ravines (Ferriol-Gabarda, 2013). Currently, the lake is predominantly fed by water from an extensive network of irrigation ditches and paddies, which are supplied not only by irrigation surplus but also by surrounding springs, referred to as "ullals". The paddies surrounding the lake are irrigated with water from it, demonstrating the circulation of water within the system. Conversely, paddies located farther from the lake's shores are irrigated with natural freshwater from the Túria and Júcar River. Additionally, the lake receives tertiary treated effluent from two wastewater treatment plants (WWTPs), namely Pinedo and Albufera Sur. However, there are still small flows of untreated urban and industrial wastewater discharged directly into ditches and watercourses that eventually lead to the lake. Finally, the lake receives water from direct precipitation and urban/agricultural runoff.

The water levels are handled according to rice and environmental requirements. Inflows to the lake are affected both by exceptional drought conditions and by the improvement of agricultural management and irrigation modernisation, which could imply a reduction of the entrances to the lake and in the groundwater recharge (Pool et al., 2021). In Figure 17, the Albufera Natural Park is depicted along with its position within the Túria and Júcar River basins, while in Figure 18 the subbasins that drain into the lake are shown (CHJ & TYPSA, 2004). The density of the irrigation ditches network around the lake is shown in Figure 19, with each blue line representing a ditch.

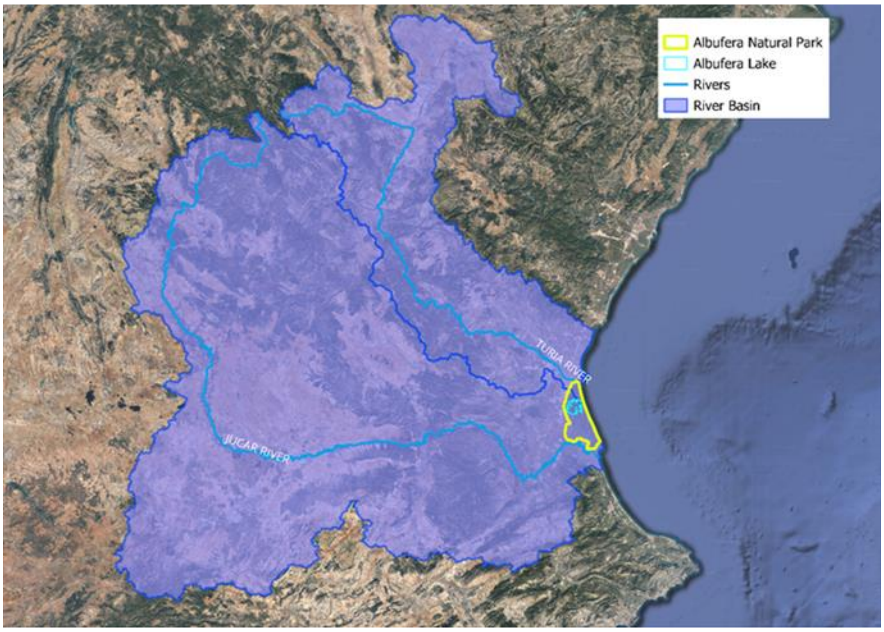

Figure 17 Albufera Natural Park within the Túria and Júcar River basins.

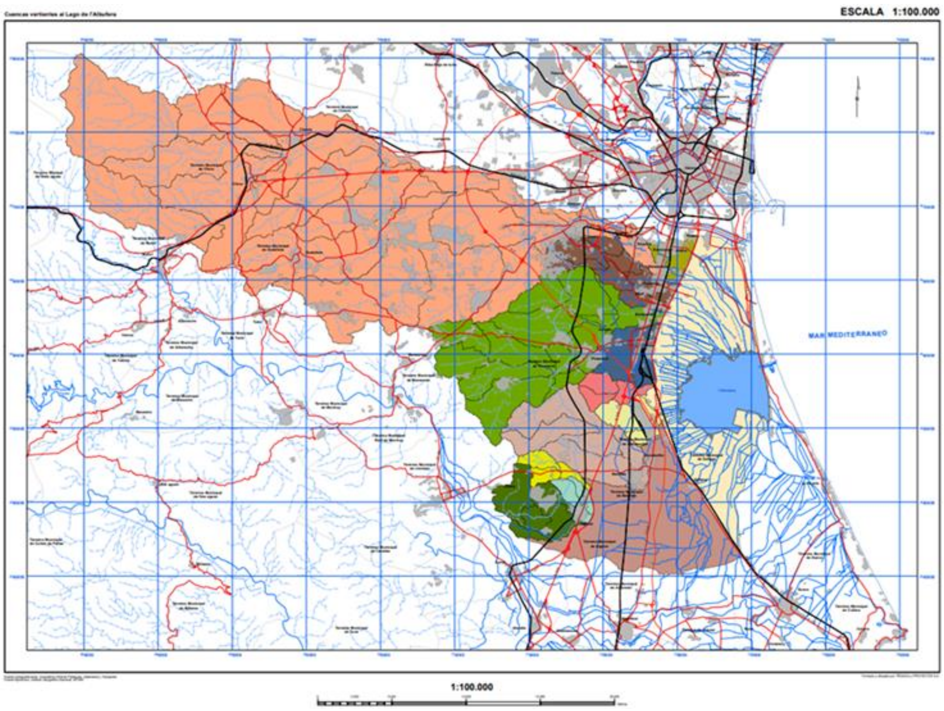

Figure 18 Subbasins that drain into the Albufera lake (CHJ & TYPSA, 2004).

Figure 19 Density of the irrigation ditches network around the Albufera Lake (CHJ & TYPSA, 2004).

The lake's connection to the Mediterranean Sea is facilitated by three channels known as "golas" (El Pujol, El Perellonet, and El Perelló). Gates have been installed at the ends of these channels to regulate the water level in the surrounding fields. As rice cultivation dominates the area, Albufera's hydrologic cycle is intertwined with irrigation schedules and agricultural runoff. Consequently, water management policies rely significantly on the operation of the gates. Channel gates open from January to March, allowing the lake's water level to rise for irrigation. During the rice growing season (May–September), the gates remain preferably closed, leading to minimal water influx. In September–October, the gates reopen to dry rice fields for harvesting, closing again in November–December to flood harvested fields (named perellonà), promoting nutrient mineralisation (Romo et al., 2008).

Figure 20 highlights additional elements crucial for understanding the hydrodynamics of the park and its surroundings including wastewater treatment plants (WWTPs), constructed wetlands (CWs), outlet channels, and hydrometry stations.

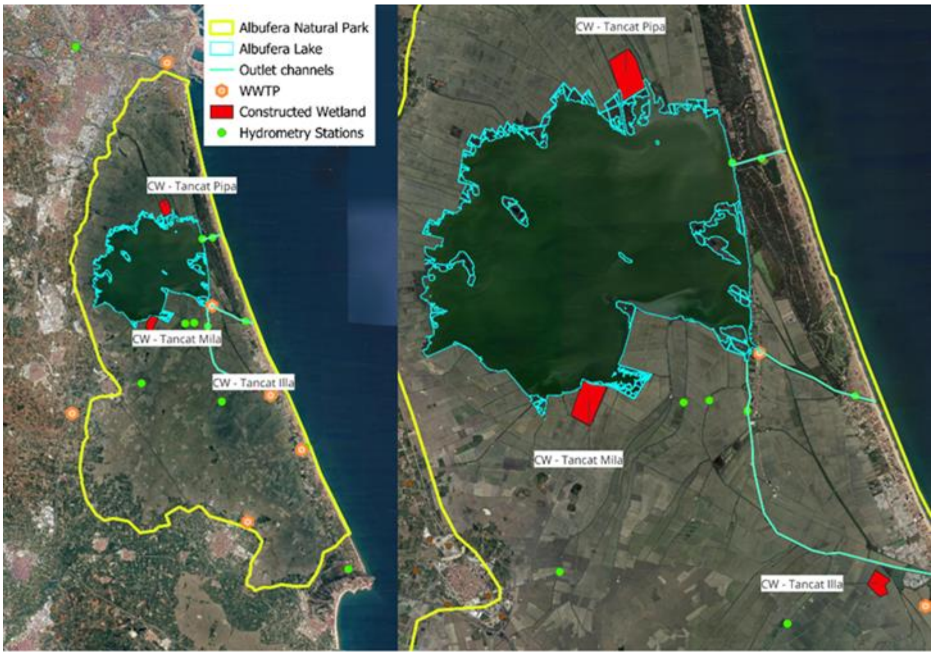

Figure 20 Elements for understanding the hydrodynamics of the Albufera Natural Park and its surroundings.

Figure 21 illustrates the water level fluctuations in the lake spanning from 2015 to 2023, while Figure 22 shows the variation from August 2022 to December 2023, providing more detailed insights into its dynamic nature over time. Additionally, Figure 23 presents both the water level variations and the flow rates observed in the outlet channel El Pujol.

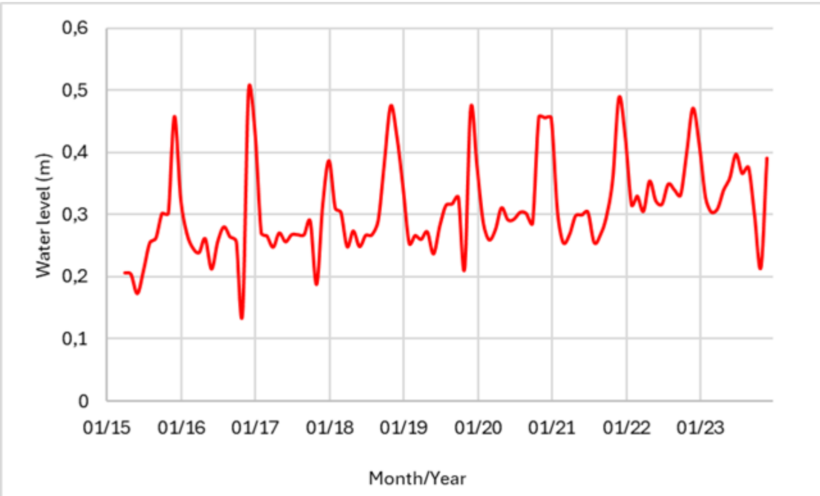

Figure 21 Water level fluctuations in the Albufera lake.

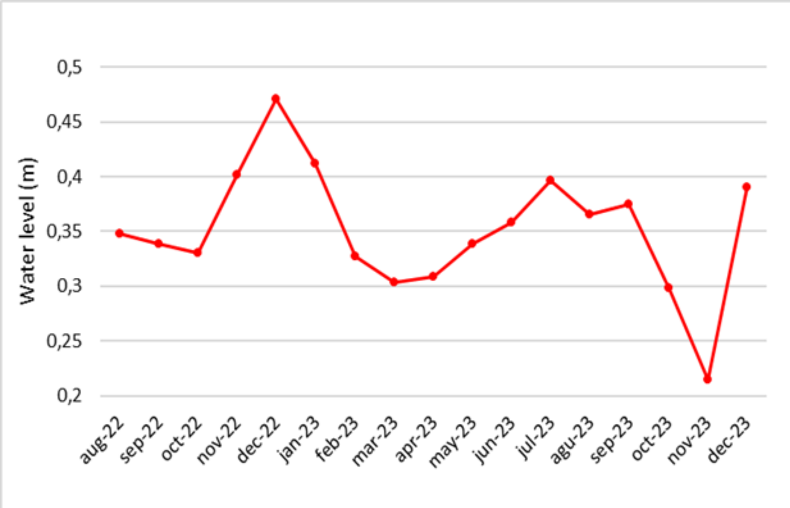

Figure 22 level variation in the Albufera Lake from August 2022 to December 2023.

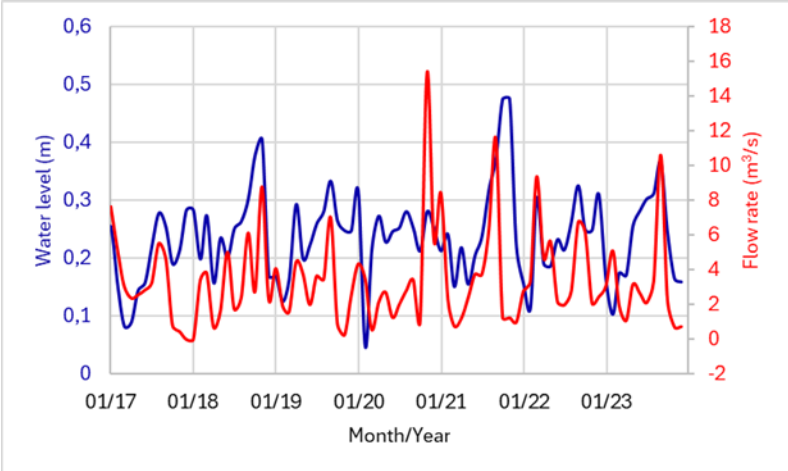

Figure 23 Water level and the flow rates observed in the outlet channel El Pujol.e.

Regarding the hydrogeologic context of the Albufera zone, it is situated within the hydrogeological system known as La Plana de Valencia. It comprises a combination of Tertiary and Quaternary sediments that fill the Valencian basin, facilitating water exchange with neighbouring systems due to mostly open boundaries. This hydrogeological system resembles a multilayer aquifer, with four primary groups: The uppermost layer is composed of highly permeable Quaternary detritic materials, including gravels, sands, and limestone conglomerates, with varying consolidation levels. Finer materials like fines, silts, and clays are also present but don't hinder hydraulic connectivity. This layer, up to 120 meters thick, extends consistently across the hydrogeological system, gradually weakening towards the east. Below the upper formation is a permeable Tertiary section consisting of Pliocene sandstones and conglomerates, with slightly lower permeability. It also contains lacustrine limestones from the terminal Miocene. A low-permeability Miocene loamy section lies beneath the two previous formations. While it discontinuously appears in the western half of the aquifer, it gains significant continuity and strength in the eastern half, filling graben zones with thicknesses of up to 400 meters. The deepest layer comprises high-permeability Cretaceous carbonates, irregularly distributed and affected by fractures and deformations, even surfacing in the Muntanyeta dels Sants. The impermeable base of the aquifer system consists of loamy Cretaceous sections and/or gypsum-rich clays from the Keuper (Ballesteros Navarro & Navarro Odriozola, 2022).

The Valencia plain's substratum is complex, dividing it into two sub-basins. An 8-kilometre-wide elevation, resembling clayey formations of the Keuper Triassic, separates the northern and southern sectors. As a result, the hydrogeological system is divided into La Plana de Valencia North and La Plana de Valencia by the Júcar Water Authority (CHJ). Figure 24 shows the two hydrogeological systems found in the study area.

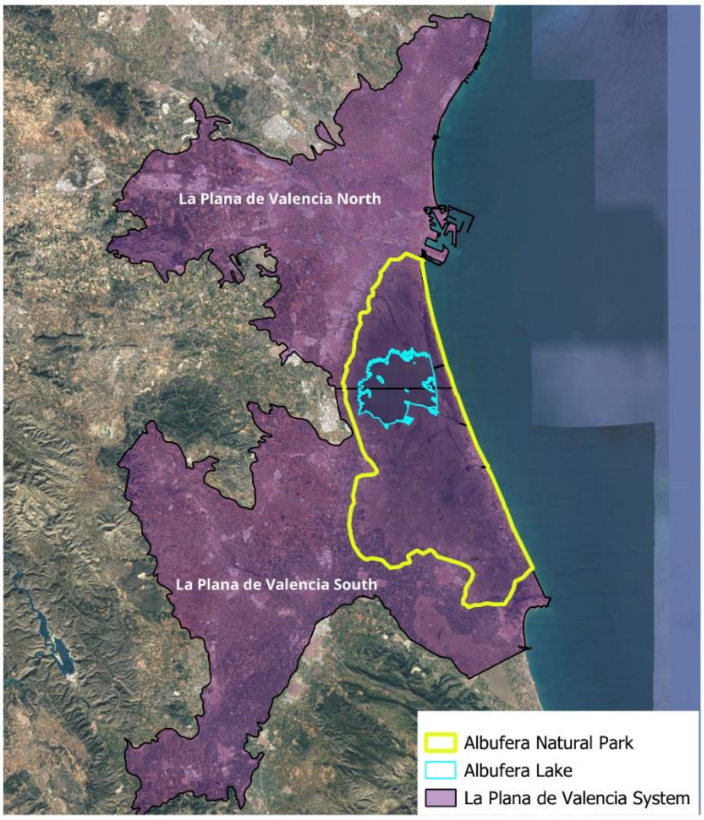

Figure 24 Hydrogeological system of the Albufera Natural Park.

The significant lithological heterogeneity of the two main aquifer formations in the plain results in varied spatial distribution of their hydrodynamic characteristics with the highest transmissivity values observed in wells located in the upper section, particularly those near the River Júcar. Regarding the area of interest in this project, permeability is predominantly high, except for the southern and innermost limits of the sandbar zones, where lower permeability values are identified. Figure 25 details the permeability of the Albufera Natural Park, according to the permeability map 1:200,000 (del Pozo Gómez, 2009).

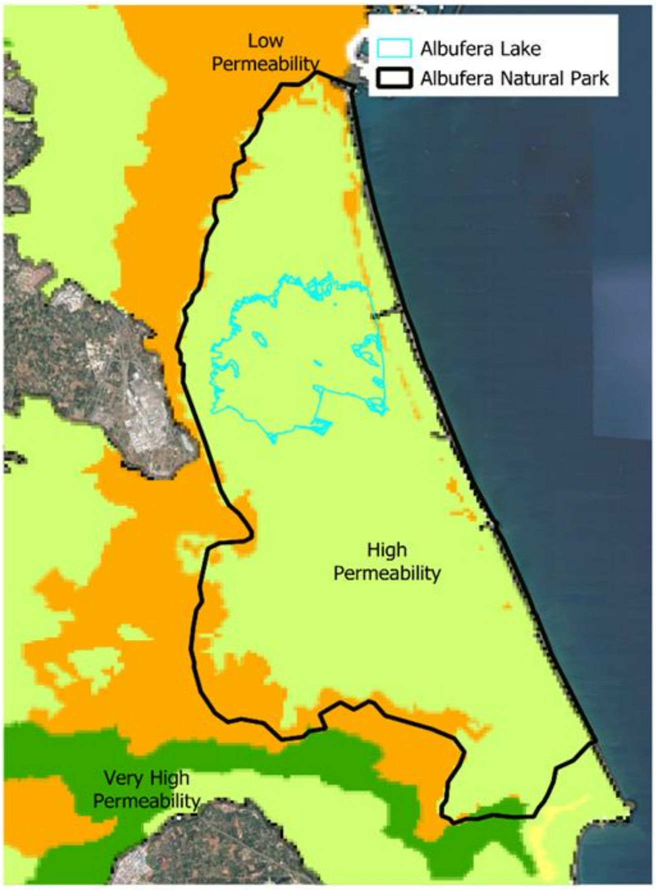

Figure 25 The permeability of the Albufera Natural Park.

Considering the La Plana System, the lowest values of piezometric heads are located along the entire alluvial valley of the Júcar River and in the discharge areas of the aquifer. This scheme is locally modified because it is generated by the concentration of exploitations. The groundwater flow is predominantly in a west-east direction, starting from the westernmost areas where border units transfer their resources to the plain, ultimately reaching the Albufera and the Mediterranean Sea. The operational piezometer network in the Albufera Natural Park and two monitored springs around the park are depicted in Figure 26. Figure 28 to Figure 32 illustrate the behaviour of piezometric heads for selected piezometers from January 2006 to January 2024, while Figure 33 and Figure 34 show the water flow in the two monitored springs. Indeed, discussing groundwater in the Albufera Natural Park necessitates addressing its springs, which are shown in Figure 27. While presently encircled by rice fields and experiencing shallow water levels, these springs remain of considerable importance, particularly concerning ecological diversity (Soria, 1989).

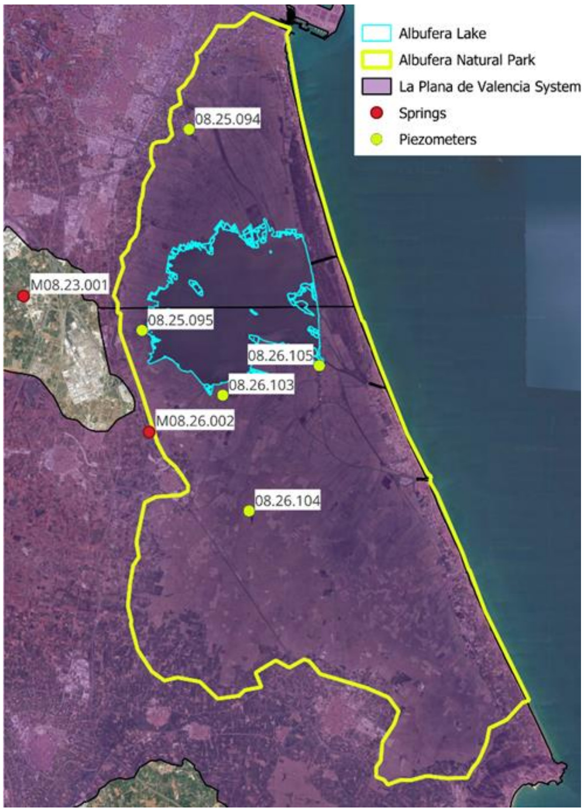

Figure 26 The operational monitoring network in piezometers and springs.

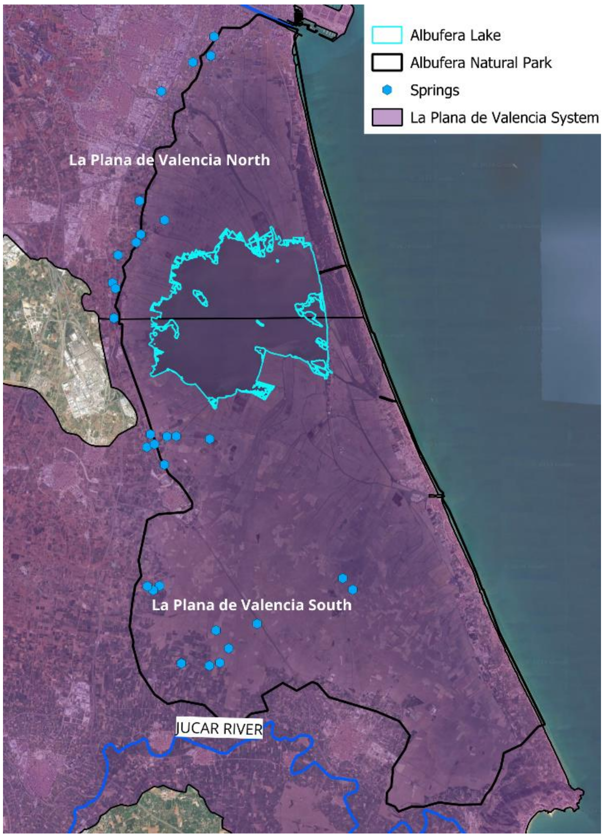

Figure 27 Springs in the Albufera Natural Park.

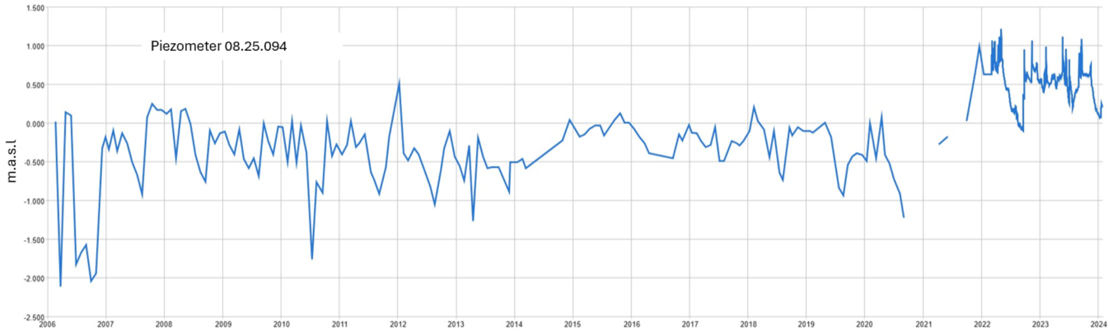

Figure 28 Piezometric heads in piezometer 08.25.094.

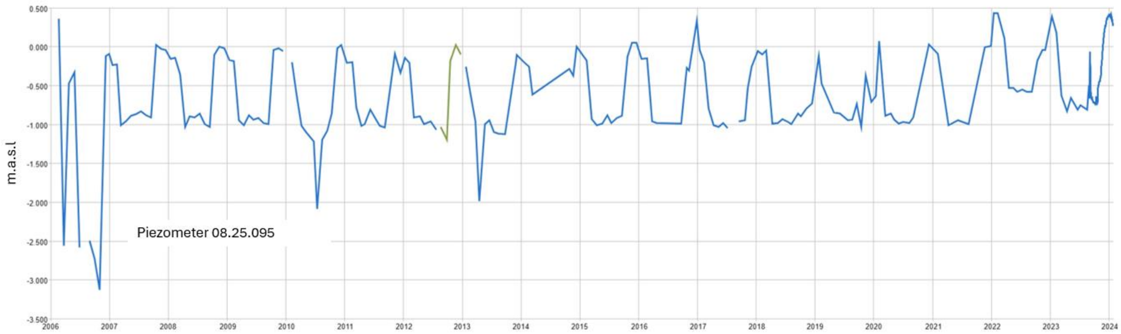

Figure 29 Piezometric heads in piezometer 08.25.095.

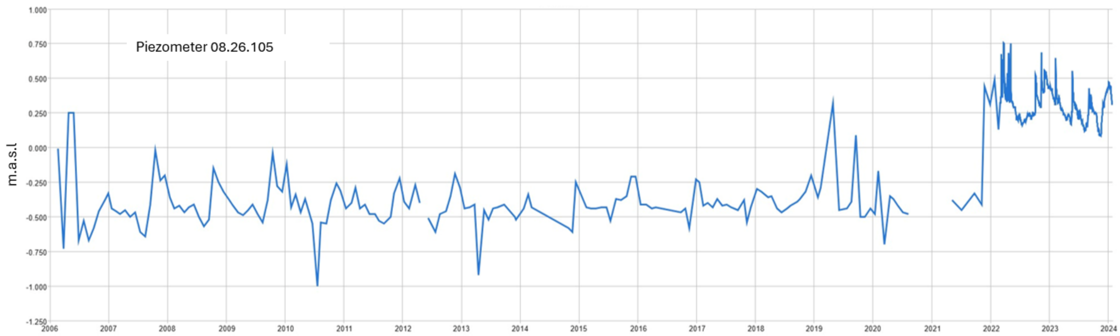

Figure 30 Piezometric heads in piezometer 08.26.105.

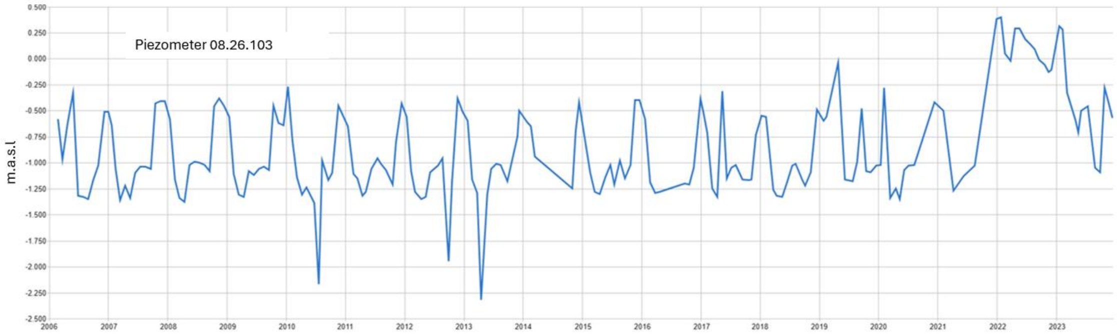

Figure 31 Piezometric heads in piezometer 08.26.103.

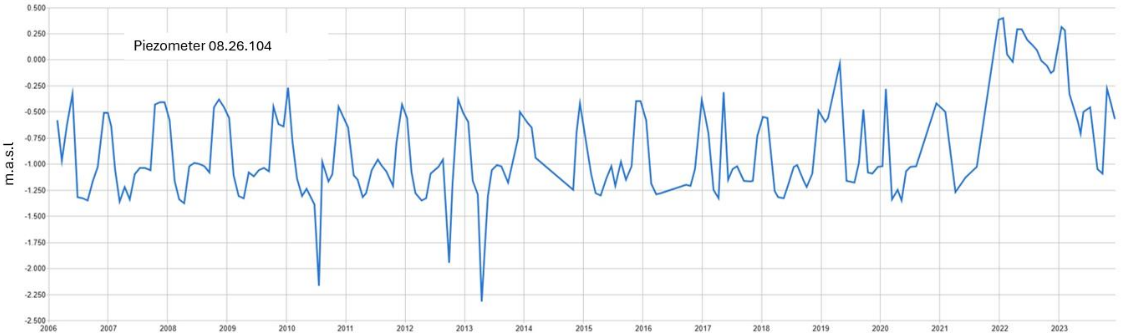

Figure 32 Piezometric heads in piezometer 08.26.104..

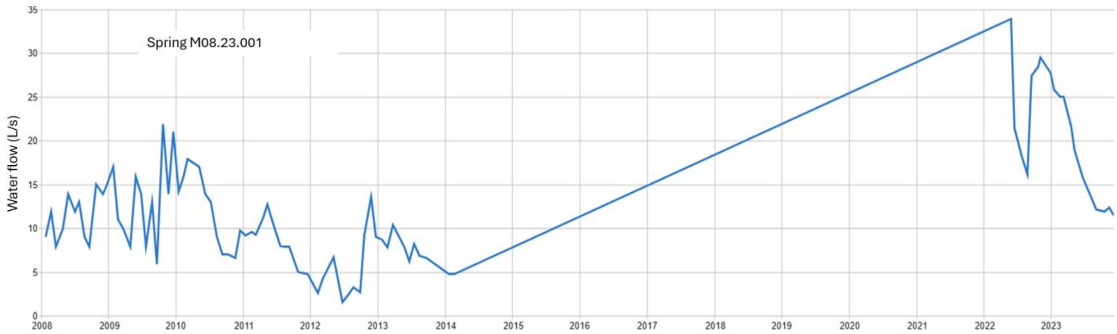

Figure 33 Water flow in the spring M08.23.001.

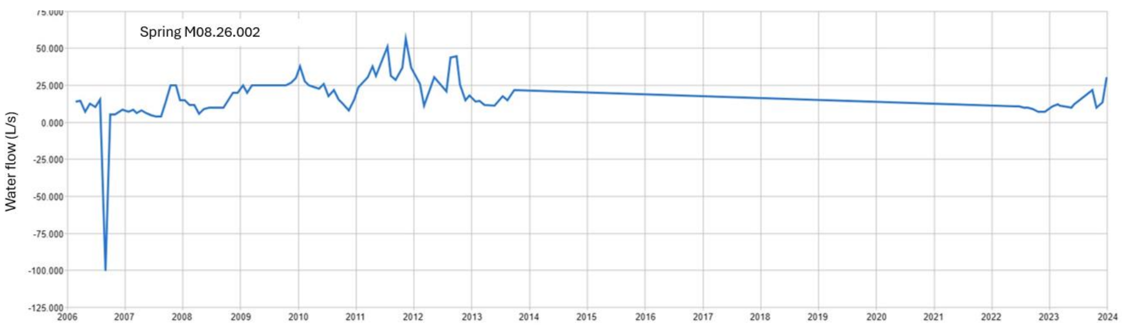

Figure 34 Water flow in the spring M08.26.002.

In terms of total resources, it is estimated to be approximately 472 hm^3/year, which is equivalent to the average annual flow of the Túria River (CHJ, 2023). Water inputs into the hydrogeological system originate from various sources, including the infiltration of precipitation and irrigation surpluses. Additionally, water infiltrates from surface watercourses in their losing reaches and through lateral groundwater transfers from adjacent systems. Outflows occur through lateral groundwater transfers, drainage channels within La Albufera Natural Park, springs surrounding the park, and from the lakebed itself in a zone where there is no siltation of the bottom of the lake. The system is also drained by rivers with winning sections, underground outlets to the Mediterranean Sea, and through surface uses and pumping (Ballesteros Navarro & Navarro Odriozola, 2022).

2.3.1.3. Water resources infrastuructures

The recent evolution of ecosystems within the Albufera Natural Park has been significantly influenced by water resources and hydraulic infrastructures (Mondría-García, 2010). In the Park, water resource infrastructures comprise a network of irrigation ditches, channels, wells, and weirs. Additionally, the park features wastewater treatment plants and constructed wetlands, as previously mentioned. While the park itself lacks dams or reservoirs, it is intricately linked to the Júcar and Túria systems, which feature numerous dams, weirs, and reservoirs. Figure 35 illustrates the water resource infrastructures within the park and the primary structures in its vicinity, while Figure 36 offers a more detailed view focused on the lake itself. Only the thirteen most significant irrigation ditches in terms of volume contributed to the lake are depicted in the figure (CHJ & TYPSA, 2004). Notably, the significant concentration of wells in the southern part of the park underscores the considerable demand for water resources in this region, indicating notable pressures on the water resources. Figure 37 illustrates the sanitation infrastructures interconnected within the Albufera Natural Park through wastewater treatment plants.

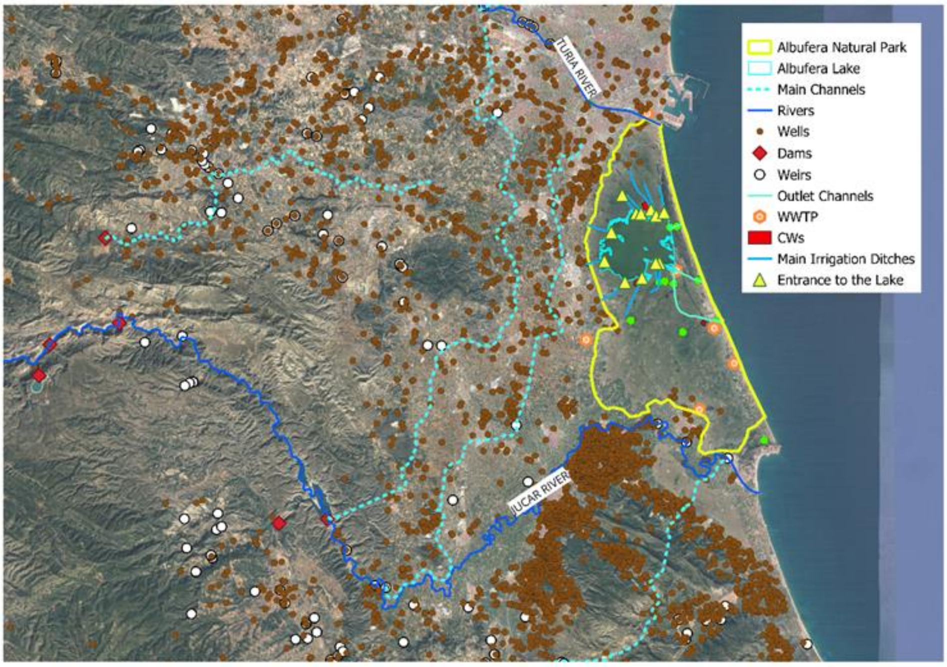

Figure 35 Primary water resource infrastructures.

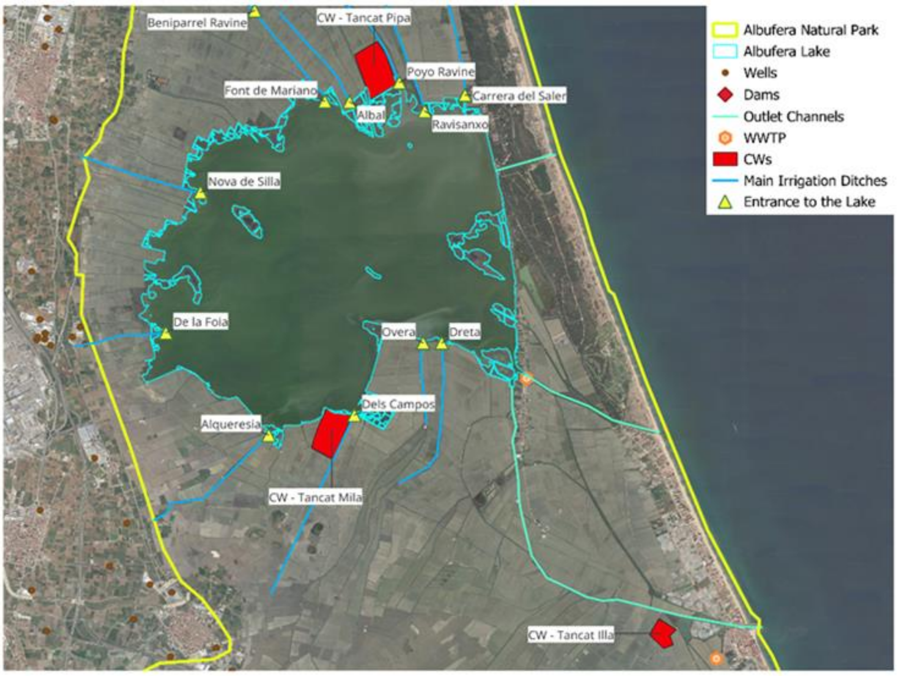

Figure 36 Primary water resource infrastructures closest to the lake.

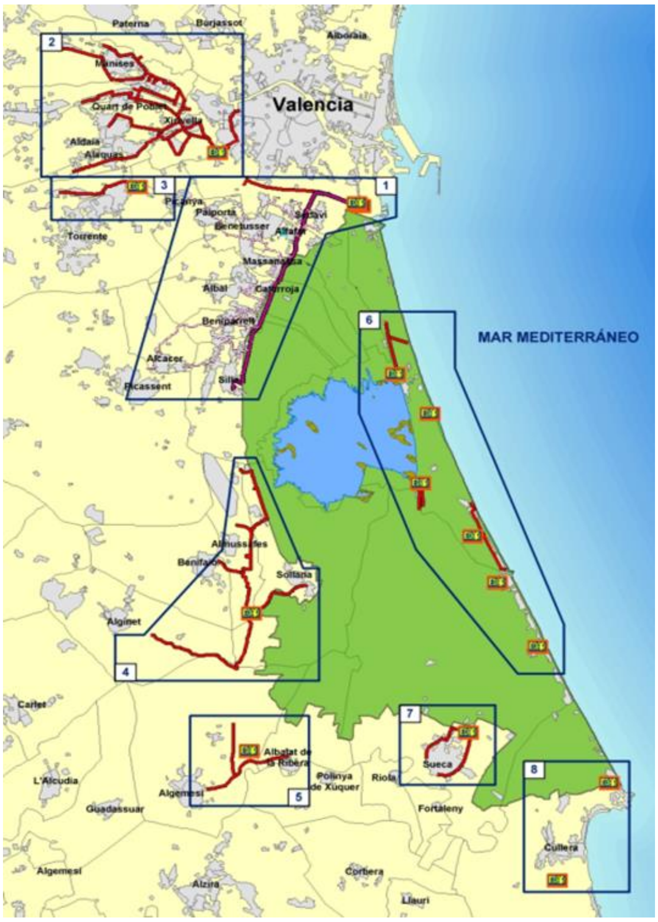

Figure 37 Sanitation infrastructures interconnected within the Albufera Natural Park.

2.3.1.4. Ecological and ecosystmes context an footprint

The Albufera Natural Park stands as a sanctuary of biodiversity and ecological richness. This unique wetland ecosystem encompasses a diverse range of habitats, including freshwater lagoons, marshes, dunes, and forests, each playing a vital role in supporting a myriad of plant and animal species. The ecological context of the park is shaped by its location along the Mediterranean coast, providing crucial habitat for numerous migratory bird species and serving as a critical stopover point during their journeys.

In addition, the ullals (springs) within the Albufera Natural Park in Valencia stand out as vital ecosystems. Renowned as biodiversity hotspots, they harbour a rich variety of plant and animal species, encompassing aquatic plants, insects, amphibians, and birds. These ullals serve as indispensable habitats and breeding grounds, making a substantial contribution to the region's biodiversity. According to the Valencian Regional Government in a presentation about the springs of the Albufera Natural Park, nowadays, fifteen springs are in good conservation state and four are accessible to the public[10].

As a recognition of its environmental relevance, the Albufera is included in the Catalog of Wetland Areas of the Valencian Community and the Ramsar List of Wetlands of

[10] https://parquesnaturales.gva.es/va/

International Importance. It was declared a Special Protection Area for Birds (SPA)(CHJ, 2019), and it is also part of the Natura 2000 network which serves as a crucial benchmark for the abundance of Spain's natural heritage and biodiversity (CHJ, 2019).

Despite its now widely recognised ecological importance, the lake unintentionally served as a wastewater treatment facility (facultative lagoon) for over 40 years due to the urban development in the surrounding area. During the early twentieth century, villages surrounding the lake, primarily reliant on agriculture, managed their urban wastewater through individual seeping cesspits or direct discharge into irrigation channels. However, from the mid-twentieth century onwards, the disconnection of cesspits from sewage networks, coupled with industrial and population growth (rising from 93,691 in 1950 to 281,563 inhabitants in 1980), significantly increased the volume of wastewater generated, often discharged directly into the nearest irrigation channels, many of which ultimately flowed into the lake (Mondría-García, 2010).

The condition of the lake had been declining steadily, with noticeable deterioration becoming evident by the mid-1970s. According to Martín et al. (2020), it wasn't until the early 1990s, approximately two decades after reaching a hypereutrophic state, that the first sanitation measure to protect the lake was initiated. From 1990 to the present day, various engineering techniques have been employed in the area, evolving in accordance with contemporary methodologies and paradigms. Initially, there was a reliance on traditional grey hydraulic and sanitation infrastructures during the twentieth century. However, modern approaches have shifted towards more nature-based solutions in recent times.

As per the "Study for the Sustainable Development of L'Albufera de Valencia," commissioned by the Environmental Ministry and concluded in 2004, the factors gradually undermining the ecological integrity of the lake are primarily linked to urban and industrial development. Despite advancements in sanitation, untreated discharges persist, exacerbating water quality issues. Pollution stemming from urban and industrial waste, pesticide usage, and siltation has inflicted significant harm on the lake's biological health, resulting in a hypertrophic system with disrupted nutrient cycles. Accelerated siltation, compounded by the depletion of natural sediment traps due to human interventions, poses a further threat to ecosystem stability. The pressures of urbanisation and tourism development complicate land use management, leading to a decline in environmental diversity. Additionally, the gradual decline in contributions received through irrigation returns throughout the last century has further hindered the attainment of environmental objectives for this body of water. Even though those problems are not new, they persist today despite considerable efforts to enhance the environmental quality of the Albufera.

In November of 2021, the Júcar Basin Authority disclosed the Hydrological Plan of the Júcar Hydrographic Demarcation for the 2022-2027 term, which was finally approved by January 2023 in which a range of pressures were identified for the area of the Albufera Natural Park, considered a high modified zone (CHJ, 2023). Figure 38 depicts the pressures associated with surface water, whereas Figure 39 illustrates the effects on groundwater. Based on the figures, it is evident that the pressures surrounding and within the park are varied, primarily stemming from nitrogen (mainly in this form as nitrate) contamination due to agricultural activities and wastewater overflow and discharges.

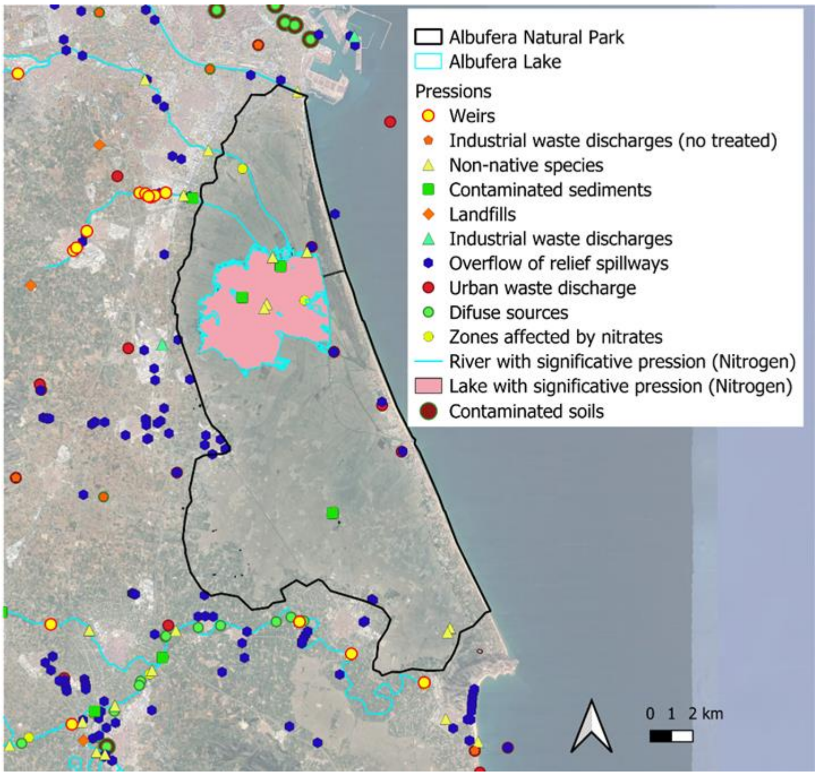

Figure 38 Pressures associated with surface water.

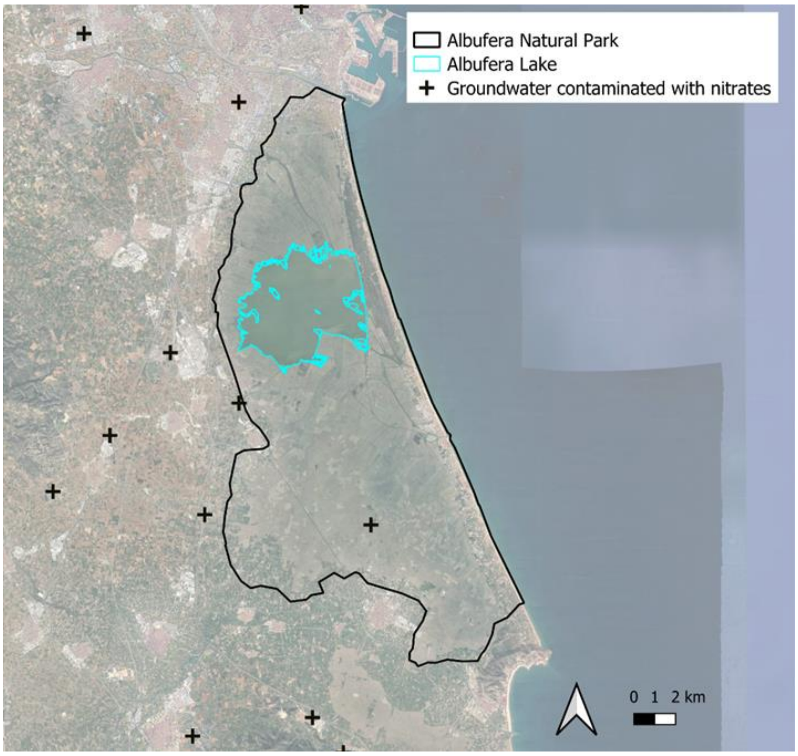

Figure 39 Pressures associated with groundwater.

To improve comprehension of the pressures in an intricate system, efforts have been made to implement, manage, and monitor a network aimed at controlling the evolution of its key hydro-morphological, physico-chemical, and biological parameters. Figure 40 shows the entire quality monitoring network for surface and groundwater while Figure 41 the monitoring points closest to the lake are shown.

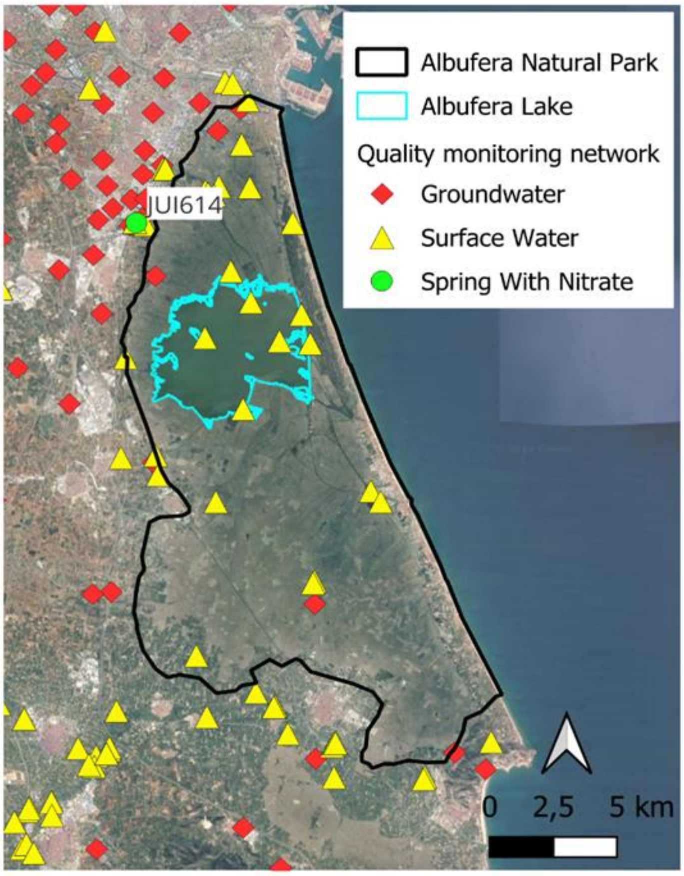

Figure 40 Quality monitoring network for surface and groundwater.

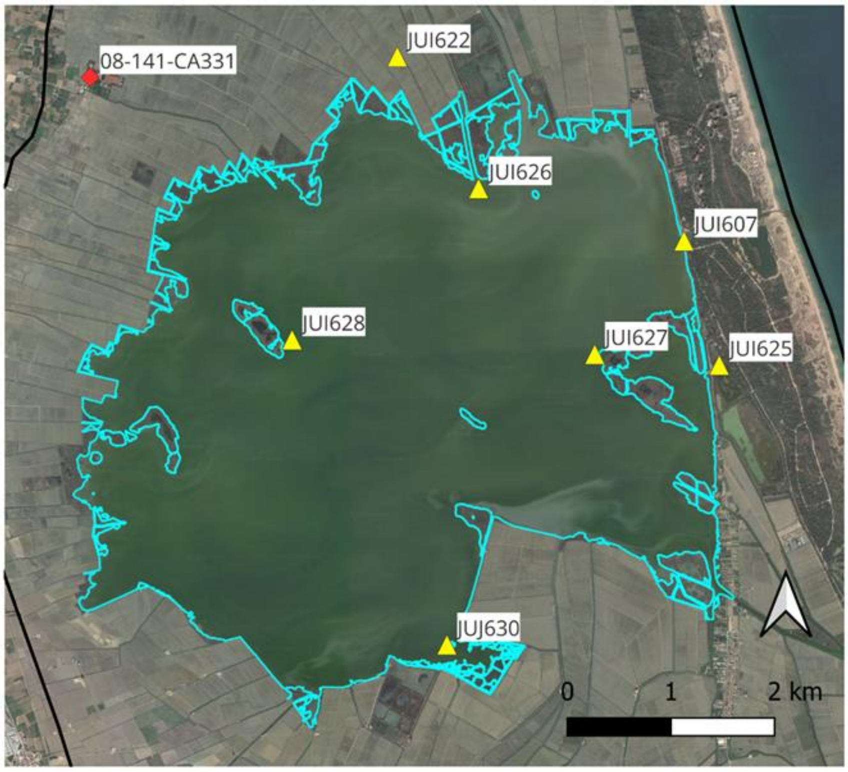

Figure 41 Quality monitoring network closest to the Albufera Lake.

In Figure 42 to Figure 51 quality parameters for some selected points are depicted. Presently, the lake continues to exhibit hypertrophic characteristics, marked by heightened phytoplankton levels. Although a common classification (OECD, 1989) suggests a transition threshold from eutrophic to hypereutrophic systems at 25 µg Cl a/L (annual mean) and 75 µg Cl a/L (annual maximum), recent years have shown a decrease in the maximum recorded value to 500 µg Chl a/L, with an annual average of 105 µg Chl a/L. Although high, these values indicate an improvement compared to previous decades when, during the 1980s, Chlorophyll a concentration in Albufera was recorded near individual readings of 800 µg Chl a/L.

Dissolved oxygen (DO) concentrations and pH may also be used to identify eutrophicated status. The greater the daily variability in DO, the greater the phytoplankton concentration. In Figure 46, DO concentrations taken inside the lake every 15 minutes are represented during a year. DO values are far from equilibrium (saturation), sometimes above, sometimes below, showing a very stressed aquatic ecosystem.

Regarding nutrients, a common feature of highly productive ecosystems is that concentrations are usually low. The recycling of nutrients is so high that as soon as they are available, they are assimilated by phytoplankton. Phosphates and ammonia concentrations, the first nutrients to be consumed, are close to zero. The presence and variability of nitrates are higher because the inflows have concentrations as high as 250 mg/L. Moreover, additional transformation processes inside the lake, such as denitrification, play a significant role in such as aerobic/anaerobic lakes.

It is notable that despite the existence of an extensive quality monitoring network, data collection, especially regarding groundwater, remains limited. For instance, the monitoring point closest to the lake (point 08-141-CA331) had only one measurement recorded in May 2010. Conversely, at point JUI614 (Figure 50), where water from a spring is monitored, nitrate concentrations have consistently exceeded 250 mg/L since 2007 (see Figure 47) indicating significant pressure on the aquifers.

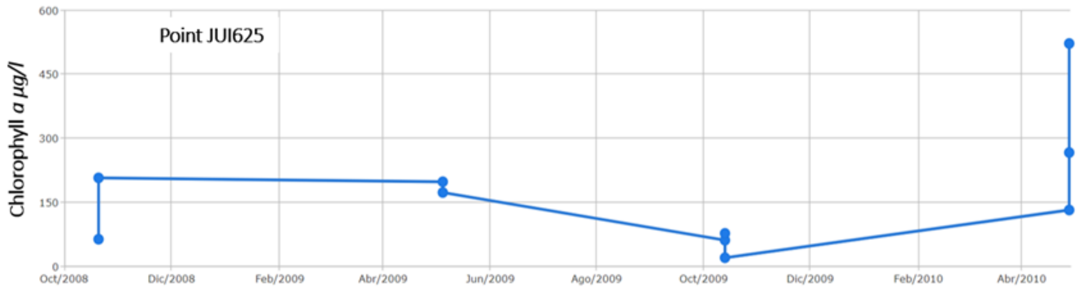

Figure 42 Chlorophyll a concentration (point JUI625).

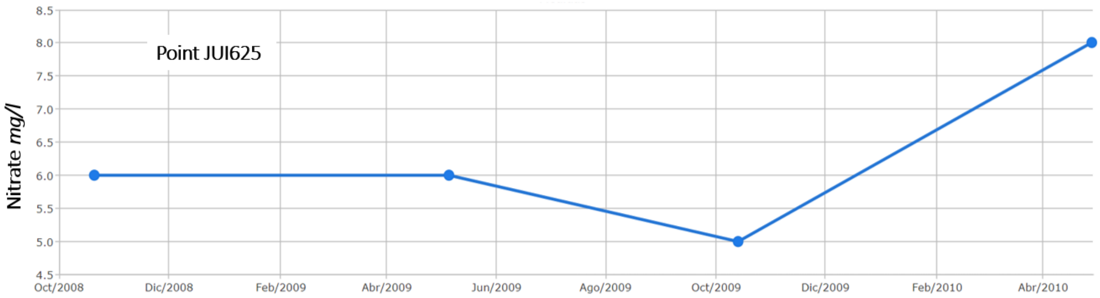

Figure 43 Nitrate concentration (point JUI625).

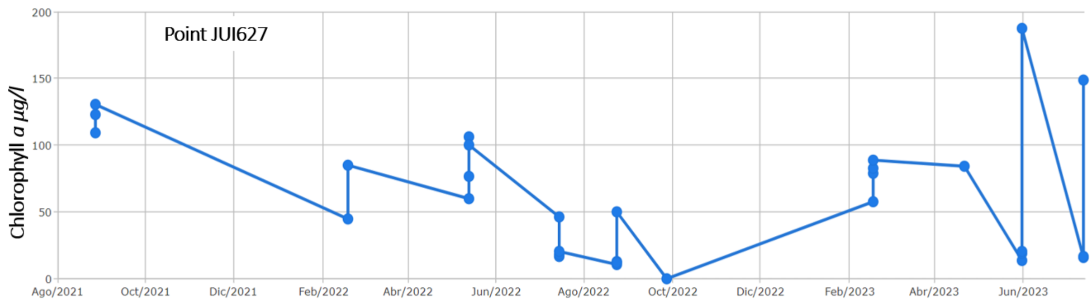

Figure 44 Chlorophyll a concentration (point JUI627).

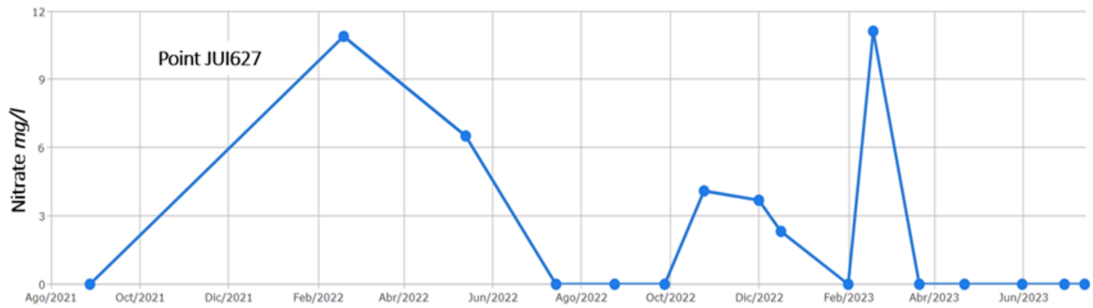

Figure 45 Nitrate concentration (point JUI627).

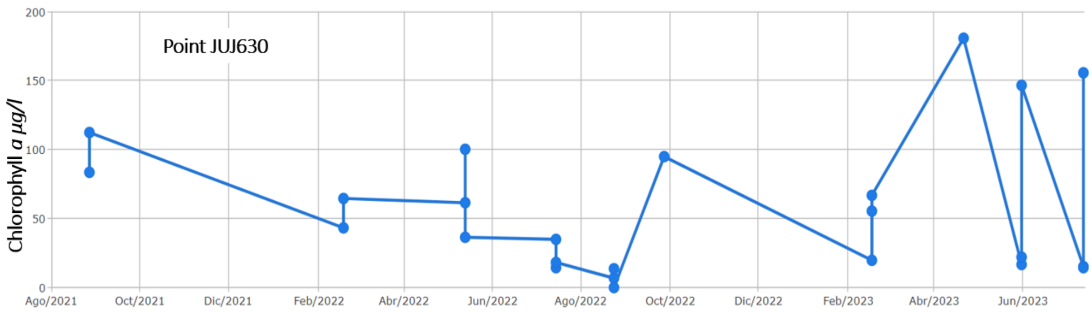

Figure 46 Chlorophyll a concentration (point JUI630).

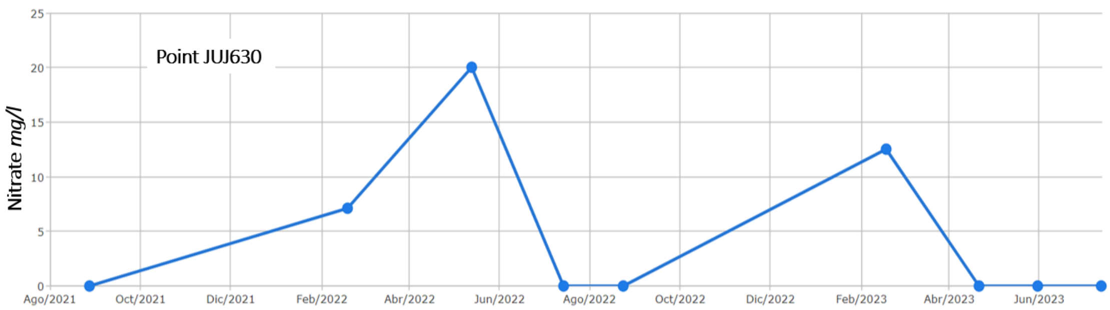

Figure 47 Nitrate concentration (point JUI630).

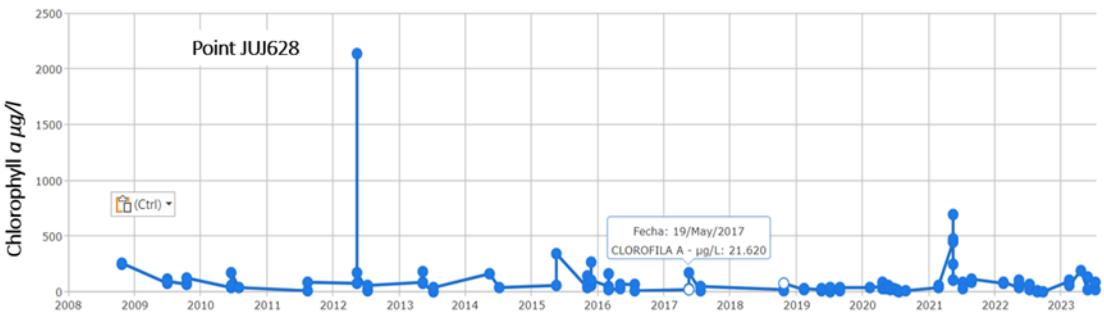

Figure 48 Chlorophyll a concentration (point JUI628).

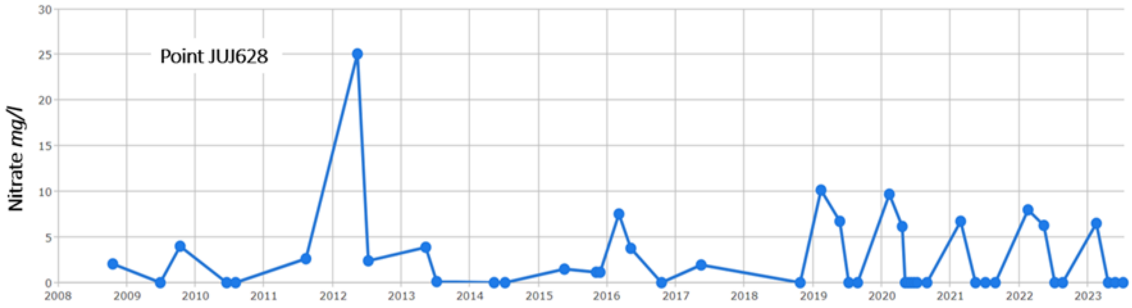

Figure 49 Chlorophyll a concentration (point JUI628).

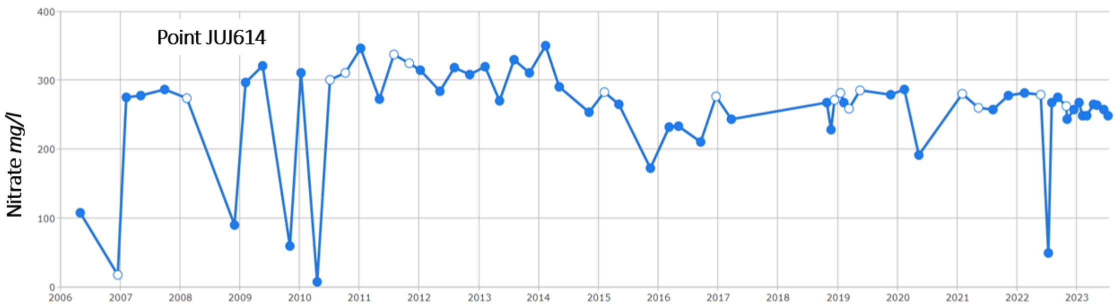

Figure 50 Nitrate concentration (point JUI614).

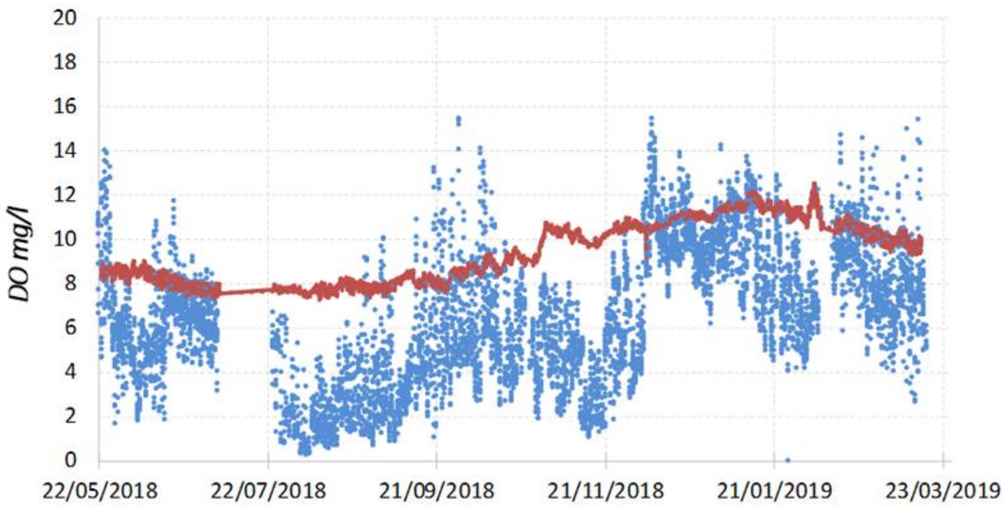

Figure 51 Blue points are measured DO concentrations. The red point is DO saturation according to temperature and salinity.

2.3.1.5. Soil and Land use

The Albufera Natural Park is characterised by a diverse array of land uses. According to the CORINE Land Cover (CLC) program, paddy fields dominate over 65% of its expanse, with the lake itself comprising 12% of the total area. Around 8% is designated for orchards, while an additional 3% is dedicated to permanently irrigated land. Urban development occupies roughly 2.5% of the territory, while a mix of crops and coniferous forests each claim 2%. The remaining land is utilised for various agricultural activities, marshlands, tourism, and sports. Figure 52 illustrates the distribution of land use within the study area.

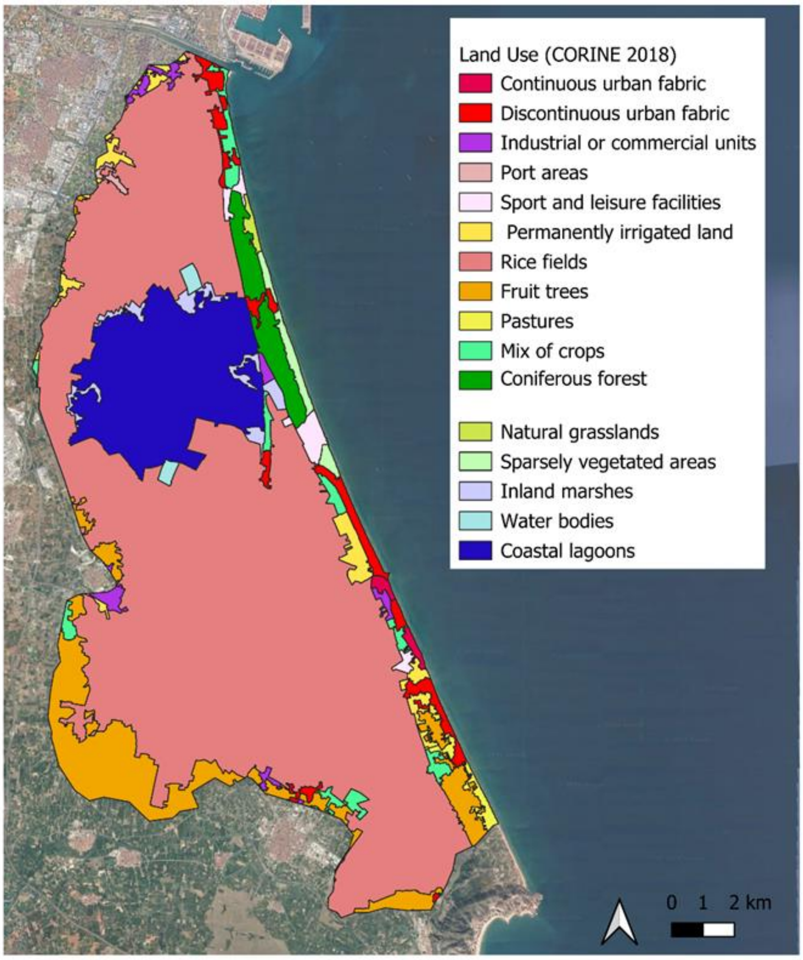

Figure 52 Distribution of land use within the Albufera Natural Park.

2.3.2. Water development and management

This section provides an overview of the Albufera Natural Park's water management system, detailing the various sources of water supply and the infrastructure in place. It discusses the park's integration with the Júcar and Túria river systems, the classification of demand units by the Júcar Water Authority, and the specific challenges and strategies for managing water resources in the region. Key issues such as eutrophication, the optimization of reclaimed waters, and measures to maintain high water levels are addressed, highlighting the importance of sustainable practices in balancing agricultural, environmental, and recreational needs.

2.3.2.1. Water supply, water storage and distribution

The Albufera Natural Park, located between the Túria River to the north and the Júcar River to the south, receives its main water supply from irrigation ditches, paddies, and surrounding springs. While paddies near the lake are irrigated by these sources, those farther away rely on freshwater from the Túria and Júcar rivers. Additionally, the lake receives treated effluent from two wastewater treatment plants and small amounts of untreated wastewater from urban and industrial sources. Direct precipitation and urban/agricultural runoff further contribute to the lake's replenishment.

Within the park, water resource infrastructures include a network of irrigation ditches, channels, wells, and weirs. Moreover, wastewater treatment plants and constructed wetlands are present. Although the park itself lacks dams or reservoirs, it is intricately connected to the Júcar and Túria systems, which feature numerous dams, weirs, and reservoirs. Nonetheless, the Albufera Lake serves as a natural reservoir within this complex hydrological network.

2.3.2.2. Water uses

For management purposes, the Júcar Water Authority has grouped as Demand Units (DU) distinct geographical areas within the Júcar River basin, each with specific water requirements for diverse demands including urban supply, agriculture, industry, and irrigation. Each demand unit exhibits unique water demands influenced by factors such as population density, economic activities, and prevailing climatic conditions. These units are delineated to facilitate efficient and equitable management of the basin's water resources. Figure 53 illustrates the agricultural and urban demand units, while Figure 54 depicts those for industry, livestock, and tourism within the Albufera Natural Park. Table 2 to Table 4 provide a detailed breakdown of their usage in 2018, the most recent information available. In terms of agricultural usage, it's noteworthy that the efficiency in transportation, distribution, and utilisation is approximately 66%. As for urban demand units, it's crucial to highlight that the Albufera Natural Park partially falls within unit U4070, which encompasses the city of Valencia and its surrounding area, boasting a population of over 1.5 million inhabitants. The two livestock units in the region have a combined demand of approximately 1.85 hm^3/year from groundwater sources, while the sole leisure unit demand in the area originates from a golf course with no allocation planned for the upcoming years.

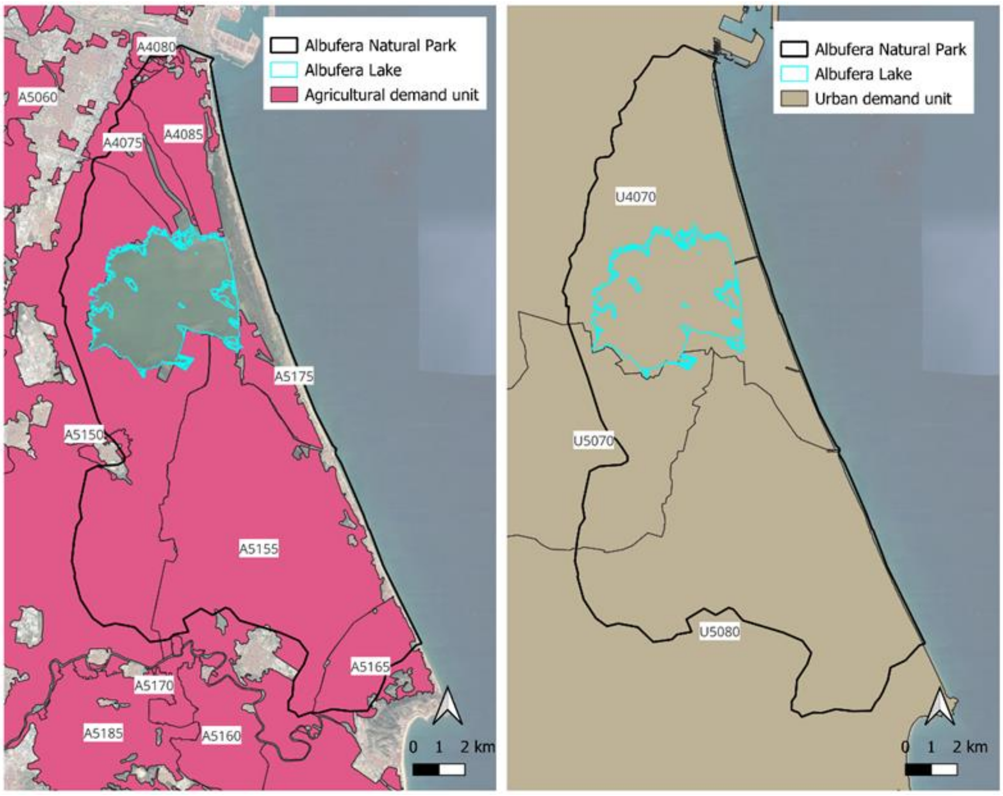

Figure 53 Agricultural and urban demand units.

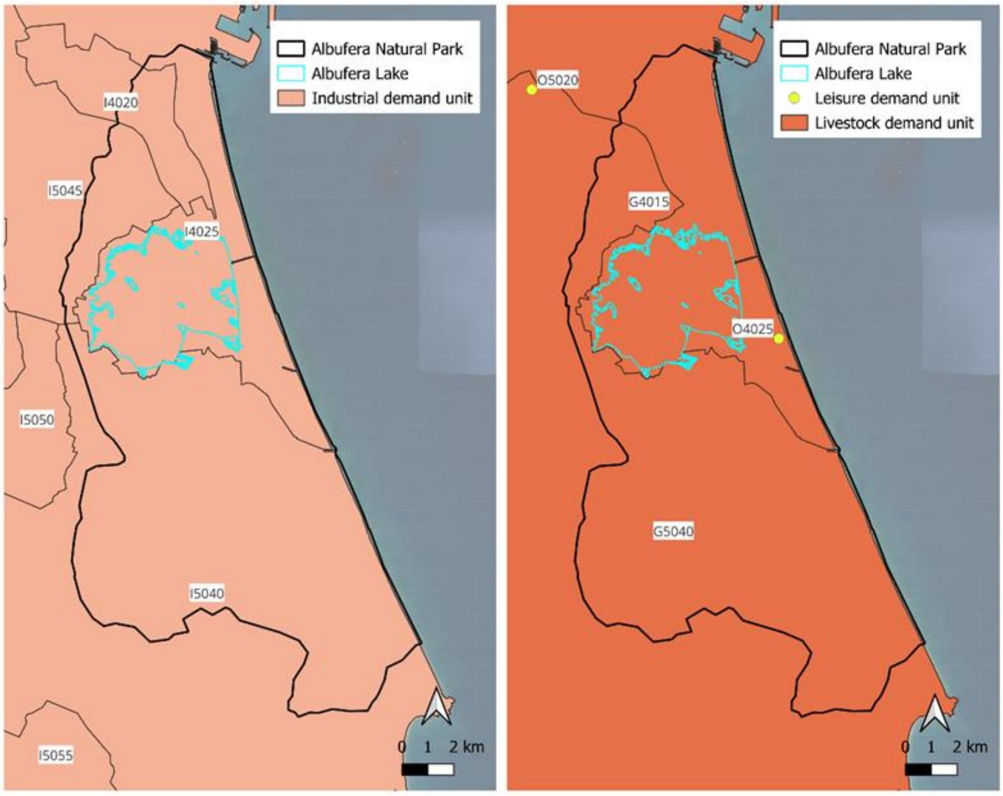

Figure 54 Industry, livestock, and tourism demand units.

Table 2 Details on the agricultural demand units.

Agriculture					
DU code	Irrigated Area (ha)	Net Allocation (m^3/ha/year)	Net Demand (hm^3/year)	Gross Demand (hm^3/year)	Main source
A5165	3,429	6,091	21	105	Surface
A5155	7,669	7,027	54	211	Surface
A5175	555	5,667	3	7	Groundwater
A5150	19,014	4,964	94	226	Surface
A4085	1,331	7,568	10	28	Reuse
A4075	2,951	5,061	15	108	Surface/Reuse

Table 3 Details on the urban demand units.

Urban				
DU code	Permanent Population	Total Demand (hm^3)	Total Allocation (l/Inhab./day)	Main Source
U4070	1,572,388	137	231	Surface
U5070	38,846	4	272	Mixed
U5080	157,865	16	260	Mixed

Table 4 Details on the industrial demand units.

Industry					
DU code	Total Demand (hm^3)	From Urban Suppy (hm^3)	From Groundwater (hm^3)	Total Rights (hm^3)	Main Source
I4020	14	5	9	12	Groundwater
I4025	26	13	13	8	Groundwater
I5040	6	3	3	8	Groundwater

2.3.2.3. Water management strategies

In the Albufera Natural Park, effective water management strategies aim to balance the demands of agriculture, hunting, and environmental conservation while addressing challenges such as fluctuating water availability and the impact of droughts.

In a normal hydrological year, water stored in Tous (Júcar Basin) and Benagéber/Loriguilla (Túria Basin) reservoirs supplies enough water to flood the rice fields both in the growing season and in perellonà. As water availability decreases, the surface flooded in perellonà also decreases. With the objective to ensure the next irrigation campaign, Júcar Water Authority may decide not to supply any flow for the perellonà. This decision affects another of the activities that take place in the Natural Park: hunting. Between mid-October and mid-January, hunters need to flood hunting grounds, so they resort to lake pumping. This can cause very significant drops in water levels.

The water management in UD U4085 and some surface in UD U4075 are quite different because the farmers have the permits to use reclaimed waters from Pinedo WWTP, so they have the irrigation assured. However, the permit is not extended to perellonà. Exceptionally, in the winter of 2023/24, the perellonà with reclaimed waters from Pinedo WWTP has been authorised due to the critical situation of the lake.

In recent years, some emergency solutions have been implemented to reduce the impact of droughts. For example, In UD A5175, the constructed wetland “Tancat de L’Illa” is used as a water storage system for the irrigation of fruits and vegetables. This CW is fed by reclaimed waters from Sueca WWTP, so its water quality is very high.

In the event of extreme droughts, Júcar Water Authority activates emergency wells and repumping systems.

2.3.2.4. Main issues

For the Albufera Natural Park demo site, the main issues, followed by the proposed solutions, are presented as follows:

1. Addressing eutrophication: Increasing the number of constructed wetlands to improve water quality and enhance the naturalization of Albufera Park.
2. Optimisation of reclaimed waters: Enhancing the utilisation of treated wastewater from major wastewater treatment plants (WWTPs) in the area such as Pinedo, Quart-Benácher, Albufera Sur, and Sueca is imperative to bolster the reliability of irrigation practices.
3. Integration of reclaimed waters in perellonà: Implementing reclaimed water systems in perellonà areas can significantly contribute to sustainable irrigation practices.
4. Water swaps initiatives: Developing mechanisms for water swaps, wherein regenerated water is utilised for irrigation while providing natural water sources to the lake, can optimise water resource management.

5. Maintaining high water levels: Sustaining elevated water levels is crucial to mitigate the risk of salinisation resulting from sea intrusion, safeguarding the ecological balance of the region.

2.3.3. Water resources governance system

The Spanish water governance system operates on two primary scales: national and river basin. At the national level, the Ministry for Ecological Transition and Demographic Challenge (MITECO) holds authority over water. River basin management is overseen by autonomous public bodies known as Water Authorities, which are affiliated with MITECO through the General Directorate for Water under the Secretary of State for the Environment. Each Water Authority is responsible for managing the water resources within its designated hydrographic demarcation, encompassing terrestrial and marine areas along with associated groundwater and coastal waters.

The organisational structure of water governance authorities in Spain is illustrated in Figure 55. For instance, the Júcar Water Authority oversees the management of specific groundwater masses and operates offices across its territory, including in Teruel, Albacete, Alicante, and Valencia.

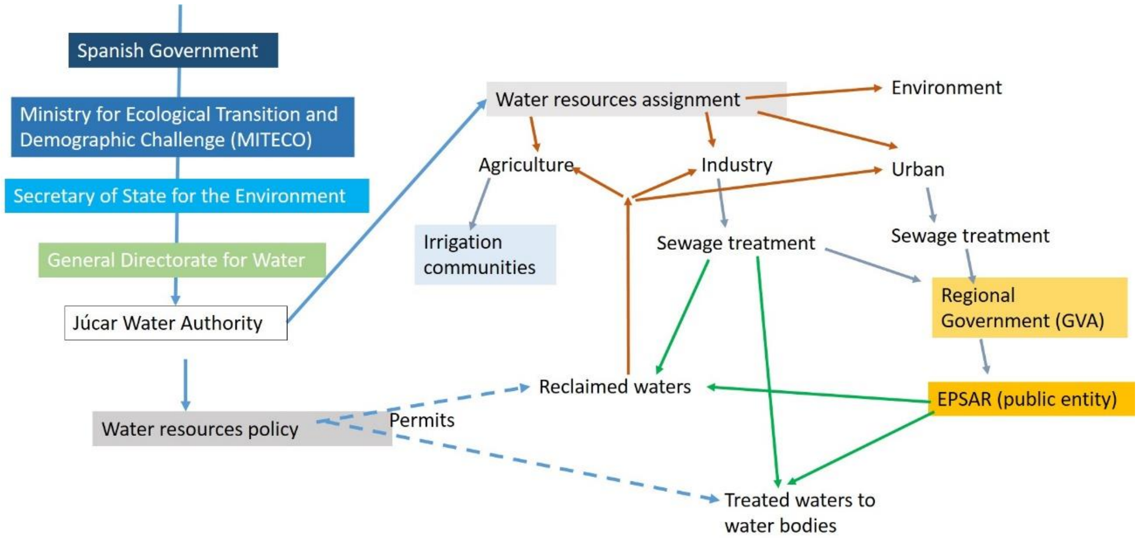

Figure 55 Organisational structure of water governance authorities in Spain.

2.3.3.1. Water policy and current instruments of water regulation

The national hydrological plan, ratified by the Spanish Congress under Law 10/2001[11] (BOE-A-2001-13042) on July 5th and subsequently amended by Laws 53/2002 and 62/2003 on December 30th, as well as Royal Decree-Law 2/2004 on June 18th, and Law 11/2005 on June 22nd, is a comprehensive hydrological planning tool implemented at the national level in Spain. This plan delineates policies, strategies, and measures aimed at the integrated management of water resources across the entirety of Spanish territory.

[11] https://www.boe.es/buscar/act.php?id=BOE-A-2001-13042

Its primary aim is to ensure the availability and sustainable utilisation of water, while also safeguarding aquatic ecosystems and mitigating risks such as floods and droughts

At the basin level, the basin hydrological plans are aligned with the strategies outlined in the national hydrological plan. Moreover, their composition adheres to the principles outlined in the Directive 2000/60/EC[12] (BOE-L-2000-82524) of the European Parliament and the Council, commonly known as the EU Water Framework Directive, as well as the principles outlined in the consolidated Law of Water, ratified by Royal Legislative Decree 1/2001[13] (BOE-A-2001-14276) dated July 20. According to that law, the territorial scope of each basin hydrological plan must correspond to the boundaries of the respective river basin district (or demarcation), which is composed of the natural boundaries of river basins and their associated drainage networks. Furthermore, it specifies that these plans are developed either by the corresponding basin organisation or by the competent hydraulic administration. These plans lay out precise guidelines to ensure optimal water management within each basin district. They are required to provide, at minimum, a comprehensive description of the river basin, encompassing both surface water and groundwater. This includes the provision of maps, a thorough inventory of water resources, and an assessment of anthropic impacts. The plans also detail various aspects such as water usage, pressures, and conservation strategies, in addition to setting environmental objectives, economic measures, action plans, and monitoring systems. Updates to these plans are mandated to incorporate progress evaluations and explanations for any measures that have not been implemented.

In addition to the hydrological plan, the regulation of water usage volumes and the requirements for measurement and recording procedures are outlined in Order ARM/1312/2009[14] (BOE-A-2009-8731), dated May 20. It obligates that both user communities and private users must furnish the Júcar Water Authority with their consumption data every six months for each catchment area, including details such as irrigated acreage and crop types utilised.

Additionally, in 2018, the Special Drought Plan for the Júcar Hydrographic Demarcation was ratified via Order TEC/1399/2018[15] (BOE-A-2018-17752), dated November 28. This plan is designed to mitigate the environmental, social, and economic repercussions of droughts by distinguishing between prolonged drought situations (meteorological and hydrological droughts), linked to reduced rainfall and natural water resource availability, and temporary shortages arising from transient challenges in meeting various socioeconomic water demands. Structural scarcity, characterised by permanent water resource deficiencies in specific areas, is addressed within the framework of overall planning strategies. After the period of public consultation in 2023, the review of the Special Drought Plan is under ordinary strategic environmental assessment.

To address groundwater contamination, Europe relies on Directive 2006/118/EC[16] (EC, 2006) of the European Parliament and the Council, dated December 12, 2006, concerning

[12] https://www.boe.es/buscar/doc.php?id=DOUE-L-2000-82524
[13] https://www.boe.es/buscar/act.php?id=BOE-A-2001-14276
[14] https://www.boe.es/eli/es/o/2009/05/20/arm1312
[15] https://www.boe.es/diario_boe/txt.php?id=BOE-A-2018-17752
[16] https://eur-lex.europa.eu/eli/dir/2006/118/oj

the safeguarding of groundwater from pollution and deterioration. This directive outlines the criteria for assessing the chemical condition of groundwater. In Spain, Directive 2006/118/EC was implemented through Royal Decree 1514/2009[17] (BOE-A-2009-16772), issued on October 2, which establishes regulations for safeguarding groundwater from pollution and degradation.

Spain also has a robust policy framework for managing wastewater. Key regulations include Royal Decree-Law 11/1995[18] (BOE-A-1995-27963) and Royal Decree 509/1996[19] (BOE-A-1996-7159), which set treatment standards for urban wastewater. Discharge authorisation is governed by the Regulations of the Public Hydraulic Domain, aligned with the Water Law. Application procedures are outlined in Order AAA/2056/2014[20] (BOE-A-2014-11411). Since 2007, wastewater reuse is regulated by Royal Decree 1620/2007[21] (BOE-A-2007-21092), facilitating the legal framework for reclaimed water reuse.

The OurMED Spanish demo site of Albufera Natural Park falls under the regulatory framework of the hydrological plan of the Júcar Hydrographic Demarcation for the 2022-2027 term (CHJ, 2023), which was approved by Royal Decree 35/2023[22], dated January 24, and authored by the Júcar Basin Water Authority, is the territorial jurisdiction of the Júcar Water Authority. It was delineated in Article 2.3 of Royal Decree 125/2007[23], dated February 2. Figure 56 depicts the Júcar Hydrographic Demarcation and the position of the Albufera demo site within it. The Júcar Hydrographic Demarcation's hydrological plan includes a comprehensive description of the area, covering surface waters, groundwater, and their characteristics. It assesses water usage, pressures, and human impacts, allocates resources, and defines ecological flow rates. Additionally, it incorporates environmental protection measures like protected areas and monitoring systems. Economic analyses, action programs, and strategies for water management, legislation compliance, and infrastructure development are also outlined.

[17] https://www.boe.es/buscar/pdf/2009/BOE-A-2009-16772-consolidado.pdf
[18] https://www.boe.es/eli/es/rdl/1995/12/28/11
[19] https://www.boe.es/eli/es/rd/1996/03/15/509
[20] https://www.boe.es/eli/es/o/2014/10/27/aaa2056
[21] https://www.boe.es/eli/es/rd/2007/12/07/1620/con
[22] https://www.boe.es/eli/es/rd/2023/01/24/35
[23] https://www.boe.es/eli/es/rd/2007/02/02/125

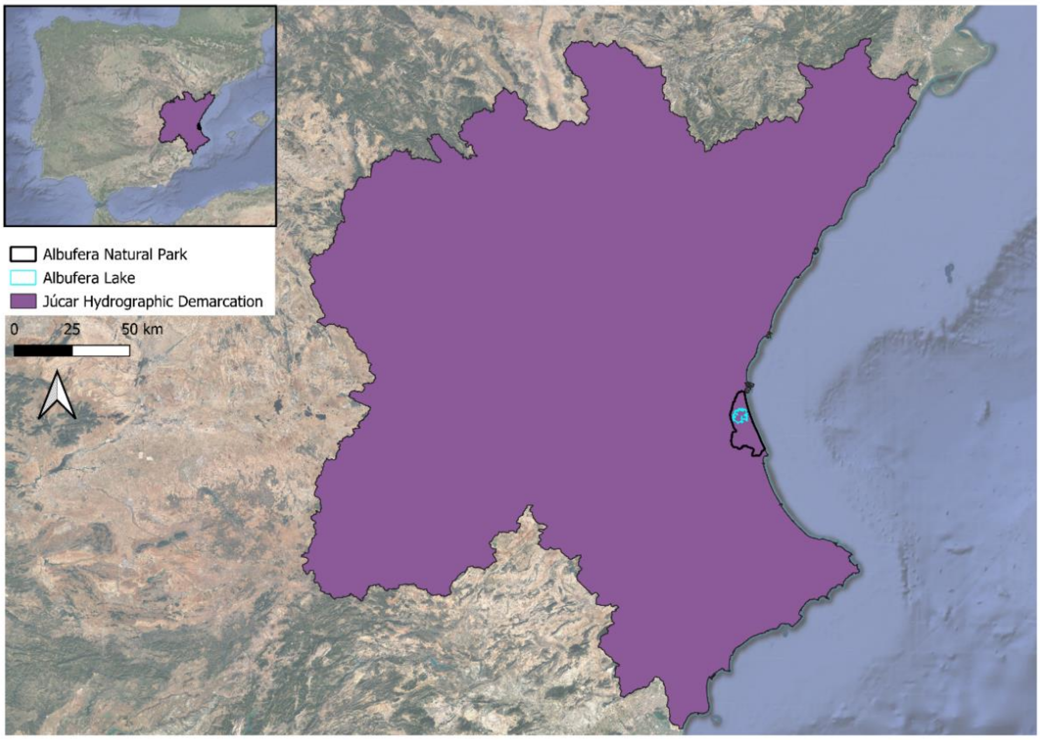

Figure 56 Júcar Hydrographic Demarcation.

The Albufera Natural Park's water management is also regulated by the Special Plan for the Albufera, which acknowledges the environmental, historical, and cultural importance of the area. This plan details measures for conservation and sustainable development, prioritizing the protection of biodiversity, natural resources, and cultural heritage. It encompasses strategies for ecosystem conservation, water resource management, flora and fauna protection, and land use planning. Serving as a consensus solution among all administrations, it aims to facilitate the attainment of the water body's environmental objectives (CHJ, 2019).

In the context of hydrological planning, the initial mention of the Special Plan Albufera arises in Royal Decree 595/2014[24], dated July 11, which sanctions the Hydrological Plan of the Júcar Hydrographic Demarcation. Specifically, in Article 7 on Environmental Objectives, it stipulates:

"In the specific instance of the surface water body of the Albufera lake in València, Public Administrations, within their jurisdictional authority, will advocate for the development of a special plan aimed primarily at attaining the ecological potential outlined in Appendix 5."

In the actual hydrological plan (CHJ, 2023), Annex 10 dedicates a section to dealing with measures to achieve environmental objectives in the Albufera of Valencia, especially to delineate those which are present both in the Hydrologic Plan and in the Special Plan for the Albufera. Some of the most relevant actions are (CHJ, 2019, 2023; Martín et al., 2020):

[24] https://www.boe.es/buscar/doc.php?id=BOE-A-2014-7371

- Establishment of a water reserve from the River Júcar in Tous reservoir.
- Enhancement of water supply and purification in the area surrounding the Park.
- Augmentation of the hydraulic capacity of the Western Collector (Valencia) (see number 1 in Figure 57).
- Complementing stormwater detention tanks with stormwater wetlands or basins.
- Increasing 100 ha of the surface of CWs around the lake and spreading sustainable urban drainage systems.
- Maintenance, management, and improvement measures for the CW Tancat de la Pipa.
- Improvement of agricultural practices to mitigate diffuse contamination.
- Strong governance and oversight.
- Monitoring of water body conditions.
- Amelioration of ecological state quality by reducing the level of eutrophication in the lake, reducing the Chlorophyll a concentration to 30 µg/L by 2027.
- The minimum water requirements for Albufera Lake are set at 210 hm^3/year.

2.3.4. SWOT analysis of project actions

Strengths:

Biodiversity: The park is home to a diverse range of flora and fauna, including numerous bird species, fish, and plants.

Cultural and historical significance: The Albufera has been an integral part of Valencia's cultural heritage for centuries, attracting tourists and researchers interested in its history and traditions.

Ecotourism potential: The park offers opportunities for eco-friendly tourism activities such as birdwatching, hiking, and boat tours, contributing to the local economy.

Environmental importance: The park plays a crucial role in maintaining ecological balance, serving as a habitat for migratory birds and helping to regulate water quality and quantity in the region.

Weaknesses:

Pollution: The Albufera faces challenges related to pollution from agricultural runoff, urban development, and waste disposal, which can degrade water quality and harm wildlife.

Overcrowding: During peak tourist seasons, the park may experience overcrowding, leading to environmental degradation and disturbances to wildlife.

Invasive species: Non-native plant and animal species pose a threat to native biodiversity within the park, potentially disrupting ecosystems, and outcompeting native species.

Water management issues: The park's hydrological system is vulnerable to changes in water availability and quality, which can impact the health of wetland habitats and wildlife populations.

Opportunities:

Conservation initiatives: There are opportunities to implement conservation projects aimed at restoring and protecting wetland habitats, improving water quality, and conserving endangered species within the park.

Sustainable development: The park can serve as a model for sustainable development practices, such as eco-friendly tourism, organic farming, and green infrastructure projects.

Education and outreach: There is potential to increase public awareness and appreciation of the park's natural and cultural heritage through educational programs, interpretive centres, and community engagement initiatives.

Research opportunities: The park provides a valuable research environment for studying wetland ecosystems, biodiversity conservation, and sustainable land management practices.

Threats:

Climate change: Rising temperatures, changing precipitation patterns, and sea-level rise pose significant threats to the park's ecosystems, potentially altering habitats, increasing the frequency of extreme weather events, and exacerbating water management challenges.

Urbanisation and development: Pressure from urbanisation and development projects in the surrounding area could encroach upon the park's boundaries, fragmenting habitats, and disrupting wildlife corridors.

Agricultural intensification: Intensification of agriculture in the region may lead to increased use of fertilisers and pesticides, contributing to pollution and habitat degradation within the park.

Natural disasters: The park is susceptible to natural disasters such as floods, droughts, and wildfires, which can have devastating effects on ecosystems, infrastructure, and human communities.

2.4. Case study Arborea

The Italian demo site is in central-western Sardinia, Italy, in the coastal Oristanese district downstream the left bank of the river Tirso, encompassing the villages of Arborea, Marrubiu, and Terralba, with a total population of approximately 18,800 people.

Historically, the Arborea plain was an uninhabitable swamp infested with malaria-carrying mosquitoes. Between 1920 and 1930, extensive land reclamation efforts transformed its landscape. During this period, sand dunes were flattened, brackish and salted wetlands were drained, and new agricultural land was created. The resulting plain was divided into rectangular fields 2 to 4 hectares in size, aligned in a north-south orientation and surrounded by Eucalyptus windbreaks. A comprehensive drainage network, comprising primary and subsidiary channels oriented both east-west and north-south, was implemented, complete with dewatering pumping stations. This transformative process was combined with the immigration in the region of farmers and their families, primarily from northeastern Italy, fostering a cohesive community that were assigned land according to a sharecropping system that eventually evolved into a robust cooperative system made of some 200 dairy farm owners. Today, this cooperative system comprises some 150 farms managing 30,000 dairy cattle across a 6,000-hectare irrigated plain, making it one of the most productive agricultural sites in Italy and Europe.

In the surrounding of the dairy farming Arborea district, there is a diverse array of agricultural systems, including paddy rice cultivation (some 3,000 ha), mostly for seed production, alongside the cultivation of artichokes, tomatoes, melons, winter cereals such as durum wheat and barley, and forage crops. Other economically relevant activities in the region include fish farming in the residual wetlands. These marsh wetlands are pivotal ecological assets, consisting of approximately half of the Sardinian wetland heritage. They are designated as Sites of Community Importance and Special Protection Areas under the EU Natura 2000 directive and are protected under the Ramsar Convention.

Figure 57 Arborea Nitrate Vulnerable Zone and adjacent wetlands.

2.4.1. Biophysical attributes

The Arborea plain, located in the northern part of the Campidano rift, enjoys a Mediterranean climate characterized by mild, wet winters and hot, dry summers. The region's hydrology is defined by two main aquifers: the Sandy Hydrogeological Unit (SHU) and the Alluvial Hydrogeological Unit (AHU). These aquifers are vital for agricultural activities and the local ecosystem, supported by an extensive network of drainage, irrigation, and flood control infrastructure, including the Eleonora di Arborea dam.

Agriculture in Arborea is dominated by intensive dairy farming, which significantly impacts the environment. The area is designated as a Nitrate Vulnerable Zone due to high nutrient levels leading to groundwater contamination. Land use is primarily focused on forage crops for dairy livestock, with the soil enriched by long-term fertilization practices. More detailed information on the climate, hydrology, water resources infrastructure, ecological footprint, and land use of the Arborea plain is provided in the following sections.

2.4.1.1. Climate

The climate in this region is Mediterranean, characterized by a mean annual temperature of 16.7 °C and an average annual precipitation of 575 mm, 75% falling between October and March. Additionally, the annual average reference evapotranspiration is 1164 mm, resulting in an aridity index of 0.49.

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

2.4.1.2. Hydrological/ hydrogeological context

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

- The Sandy Hydrogeological Unit (SHU) is a phreatic aquifer situated within the Holocene littoral sands prevalent in the plain. Discontinuous clay lenses of lagoonal origin, which give rise to perched aquifers, characterize the aquifer, thereby making it locally confined. The aquifer has good porous permeability, with a K value ranging between 10−5 and 10−6 m s^{-1}. It is underlain by a layer of lagoonal deposits composed of silt clays and peaty mud that outcrop at the reclaimed Sassu Lagoon. As reported by Ghiglieri et al. (2016), in the southern part of the plain, lagoonal clays that demarcate the base of the sandy aquifer are absent, such that the Holocene sands of the SHU and alluvial aquifers of the AHU (Pleistocene continental deposits) are in hydraulic communication with each other.
- The Alluvial Hydrogeological Unit (AHU) comprises a multi-layer aquifer situated within the Pleistocene continental deposits. This aquifer consists of gravel, with occasional sand or clayey sand outcrops distributed across the region surrounding the Arborea plain up to Monte Arci. The AHU aquifer is confined in the plain due to the presence of a clay layer that separates it from the sandy aquifer (SHU). The impermeable layers in this hydrogeological unit are characterized by lagoonal clays. Additionally, the AHU includes gravelly-sand formations with good permeability (K=10−4–10−5 m s^{-1}), which were deposited by fluvial action and

intercalated within the continental deposits. However, the permeability of the sand-clay layers decreases.

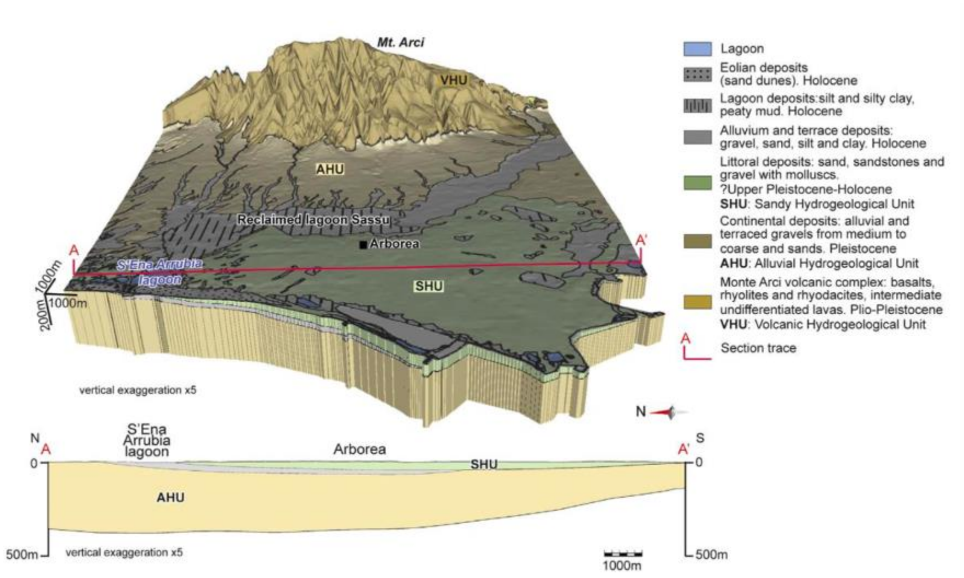

Figure 58 Hydrogeological scheme of the Arborea plain. Source: Ghiglieri et al., 2016.

2.4.1.3. Water resources infrastuctures

The reclamated plain was artificially generated by fundamental water infrastructures for the drainage and pumping of the water in the areas located below sea level (the Sassu and Luri wetlands), the diversion of rivers that originally fed the wetlands and the protection of the plain from floodings. A network of channels and ditches ensure drainage while irrigation water is delivered through a dedicated pressure water network that reaches each farm field.

The new Eleonora di Arborea dam, managed by the regional water agency ENAS (Ente Acque Sardegna) enhanced the capacity of the reservoir to a potential of 800 Mm^3, which is currently authorized to store up to 400 Mm^3.

The wetlands are managed by different fishermen cooperatives for aquaculture including fish and mussels. The wetland freshwater is supplied by the drainage water pumped by the consortium, by the channels that diverted the original riverbeds and by the ditches directly draining the agricultural fields.

An overlooked water infrastructure is represented by the windbreaks surrounding the agricultural fields, which in the east-west field sides coincide with the drainage ditches. This live infrastructure was originally designed as a windbreak and to drain the shallow groundwater. Eucalyptus trees are tall and known for high evapotranspiration rates. Preliminary results from a past experiment showed that these hedges, that on average represent some 7-10% of the total agricultural areas, play a role in the nitrogen and water cycles, by providing an ideal habitat for denitrifying bacteria (high organic matter, nearly saturated soils in the drainage ditches)

2.4.1.4. Ecological and ecosystems context and footprint

The intensive dairy cattle system in Arborea is characterised by significant nutrient input, primarily nitrogen (N) and phosphorus (P), which are fundamental for soil fertility enhancement yet also primary contributors to groundwater contamination with nitrates and eutrophication in the neighbouring wetlands and lagoons. In response to these concerns, the implementation of the Nitrate Directive 91/676 led to the designation of the Arborea district as a Nitrate Vulnerable Zone (NVZ) in 2005. Central to compliance efforts is the prescribed maximum N rate from organic fertilizers, set at 170 kg ha^{-1} N, constituting roughly half of the net N uptake (approximately 350-400 kg N ha^{-1} $year^{-1}$) of the intensive forage crop systems servicing dairy farms. However, the significant annual effluent output per farm exceeds the prescriptions outlined in the Nitrates Directive. To ensure compliance with the Nitrates Directive, farmers must purchase mineral N fertilizers to meet crop requirements following a designated fertilization plan. Moreover, surplus manure and slurry must be exported outside the NVZ, incurring additional costs. Despite efforts to align with the EU Nitrate Directive, nitrate concentrations remain high, surpassing the recommended threshold of 50 mg L^{-1}. The long-term turnover of the aquifer, estimated to be 20 to 30 years, exacerbates this issue (ARPAS, 2023; Ghighlieri et al., 2016; Linker et al., 2024 under revision).

2.4.1.5. Soil and Land use

The forage cropping systems for dairy livestock are nowadays based on the import of grains and plant proteins from abroad and the local production of fibrous forage from the double cropping of silage maize (Zea mays) and Italian ryegrass (Lolium multiflorum) for hay or a winter cereal for silage, representing some 90% of the total agricultural area in the Arborea plain. Almost all the remaining land in the district is cultivated with horticultural crops (potatoes, carrots, watermelon, melon, strawberries etc.). In the recent past, some 20% of the irrigated land was grown with alfalfa, which is now mainly imported from other districts.

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

2.4.2. Water development and management

The Arborea region, managed by the Oristano Irrigation and Land Reclamation Consortium, exemplifies a complex water management system that integrates both surface and groundwater resources to meet the agricultural and industrial demands. The area receives high-pressure irrigation water from the Eleonora d'Arborea dam, which is one of the largest in Europe. This water is distributed at the field level through a permanent sprinkler system managed by the consortium, while groundwater is primarily used for non-drinking purposes such as washing livestock facilities and for industrial processes. The integration of surface water from the dam and groundwater helps balance the water needs of various stakeholders, including farmers and cooperatives involved in milk processing and horticulture. However, a significant amount of irrigation water is lost due to leakages in the distribution channels, indirectly aiding groundwater recharge but also leading to inefficiencies and additional costs for the consortium.

The Arborea plain's water management faces several challenges, particularly concerning water quality. Extensive monitoring by ARPAS has highlighted significant nitrate pollution in groundwater, attributed to intensive agricultural activities and the use of fertilizers. The nitrate concentrations in the region often exceed the recommended thresholds, posing risks to both human health and the environment. Studies have shown that despite improvements in irrigation techniques, nitrate leaching remains a persistent issue, especially during the autumn-winter season. The consortium has implemented various strategies to address these issues, including precise monitoring of water usage and efforts to reduce leakages. Nonetheless, the continuous use of both synthetic and organic fertilizers and the lack of precision irrigation systems at the farm level suggest that ongoing efforts and innovative solutions are needed to mitigate nitrate pollution and enhance the sustainability of water resources in the region.

2.4.2.1. Water supply, water storage and distribution

The demo site is part of the Oristano Irrigation and Land Reclamation Consortium, which encompasses a total area of 85,363 hectares, out of which approximately 36,000 hectares are served by irrigation and 15,000 hectares are irrigated (Figure 59).

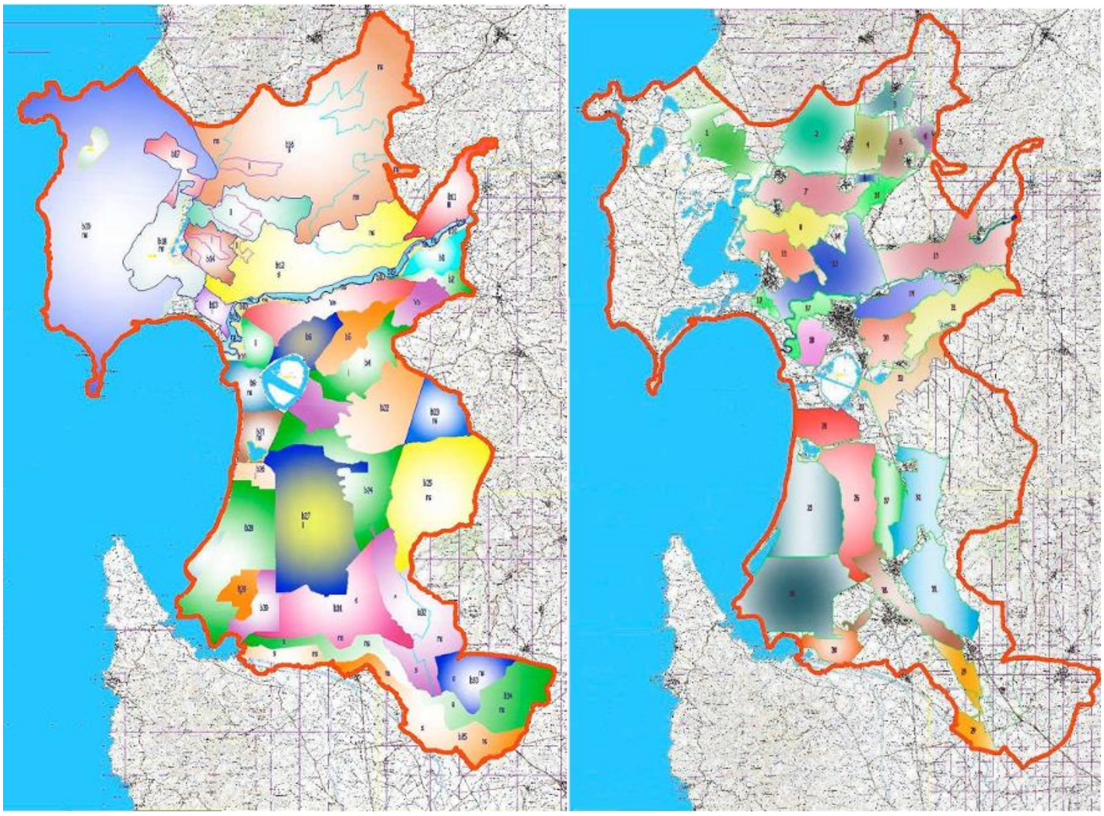

Figure 59 The Oristanese irrigation and land reclamation consortium. Left: total area; Right: irrigated districts. Source: www.bonificaoristanese.it.

The irrigated consortium receives high-pressure irrigation water from the Eleonora d'Arborea dam, one of the biggest in Europe. This surface water is currently distributed at field scale by the Oristanese Land Reclamation Consortium through a permanent sprinkler system. Groundwater is used for non-drinking purposes (washing livestock facilities, cattle watering, and industrial processes).

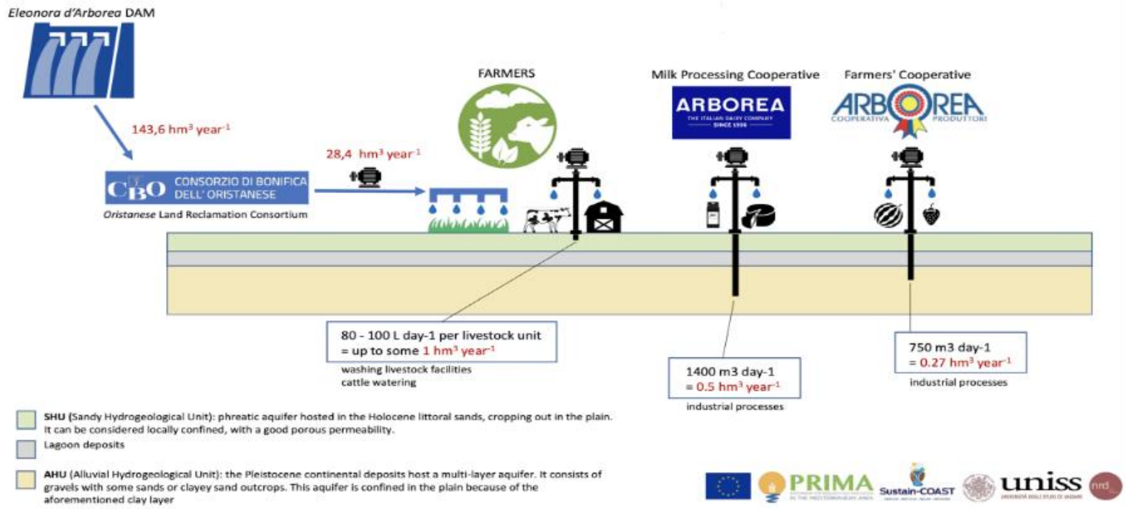

Figure 60 Scheme of the water storage and distribution system in the Oristanese Irrigation Consortium. Source: PRIMA Sustain-Coast project deliverables.

2.4.2.2. Water uses

Crop irrigation is the most important water use in the Arborea plain and in general in the Oristanese area. Some 35 Mm^3 are consumed every year by the district of Arborea for this purpose. Other uses include the drinkable water for civil uses supplied by the regional agency for drinking water and wastewater (Abbanoa) which is supplied by the same dam. Groundwater is used for non-drinking purposes (washing livestock facilities, cattle watering, and industrial processes). The dairy factory is the main groundwater user (some 600,000 m^3 $year^{-1}$) followed by the horticultural processing industry and the dairy farms (Figure 60). Some farms growing vegetables with drip irrigation also use groundwater as the dam water delivered by the consortium does not have sufficient quality to be used for drip irrigation.

The wetlands receive water from different sources. The drainage freshwater from the district are pumped by the Consortium from the Sassu drained wetland to the S'Ena Arrubia wetland and from the Luri drained wetland to the Marceddì wetland, while the Corru S'Ittiri wetland is directly fed by freshwater drained by field ditches in the district. S'Ena Arrubia also receive freshwater from a channel collecting water from the original river that was diverted and from a drainage channel collecting water from the NVZ.

The Corru S'Ittiri wetland receive freshwater from the diverted Rio Mogoro and from a surrounding catchment draining water from old mining areas.

The dynamics of the water characteristics of the wetland in terms of salinity, turbidity and nutrient content are influenced by natural (rainfall) and anthropic (irrigation and drainage) dynamics, hence are quite complex to simulate.

Finally, a considerable proportion of the irrigation water supplied by the Consortium is lost as leakage in the channels upstream the pumping stations. This situation generates extra costs to the Consortium and indirectly contributes to the groundwater recharge.

2.4.2.3. Water management strategies

The Consortium has put in place numerous strategies to minimize the leakages and to accurately monitor the actual delivered water for irrigation. Each farmer has a counter and the actual consumption can be accurately monitored. Overall, the actual water consumption figures are consistent with the water requirements of the cropping systems. The situation has improved with respect to some decades ago, when the main irrigation strategy was based on low efficiency surface irrigation systems. The shift to sprinkler irrigation systems, that occurred some three decades ago, reduced the input of freshwater to the wetlands and increased the water salinity, generating a new habitat for aquaculture and a shift from the breeding of eels to the breading of sea fishes like sea bass and sea bream.

At farm scale, irrigation is managed at the moment without precision irrigation systems, as the water price is only partially dependent on actual consumptions.

The dairy factory made a specific choice of using hi quality groundwater collected from deep aquifers fed by the Mount Arci. Occasionally, in very dry years, the deep aquifer also showed high salinity values.

2.4.2.4. Main issues

Several concerns related to water quality were identified, particularly groundwater pollution with nitrates and eutrophication caused by phosphorus in the surrounding wetlands.

Surface water

The Regional Agency for Environmental Protection (ARPAS) has been monitoring the quality of surface water in the Arborea NVZ since 2007. This monitoring involves the assessment of various parameters, including pH, temperature, dissolved oxygen, oxygen saturation, electric conductivity, salinity, phosphorus, Chlorophyll a, turbidity, and microbial and algal growth (ARPAS, 2017). While nitrate concentrations in surface water generally remain below the threshold of 50 mg L^{-1}, the presence of elevated total phosphorus concentrations exceeding 2.0 mg L^{-1} suggests significant eutrophication. This eutrophication primarily stems from phosphorus pollution rather than nitrate concentration, posing a threat to the health of aquatic ecosystems within the NVZ (ARPAS, 2017).

Groundwater

Extensive hydrogeological studies conducted between 2010 and 2015 have revealed significant levels of nitrate pollution in groundwater across the Arborea plain (Ghiglieri et al., 2016). The investigation involved examining over 350 wells that were associated with the SHU and AHU aquifers. In the central region of the Arborea Non-Water Use Zone (NVZ), the piezometric surface suggests a local area of recharge for the SHU aquifer, with water flowing towards the sea. In the southern part of the district, the piezometric contour lines indicate a general flow from east to west, with a gradient that decreases in this direction, indicating an increase in transmissivity. The flow paths suggest lateral recharge from the AHU to the SHU aquifer (Figure 61).

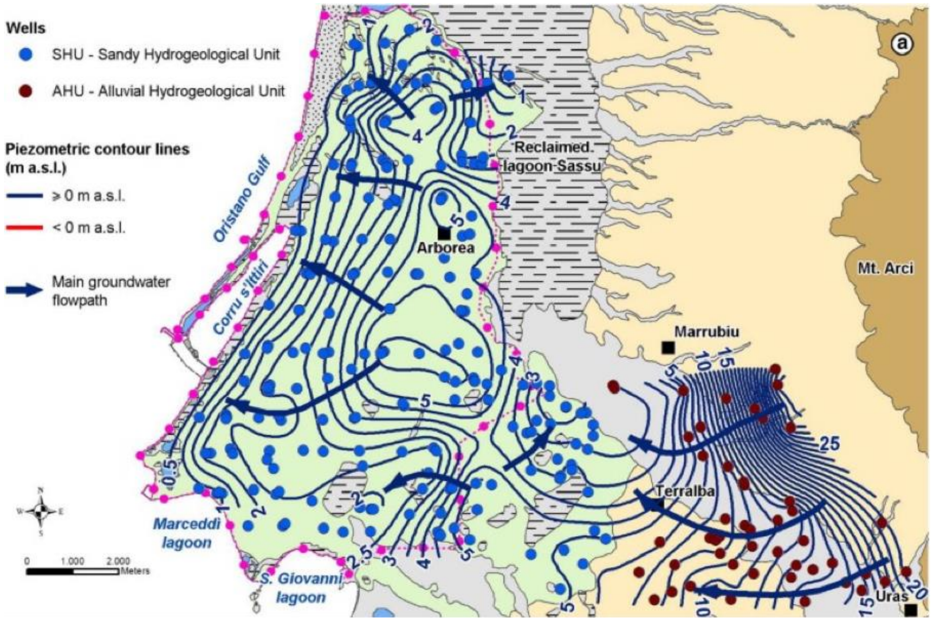

Figure 61 Piezometric contour lines and main groundwater flow directions (SHU) (modified from Ghiglieri et al., 2016).

The nitrate concentration measured on samples taken from 350 wells in the plain ranged between 1.58 and 406 mg L^{-1}. Almost 50% of SHU and AHU waters exceeded the 50 mg L^{-1} threshold value recommended by WHO; the maximum value of 406 mg L^{-1} was observed in SHU samples. In the southern part of the plain, the concentrations were almost uniformly above 50 mg L^{-1}. An increasing trend from east to west in the direction of the main groundwater flow prevailed, highlighting an additional pollution source located outside the Arborea NVZ (Figure 70). Contributions from nitrate sources located within the southern part of the NVZ directly affect SHU. A second highly polluted area was identified in the NE sector of the NVZ. In this area, the recharge of SHU is local, and there is no contribution from AHU outside of the NVZ. Therefore, the high nitrate concentrations were attributed to the local anthropogenic activities.

NRD-UNISS carried out an agronomic study at a field scale in the Arborea area to evaluate the impact of four fertilization systems on nitrate losses in the double-crop system (Demurtas et al 2016). Monthly monitoring of the nitrate concentrations in the soil solution was carried out from June 2009 to May 2012 using 10 cm diameter disk lysimeters. A clear seasonal dynamics of nitrate concentration was observed in the three years, with the maximum occurring in autumn–winter. The main findings of this study showed that: (i) replacing organic with mineral sources of N did not substantially reduce nitrate leaching in the short term; (ii) nitrate leaching is unavoidable in autumn-winter, even without any fertilization for the autumn-spring crop; (iii) nitrate concentrations were still high at the end of the maize crop cycle despite the high N removal of the maize crop; (iv) the lowest nitrate concentration during the leaching period was observed when using only organic fertilizer with high C/N ratio for the ryegrass, but crop yield was halved because of the nitrogen stress observed at the end of the winter.

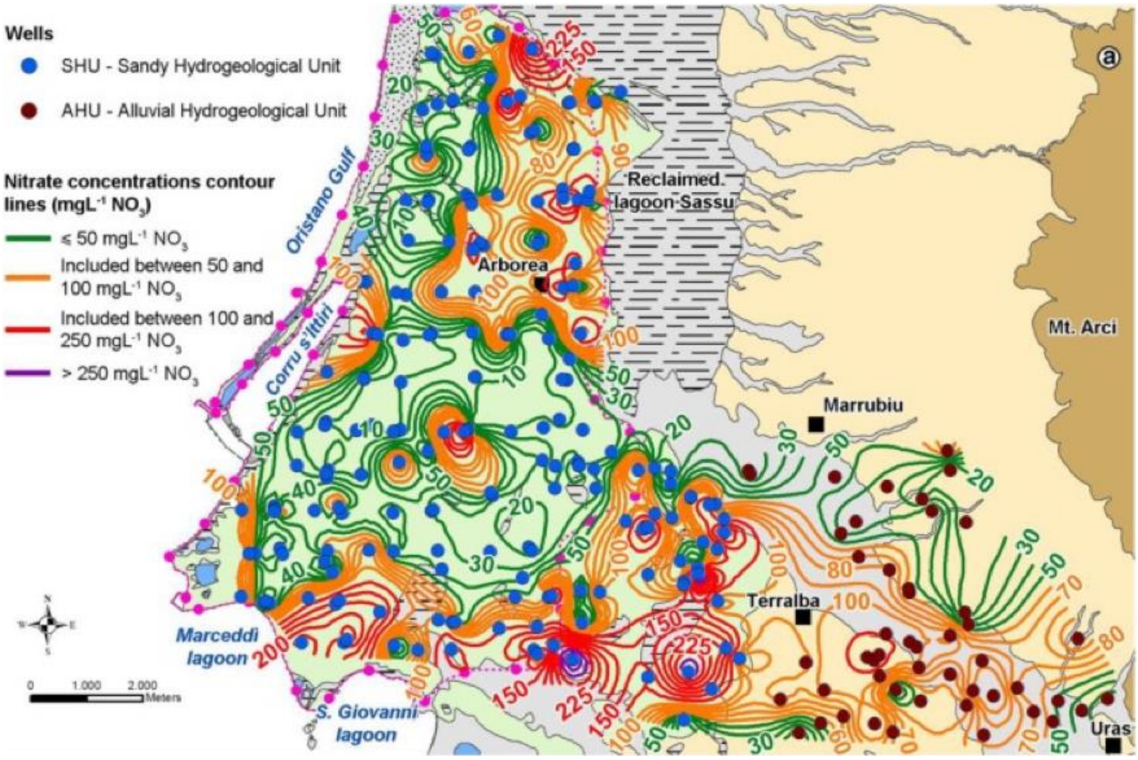

Figure 62 Cumulate distribution function plot for NO3 concentrations in the SHU, AHU; (b) NO3 concentration contour lines (SHU) (modified from Ghiglieri et al., 2016.

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

Since 2007, ARPAS has also carried out the monitoring of the quality of groundwater in the NVZ. The monitoring network consists of 44 sampling points (28 piezometers and 16 wells. The groundwater monitoring has a tri-monthly frequency and since March/April 2007: 46 sampling campaigns have been carried out. From 2007 to 2015 the chemical analysis foreseen by the monitoring plan included an extended suite of parameters (including also heavy metals and organic contaminants) both for the hydrogeochemical characterization of the aquifer and the detection of pollutants in groundwater. Since 2016 the plan has been revised to reduce the number of parameters to be monitored essentially with the aim to highlight the issues related to the high concentrations of nitrogen compounds, due to intensive agro-zootechnical activities, and primarily to control the nitrate content in groundwater. In Figure 63, the average annual nitrate concentrations of the 44 groundwater sampling points under the monitored period (2007-2020) are reported. As indicated by the values in bold, 18 points over 44, distributed in the whole NVZ, showed average nitrate concentrations up to 6 times above the threshold value of 50 mg L^{-1}.

Sample No.	NO_3 mg L^{-1}		Sample No.	NO_3 mg L^{-1}		Sample No.	NO_3 mg L^{-1}	
17PZ008	11,55	*11,78*	P 15	**89,02**	*30,46*	P 33	23,22	*26,91*
P 01	12,88	*7,80*	P 16	43,13	*23,78*	P 34	**53,38**	*32,38*
P 02	**171,51**	*26,79*	P 17	44,09	*15,71*	P 35	**68,51**	*16,49*
P 03	23,76	*26,02*	P 20	**286,70**	*70,92*	P 36	40,04	*18,60*
P 04	**329,81**	*59,81*	P 21	22,01	*31,33*	P 37	5,73	*19,21*
P 05	32,93	*38,13*	P 22	**148,99**	*37,82*	P 38	**141,24**	*46,03*
P 06	**98,45**	*54,44*	P 23	**198,40**	*84,22*	P 39	**56,37**	*38,81*
P 07	30,05	*15,32*	P 24	**57,34**	*32,41*	P 40	**53,73**	*16,24*
P 08	**97,76**	*37,43*	P 26	**226,38**	*26,00*	P 41	32,35	*18,71*
P 09	**83,07**	*69,89*	P 27	**64,33**	*12,57*	P 42	**56,97**	*20,58*
P 10	**125,11**	*23,07*	P 28	**80,38**	*23,61*	P 43	**84,23**	*24,77*
P 11	**115,62**	*37,07*	P 29	2,96	*5,22*	P 45	3,25	*2,58*
P 12	**189,43**	*74,92*	P 30	3,06	*7,81*	P 46	5,54	*1,91*
P 13	**76,25**	*29,89*	P 31	2,50	*2,75*	P 47	14,02	*23,53*
P 14	**181,03**	*44,61*	P 32	1,50	*1,09*			

Figure 63 Mean and SD (italics) values of nitrate concentration in the ARPAS' s groundwater monitoring network of the Arborea NVZ under the monitored period (2007-2020). Source: Arpas.

2.4.3. Water resources governance system

Italian law (D.L.112/2008) establishes that water and the entire water network - from collection to sewage treatment plants - is public. The management can however be entrusted to private or public-private companies. In compliance with Italian law, water management in Sardinia is entirely under the public sector, and water is owned by the Autonomous Region of Sardinia. Sardinia's water governance system is summarized in Figure 64.

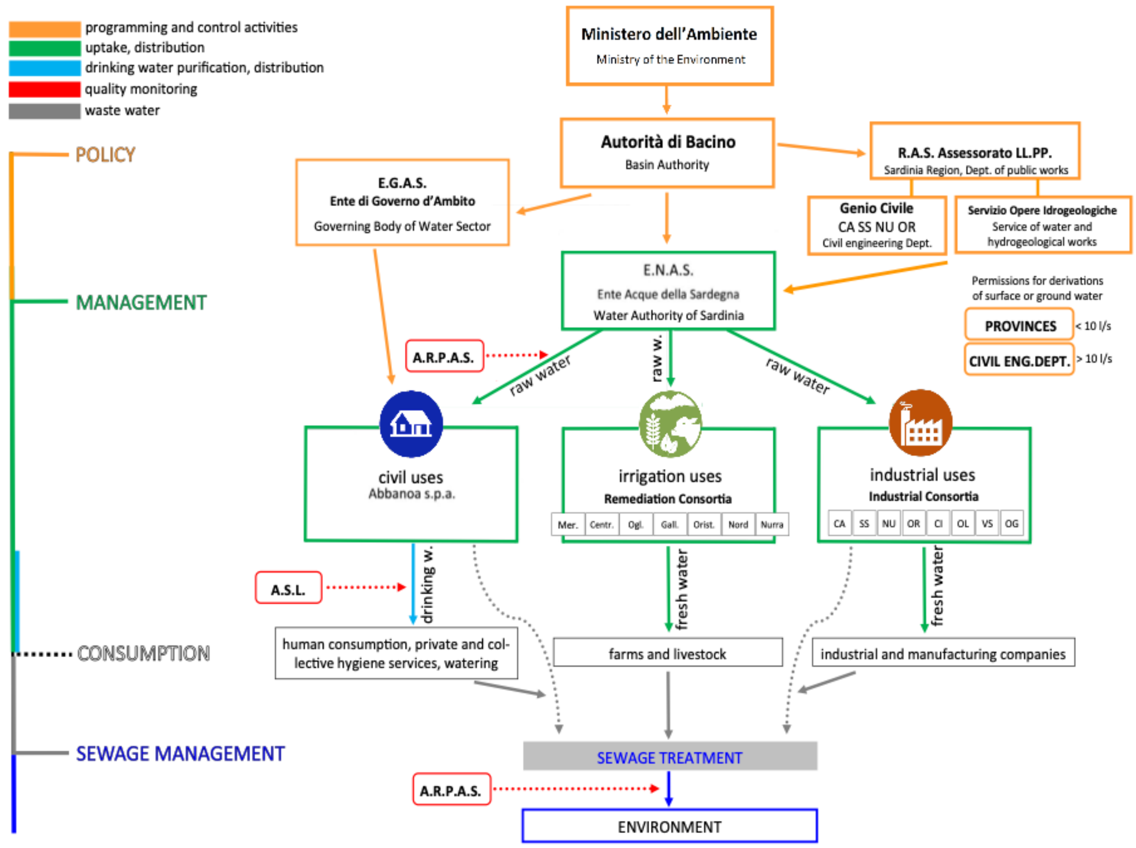

Figure 64 The water governance structure of Sardinia. Source: Maurizi (2020).

In Sardinia, most water used for civil and agricultural purposes comes from reservoirs, with a total potential capacity of 58 dams at 2,790 Mm^3, ranging in capacity from 0.043 to 792 Mm^3. These dams are owned and managed by ENAS (Water Authority of Sardinia), which oversees the extraction and distribution of raw water for various purposes, including civil, irrigation, and industrial uses. ENAS then sells the raw water to Abbanoa S.p.a. (for civil uses), the Remediation Consortia (for irrigation uses), and the Industrial Consortia (for industrial uses), who are responsible for distributing the water to end users.

Regarding the monitoring of water for hygienic, sanitary, and environmental purposes, two regional agencies in Sardinia, ARPAS and ASL, are responsible for overseeing these processes. Lastly, private citizens who wish to use surface water (rivers) or groundwater (wells) for different purposes must obtain a written license from the provincial authority.

2.4.3.1. Water policy and current instruments of water regulation

In adherence to Italian law (D.L.112/2008), water, and the entire water infrastructure spanning from collection to sewage treatment plants, is deemed a public resource. This legal framework finds its roots in the 1989 Water Resources and Soil Conservation Act, which delineates the principles of integrated water resources management and assigns competencies between the central government and regional/local administrations. Irrigation entities (Consortia) are responsible for the management of collective irrigation. In the context of climate change, both the National Strategy for Climate Change

Adaptation and the National Climate Change Adaptation Plan comprehensively address water-related risks across all sectors.

The existing EU legislation imposes a protective framework with standards for all water bodies within member countries, particularly targeting pollution sources. Key directives driving this effort include the Water Framework Directive (WFD) (2000/60/EC), the Nitrates Directive (91/676/EEC) and the Floods Directive (2007/60/EC).

Since 2009, a series of plans and decrees have aimed at managing water quantity effectively. In 2015, the Ministry of Agriculture introduced the Ministerial Decree "Guidelines for the regulation by the regions of the methods for quantification of water volumes for irrigation", which promotes the use of water metering and the application of water pricing instruments based on consumption volumes. Key instruments for managing water use include robust metering, monitoring, and reporting systems that facilitate quantifying irrigation volumes, issuing permits, and setting future usage targets, especially within the agricultural sector. Furthermore, policy instruments such as subsidies, cost recovery mechanisms for water supply, and targeted agricultural advice and research further incentivise water use efficiency.

Concerning water quality, key policy instruments include the Inter-ministerial Decree, stipulating criteria and technical standards for regional regulation of agronomic use of livestock manure and wastewater. Additionally, Action Programs of Vulnerable Areas by Nitrates of Agricultural Origin are established at regional level. These multifaceted policy instruments underscore a comprehensive approach to managing water resources and enhancing water quality in Sardinia.

2.4.4.SWOT analysis of project actions

STRENGHTS:	WEAKNESSES:
Presence of a national legal framework for water governance. The water network is public. Water availability in reservoirs (total potential capacity of 58 big dams is 2,790 Mm3 with dams' capacity ranging from 0.043 to 792 Mm3). Presence of regional agencies responsible for hygienic-sanitary-environmental monitoring. Reasonable stability of funding and operating conditions for public water management actors.	Lack of coordination inside and between water-concerned institutions. High costs for the maintenance and building of infrastructures for water purification, water pumping, etc. Limited awareness about water issues and challenges.
OPPORTUNITIES:	**THREATS:**
Living Labs as an opportunity for generating social learning spaces and promoting sustainable water storage and distribution. Use of renewable energy as an opportunity to reduce energy costs related to water uptake and distribution.	Water pollution from diffuse sources due to concentration of intensive farming systems. Climate change. Increased cost of energy.

Existence of national and international initiatives for promoting sustainable water storage and distribution.	

2.5. Case study Mujib

The Mujib River Basin (MRB) 31°16'53.76" N, 36° 4'18.54" E (center point), is a unique geographical feature that encompasses 6,600 sq km characterized by smooth rolling hills, steep slopes, and talus sediments produced by landslides nestled in the middle of Jordan. MRB represents semi-arid to arid plateau land, forming 91% of the total area and 7% of the Kingdom's territory.

Administratively, the MRB is a vibrant area, with high to moderate population density, extending across five governorates. The most significant expansion is in Amman, with an area of (2338.7 km^2), then in Karak (2132.7 km^2), Ma'an (1712.8 km^2), Madaba (399.4 km^2), and Tafila (10.6 km^2).

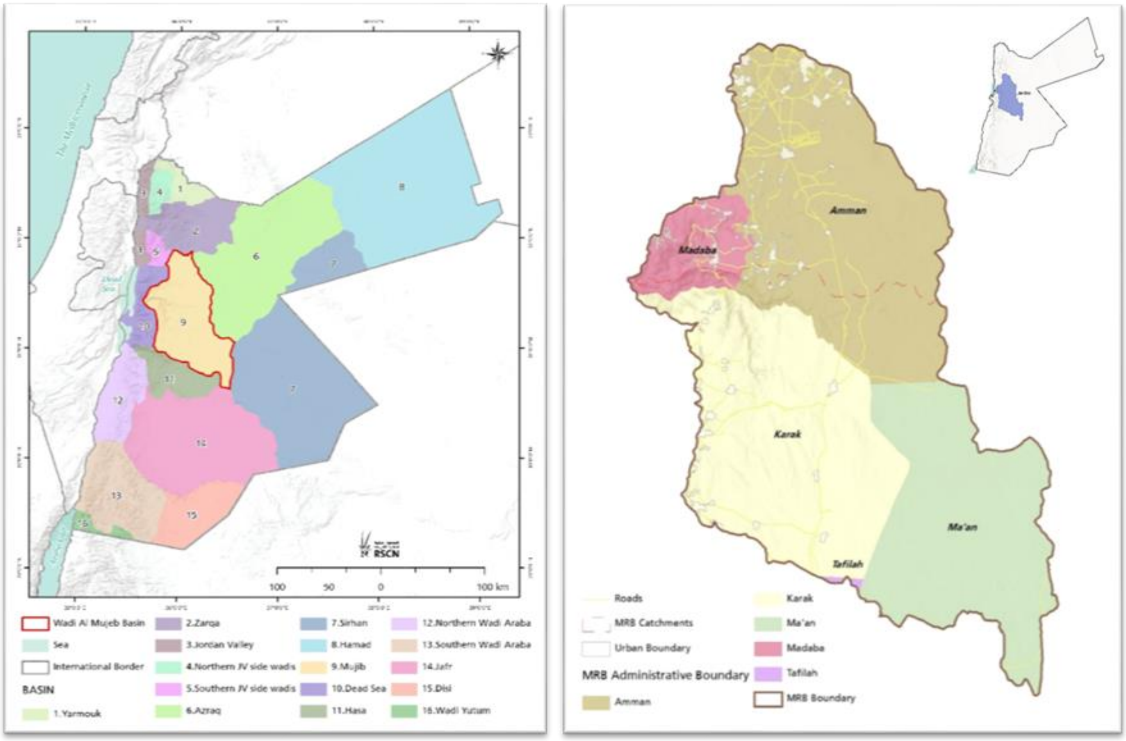

Figure 65 Jordan Surface Basin (Data source: MWI, 2024), The administrative divisions of the Mujib River Basin.

2.5.1. Biophysical attributes

MRB is One of Jordan's sixteen watersheds, which merges between the eastern portion of Jordan's highlands with an altitude starting from 1300 m above sea level and the Jordan Valley (central zone) morphology with an altitude ending at -420 below sea level. The Mujib Basin drains to the Jordan Rift, which flows westward and discharges directly into the Dead Sea. It consists of two significant catchments: The W. Mujib (453,7 km^2) and W. Wala (205,6 km^2). Both catchments have main tributaries, Mujib and Al-Haidan, which merge 3 km in the confluence point locally known as (Malaqi in Arabic = meeting point) before the final discharge into the Dead Sea.

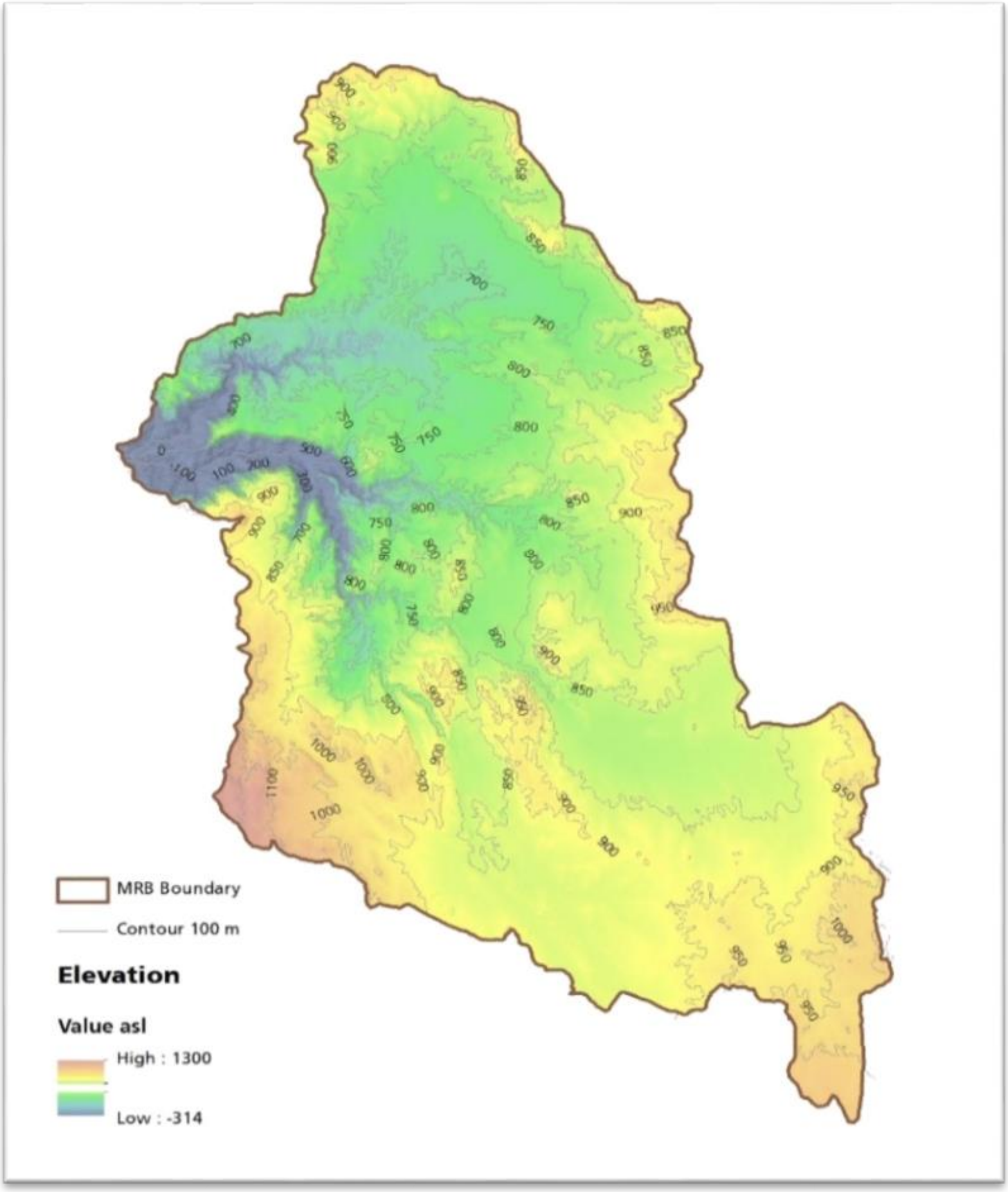

Figure 66 Elevation of the Mujib River Basin (Data source: ALOS Digital Elevation Model 12.5 m).

2.5.1.1. Climate

The Mujib Basin boasts a diverse climate, predominantly Mediterranean type, with its unique character. It is a land of contrasts, with scorching hot, dry summers and cool to cold, wet winters. The data from the Jordan Meteorological Department reveals a wide range of mean annual rainfall, from less than 50 mm in the southeastern part of the flat area of Ma'an to 350 mm in the northwestern part in the mountains of Karak. The average temperature varies significantly, ranging between (28-32) °C in the summer and (2-5) °C in the winter. The prevailing wind direction adds another layer of complexity, mainly west and northwestern in the summer and southwestern in the winter, with speeds ranging from 2 to 28 km/h.

MRB has six rainfall stations and three climate stations affiliated with the Meteorological Department of Jordan. The three climate stations measure the daily maximum and minimum temperatures, rainfall amounts, evaporation, wind speed, and direction.

Table 5 Locations of climate and rain stations (Data Source: MWI, 2024).

NO.	Station ID	Station Name	Governorate	Station Type	Elevation
1	CD0006	WADI WALA EVAP.ST	Madaba	Climatic Station	500
2	CD0010	RABBA EVAP.ST	Karak	Climatic Station	949
3	CD0020	SIWAQA EVAP ST.	Amman	Climatic Station	750
4	CC0004	MUSHAQQAR EVAP. ST	Amman	Climatic Station	770
5	CD0003	EL-MUWAQQAR	Amman	Rainfall Station	900
6	CD0016	JUDAYDA	Madaba	Rainfall Station	750
7	CD0001	SAHAB	Amman	Rainfall Station	864
8	CD0007	DHIBAN	Madaba	Rainfall Station	700
9	CD0011	QATRANA	Karak	Rainfall Station	800
10	CD0023	QASR EVAP. ST	Karak	Rainfall Station	900

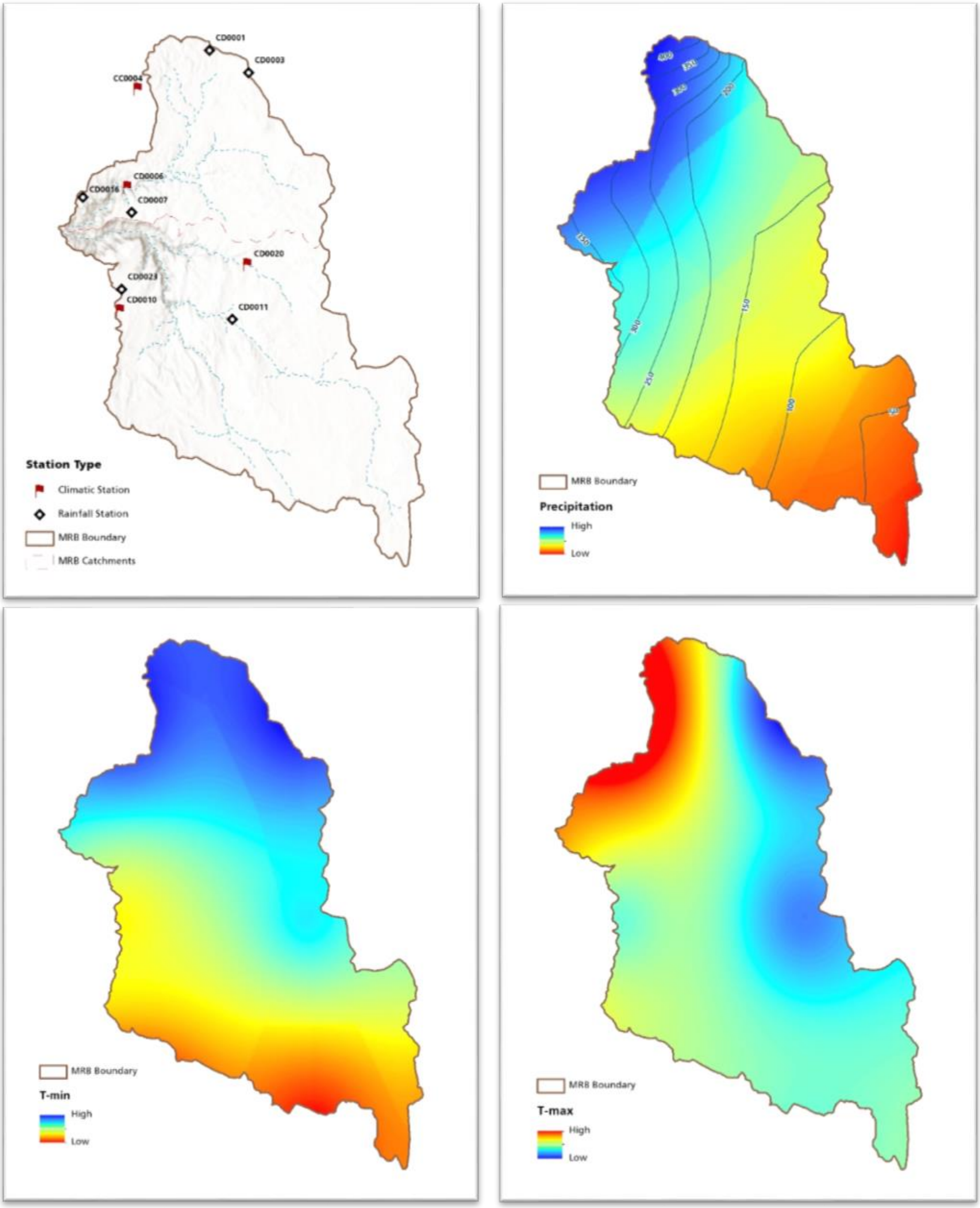

Figure 67 Locations of climate and rain stations in the MRB, precipitation, maximum temperatures, minimum temperatures (Data Source: CRU TS v4.07 2022).

Current climate changes have contributed to changing rainfall patterns, with annual rainfall rates varying between parts of the basin from the northern to southern sides, recording the highest at Al-Wala station, at 441 mm, and decreasing to reach 167 mm at the Qatrana station. The dams of the basin (Mujib and Al-Wala) are also exposed to the risks of recurrent floods associated with sudden, short-term heavy rain storms, including the storms that occurred during the periods (2018-2021). These floods have led to significant damage in different areas of the basin. Due to these floods, the Mujib and Al-Wala Dams reached a storage capacity estimated at 29 MCM and 1.8 MCM, respectively.

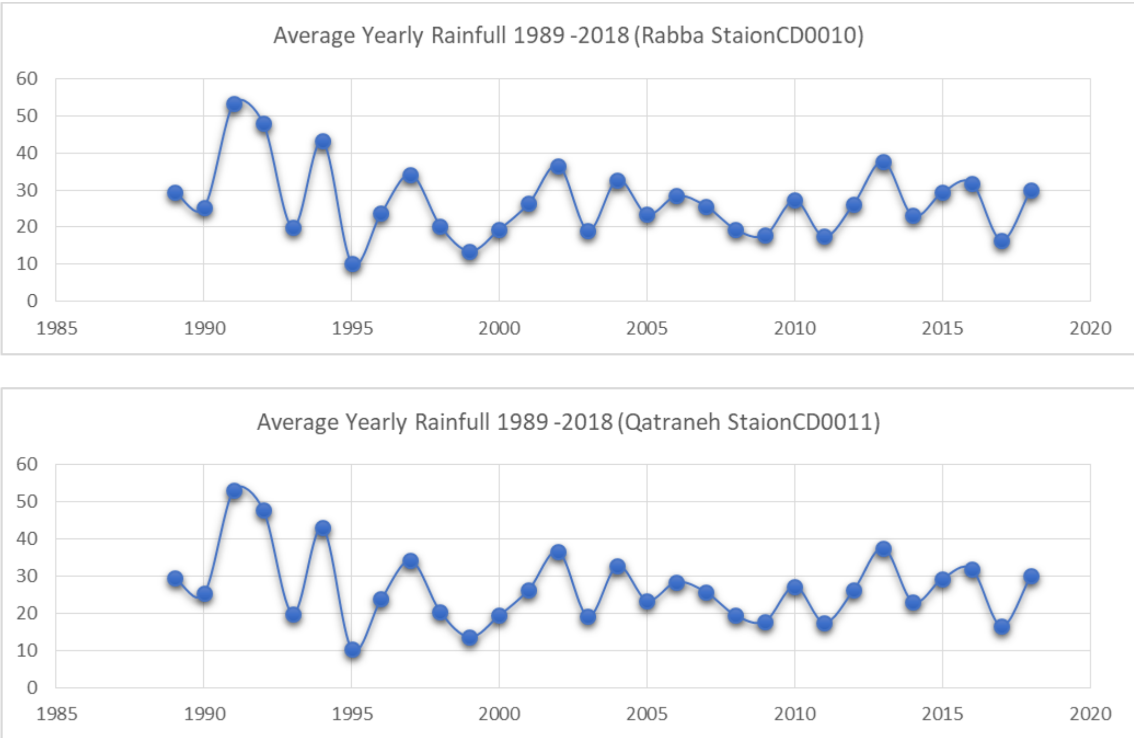

Figure 68 Average anual rainfall records at Rabba and Qatraneh stations for the period 1989-2018.

2.5.1.2. Hydrological/hydrogeological context

Surface water resources form about 37% of the total water supply from 16 basins (Al-Ansari et al., 2014). Figure 69 represented the surface basin in Jordan. The Mujib Basin has a surface area of around 6,600 km^2 and is divided into two hydro-graphic pathways; the lower part of the Mujib subbasin, 4,537 km^2, is the largest drainage system, including the Mujib River, and the upper part of Wala subbasin, (Haidan basin) 2,056 km^2 including Haidan River.

The two rivers meet at the local confluence point before draining into the Dead Sea. The Wadi al-Mujib catchment region is located at a height of 700-900 meters above sea level, with a peak of 1100 meters in the Karak and Mazar localities (El-Naqa, 1993), the dam's maximum storage capacity is about 31.2 MCM (El-Radaideh et al., 2017).

The precipitation range in the catchment area varies from 350 mm/year up mountains down to 100 mm/ year in the Dead Sea area. However, the potential evaporation is 2450 mm/year in the Dead Sea area to 3500 mm/year in the catchment's eastern sections (Salameh & Bannayan, 1995).

The two Wadi spring discharges maintain the basin's 35 Mm^3 average annual base flow, representing the springs and well distribution in the study area. The Wadi Haidan lower reaches, which drain base flow, have a yearly groundwater runoff of 20 Mm^3. Intense storms that occur throughout the rainy season, which lasts from late October to early May, produce flood water. Estimated total flood flows are 65 Mm^3/year. A few days after a rainstorm, floods hit the Dead Sea, and most Wadi dry up (Abu-Allaban et al., 2014).

Based on the various hydrogeological investigations carried out, the following are the major aquifer systems in Jordan: (i) The Upper Aquifer (shallow) System, of the Quaternary – Tertiary age. The aquifers of this system are dominated by carbonate rocks (B4/B5 Formation of the Balqa Group) in addition to alluvial deposits and the basalt Aquifers; (ii) The Middle Aquifer System dominated by Carbonate Rocks aquifers (led by the Amman-Wadi Es Sir Formation "B2/A7" aquifer), and (iii) The Lower Aquifer System, of the Palaeozoic-Early Cretaceous age with Sandy Facies, dominated by the Kurnub and Rum aquifers.

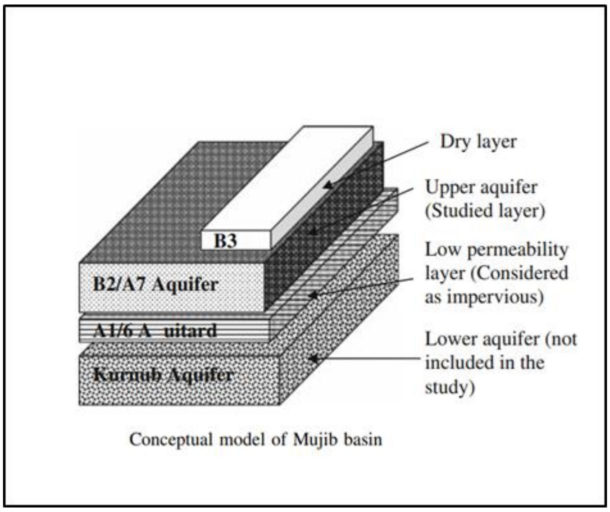

Figure 69 Conceptual model of the Mujib basin.

Going micro-scale to the study area, the three major aquifer systems of Jordan are exposed within the "MRB" area. The A1-6 Aquifer is outcropping in the western corner of the basin, while the Kurnub Sandstone exists in the western corner of the basin, and the B4 aquifer outcrops within limited areas at the eastern and northeastern corners of the Basin.

The Amman /Wadi Esir (B2/A7) aquifer dominated in the study area and extends mainly all over the western section of the Mujib basin. The (B2/A7) is formed of karstified, silicified limestone with horizons of phosphate. It is characterized by high permeability, storage capacity, and annual recharge with a wide geographic distribution, including dense population areas.

The B2/A7 aquifer is characterized by karstification, which results in the enlargement of joints and fissures. The thickness of the B2/A7 unit may reach up to more than 300 m within the central and northern parts of Jordan. Within the Mujib Basin, the B2/A7 aquifer is highly exploited by wells ranging in depth from 50 m to more than 600 m.

Wadi MRB consists of four aquifer systems: B2A7, A4, A2, and Kurnub. The B2A7 aquifer is a uniform unit widespread throughout the Basin with a 100 to 300m thickness. The Amman Wadi Es-Sir B2A7 Aquifer System is the study area's upper and most important aquifer.

Annual groundwater pumping from this basin was about 79.41 MCM in 2022, with a recharge rate of 39.1 MCM/year (MWI, 2022). Groundwater development in the Dead Sea Basin began in the early 70s to cover local water needs. This development expanded to transboundary water pumping in the 90s, with more than 150 wells drilled in the upper cretaceous limestone aquifer known locally as B2A7 (Salameh, 1996). Over-exploitation of the B2A7 aquifer system has resulted in a rapid plunge of the water table to more than 3.5 m in some areas, which affects wells ‘productivity, spring discharge, and related ecosystem services (USGS, 2013).

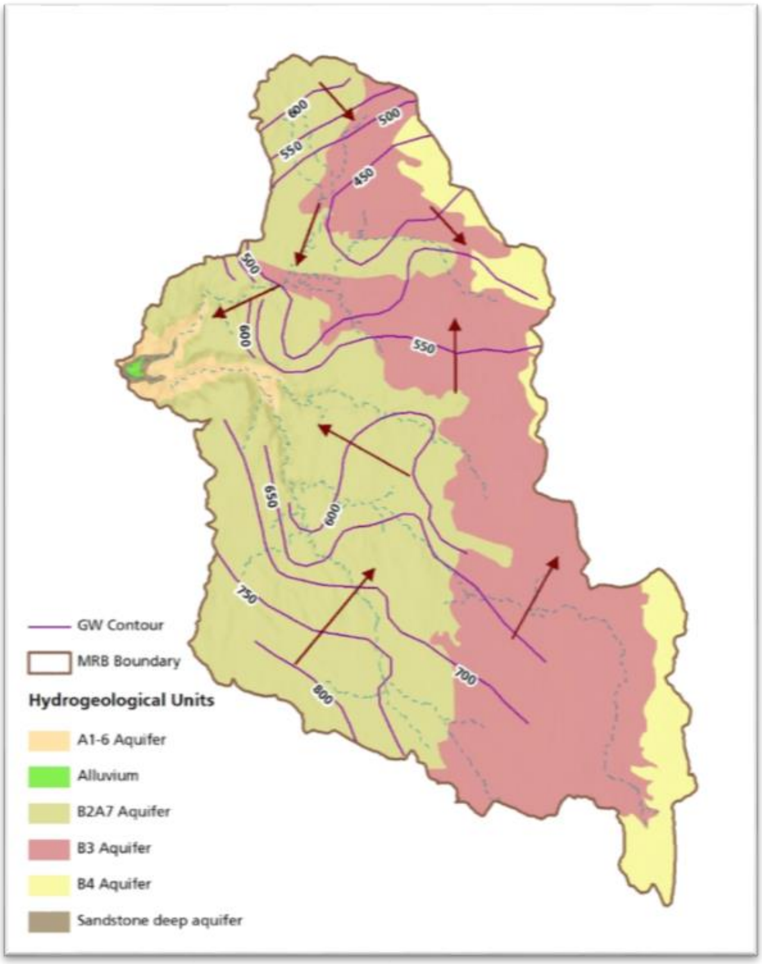

Figure 70 The Hydrogeological Formation of the MRB.

2.5.1.3. Ecological and ecosystmes context and footprint

The MRB derives its ecological importance from the presence of four biogeographic zones and six vegetation covers (Figure 70, Figure 71). This difference makes the region diverse in ecosystem services, especially the area around the water vegetation, which represents 2.6% of the MRB total vegetation type.

The Mujib Biosphere Reserve has been given special ecological importance in the MRB because it represents its central biodiversity area, especially associated with the aquatic ecosystem. Most of the natural flow is located within and surrounds the reserve areas.

The Mujib Biosphere Reserve (NBR) formation resulted from water runoff during geological times. This harmonious natural pattern made the place an unparalleled natural icon at the local and regional levels and made it one of the most important national natural and heritage sites that represents a unique geological diversity. Freshwater flow into the valleys also resulted in significant biodiversity, including important plants and animals, endangered animal species, such as a group of endemic plants, threatened mammals, and rare fish

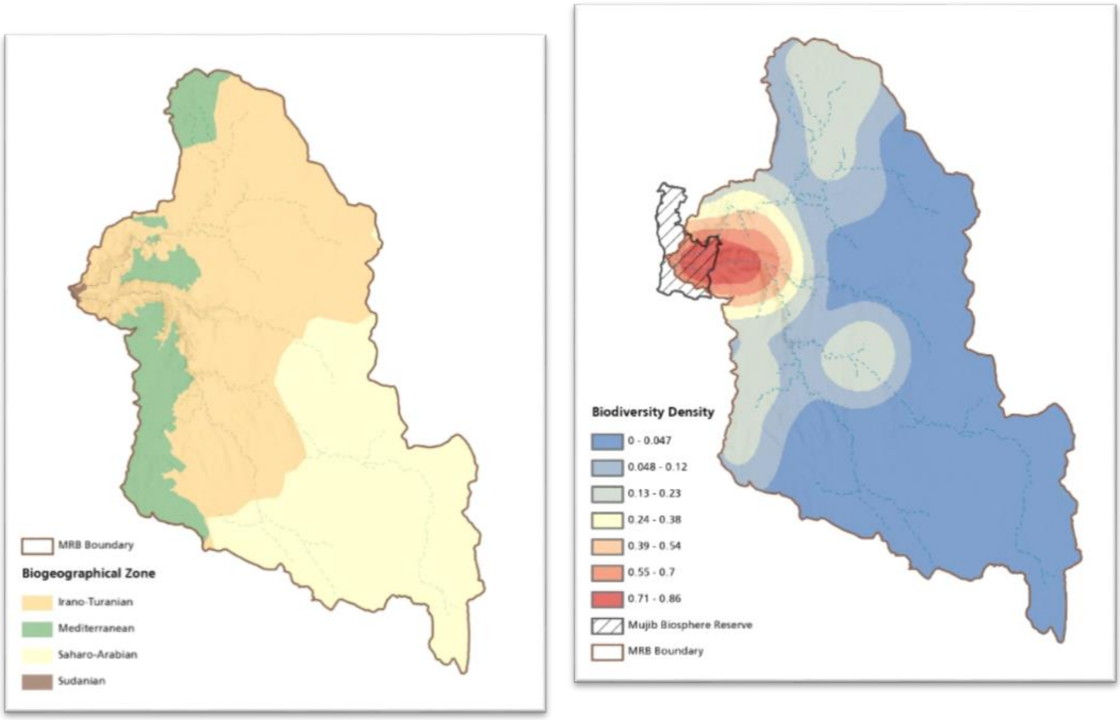

Figure 71 Biogeographical Zone (Data Source: Taifour, et al.,2022), Biodiversity Density of MRB (Data Source: RSCN, 2024).

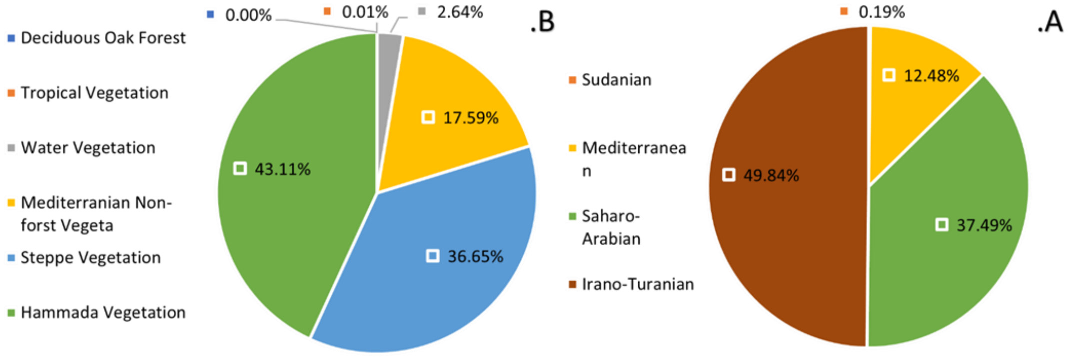

Figure 72. A. Biogeographical Zone (Data Source: Taifour, et al.,2022), B. MRB Vegetation Cover (Data Source: Dr. Daoud Al Essawi, 2017).

2.5.1.4. Soil and Land use

The Wadi Mujib geological history spans more than 500 million years, from the Late Cambrian 500 million years to the Recent (Holocene) periods; the elevation difference between its peak and bottom might be over 1000 meters. Wadi Mujib protects and exposes the majority of Jordan's geological heritage (Abed, 2017).

The bulk of the MRB soil is loamy in texture, ranging from clay loams in the north to sandy loams in the south. In the south, there are gravelly and stony sandy loams. Soil with a limited adequate field capacity is common in the basin and can speed up pollutant transport to the reservoir.

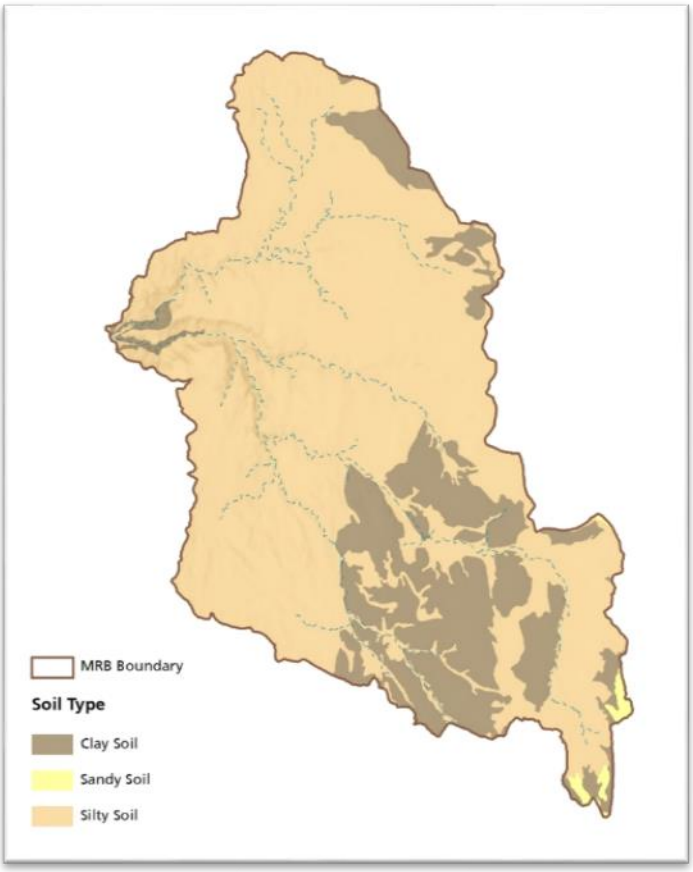

Figure 73 Soil Type (Data Source: Alnawaiseh, Samer and Alzghoul, Maysoon (2022)).

The catchment's land cover is primarily barren, 53% of which is predominant in the southern portion, while agricultural fields cover the northern and western catchments 14.3 % (El-Radaideh et al., 2017). In the catchment, coarse-textured soils are common, which might speed up pollutant transport to reservoirs.

MRB has primary land uses that are recognized as the following: Bare soil, basalt, and barren lands, Agricultural use, Tourist use, Residential use, Industrial use, Rangeland uses, and Major, moderate, and small-size water collection structures. Moreover, the "MRB" hosts the lowest-altitude natural reserve in the world, known as Mujib Reserve, at 420 m.b.s.l. located in the western parts of the basin.

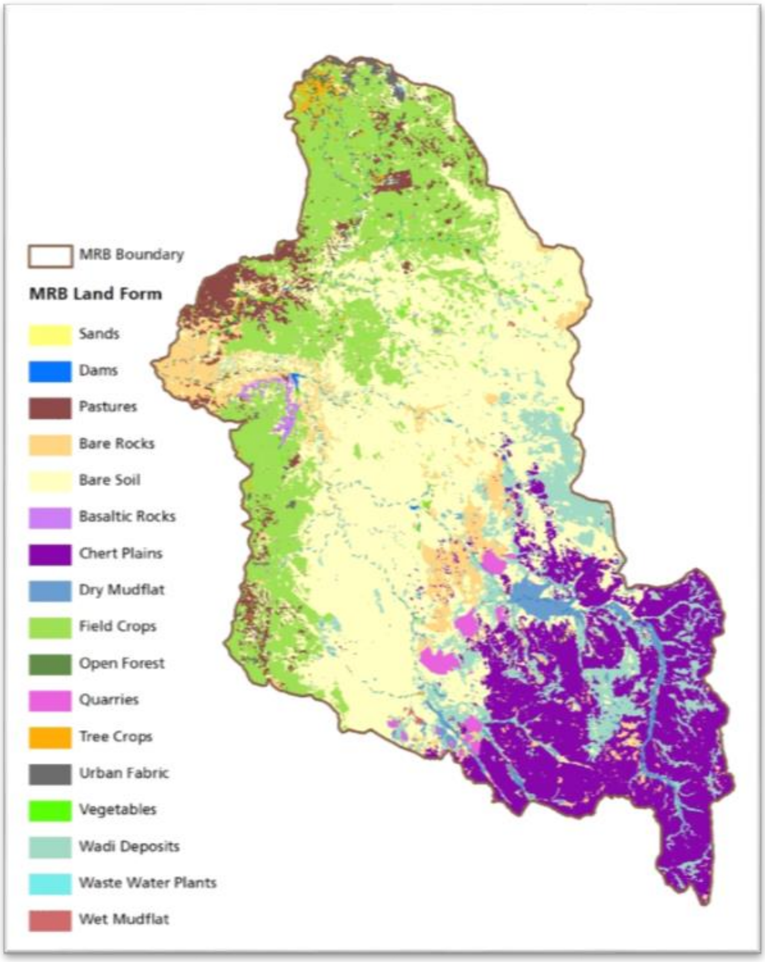

Figure 74 Landform of MRB (Data Source: The National Agricultural Research Center (NARC), 2021).

Mining in MRB represents one of the main land use forms in the northern regions, and it takes place in various localities and forms. Including Phosphate Mining, Uranium Mining, Oil Shale Mining, Gypsum Mining, and Limestone Mining. On the other hand, mining is a substantial economic activity in MRB with a high value for local employment and income and a large contribution to the national economy. Because of this, addressing mining in the context of MRB poses a serious obstacle to developing and implementing an integrated water basin planning and management strategy based on the concepts of ecosystem management and integrated river basin methods.

Agricultural activities in the MRB are divided into field crops, irrigated vegetables, forests, rangelands, and irrigated and rain-fed mixed trees. According to the Department of Statistics 2017, the area of irrigated crops is 411 sq km, concentrated in the northern and eastern regions of the MRB, while the area of rain-fed crops is 229 sq km in the western part of the region.

Table 6 Types and areas of the agricultural lands in the Mujib River Basin (DOS, 2017).

Agricultural Type	Rainfed	Irrigated
Fruit trees	34043.4	58805.6
Covered vegetables	0	3559.6
Uncovered vegetables	651	23388.7
Field crops	274015.8	9963.4
Total Area (Dunam)	411310.2	228924.4

2.5.1.5. Water resources infrasturctures

Sustainable water sources in the MRB are derived from two primary resources: surface water and groundwater. The Dead Sea groundwater basin is one of twelve vital sources of groundwater basins in Jordan, supplying about 8% of the total supply. Annual groundwater pumping from this basin was about 79.41 MCM in 2022, with a recharge rate of 39.1 MCM/year (MWI, 2022). The number of private and governmental legal operating wells until 2020 was 428; many illegally operated wells were uncovered and backfilled yearly. Population inflation and increased demand for water have exceeded the MRB safe yield. This has led to a significant decline in the water table within major aquifers. The rate of decrease is alarmingly rapid and in severely affected areas.

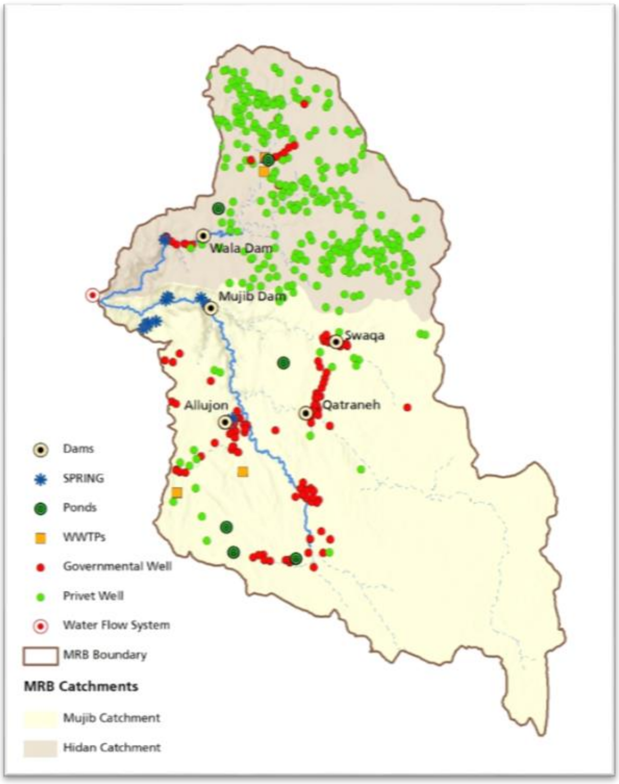

Figure 75 Water Resources Infrastructures, the Hydrogeological Formation of the MRB.

Table 7 Locations of Main Dams in the MRB (Data Source: MWI, 2024).

MRB Dam Name	Wala Dam	Mujib Dam	Allujon Dam
Capacity MCM	8.18	30	1
Location	Madaba Governorate	Madaba Governorate	Karak Governorate
Year of Construction	1999	1999	2014
Start of Service	2002	2003	2018
Type	rolled concrete dam with abutments of clay-core rockfill	rolled concrete dam with abutments of clay-core rockfill	rolled concrete dam with abutments of clay-core rockfill
Uses	Irrigation and underground recharge	Drinking, industry, and irrigation	Irrigation and underground recharge
Storage End of 2020 MCM	5.52	7.74	0.13

MRB's total rainfall volume is estimated to be about 620.63 MCM (million cubic meters) of precipitation. More than 91% of the rainfall goes for evaporation. Surface water resources in the MRB consist mainly of dams, Ponds, excavations, and springs. There are Three dams; the Mujib Dam is considered the largest dam among the dams on the MRB. The Mujib, Wala, and Allujon dams were built to offer a more consistent and long-term sustainable water supply to charge the aquifer for drinking and agricultural uses.

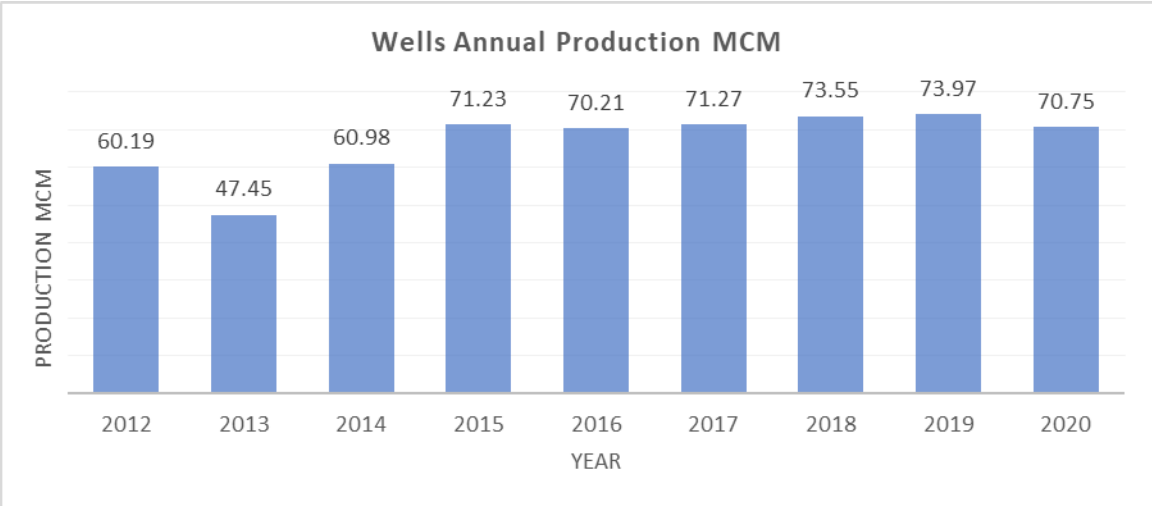

Figure 76 Wells annual production in the Mujib river basin.

There are also 14 springs in the Wadi Mujib area with a discharge amount of around 3.99 m^3/h, 5 bonds with 156,08 design capacity, and 50 excavations with 152,220 design capacity.

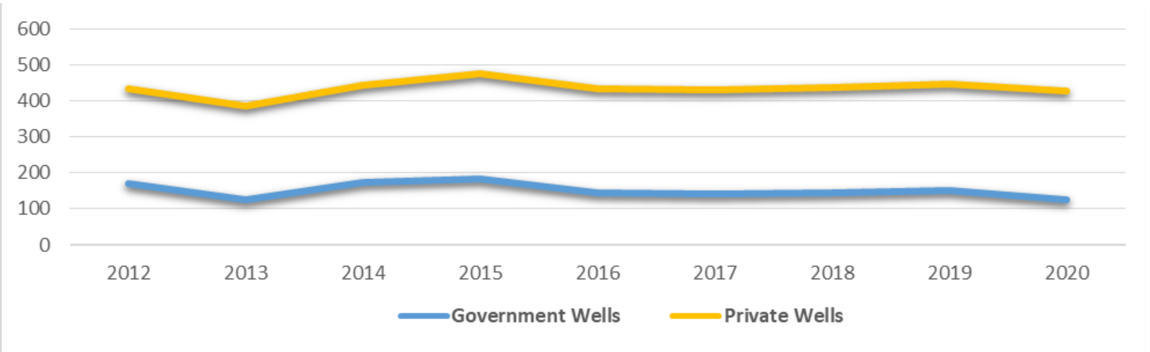

Figure 77 Number of wells in the Mujib river basin for the period 2013-2019.

2.5.2. Water development and management

Jordan was one of the world's first countries to take action to achieve the Sustainable Development Goals. One of the goals, Goal 6, is to “Ensure availability and sustainable management of water for all” (Al-Omari, 2020). Therefore, the Integrated River Basin Management (IRBM) application was directed to solve this widespread water management problem, at least in approach, by creating an institutional framework around the basin or watershed rather than political or administrative units such as countries (Moore, 2021).

At present, Jordan faces a constant challenge due to water scarcity. To address this problem, the country has developed a strong policy framework that includes various tools for water regulation. The MRB is an essential component of this policy framework and is managed mainly by the institutions included. Here's a breakdown of key aspects:

Legal Framework:

- Three main laws form the foundation:
  - Water Authority of Jordan (WAJ) Law (1988): Establishes the WAJ, an autonomous body responsible for water management.
  - Jordan Valley Authority (JVA) Law (2001): Defines the JVA's role in water management within the Jordan Valley.
  - Ministry of Water and Irrigation (MWI) Law (1992): Outlines the MWI's water management policy and planning responsibilities.

National Water Strategy (2016-2025):

This strategy emphasizes several key points:

- Efficient water uses and reuse across all sectors (domestic, agriculture, industry)
- Shared responsibility between citizens, public and private sectors for water management and protection
- Improved data collection and knowledge on water availability, quality, and protection for informed decision-making
- Exploring new water resources like desalination while considering costs

Instruments of Water Regulation:

- Demand Management:
  - The Water Demand Management Unit (WDMU) promotes water-saving practices across sectors.
  - Building codes mandate water-efficient plumbing fixtures in new constructions.
- Supply Management:
  - Desalination plants are a major strategy to increase water availability.
  - Regulations on groundwater extraction to prevent over-pumping.

During the last decade, there has been immense interest in Jordan to follow an IWRM approach in developing water strategies and policies. This is evident in the formulation of national water strategies and implementation action plans and the enactment of numerous regulations in support of IWRM policies. However, a significant gap remains with respect to the ability of present institutional frameworks to implement IWRM effectively. This is fundamentally because the existing water resources management culture and its associated institutional arrangements, legislation, and instruments- which take a sector-based approach - are inadequate to achieve an integrated and participatory IWRM that is multi-sectoral oriented by its nature. Governance systems for IWRM thus require integrated approaches to social, economic, and environmental policy planning, natural resource preservation, as well as appropriate modalities for public participation.

2.5.2.1. Water supply, water storage and distribution

The water supply of the Mujib basin participates in covering water demands for different practiced human activities within the geographical boundaries of the basin or going on in other parts, especially at the Capital, Amman, and Karak and Madaba governorates.

The surface water supplies include different types of dams, excavations and ponds. The collected water at the said dams is used to cover part of the domestic water demands for the capital Amman and Karak Governorate while the other collected water is used to cover part of irrigation demands in Karak and Madaba.

Moreover, the groundwater supplies include governmental wells and private wells, in addition to the water springs used to cover part of the domestic water demands for the capital, Amman, and the Karak and Madaba governorates. The spring water is used to cover part of the domestic water demands and participate in covering part of the irrigation demands for the agricultural lands located downstream of such springs.

The major components of the Mujib River Basin water budget are as follows:

a) Abstraction from The Governmental Groundwater Wells: In the year 2017 the total annual abstraction rate from the said wellfields was 33 MCM, where about 36% of the abstracted volume came from the Hidan/Wala wellfields.

b) Abstraction from The Private Groundwater Wells: The Mujib Basin in the year 2017 hosts 331 private groundwater wells. The abstracted water from the said wells covers different water demand sectors and includes the agricultural sector, The industrial sector, the Commercial sector, including the wells used for selling water for drinking and non-drinking purposes, and the domestic sector (drinking purposes). The annual groundwater abstraction from the private wells for the year 2017/2018 was about 37.96 MCM, whereas the abstraction by the agricultural sector for irrigation purposes presented about 81.4% for the above-mentioned annual groundwater abstraction.

Surface Water Supply from The Dams: Under this category, the Mujib dam provides about 20 MCM in average of raw water for the Zara-Ma'een desalination plant, which provides fresh water for Amman and other areas. Water Supply from The Springs: Within the MRB, the base flow is sustained by local springs on the escarpment to the Dead Sea with an annual volume of 20MCM-35MCM. The said value can be attributed to the wet years. About 5% of the said base flow quantity is used to cover the domestic water demands through springs such as Ein Sarah Spring and Al-Shababaiah Spring.

2.5.2.2. Water uses

Drinking and domestic use account for 52% of water in the MRB. Groundwater resources cover the largest part of this use, while surface water is divided into drinking, agriculture, industry, and groundwater charging. The amount of surface water used in the potash industry is estimated at 3.6 MCM/year.

Table 8 Quantities and uses of groundwater extracted from the MRB (MWI, 2022).

Water Use	Number of Wells	Production (MCM)
Government irrigation	17	4.85
tourism	9	0.34
Private irrigation	307	36.31
Industrial	54	8.11
Poor areas and livestock	14	0.65
Government Municipality	127	45.55
Private municipality	18	1.61
Total Use	546	97.41

2.5.2.3. Water manageent strategies

The government has developed several policies, strategies, and plans to enhance water resource development, management, and use. This national strategy produces a time-based action plan that directs government, agencies, and donors to achieve sustainable water solutions. Jordan's "Water for Life" strategy 2008–2022 highlights the future challenges to be addressed through proper policies and regulations and focuses on proposed solutions such as Water Harvesting, Brackish Water and Desalination, and Rational Water Use.

According to the ministry statement, the Ministry of Water and Irrigation has announced that the recently approved 2023-2040 National Water Strategy reflects the government's plan and objectives in the water sector. The current national strategy was developed with the aim of achieving long-term water solutions that address the challenges facing Jordan in this sector by using water technology, identifying and addressing the issue of wasted water, taking the necessary measures to treat and reuse water in agriculture and industry, and confronting the impact of climate change in the water sector.

Table 9 The Elements of the hydrological water budget for the Mujib Surface Basin 2022 (MWI, 2022).

MRB	Amount (MCM)	Percentage
Rain	620.63	94.22
Runoff	11.17	1.8
Evaporation	570.36	91.9
Recharge	39.10	6.3

2.5.2.4. Main issues

The MRB faces several challenges, especially considering its importance to Jordan's water resources. Here are some of the main issues:

- Water scarcity: This is a national challenge for Jordan, and the Mujib basin is no exception. Increased water demands and climate change put pressure on the basin's limited water resources.
- Overuse of groundwater: Groundwater pumping is essential for agriculture and other uses in the basin, but overuse can lead to depletion of aquifers and saltwater intrusion.
- Pollution: Activities like agriculture and industrial development can pollute the basin's water, harming water quality and ecosystems.
- Soil erosion: The dramatic elevation changes and limited vegetation cover make the basin susceptible to soil erosion, reducing water quality and agricultural productivity.
- Balancing development and conservation: The Mujib Biosphere Reserve is a valuable ecological area, but development pressures like tourism and infrastructure projects can threaten its natural habitats.

These issues are interrelated. For instance, overuse of groundwater can contribute to soil erosion, and pollution can worsen water scarcity. Finding sustainable solutions requires a holistic approach that addresses all these challenges.

2.5.3. Water resources governance system

Government institutions, agencies, local authorities, the private sector, civil society organizations, and partnerships all constitute an institutional framework for implementing policy and legal provisions.

The government of Jordan's policy is to protect and conserve Jordan’s limited water resources and ensure sustainable development. This policy has been integrated into almost all governmental plans and programs. The Ministry of Water and Irrigation (MWI) with its operational hands, the Water Authority of Jordan (WAJ), and the Jordan Valley Authority (JVA) are the owners of the Water sector in Jordan with the support of other governmental agencies that hold substantial involvement, such as the Ministry of Health

(MoH), The Ministry of Environment (MoEnv) and the Ministry of Agriculture (MOA). Moreover, other governmental agencies, such as the Ministry of Municipal Affairs and the Ministry of Interior, indirectly participate in conserving and protecting the water resources in Jordan. Each of these institutions has articles in their respective laws granting them the responsibility to maintain and monitor some aspects of environmental quality.

The Ministry of "MWI" is responsible for enforcing the relevant legislations (laws, regulations, and guidelines) related to protecting, conserving, and managing the water resources and the other elements of the environment that have direct and indirect impacts on the water resources (quantity & Quality wise). In addition to "WAJ," the water utilities operators (Meyahona in the Center and Yarmouk Water Company in the North, and Aqaba Water Company for the Aqaba region) participate in operating and managing the water supply systems (each in his responsibility areas).

Non-governmental organizations (NGOs) play an important role in Jordan's environmental management infrastructure. Their programs often complement the government's work and fill gaps in areas where the government is less active. NGOs sometimes advocate the conservation of resources and protection of the environment in cases where the government's focus on providing services fails to protect the resource base.

On the other hand, some governmental agencies provide in-kind contributions to protect and conserve Jordan's water resources by closely monitoring the implementation of its relevant laws. The best examples are the Ministry of Interior (MoI) and Municipal Affairs (MoMA) (Water Resources at the MRB report, RSCN 2019).

2.5.3.1. Water policy and current instrumnets of water regulation

Regarding water governance, the Ministry of Water and Irrigation (MWI) is responsible for the overall Policies, strategic direction, and planning; the MWI works with the Water Authority of Jordan (WAJ) and the Jordan Valley Authority (JVA).

Considering the ongoing water challenges, A National Water Strategy has been created to manage the water sector and to ensure optimal service levels. The National Water Strategy (2016–2025) is part of the MWI's plan, which explores the need for more development of water legislation, including the need for a comprehensive water law and moving toward realizing humans' rights to water and sanitation while recognizing these rights and their standard content for all. The strategy's key areas are as follows: (i) Integrated Water Resources Management (IWRM); (ii) water, sewage, and sanitation services; (iii) water for irrigation, energy, and other uses; (iv) institutional reform; and (v) sector information management and monitoring. The strategy also addresses the issues related to climate change adaptation, transboundary/shared water resources, public-private partnerships, and the economic dimensions of water. Within the timeframe for this strategy, the MWI aims to adopt a sector-wide, integrated water-resource planning and management approach; develop sector policies and legislation to enhance performance, equitable service provision, and optimization of available resources; initiate institutional reforms to restructure sector management; enhance fiscal discipline for cost recovery; improve internal efficiencies for sector coordination and management; and build technical capacity (MWI 2016).

From this standpoint, many policies have been created to achieve these goals and place them within a legislative framework approved by the Prime Minister of Jordan, such as Water Demand Management and Groundwater Sustainability Policies 2016 and Vulnerable Water Resources in Jordan 2020.

Currently, Jordan’s water policy efforts are primarily directed toward managing water demand and moving forward with implementing the national water plan. Moreover, water policy encourages water harvesting, conserving, and protecting resources. In contrast, the water substitution and reuse policy propose the reuse of treated wastewater in irrigation to enable the freeing of fresh water for municipal uses.

In irrigation, it is recommended that water-saving technologies and replacing groundwater with treated wastewater be considered for farms near existing or planned wastewater plants.

2.5.4. SWOT analysis of project actions

Strengths: Scientific competencies and practical experiences The availability of reference databases and historical reports for the demos site Using Earth observation and remote sensing technologies Use of agrotechnology and agricultural applications Well-established national committee	**Weaknesses**: Lack of time allocated to implement some project activities. Difficulty in direct contact and communication The length of time it takes to obtain information from official authorities
Opportunities: Database linked with the government sectors. The possibility of predicting the upcoming water and climate situation for the study area Evaluate and suggest different management options	**Threats**: climate changes in the Region Increase the Water demand. Lack of response from the local community, especially farmers

2.6. Case study Sebou

The Sebou basin, centrally located in Morocco, is a vital hydrological system covering an expansive area of 40,000 km². This significant river system stands as one of Morocco's largest and most essential watersheds, playing a critical role in the northern region's hydrological, ecological, and socio-economic framework. The basin supports a diverse array of ecosystems and provides crucial resources for over 6 million inhabitants, underpinning various socio-economic activities.

The Sebou River, along with its major tributaries, such as the Ouergha and Inaouene, traverses a variety of terrains that host a rich tapestry of biodiversity. These waterways are instrumental in sustaining agricultural practices, which dominate the land use and economy of the basin. The Sebou basin also supports industrial activities and provides essential water resources for domestic use in major cities and numerous smaller communities. The interdependence between these human activities and the ecological health of the basin highlights the need for integrated and sustainable water management strategies.

The ecological significance of the Sebou basin is further emphasized by its extensive network of wetlands, which includes several Ramsar sites recognized globally for their biodiversity conservation value. These wetlands are crucial for water purification, flood control, and providing habitats for numerous species of flora and fauna. However, the basin faces several environmental challenges, including rapid urbanization, intensive agricultural practices, industrial expansion, and the impacts of climate change. These pressures result in water quality degradation, habitat loss, and biodiversity decline, necessitating urgent and sustainable management strategies.

The Sebou basin serves as an ideal demonstration site for OurMED Project to promote sustainable water management practices through collaborative, science-based approaches, and nature-based solutions. This report section will delve into the biophysical attributes of the Sebou basin, providing a comprehensive understanding of its climate, hydrological and hydrogeological context, water resource infrastructures, ecological and ecosystems context, and land use patterns.

2.6.1. Biophysical attributes

The Sebou basin biophysical attributes are characterized by its diverse climate, complex hydrological and hydrogeological context, extensive water resource infrastructures, and rich ecological and ecosystem diversity. Understanding these attributes is essential for developing effective water management and conservation strategies tailored to the basin's unique environmental dynamics.

2.6.1.1. Climate

The climate prevailing throughout the Sebou basin is Mediterranean with oceanic influence, transitioning to continental towards the interior. It is characterized by rainy winds from the West and precipitation decreasing as one moves away from the sea and into sheltered valleys like those of Beht or the upper Sebou, before rapidly increasing on the slopes of the Rif. Altitude, latitude, and exposure influences combine to create local microclimates where cold, frost, snow, and winter rains can contrast with the heat and summer storms (ABHS, 2021).

These microclimates manifest as:

- Thunderstorms: The most affected region in the basin is Saïs (17 to 18 days/year), with two favorable periods: late summer and late spring. In the mountains, frequencies are naturally higher, with the Middle Atlas being more affected than the Rif.

- Hail: Along the coastal regions, hail is entirely absent in summer. Hills and plateaus inland are primarily affected in early winter and spring. In the mountains, the peak is in spring, but high frequencies extend into summer.
- Snow: Snowfall affects the basin for altitudes above 800 m, occurring between November and March (in the Middle Atlas and High Rif).

Precipitation: The average annual precipitation across the Sebou basin, calculated for the period 1973-2008, is approximately 600 mm (640 mm for the period 1939-2008). Minimum values, ranging from 400 to 550 mm, are observed in the Upper Sebou and then the Middle Sebou basins (Fès region, Oued Rdat, Oued R'dom, Oued Beth). They are slightly higher (500 to 600 mm) along the coastal edge and significantly exceed these values in mountainous areas (700 to 900 mm in the Middle Atlas at Ifrane, 1,000 to 1,500 mm in the Rif relief – upper basin of Oued Ouergha).

Temperatures: In winter, cold episodes and warm or even hot periods alternate, but low minimum temperatures are never absent. These low temperatures undergo spatial variations, resulting in occasional frost in Meknès (protected by its basin position) and more frequent frosts in Fès. Taza, located in the continental air flow, appears particularly affected. In summer, temperatures exhibit two types of behavior: clear weather with high or moderate maximum temperatures but with nocturnal cooling, and hot weather with very high temperatures and little nocturnal cooling. Temperatures are highest in July and August and lowest in January. Annual average temperatures vary according to altitude and continentality between 10 and 20°C.

Evaporation: The average potential evaporation is quite high in the basin, ranging from 1600 mm on the coast to 2000 mm inland. It peaks in July-August with nearly 300 mm/month and is minimal in December-January with less than 50 mm/month. On the coast and in the central basin, the high summer temperatures and the almost absence of significant precipitation during this period explain the high evaporation in the watershed (1500 mm on the coast and 2000 mm/year inland), justifying significant unit irrigation water needs.

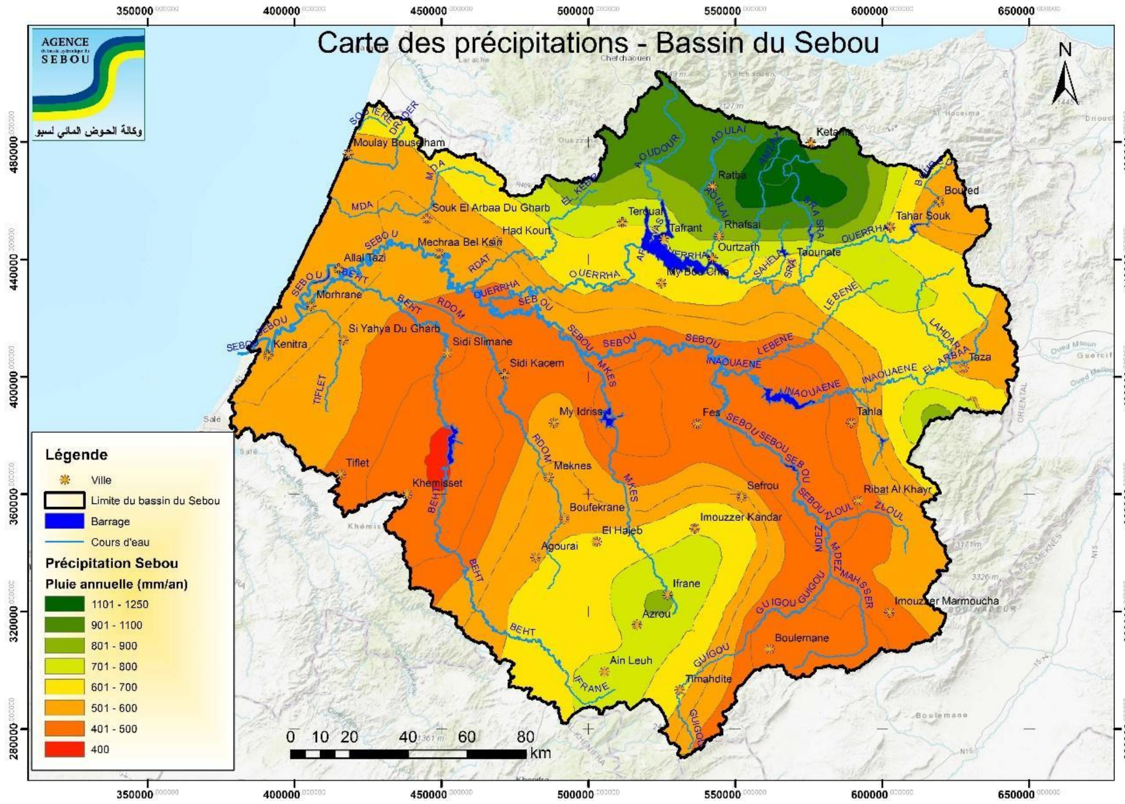

Figure 78 Precipitation Map of the Sebou Basin in Morocco (ABHS, 2018).

2.6.1.2. Hydrological/hydrogeological context

From a hydrological perspective, the basin can be divided into four main components:

- The Sebou, originating from the Middle Atlas and comprising the basins of the Upper Sebou (6,000 km^2), Inaouène (5,200 km^2), and Middle Sebou (5,400 km^2).
- The Ouergha, with an approximate area of 7,300 km2.
- The Beht, covering an area of around 9,000 km^2, receiving the Oued R'dom before joining the Sebou in the Gharb plain.
- The Lower Sebou, with an area of about 6,000 km^2, forming an unstable and insufficient channel to accommodate peak flows.

The average annual water inputs from the Sebou Hydraulic Basin Agency's operational area amount to 5,560 Mm^3 per year, averaging 887 m^3/capita. This is one of the highest levels in Morocco (national average 604 m^3/capita). Similar to the rest of Morocco, the Sebou faces significant variability in water inputs, both temporally and spatially, with variations that can range from 1 to 20. Spatial, seasonal, and inter-annual variations observed in precipitation are also amplified in the contributions of different sub-basins. The coefficient of variation (the ratio of the standard deviation to the mean) generally ranges between 0.60 and 0.80, indicating a high annual variation.

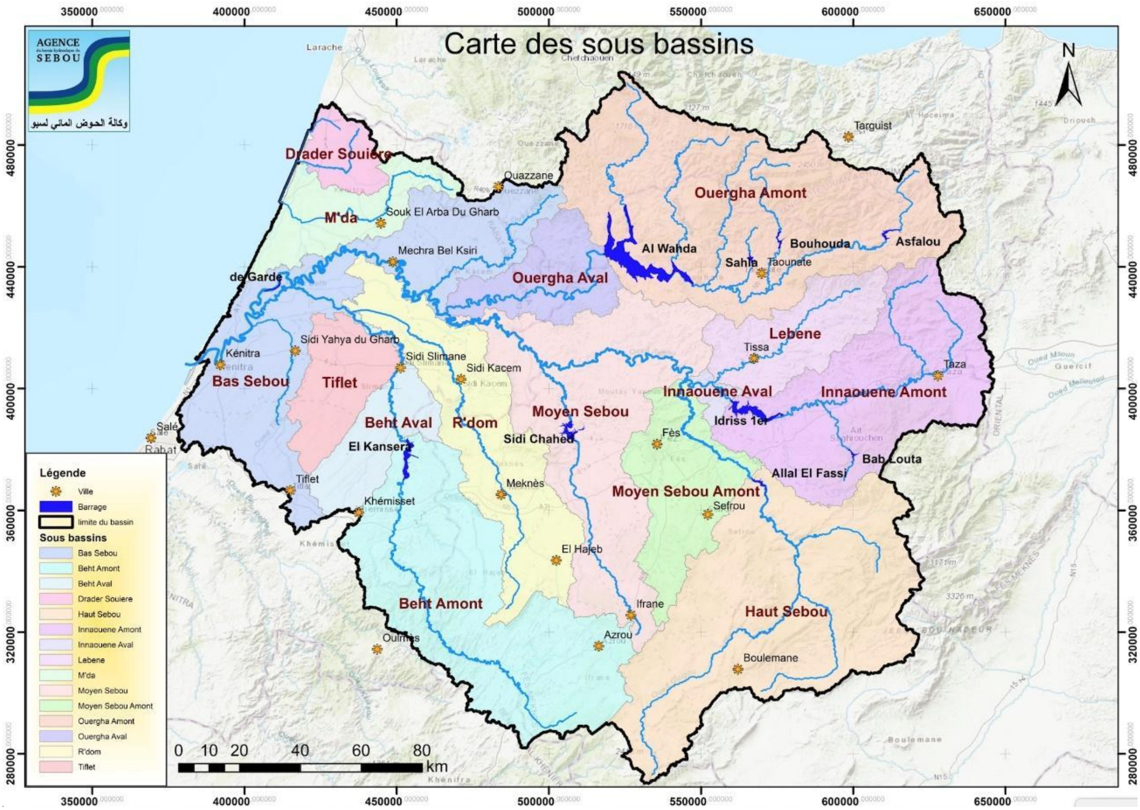

Figure 79 Precipitation Map of the Sebou Basin in Morocco (ABHS, 2018).

From the perspective of groundwater resources, the Sebou basin is among the richest in groundwater in Morocco. Its exploitable resources (1020 Mm^3) represent approximately 25% of the mobilizable potential of Morocco.

The groundwater resources of the Sebou basin are contained in several aquifers, with the most significant ones being:

- The Dradère-Souière aquifer.
- The Mamora aquifer.
- The Gharb aquifer.
- The Bou Agba aquifer.
- The aquifers of the Fès-Meknès basin (phreatic and deep).
- The aquifers of the Fès-Taza corridor (phreatic and deep).
- The aquifers of the Causse du Moyen Atlas (Quaternary basalts and Jurassic limestones and dolomites).
- The aquifer of the folded Middle Atlas.

These groundwater resources play a crucial role in meeting water demands in the Sebou basin and contribute significantly to the overall water availability in Morocco.

The net contributions of the groundwater in the Sebou basin amount to 1579 Mm^3/year. However, the annual exploitable potential is only 1020 Mm^3 due to several factors:

- 300 Mm^3: Outflows from sources directly drained by rivers (base flows), already accounted for in the surface water balance.
- 170 Mm^3: Outflows towards the Oued Oum Erbia from the Middle Atlas Tabular aquifer (Timahdit-Guigou zone).
- 89 Mm^3: Direct outflows to the ocean and Merja Zerga (Gharb-Maamora and Dradère-Souiere).

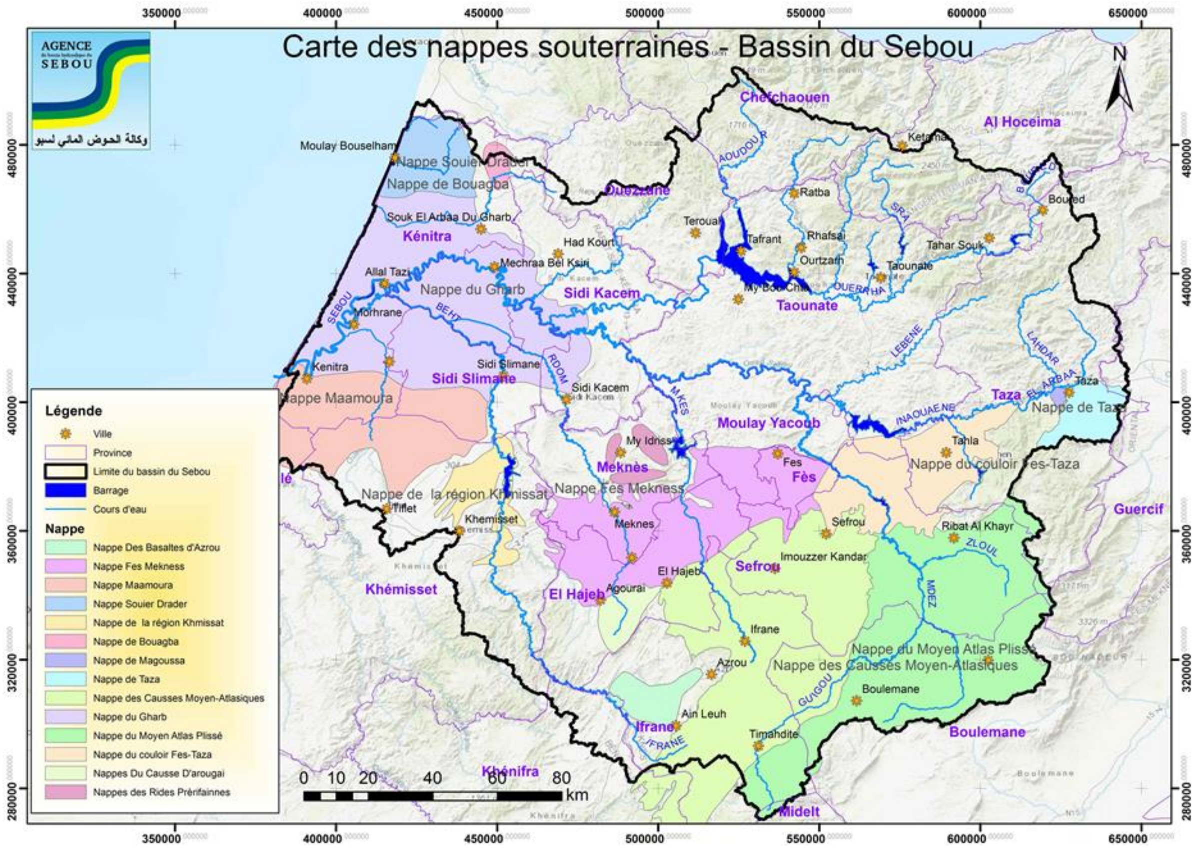

Figure 80 Map of the Phreatic Aquifers in the Sebou Basin.

Direct withdrawals amount to 769 Mm^3/year, with 22% for drinking water supply and 78% for private irrigation in particular.

The most stressed aquifers are those of the Folded Middle Atlas, Fès-Taza Corridor, Middle Atlas Tabular, Fès-Meknès, Gharb, and Dradère-Souiere.

The overall groundwater balance in the basin shows a deficit of approximately 157 Mm^3/year. This deficit explains the continuous decline observed for several years in the groundwater levels, which can be significant for some of them (for example, a decrease of 65 meters between 1979 and 2004 for the Lias aquifer south of the Meknès plateau).

2.6.1.3. Water resources nfrasturctures

The Sebou River, the backbone of the basin's hydrological network, is subject to flow regulation imposed by an extensive dam system. These hydraulic structures not only modulate the surface water flow but also have significant implications for the basin's groundwater regimes. The strategic placement of these dams serves various hydrogeological functions, from flood control to maintaining the ecological flow, highlighting the basin's complex hydrological interdependencies.

In terms of water resource infrastructure, the Sebou Basin is equipped with 10 large dams, including a guard dam, and 45 small to medium-sized dams or hillside lakes. These dams collectively boast a significant storage capacity of 5,872 Mm^3, allowing for the regulation of a substantial volume of approximately 1,830 Mm^3. The primary functions of these reservoirs encompass a wide range of applications: irrigation support for the agricultural lands of Gharb and Beht, potable water supply, electric energy production, flood defense, salinity intrusion control, and direct water withdrawals. This infrastructure underpins the socio-economic development of the region and reflects the multifaceted nature of water resource management in the basin.

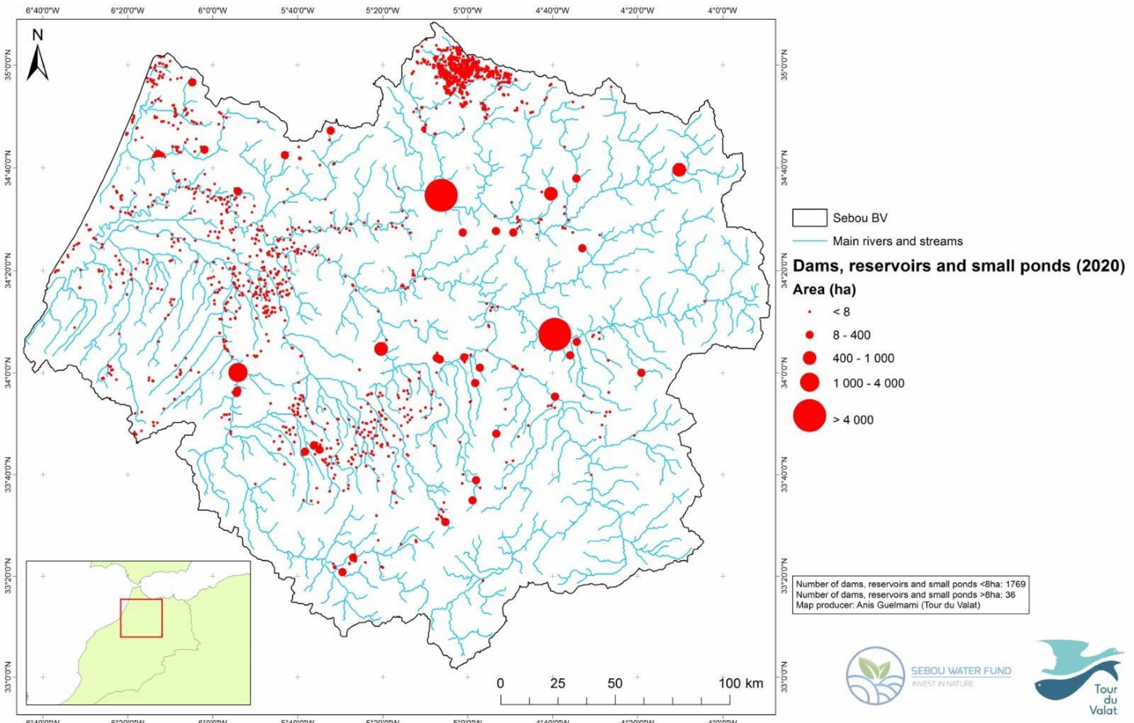

Figure 81 Sebou water resources infrastructures (TdV, 2021).

2.6.1.4. Ecological and ecosystems context and footprint

The Sebou Basin supports a diverse range of ecosystems due to its varied climate and topography. The ecological context includes natural wetlands and drylands that provide vital habitats for a range of species. The ecological footprint of human activity is evident in the land-use patterns and water resource exploitation. Efforts are made to balance development with conservation, to protect the rich biodiversity that includes endemic and migratory species, and to sustain the ecological functions that are essential for the region's environmental health.

A brief overview of the known environments in the Sebou basin reveals a great diversity of natural and artificial habitats and a high abundance of water. These characteristics are attributed to several physical and historical factors that have favored the diversity and abundance of surface waters, contributing to the Sebou's reputation. These factors can be summarized in three points: Orographic, Geological, and Climatic diversity (Dakki et al, 2023). The combined action of the three aforementioned factors has resulted in the Sebou hydrographic network encompassing over 40 types of wetland ecosystems, representing virtually all major categories recognized in Morocco. They are presented below in accordance with the classification of wetlands in Morocco (Dakki, 2022).

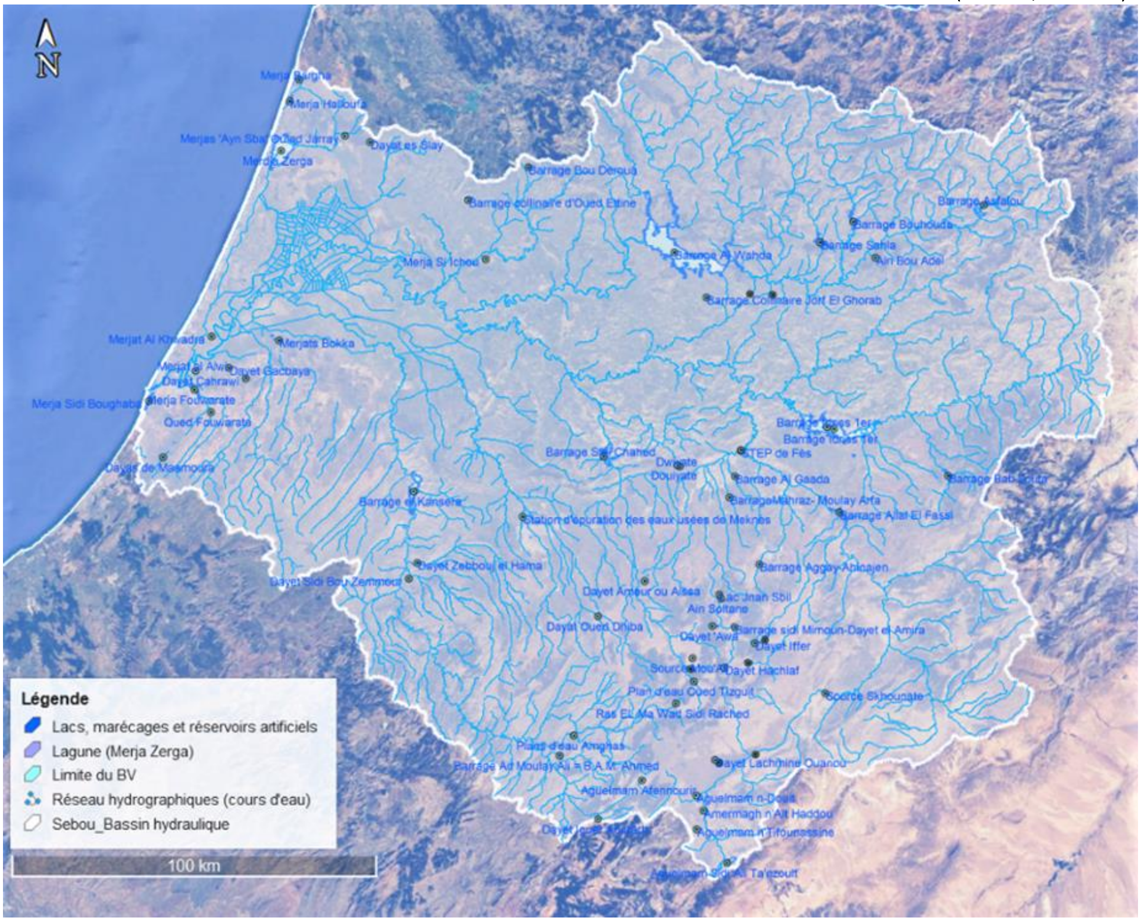

Figure 82 Primary wetland areas in the Sebou basin that have been the subject of ecological studies.

2.6.1.5. Soil and Land use

The Sebou Basin's land is primarily used for agricultural purposes, accounting for 60.01% of the area, reflecting its role as a critical breadbasket for the region. Urban areas make up 2.76%, while natural drylands represent 34.61%, indicating significant coverage by natural vegetation. The basin's soil types vary, with fertile soils in agricultural zones and more arid soils in dryland areas, each presenting unique management challenges and opportunities.

The Sebou basin is one of the main regions in the country with an agricultural vocation. It has 20% of irrigated utilized agricultural area (i.e. 357,000 ha), and 20% of the utilized agricultural area of Morocco (i.e. 1,800,000 ha). The land use is relatively diversified with a predominant share of grain crops (60%), the remaining being occupied by fruit plants (14.4%), legume plants (6.6%), industrial crops sugar beet and cane (4.2%), oilseed crops (3.6%), vegetable crops (3.1%) and forage (1.7%).

Forest covers a total area of 1,200,000 ha. It is primarily composed oak, cedar, thuya and matorrals trees. In addition to its role of grazing land and wood collection for local communities, forest adds significantly to the stabilization of lands and therefore to reduce erosion and silting of reservoirs.

The industrial sector is highly developed in the Sebou basin, especially in the agribusiness (oil, sugar), leather and textile i.e water consuming activities. There are 200 major mills producing over 65% of national olive and vegetable oils production. 184,000 tons of sugar is produced annually in the basin, which accounts for half of national production. Leather and textile industry is highly developed in the basin. The region has a large number of tanneries especially in Fez, Meknes and Kenitra cities, and produces 60% of national production. These tanneries are a major cause of pollution of the Sebou river downstream.

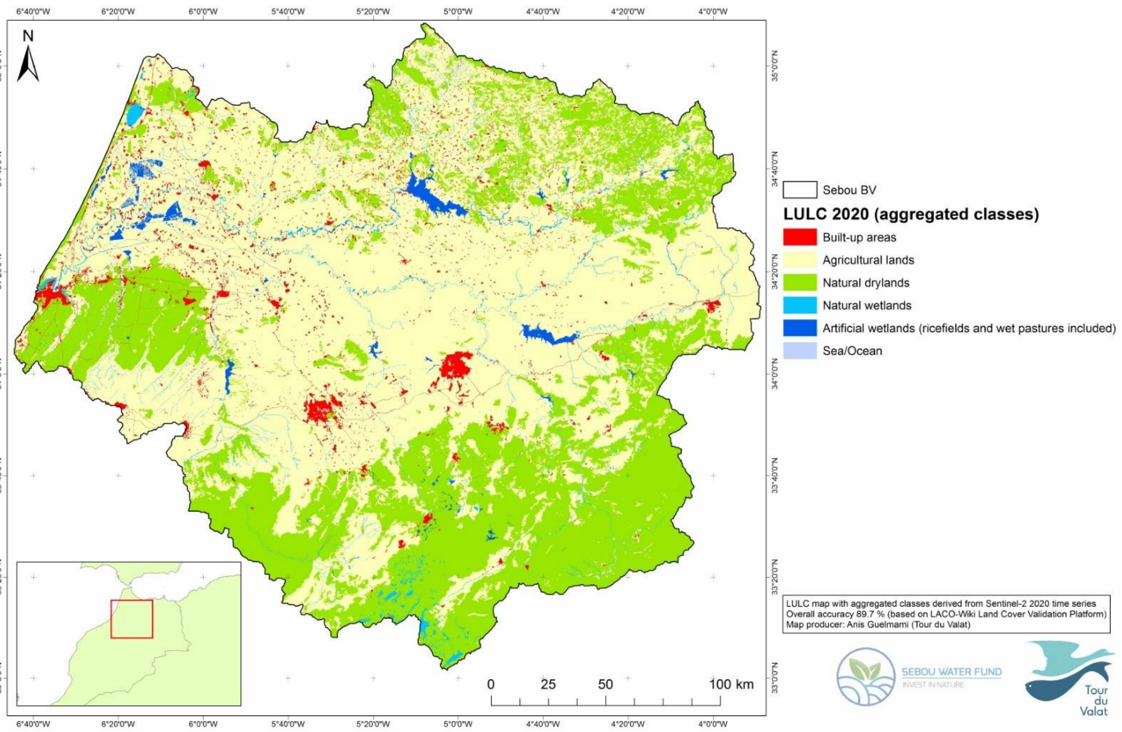

Figure 83 LULC Map of Sebou Basin with aggregated classes (TdV, 2021).

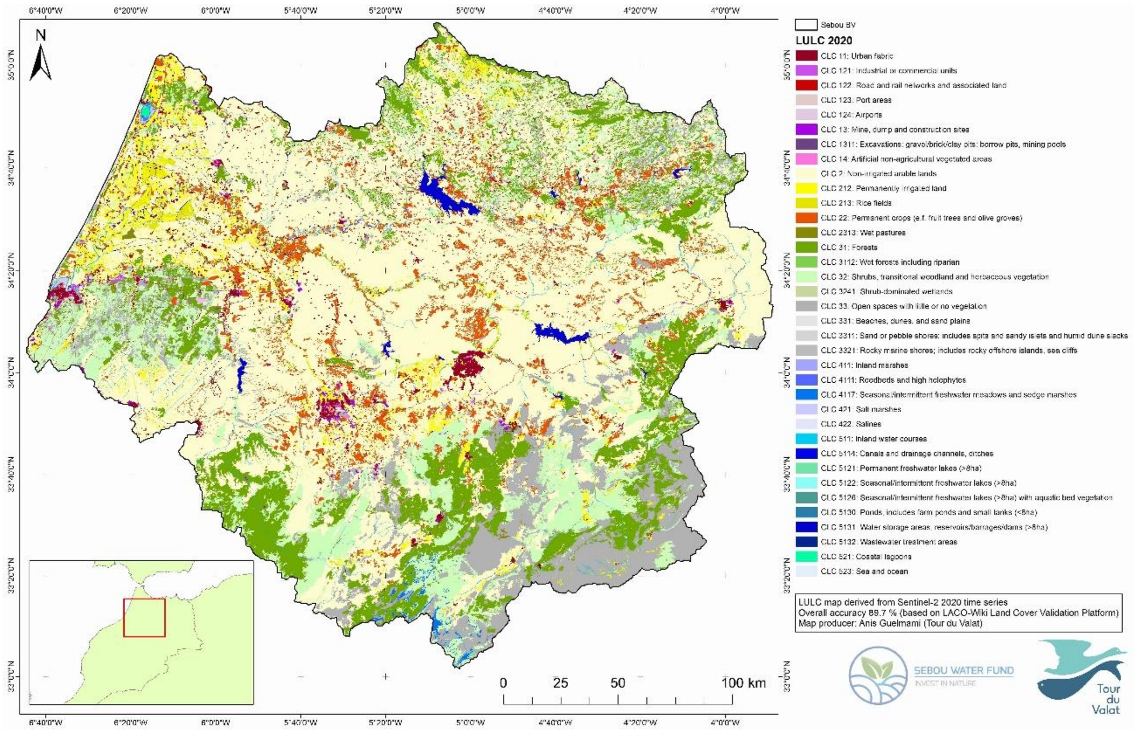

Figure 84 LULC Map of Sebou Basin with detailed classes (TdV, 2021)

2.6.2. Water development and management

The Sebou Basin is a vital hydrological region in Morocco, playing a crucial role in the country's water resource management. The development and management of water resources in the Sebou Basin are fundamental to sustaining its diverse ecosystems, supporting its agricultural productivity, and meeting the water demands of its urban and industrial sectors. Given the region's climatic variability and the increasing pressures from population growth, industrial activities, and climate change, effective water management strategies are essential to ensure long-term sustainability and resilience.

2.6.2.1. Water supply, water storage and distribution

The Sebou Basin's water supply system is underpinned by its extensive dam infrastructure, which ensures the capture and storage of water to meet the demands of various sectors. The distribution network is designed to adapt to the temporal and spatial variability of water availability, supplying urban centers, agricultural areas, and industrial zones. This system's efficiency is critical during periods of drought and is essential for maintaining the socioeconomic stability of the region.

- **Dam Infrastructure and Water Storage:** The Sebou Basin is equipped with a significant dam infrastructure, comprising 10 large dams and 45 smaller dams or hillside lakes. These dams collectively have a storage capacity of 5,872 Mm³, enabling the regulation of approximately 1,830 Mm³ of water annually. Major dams such as Al Wahda, Idriss I, and Allal Al Fassi are pivotal in managing the basin's water resources, supporting irrigation, potable water supply, hydroelectric power generation, and flood control. The strategic placement of these dams across the basin's tributaries ensures a steady and controlled distribution of water.

- **Water Distribution Network:** The water distribution network in the Sebou Basin is designed to address the temporal and spatial variability of water availability, efficiently supplying urban centers, agricultural zones, and industrial areas. This network includes an intricate system of canals, pipelines, and distribution points that ensure water is delivered where it is needed most. The distribution system is particularly crucial during periods of drought, where efficient water management is necessary to prevent shortages and maintain socioeconomic stability.
- **Urban Water Supply:** Urban centers within the Sebou Basin, including major cities like Fez, Meknes, and Kenitra, rely heavily on the basin's water resources for their domestic water supply. The infrastructure ensures that potable water is treated and distributed to meet the needs of the urban population, supporting daily life and economic activities. Advanced water treatment facilities are in place to ensure that the water quality meets health and safety standards, thereby safeguarding public health.
- **Agricultural Water Use:** Agriculture is the dominant water consumer in the Sebou Basin, with extensive irrigation systems in place to support the region's agricultural productivity. The basin's fertile plains are intensively cultivated, with irrigation infrastructure providing the necessary water for crops. Techniques such as drip and localized irrigation are promoted to enhance water use efficiency and reduce wastage. The regulation of water flow from the dams ensures a reliable supply for irrigation, which is vital for the region's food security and economic stability.
- **Industrial Water Use:** The industrial sector in the Sebou Basin also demands substantial water resources, particularly in areas with significant industrial activities such as the agribusiness, leather, and textile industries. The water distribution system ensures that industrial users receive adequate water for their operations, while also emphasizing the need for sustainable practices and efficient water use to minimize environmental impacts.

2.6.2.2. Water uses

Water use within the Sebou Basin is multifaceted, with agriculture consuming the lion's share for irrigation purposes, which is vital for both local consumption and broader regional food security. Municipal water supply for domestic use is another significant demand, followed by industrial water use which supports the basin's economic activities. The generation of hydroelectric power is an integral part of the basin's sustainable energy initiatives.

- **Agriculture:** Agriculture dominates water use in the Sebou Basin, consuming approximately 80% of the available water resources. The irrigation of crops such as cereals, vegetables, and fruits is crucial for local and national food security. The use of advanced irrigation techniques, such as drip irrigation, helps to optimize water use efficiency and reduce wastage, ensuring that water resources are utilized sustainably.

- **Municipal Water Supply:** The municipal water supply is essential for the daily needs of the population residing in urban and rural areas within the Sebou Basin. Ensuring a reliable supply of clean and safe drinking water is a top priority for water management authorities. The water treatment plants in the basin employ advanced technologies to treat and distribute potable water, adhering to stringent quality standards to protect public health.
- **Industrial Water Use:** The industrial sector in the Sebou Basin, including agribusiness, leather, and textile industries, is a significant water consumer. Industrial processes require substantial amounts of water, necessitating efficient water management practices to minimize environmental impacts. The promotion of sustainable industrial practices and the treatment of industrial effluents are crucial for maintaining water quality and supporting economic activities in the region.
- **Hydroelectric Power Generation:** The generation of hydroelectric power is a key component of the Sebou Basin's water use. The dams in the basin are equipped with hydroelectric power plants that harness the energy of flowing water to produce electricity. This renewable energy source contributes to the region's energy security and supports sustainable development goals.

2.6.2.3. Water management strategies

The Sebou Basin employs an integrated water management approach that includes the modernization of irrigation techniques to improve water use efficiency, the adoption of advanced water treatment technologies to ensure safe drinking water, and the implementation of stringent water conservation measures. The strategies are aimed at sustaining the basin's water resources in the face of increasing demand and the challenges posed by climate change.

- **Modernization of Irrigation Techniques:** Modernizing irrigation techniques is a key strategy for improving water use efficiency in the Sebou Basin. The adoption of drip and localized irrigation systems helps to reduce water wastage and ensure that crops receive the optimal amount of water. This approach not only conserves water but also enhances agricultural productivity and supports sustainable farming practices.
- **Advanced Water Treatment Technologies:** The implementation of advanced water treatment technologies is essential for ensuring the supply of safe and clean drinking water. Water treatment plants in the Sebou Basin utilize state-of-the-art technologies to remove contaminants and pathogens, providing high-quality water for domestic and industrial use. These technologies help to protect public health and support the region's socio-economic development.
- **Water Conservation Measures:** Water conservation measures are crucial for managing the Sebou Basin's water resources sustainably. These measures include promoting water-saving practices among residents and industries, implementing

regulations to prevent water wastage, and encouraging the reuse and recycling of water. Water conservation efforts help to ensure that water resources are available for future generations and support the basin's resilience to climate variability.

2.6.2.4. Main issues

The main issues confronting water resources in the Sebou Basin include the need to balance water demand with conservation, the over-exploitation of water, pollution from agricultural and industrial sources, the degradation of natural habitats, and the aging water infrastructure. Climate change exacerbates these challenges, underscoring the need for innovative, integrated water management approaches and strengthened water governance.

- **Balancing Water Demand and Conservation:** Balancing the increasing water demand with the need for conservation is a significant challenge in the Sebou Basin. The growing population, expanding agricultural activities, and industrial development exert pressure on the available water resources. Implementing effective water management strategies that promote conservation while meeting the demands of various sectors is crucial for sustainable water use.

- **Over-Exploitation of Water Resources:** The over-exploitation of water resources, particularly groundwater, is a critical issue in the Sebou Basin. The excessive extraction of groundwater for irrigation and industrial use has led to the depletion of aquifers and a decline in water levels. Sustainable water management practices, including the regulation of water extraction and the promotion of alternative water sources, are essential to address this issue.

- **Pollution from Agricultural and Industrial Sources:** Pollution from agricultural runoff, industrial discharges, and urban wastewater poses a significant threat to water quality in the Sebou Basin. The use of chemical fertilizers and pesticides in agriculture, along with untreated industrial effluents, contaminates water bodies and degrades water quality (Perrin et al., 2014). Implementing pollution control measures, such as stricter regulations and the promotion of sustainable agricultural practices, is critical for protecting water resources.

- **Degradation of Natural Habitats:** The degradation of natural habitats, including wetlands and riparian zones, is a pressing issue in the Sebou Basin. Human activities, such as land conversion for agriculture and urbanization, have led to habitat loss and fragmentation. Protecting and restoring natural habitats is essential for maintaining biodiversity and supporting the ecological functions of the basin.

- **Aging Water Infrastructure:** The aging water infrastructure in the Sebou Basin, including dams, canals, and pipelines, requires significant investment and maintenance. Upgrading and modernizing the infrastructure is necessary to ensure efficient water distribution, reduce water losses, and support the region's water management goals.

- **Climate Change Impacts:** Climate change exacerbates the challenges facing water resources in the Sebou Basin. Altered precipitation patterns, increased frequency of extreme weather events, and rising temperatures impact water availability and quality. Developing and implementing climate adaptation strategies, such as building climate-resilient infrastructure and promoting community-based adaptation programs, is essential for enhancing the basin's resilience to climate change.

2.6.3. Water resources governance system

The governance system involves multiple stakeholders with a focus on integrated water resource management and stakeholder engagement. Effective governance is essential for ensuring the sustainable management of the Sebou Basin's water resources.

- **Stakeholder Engagement:** Engaging a wide range of stakeholders, including local communities, government agencies, NGOs, and industry representatives, is crucial for successful water management. Inclusive stakeholder participation ensures that diverse perspectives are considered, and collaborative solutions are developed to address water management challenges.
- **Integrated Water Resource Management (IWRM):** The Sebou Basin employs an IWRM approach that integrates water, land, and ecosystem management. This holistic approach ensures that water management strategies are coordinated and mutually reinforcing, addressing the interconnected challenges of water quality, quantity, and ecosystem health.

2.6.3.1. Water policy and current instruments of water regulation

Policies and regulations in the Sebou Basin are designed to promote sustainable water management practices and ensure the equitable distribution of water resources among various sectors. These policies include water rights, allocation frameworks, and regulatory compliance mechanisms that are essential for maintaining the balance between water demand and conservation.

- **Water Rights and Allocation Frameworks:** Water rights in the Sebou Basin are governed by national water laws (Law 10-95, 1995 ; Law 36-15, 2016), which allocate water resources to different sectors based on priority and need. The allocation frameworks are designed to ensure that water is distributed equitably among agricultural, municipal, and industrial users. These frameworks also prioritize the maintenance of ecological flows to support the basin's ecosystems.
- **Regulatory Compliance Mechanisms:** To enforce water management policies, a range of regulatory compliance mechanisms are in place. These mechanisms include monitoring and enforcement of water quality standards, penalties for non-compliance, and incentives for adopting sustainable water management practices. Regulatory agencies work closely with stakeholders to ensure adherence to these regulations and to promote best practices in water use.
- **Policy Instruments:** The Sebou Basin employs various policy instruments to support water management goals. These include financial incentives for water-

saving technologies, subsidies for sustainable agricultural practices, and grants for research and development in water management. Additionally, public awareness campaigns are conducted to educate stakeholders about the importance of water conservation and sustainable practices.

2.6.4. SWOT analysis of project actions

The following SWOT analysis provides a detailed understanding of the current status and potential future direction of water management strategies in the Sebou Basin. This analysis is essential for developing effective, science-based strategies that ensure the sustainable management of water resources in the region.

Strengths:	Weaknesses:
Extensive Dam Infrastructure: The Sebou Basin benefits from a comprehensive network of dams, including 10 large dams and 45 small to medium-sized dams or hillside lakes. This infrastructure plays a critical role in capturing and storing water, ensuring a steady supply for various sectors, particularly during dry periods. **Integrated Water Management Approach:** The basin employs an Integrated Water Resource Management (IWRM) approach, which is designed to coordinate the development and management of water, land, and related resources. This approach helps in maximizing economic and social welfare without compromising the sustainability of vital ecosystems. **Stakeholder Engagement:** Effective water management in the Sebou Basin is underpinned by robust stakeholder engagement, involving local communities, government agencies, NGOs, and industry representatives. This collaborative framework ensures that diverse perspectives are considered in decision-making processes. **Advanced Water Treatment Technologies:** The implementation of advanced water treatment technologies ensures the provision of safe drinking water, reduces health risks, and supports industrial activities. These technologies are crucial for maintaining water quality and protecting public health.	**Over-Exploitation of Groundwater Resources:** The Sebou Basin faces significant challenges related to the over-exploitation of its groundwater resources. Intensive extraction for agricultural and domestic use has led to declining groundwater levels, threatening long-term water security. **Pollution from Agricultural Runoff and Industrial Discharges:** Pollution is a major concern in the Sebou Basin, with agricultural runoff and industrial discharges contributing to water quality degradation. The presence of pesticides, fertilizers, and industrial waste in water bodies poses serious environmental and health risks. **Aging Water Infrastructure:** Much of the water infrastructure in the Sebou Basin is aging and in need of significant maintenance and investment. Deteriorating infrastructure can lead to inefficiencies in water distribution and increased vulnerability to water shortages. **Limited Financial Resources:** There is a notable gap in financial resources required to implement comprehensive water management initiatives. Limited funding hampers the ability to upgrade infrastructure, adopt new technologies, and carry out extensive conservation projects.
Opportunities:	**Threats:**
Adoption of Advanced Irrigation Techniques: The Sebou Basin has significant potential for adopting advanced irrigation techniques such as drip irrigation and precision agriculture. These methods can significantly	**Climate Change Impacts:** Climate change is a significant threat to the Sebou Basin, leading to altered precipitation patterns, increased frequency of extreme weather events, and prolonged droughts. These impacts

improve water use efficiency and reduce wastage, enhancing agricultural productivity. **Increased Funding Opportunities:** National and international funding sources present opportunities to finance water management projects. Grants and loans from organizations such as the World Bank, FAO, and various environmental NGOs can support infrastructure upgrades and conservation efforts. **Development of Climate Adaptation Strategies:** With climate change posing increasing risks, there is an opportunity to develop and implement climate adaptation strategies. These strategies can enhance the basin's resilience to climate variability and extreme weather events. **Expansion of Stakeholder Engagement:** There are opportunities to further expand stakeholder engagement, incorporating more diverse groups into the decision-making process. Enhanced collaboration can lead to more innovative and widely accepted solutions to water management challenges.	exacerbate water scarcity and threaten the sustainability of water resources. **Increasing Water Demand:** Population growth and industrial expansion are driving up water demand in the Sebou Basin. This increasing demand places additional pressure on already stressed water resources, potentially leading to conflicts among water users. **Continued Pollution and Habitat Degradation:** Without effective pollution control measures, the continued degradation of water quality and natural habitats poses a threat to the basin's ecological health. Persistent pollution can lead to the loss of biodiversity and the decline of ecosystem services. **Potential Conflicts Among Water Users:** Competition for limited water resources can lead to conflicts among different water users, including agricultural, industrial, and domestic sectors. These conflicts can hinder collaborative efforts and compromise the effectiveness of water management strategies.

2.7. Case study Medjerda

With 23 700 km², the Medjerda basin is located in Northen Tunisia and North Eastern Algeria and ranges from 35°14 to 37°12N, and 07°17 to 10°16E. The Medhjerda is transboundary river since around 32% is in Algerian territories and reaches the sea after 500 km. It originates from Tebessa mountains, for the right bank, and the Aures, for the left bank. In Tunisia, it is separated from the Mediterranean by the Khemir and Mogods Mountains in the north and the Dosal Mountains in the south. With a general orientation East-West, the Medjerda joins the Mediterranean on the eastern coasts of Tunisia in the Ghar el Melah region. It is the largest catchment in Tunisia, contributes to more than the half of national cereal yield and around 40% of surface fresh water and 25% of the total fresh water of the country. The landscape is steep in Algerian territories as well as in Northern and southern parts in Tunisian area. The elevation reaches more that 1 700 m asl at Tebessa Mountains. It ranges between 0 and 1350 m asl respectively at Ghar el Melah the mouth of the basin and Djebel Serdj (Tunisian Dorsal). The stream network is dense over the entire watershed except the valley of main river and the area located downstream.

The largest dam in Tunisia, the Sidi Salem reservoir, controlling approximately 16,000 km², and 8 others. It is important to emphasize that new dams are planned, such as the structure on Wadi Tessa, Wadi Khalled and Wadi Chafrou contributing to control surface water resources of the watershed. More than 70% of the watershed is cropped, with a production system largely dominated by rainfed crops, dominated by cereals and fodder throughout the watershed. Irrigated crops, vegetables with more or less fruit, are generally limited to the vicinity of dam reservoirs and the lower valley. A little more than a quarter of the surface area of the Medjerda corresponds to wooded and pastoral lands, indicating the strong anthropization of the watershed, with a trend of decline in natural vegetation, as for the majority of territories in Maghreb countries.

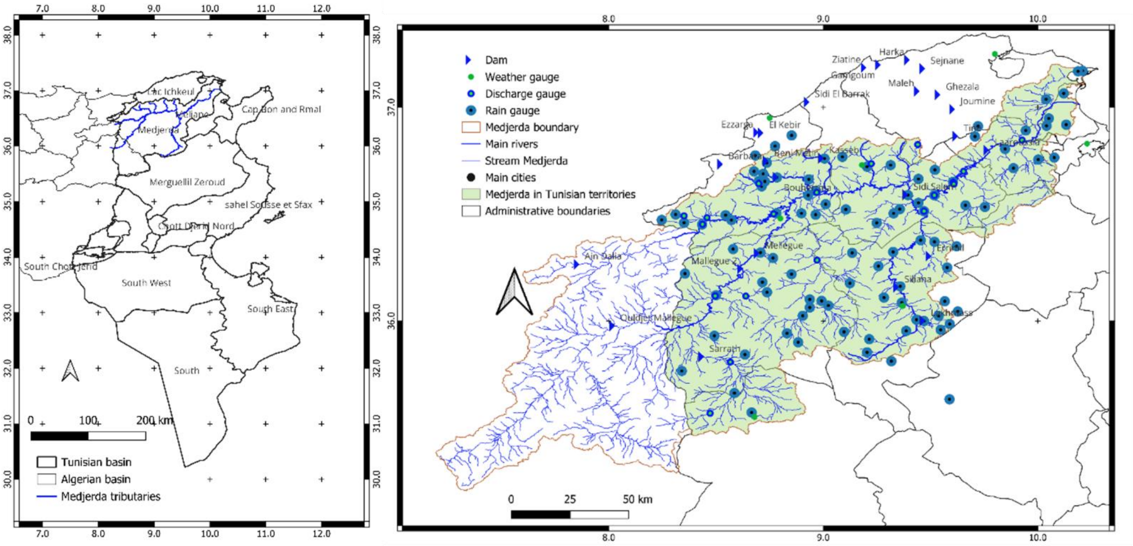

Figure 85 Location of the Medjerda basin in the Northern Tunisia and Northeastern Algeria and location of rain and flow gauges as well as climate gauges and dams.

Three Ramsar sites are located in the Medjerda basin, Ghar El Melah lagoona as wetland, Ain Dhiab caves since 2007, and Reserve Naturelle Djebel Saddine[25] as well as city with label Ramsar accredited in 2018[26]. There areas are 10,168, 560, and 2610 ha respectively, indicating the ecological interest of the demo site. These Ramsar sites have a protection status at both the national and international levels

2.7.1. Biophysical attribute

The climate of Medjerda basin is characterized by a variety of biophysical attributes influencing its hydrological properties; the climate is Mediterranean that range between humid in a limited area the North western side to arid in Southern areas. The precipitations are characterized by a high variability within and between years, which have a huge impact on flow and water availability and hydraulic infrastructures functionality. The main dam reservoirs of the country are located in the demo site; these hydraulic structures, interconnected, had been designed to store flows for irrigation, water drinking, flood protection… They are impacted by erosion reducing their storage capacity, water needs increase and droughts more frequent and more severe.

[25] https://rsis.ramsar.org/
[26] https://www.ramsar.org/

2.7.1.1. Climate

The study area belongs to semiarid Mediterranean climate with humid winters and dry and hot summers. The precipitations vary from nearly 300 mm/year in the South-West to more than 1,000 mm/year in the North. The rainfall occurs mainly during winter months while the drought period extends to more than 6 months (May–October). The water balance is strongly affected by evaporation due to high temperature and radiation (Ben Boubaker et al., 2003). Evapotranspiration is lower than 50 mm/month during winter and is higher than 200 mm/month during summer (Latiri et al., 2010). The variability of precipitations and the high temperature, evapotranspiration remains high at the scale of watershed. The evapotranspiration varies from nearly 1200 to more than 1600 mm/year in the north (Feija and Beja) and the southwest (Thala and Kef) respectively (Mjejra et al., 2014). The evapotranspiration is characterized by its high variability between season. During winter, the evapotranspiration does not exceed 100 mm, with the exception of Thala location (southwest of Medjerda) with almost 150 mm. In summer, the evapotranspiration is often beyond 500 mm, or even 700 mm (Mjejra, 2016).

Rainfall was recorded on 98 stations located in the Tunisian territories and covering the period 1950/1951 to 2014/2015. The rainfall, in average, ranges from near 300 to more 1600 mm/year, respectively at southern side and northern side. The average annual precipitation of the Medjeda watershed, including Algerian territories, is around is 415 mm (Boulmaiz, 2022). It exceeds 500 mm/year in Tunisian territories (Gader et al., 2020). During last decade, Tunisia and Medjerda basin was impacted by severe and long drought; for example, the annual flow to Sidi Salem from 2015/2016 until 2022/2023 was below 60% the historical average, except 2018/2019 where it was higher than the average. This situation impacted water supply of the whole country.

2.7.1.2. Hydrological/hydrogeologica context

The relief of the hydrosystem alternates mountains with a South West – North East orientation on the one hand, and plateaus in the western and southern territories and valleys and plains elsewhere, on the other hand. Thus, high altitudes are in the west, north and south of basin whereas lower elevations correspond the middle and east, at river mouth. In Tunisia, Medjerda basin is divided into three areas: Medjerda Upper Valley (MUP) from Algerian borders to Beja region (at the upstream side of Sidi Salem reservoir), Medjerda Middle Valley (MMV) from the MUP to Medjez el Bab city, and Medjerda Lower Valley (MLV) from the MMV to the river mouth at Ghar El Melah lagoon.

The main tributaries of the MUP are Wadi Mellegue and Wadi Tessa from the right bank and Wadi Raghay, Wadi Bouhertma and Wadi Kassab from the left bank. The main tributaries of MMV are Wadi Siliana and Wadi Khalled from the right bank and Wadi Beja and Wadi Zarga from the left bank. There are two main tributaries in the MLV: Wadi Lahmar and Wadi Chaffrou. The tributaries of right bank are characterized by their large areas whereas those of the left have a limited area but with flows because of more precipitation.

2.7.1.3. Water resources infrastructures

The Medjerda is the hydrosystem for supplying almost half of the Tunisian population with drinking water, directly or indirectly, through the transfer and adduction of the watersheds of the north basin. Being the centrepiece of the northern water plan since the 70s of the last centuries, the water resources management strategy of the Medjerda watershed was based mainly on the mobilization of renewable surface water through a network of interconnected reservoir dams (Table 10, Figure 86) to store and transfer water through hydraulic infrastructure across different regions of the country. The adopted strategy aims to guarantee the water supply for irrigation needs and the supply of drinking water for the main urban centre, the capital Tunis as well as Cap Bon, Sahel and Sfax.

Table 10 Main dam reservoirs with the Medjerda basin.

Resersoir	Damming year	River	Area (Km²)	Storage capacity (Mm³)		Flow average (Mm³)	Transfer connexion	
				Initial	Actual		in	out
Mellegue	1954	Mellegue	10300	265	51,1	183,2		Sidi Salem
Ben Metir	1954	Ellil	103	61,2	60,4	22,4		Bouhertma
Laaroussia	1954	Medjerda					Sidi Salem	
Kasseb	1968	Kasseb	101	81,9	76,9	44,1		Sidi Salem
Lakhmess	1966	Lakhmess	127	8,22	7,22	5,5	Siliana	
Bouhertma	1976	Bouhertma	390	117,5	112	83,4	Barbara, Beni Metir	Sidi Salem
Sidi Salem	1981	Medjerda	7950	814	580,4	405,0	Bouhertma, Mellegue, Kasseb	Laaroussia
Siliana	1987	Siliana	1040	70	31	36,4		
Rmil	2002	Rmil	232	4	2	10,19		
Sarrath	2016	Sarrath	1850	21	21	22,4		Mellegue

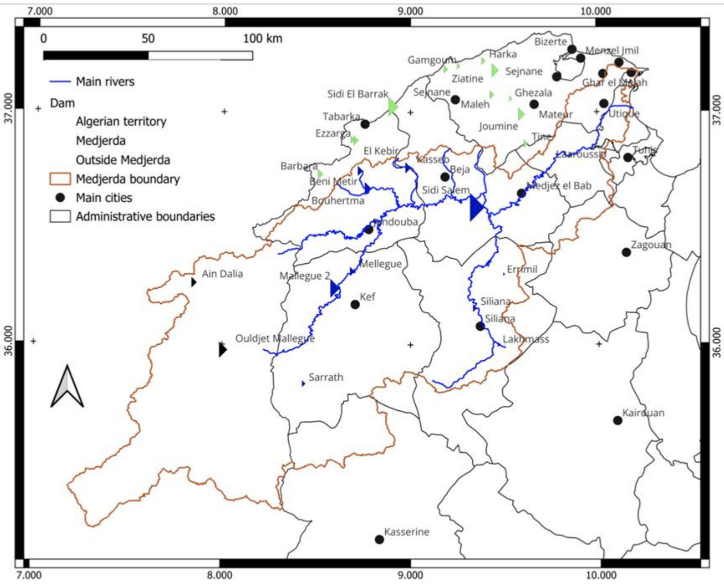

Figure 86 Main dam reservoirs with the Medjerda basin in Tunisian and Algerian territories.

2.7.1.4. Ecological and ecosystems context and footprint

The basin is highly affected by hydraulic infrastructures and agricultural land use; It can be said that urban wastewater, from cities located in the hydrosystem, is poorly treated before being discharged. The intensification of the irrigated crops may contribute to water quality alteration, surface and groundwater resourcThe main soil classes in Tunisian territories are mainly regosols/lithosols, rendzinas, brown calcareous soils, and unit complex of soils (Figure 87). The texture of the Medjerda soil varies between alluvium sand, clay, limestone materials, calcareous and gypsum crusts, encrusted pebble, and Triassic rocks in the upstream while it is marl and cretaceous limestone in the downstream side (Etteieb et al., 2017). es. There is increasing trend from the West (upstream) to the East (downstream) of the nitrate, salinity, chloride, and turbidity indicating an increase of the water pollution (Abidi et al., 2015).

2.7.1.5. Soil and Land use

The main soil classes in Tunisian territories are mainly regosols/lithosols, rendzinas, brown calcareous soils, and unit complex of soils. The texture of the Medjerda soil varies between alluvium sand, clay, limestone materials, calcareous and gypsum crusts, encrusted pebble, and Triassic rocks in the upstream while it is marl and cretaceous limestone in the downstream side (Etteieb et al., 2017).

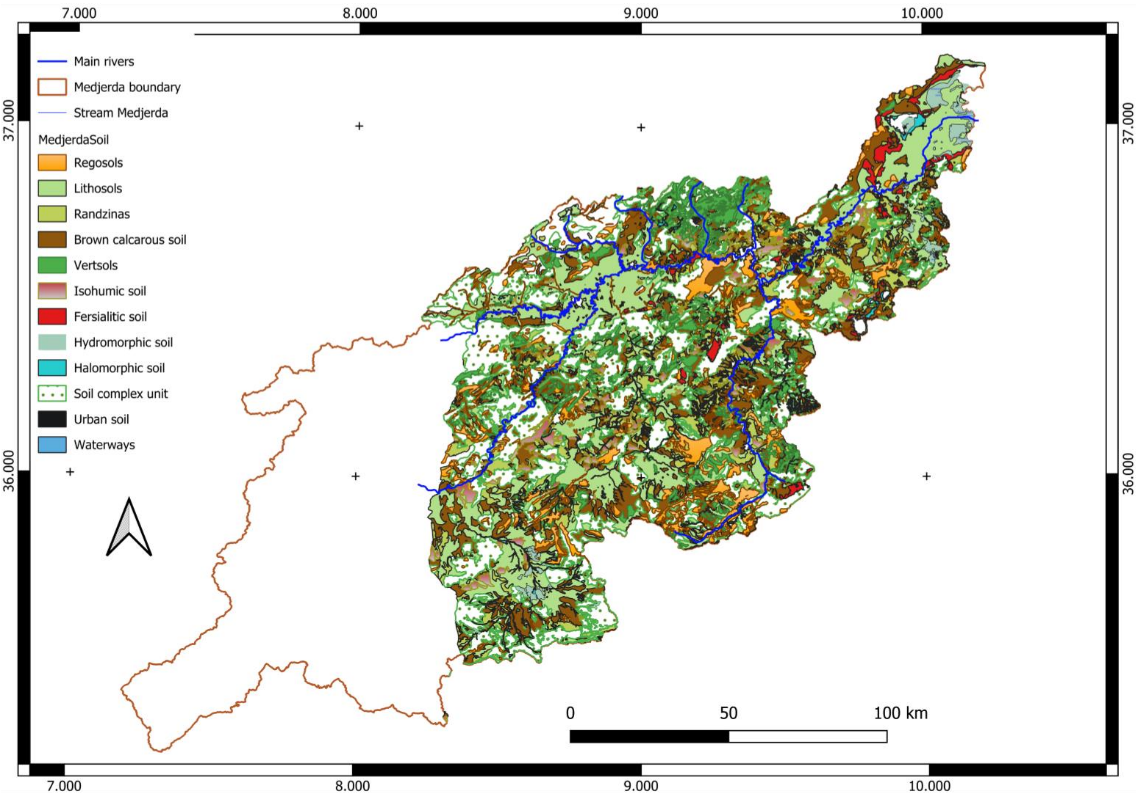

Figure 87 Soil classes of the Medjerda Basin (Source: Agricultural Map (MAHR, 2003).

Figure 88 shows that field crops (cereal crops, fodder, etc.) occupy 50% of the entire basin. Fruit trees, forest, matorral, etc.) represent 29.2% of the total surface area and are generally located in the northwest sector and along the Medjerda wadi axis. Finally, bare soils (uncovered soil, urban fabric, wet surfaces, etc.) occupy 25.1% of the study region, especially in the southwest part. The validated classification is validated by the confusion matrix and the Kappa coefficient (index of approximately 0.94). In addition, the OTD censuses make it possible to strengthen this validation: land use is proportional to the OTD data, in particular in Jendouba, Beja and Siliana.

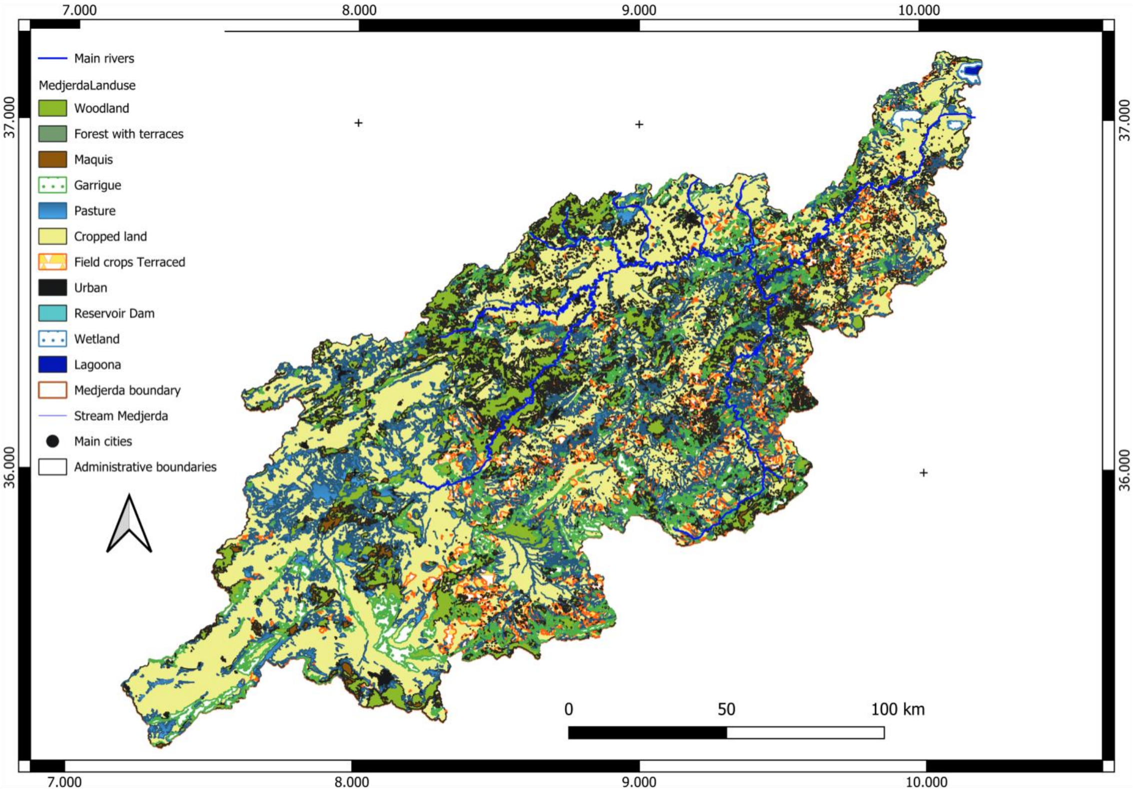

Figure 88 Landcover of the Medjerda Basin (Source: ESIM-UCLouvain, 2013).

2.7.2. Water development and management

Since the seventies of the twentieth century, the Tunisian authorities have relied on mobilizing water resources from the Medjerda to satisfy different water needs, mainly irrigation and drinking water. During the last decades, the interconnection of dams, inside the Medjerda and others outside the hydrosystem, has been carried out to satisfy an increasingly strong demand for water exacerbated by the alteration of the hydrological regime (droughts and floods, with larger duration and more frequent floods) distrubing the entire hydraulic infrastructure of the country.

2.7.2.1. Water supply, water storage and distribution

The water supply system of the Medjerda is designed on hydraulic structures that mobilize, store and distribute surface water. The main components are 10 large dams (storage capacity more than 5 Mm^3), several tens (capacity more than 500,000 m^3) of small dams (capacity more than 500,000 m^3), and more 200 hill small dams (capacity less than 500,000 m^3). Most of the large dams are connected to perform water transfer between each other and the needing regions (Figure 89). It should be mentioned that this system is also connected to the dams of the North basin of Tunisia. Water transfer is performed by gravity (upstream to downstream) or through pumping to meet water needs for agricultural, dinking and industrial uses.

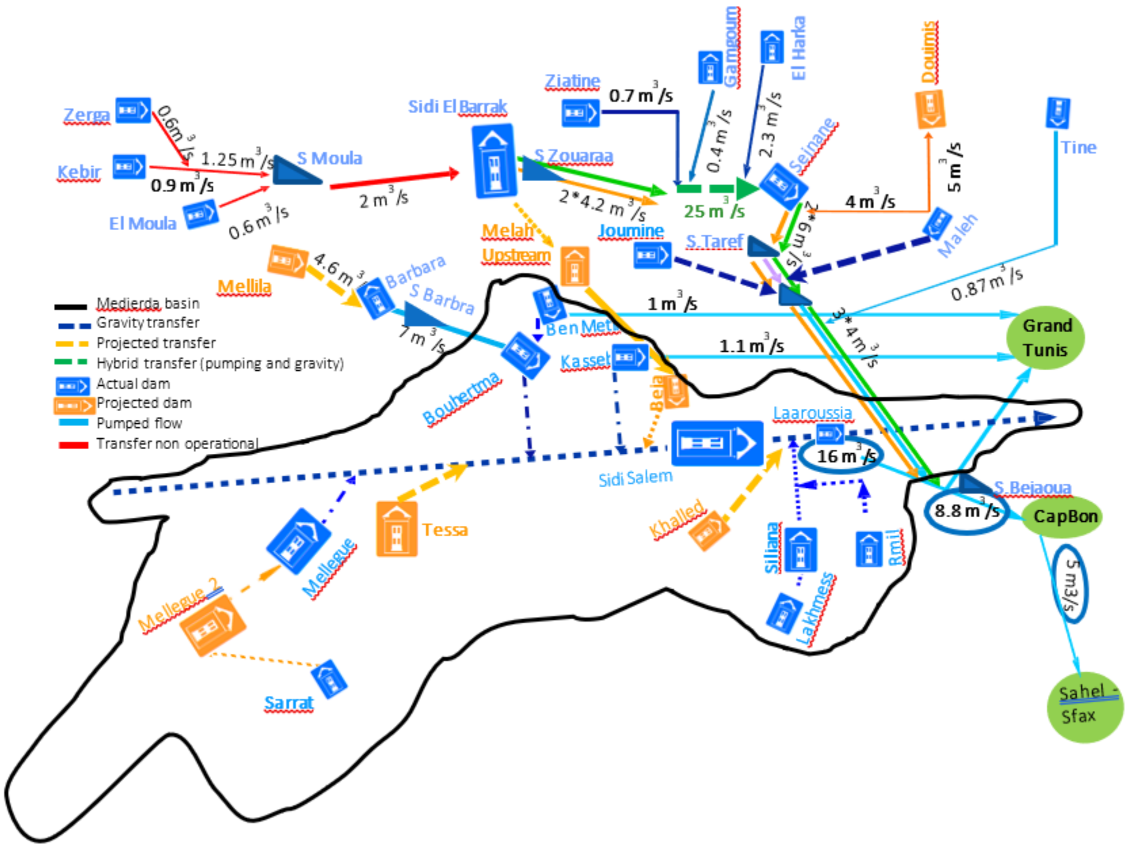

Figure 89 Scheme of current and projected transfer routes for northern dams in Tunisia (from Cherif et al., 2003).

2.7.2.2. Water uses

Water resources of the basin is used for irrigation (75%) and drinking and industrial needs (25%). Since water needs increased, water transfer from the North basin, mainly for non-agricultural use, was applied since more than 15 years ago. The historical annual flow of the Medjerda at Sidi Salem was 640 Mm^3 (ONAGRI, 2014) however during the last decade it was dropped down to around 400 Mm^3 (MARHP, 2023) due to frequent and severe droughts. The same trend is observed at all dams in the demo site. In the last three years, the flows for dams were less than 40% than the historical average. The decision taken by authorities to use water from the dams of Medjerda for agricultural purposes in March 2023 had negatively impacted the use of groundwater, whenever available.

2.7.2.3. Water management strategies

The combination of infrastructure development, water efficiency measures, and pollution control efforts have been key components of the water management strategy for the Medjerda River in Tunisia. Since 1970, several water planning and management projects have been carried out in line with improved knowledge of the resource and changes in water demand from various sectors. In the 1970s, three main plans were drawn up for the North of Tunisia with the aim of establishing a timetable for the construction of water mobilization and transfer facilities, flood protection and the development of groundwater use.

Other regional and local sector plans were drawn up for urban and rural drinking water, irrigation water and agricultural wastewater use, with the aim of defining the demands and infrastructure required to meet the needs of different sectors over different time horizons. In 1990, a national strategy to mobilize all identified resources was implemented. It included the construction of dams, hill dams, small hill dams, boreholes and recharge, and spreading structures. The objective of this strategy was to meet the water demand of the various sectors over the coming decades. In 1998, a study of the water sector was carried out, covering topics such as demand estimation, public expenditure, monitoring assessment, groundwater management, etc (Khanfir et al., 1998).

The evaluation of the state of water sector has been continued during the 2000's period. These studies present a detailed analysis of strategies and prospects. The strategies were based on the following four points: i) Maximum technical control of all water resources, through mobilizing and regulating most flows, and setting up a water supply interconnection network to pool water supply problems nationwide quality and supply problems on a national scale; ii) A program to save water and reduce losses in every sector of use (demand management for environmental reasons and reducing pressure on water resources, for example); iii) Optimal use of available water: the importance of a national allocation decision between uses and between regions in order to achieve optimal use; and iv) the importance of protecting the quality of the resource (Treyer, 2002).

With increased pressure on water resources, socio-economic development and climate variability, the issue of management and sustainability of public and private hydraulic developments were raised. An approach based on the triad Blue Water (potential resources) - Green Water (rainfed agriculture) - Virtual Water (import-export balance of agricultural products) was proposed to ensure a better optimization of the management of available natural resources and give a vision more realistic of food security (ITES, 2014 ; BPEH, 2020).

To face recent challenges in terms of water resources management, the Water Vision and Strategy for 2050 for Tunisia aims to achieve hydraulic balance between supply and demand in 2050 and this requires a paradigm shift through the proposal of administrative reforms and institutional for a new mode of effective and decision-making governance. Among its orientations: (i) strengthening resources with a view to managing extremes and resilience to climate change, (ii) a balance of drinking water supply/irrigation ensuring the security of drinking water supply and the regulation of irrigated agricultural production, (iii) an improvement in efficiency and performance of hydraulic infrastructures, (iv) valorisation of unconventional water for ecological and economic purposes, (v) revival of rain-fed agriculture, (vi) fight against pollution and (vii) "water-food-energy-ecology nexus" approach (STUDI International/GKW,2023).

2.7.2.4. Main issues

Despite the efforts that have been made to manage water resources in the Medjerda River in Tunisia, there are still challenges and inefficiencies that need to be addressed. Some of the issues contributing to the inefficacity of the water management strategy is the water governance that has been marked until now by excessive centralization and the absence a reliable and shared information system, allowing proactive monitoring of the hydraulic balance evolution and its implications. The lack of coordination and communication among different stakeholders involved in water management, including government agencies, local communities, and private sector actors lead to conflicts over water use and allocation, hindering effective decision-making and implementation of water management measures.

The second major problem in the Medjerda is the Water quality. The high water salinity, non treated and poorly treated wastewater discharged into the stream network of Medjerda and pollution from agricultural runoff, industrial activities, and urban areas continue to pose a threat to water quality in the Medjerda River. Efforts to control pollution and improve water quality may be insufficient, leading to negative impacts on ecosystems and human health.

Also, the existing infrastructure, such as dams and irrigation systems, may not be sufficient or properly maintained to effectively manage water flow and distribution in the river basin. This can lead to water scarcity in some areas and waterlogging in others, impacting water availability for drinking and agricultural production. Instead of the efforts made by the government, the promotion of sustainable water uses practices, such as water conservation and efficient irrigation techniques, may not be widely adopted or reinforced.

These problems are exacerbated by climate change which is affecting water availability and variability in the region, leading to more frequent and intense droughts. The current water management strategy may not be adequately adapted to address these changing conditions, resulting in challenges in water supply and quality.

2.7.3. Water resources governance system

Many activities related to water resources management are the responsibility of the Ministry of Agriculture, Water Resources and Fisheries (MARHP) and the directorates/institutions under its authority. While environmental aspects are the responsibility of the Ministry of Environment. The Ministry of Public Health and the Ministry of Equipment are responsible for water control in general and flood management in urban areas respectively.

The MARHP is mainly responsible for public domain management, mobilization and development of water resources, water management projects and agricultural withdrawals as well as providing water resources for domestic and other uses. The main departments within MARHP that play key roles in water resources management are:

- The General Directorate of Water Resources (DGRE);
- The General Directorate of Rural Engineering and Water Exploitation (DGGREE);

- The General Directorate of Dams and Hydraulic structures Department (DGBGTH);
- The General Directorate for Management and Conservation of Agricultural Land (DGACTA);
- The Bureau of Water Planning and Hydraulic Equilibriums (BPEH); A National Water Council has emerged supposed to bring together administration and users.

Some autonomous public companies are responsible for functions such as the drinking water supply (SONEDE), the operation of the canal of the Northern water supply (Northern Water Canal and Adductions Exploitation Company (SECADENORD), these two companies are under the supervision of the Ministry of Agriculture, and a company responsible for the management and sanitation (ONAS) together with National Agency for Protection of Environment (ANPE) under the authority of Ministry of Environment.

Through them, we could ultimately aim for a certain takeover of the water sector by the private sector, in the form of subcontracting to these companies. The Agricultural Development Bureaux were replaced in 1989 by the Agricultural Development Services, which represent the beginning of decentralization. Current policy has also moved towards more participatory and user involvement. with the creation of Collective Interest Associations (AIC) for rural drinking water supply and public irrigated areas. These AICs, until late 2000, are subject to the supervision of the CRDAs (Treyer, 2002).

These associations later evolved into agricultural development groups (GDA). The GDAs represent the main local institution for the participatory management of water systems. User participation takes place through the GDAs. GDAs are facing enormous financial difficulties, due to unpaid bills. In fact, their income comes exclusively from the sale of water. However, the rate of collection of water bills does not exceed 40% of the volumes consumed by farmers. This phenomenon has worsened since 2011, leading to an increasingly restrictive debt and affecting the ability of GDAs to ensure the maintenance of infrastructure and the water supply of farmers. Overall, the situation of the GDAs has not improved and these structures are unable to carry out their tasks (MARHP, 2023).

2.7.3.1. Water policy and current instruments of water regulation

The Water Code promulgated in 1975 governs the allocation of water resources and includes several articles to protect and preserve water resources. Over time, new challenges and threats endanger water resources, such as overexploitation of resources, degradation of quality, unsuitable governance framework, impacts of climate change. A water law reform was initiated in 2009 to reflect the actual social and economic situation in the country. the law was approved by the Council of Ministers in September 2019 for submission to the parliament. Until now the law has not yet been passed (CEDARE, 2014). Public water policies have evolved significantly since the 1960s and remain a constant concern for public authorities. Nowadays, the agricultural sector remains the largest user, using 75 % of resources, however, priority is given to drinking water when needs exceed availability.

From the 1960s to the 1990s, political strategies focused primarily on supply management, particularly through the construction of hydraulic structures and centralized resource management. The country was committed to identifying water potential, mobilizing the resources thus inventoried and hydraulic developments. The State had to increase the rate of mobilization of water resources for the creation of irrigated areas and the establishment of modern and productive irrigated agriculture. Priority was given to large dams in the north of Tunisia and namely Medjerda Region. The central objective of this policy was to ensure national socio-economic development, particularly in terms of food security and quality of life for citizens (FAO, 2023).

The years 1990-2010 saw increased mobilization of supply and the beginning of the transition towards demand management. On the one hand, identified resource mobilization strategies were implemented. They include the construction of large dams, hill dams, water boreholes and recharge and spreading structures. The primary objective of these strategies was to meet the water demand of different sectors over the coming decades, to achieve a mobilization rate of 90% of the water resources potential, and 97% of water supply, drinking water for rural areas and to improve the quality of drinking water in urban areas. However, although it has brought social and economic progress, this supply-side policy has been the subject of criticism, particularly given its social and environmental impacts (FAO, 2023). On the other hand, the transition to demand management aimed to maintain demand at a level compatible with resources.

Centred on the use and optimal development of available resources, the objectives of the new water policy orientation were accompanied by significant reforms on the institutional level (promotion of user associations, decentralization of water management); the legal ("polluter pays" principle) and economic (objective of "true prices", limitation of government' interventions). Parallel to the application of these measures during the 1990s, the exploitation of groundwater and the use of desalination of brackish water opened the way to new resources' possibilities.

Reforms have been implemented through several programs and strategies including:

- The National Strategy for the Promotion of Collective Interest Associations (1992): its objectives consist of promoting user associations within the framework of autonomous technical and financial management and redefining the role of government in water supply rural areas and the management of public irrigated areas (PPI).
- The National Irrigation Water Saving Program (1995): its objective is to rationalize the use of agricultural water. It is favoured by the decision relating to the increase in the investment subsidy granted to modern irrigation equipment.
- The establishment of adequate pricing systems and recovery of water cost: the pricing policy applies particularly in large public irrigated areas managed by CRDA with a view to recovering costs operation and maintenance granted by these management organizations. The main objective lies in optimizing the cost recovery rate based on pricing approaches acceptable to all stakeholders (FAO, 2023).

Considering that pricing is an essential tool of water policy, Tunisia established a tariff revision program from 1998. This revision providing for an annual increase of 15 percent was more or less applied during the period 1998-2003 and these increases took place until 2003. These increases then stopped, hence the low current recovery rate (MARHP, 2016).

The scarcity of water following increased demands due to the effects of climate change has prompted the responsible for managing the water system to rethink their methods of intervention. Attempts to decentralize and involve various levels of the decision-making process are underway. These adaptations should ultimately lead to the establishment of a sustainable water governance approach in Tunisia.

In connection with this trend towards demand management, the Tunisian Constitution of 2014 established the right to water and the obligation for the State and society to preserve this resource and rationalize its exploitation (article 44), as well as the right to a healthy and balanced environment (article 45). The new Constitution of 2022 stipulates that the State must provide drinking water to all in equity and must preserve water resources for future generations (article 48).

The move towards integrated water resources management (IWRM) focused on demand management is confirmed and new strategies are emerging:

- The Strategy for the Sustainability of Hydraulic Systems (2014): its objective is to upgrade GDA and their professionalization for better participatory management of hydraulic systems in a rational, autonomous and sustainable manner.
- The third Water and Soil Conservation Strategy (CES): its objective is better resilience to climate change through the promotion and revitalization of rainfed agriculture, the protection of watersheds, the recharge of water tables and the promotion of natural techniques such as agro ecology.
- The post-2020 National Environmental Strategy: it is focused on the urgency, if not to stop, at least to slow down the destruction of renewable and non-renewable resources, on the establishment of regulations to facilitate its implementation and a policy for the sustainable use of energy, land, water, terrestrial and marine biological resources as well as the reduction of pollution and nuisances of all kinds. Four strategic axes were retained with strategic orientations and quantitative and qualitative objectives: i) the strengthening the legal and institutional system for environmental protection; ii) the protection of environments (water, air, soil and subsoil); iii) the consistency of sectorial policies and programs in terms of environmental protection; and iv) the development and implementation of an environmental governance system (FAO,2023).

Water governance plays a crucial role in managing water resources effectively and sustainably in the Medjerda River basin. Strong water governance frameworks are essential to ensure equitable access to water, efficient water use practices, and effective water resource management strategies. Mechanisms such as stakeholder engagement, regulatory frameworks, monitoring systems, and enforcement mechanisms are vital in promoting transparent decision-making processes and addressing the complex water challenges facing the region. Collaborative efforts between government agencies, local communities, and other stakeholders are essential to enhance water governance in the

Medjerda River basin and ensure the long-term sustainability of water resources in the area

2.7.4.SWOT analysis of project actions

A SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis of the Medjerda River basin's water resources could reveal strengths such as relatively abundant water availability during certain seasons, weaknesses like water pollution and inefficient infrastructure, opportunities for sustainable water management practices and conservation efforts, and threats such as increasing water demand, climate change impacts, and potential conflicts over water allocation. Understanding these internal and external factors through a comprehensive SWOT analysis can help develop effective strategies to address the challenges and capitalize on the opportunities to ensure the long-term health and sustainability of the Medjerda River basin's water resources

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Strengths:	Weaknesses:
Water supply: Medjerda is the main water resource in Tunisia; the watershed provides crucial water resources for drinking, irrigation, and industrial use supporting the livelihoods and well-being of local communities. **Agricultural productivity**: The Medjerda basin supports a thriving agricultural sector, with fertile soils and ample water resources to support a variety of crops, including cereals, fruits, and vegetables. **Biodiversity:** The Medjerda watershed is home to a diverse range of plant and animal species, making it an important ecological hotspot in Tunisia. **Hydropower potential:** The Medjerda River has the potential to generate significant hydropower through the construction of dams and hydroelectric facilities, providing a renewable source of energy for the region. **Valorisation of treated wastewater**: Medjerda site present the potentialities to valorize treated wastewater and use it for irrigation of the most profitable crops, industrial processes, or even direct consumption with proper treatment. This not only helps in reducing water scarcity but also minimizes environmental pollution.	**Water governance**: The Water governance is centralized and controlled by the State. The real involvement of users in decision-making processes does not yet live up to the ambitions displayed. **Inactive consultation mechanisms**: Consultation mechanisms between water managers and operators, such as the National Water Council (CNE), are not sufficiently operational. **Water scarcity**: Despite its abundant water resources, Medjerda can experience water scarcity during dry periods, especially in the face of climate change and increasing water demands for agriculture and urban development. **Water quality:** Medjerda faces challenges related to pollution from agricultural runoff, industrial waste, and urban development, leading to water quality issues and environmental degradation. **Erosion and sedimentation**: The high levels of sedimentation of hydraulic structures in Medjerda due to erosion, deforestation, overgrazing, and poor land management practices can impact water quality, aquatic habitats, and dams' sustainability. **Inefficiency of water management strategies**: Medjerda lacks comprehensive water management strategies to address issues such as water allocation, flood control, and sustainable resource use, leading to inefficiencies and conflicts over water resources. **Inadequate infrastructure**: The existing infrastructure for water management, such as dams, transfer and irrigation canals, and flood protection measures, may be outdated or insufficient to effectively manage water resources in the Medjerda watershed. **Regulation not in line with the situation**: the current water legislation in not reflective of the evolving challenges and

	needs related to water resources and the new water code is not yet approved by the parliament.
Opportunities: **Integrated water Resource Management (IWRM):** There are opportunities to improve water management practices in Medjerda, such as implementing water conservation measures, promoting water-efficient agricultural practices, and investing in smart irrigation technologies to optimize water use. **The use of Non-conventional water for irrigation**: non-conventional waters are not fully exploited and rainwater is not utilized to its capacity in agriculture and municipal applications. Effort should be directed to establish integrated rainwater collection management programs for sustainable development. **Water conservation programs:** There are opportunities to implement water conservation programs in Medjerda, such as promoting water-saving technologies, implementing rainwater harvesting systems, and raising awareness about the importance of water conservation among local communities; **Restoration and conservation projects:** There are opportunities to implement restoration and conservation projects in Medjerda, such as reforestation initiatives, wetland restoration, and habitat conservation efforts, to restore ecosystem health and biodiversity; **Renewable energy development:** The use of new technologies especially in terms of renewable energy such as the agrivoltaic and photovoltaic, to reduce reliance on fossil fuels and promote sustainable energy production; **Collaboration and partnerships:** There are opportunities for local governments, NGOs, private sector organizations, and communities to collaborate and form partnerships to address water-related challenges in Medjerda, fostering coordinated efforts and collective action towards sustainable water management and conservation.	Threats: **Vulnerability to climate change**: Medjerda watershed is vulnerable to the impacts of climate change, including increased temperatures, altered rainfall patterns, and more frequent extreme weather events, which can further exacerbate water-related challenges in the region. **Water scarcity and competition**: for water resources particularly among different user groups such as agriculture, industry, and urban areas, can increase conflicts over water, usage rights, and access to water sources. **Sustainability of hydraulic infrastructure (dams and irrigation systems):** The Medjerda site presents dams having a siltation rate of reservoirs greater than or equal to 25%, among which, three dams have a siltation rate greater than 50%, these are Mellegue, Siliana and Rmil, However, only one of these three dams has reached a lifespan of 50 years, the other two have lifespans of 34 years and 19 years respectively. Considering the same current and future climatic conditions and if there will be no intervention aimed at reducing sedimentation, these dams will probably be completely silted up by 2050 leading to a reduction in surface water resources. **Environmental vulnerability**: The inadequate wastewater treatment facilities in the Medjerda site have significant environmental and public health implications. Properly functioning treatment plants are essential for ensuring the safe disposal of wastewater and preventing water pollution. It is crucial for authorities to address these malfunctions promptly to avoid further contamination of water sources and protect human health.

2.8. Case study Konya

The Konya Closed Basin (KCB), situated in Central Anatolia, is the largest endorheic basin in Turkey, encompassing a total area of 49,963 km2. The basin occupies 6.4% of the country's land area. KCB is geographically located between 31° 7' 29.01'' E - 35° 3' 28.94'' E and 36° 53' 45.17'' N - 39° 29' 10.33'' N (Figure 90). There are two main water bodies in the basin, one of them on the west side (Lake Beysehir) and the other on the north side (Lake Tuz). The center and north parts of the basin have a lower elevation than west and east parts (Figure 91).

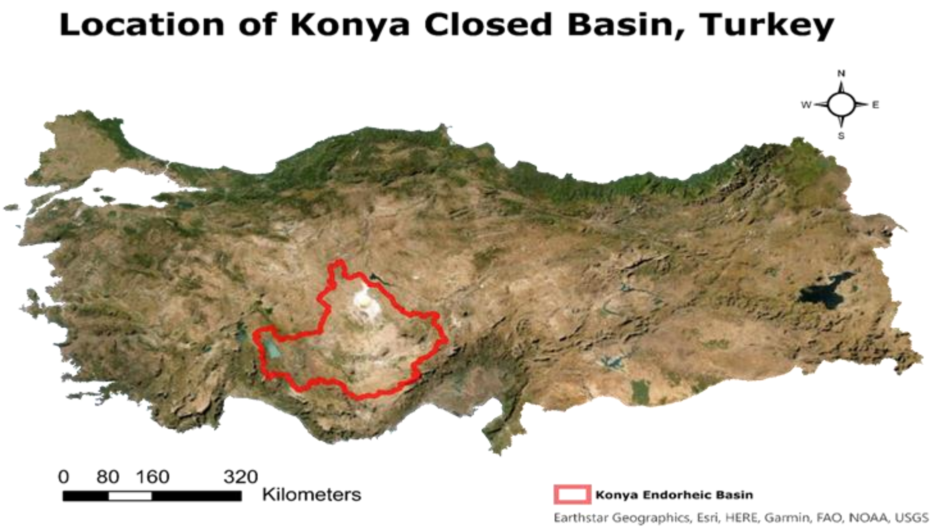

Figure 90 Location of KCB in Turkey.

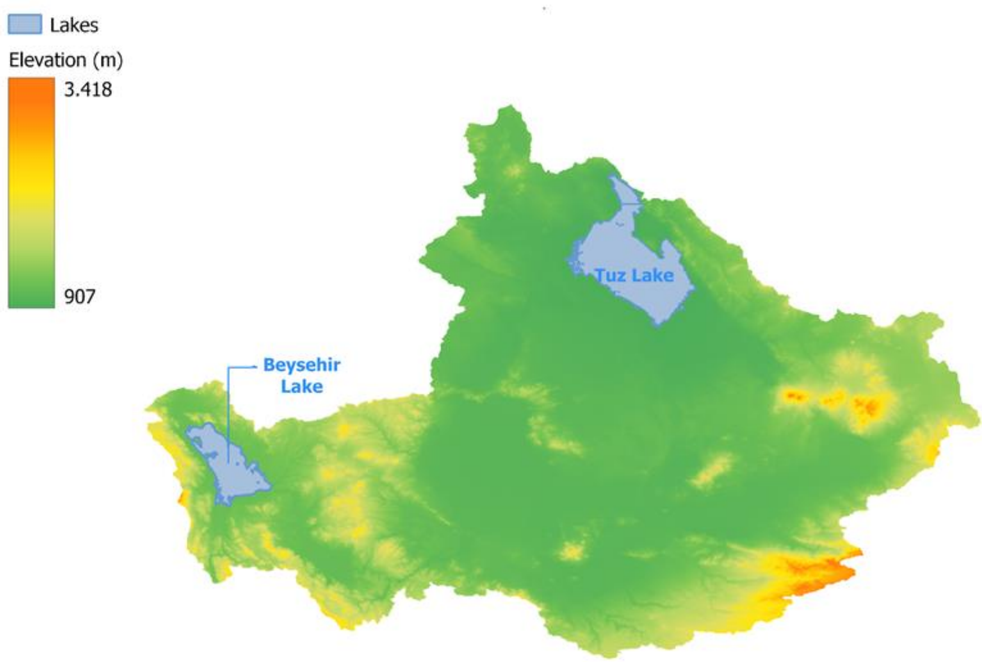

Figure 91 Digital Elevation Map (DEM) of KCB, including the water bodies of the basin.

2.8.1. Biophysical attributes

One of Turkey's twenty-five watersheds, the Konya Closed Basin, has long been the nation's main hub for wheat production. In addition, 60% of Turkey's overall salt production originates from this basin, specifically from Tuz Lake (JMO, 2010). Consequently, the inhabitants of the area have a longstanding tradition of engaging in farming, and the industrial output heavily relies on agricultural produce. In recent years, there has been a notable increase in both agricultural and agro-industry production, leading to an expansion of the region's contribution to the national economy and commerce.

Some surface water sources in the basin, like Beysehir Lake, are important sites for various bird species. This lake, a class-A wetland, is vital for ecological balance, water system regulation, and biodiversity conservation in the basin. There are thirty-two islets in the lake, all of varying sizes. However, as a result of the significant amount of water used for irrigation from this source, it led to the formation of a muddy area in 1990. Since 1991, the Turkish Ministry of Culture has granted this lake 1st-degree Natural Protection Status. Despite having legal protection, the lake faces difficulties such as fluctuations in water levels brought on by insufficient regulations, excessive vegetation growth, fishing activities, urban development, and water contamination (Dursun, 2010).

2.8.1.1. Clmate

The basin has a semi-arid climate with hot and dry summers and cold and dry winters, with annual precipitation ranging between 280 and 350 mm (FAO & GEF, 2019). Rainfall occurs mostly in the winter and spring seasons and is limited or near-zero in the summer months. The annual reference evapotranspiration (based on Hargreaves and Samani method) over the basin ranges between 1100 and 1350 mm (Figure 92).

The basin has historically observed many severe and extreme drought periods between 1972-2009, based on calculation of the SPI-12 meteorological index (Dogan et al., 2012). SPI values between -1.5 and -1.99 are considered severe droughts, while SPI values less than -2 are considered extreme droughts (McKee et al., 1993).

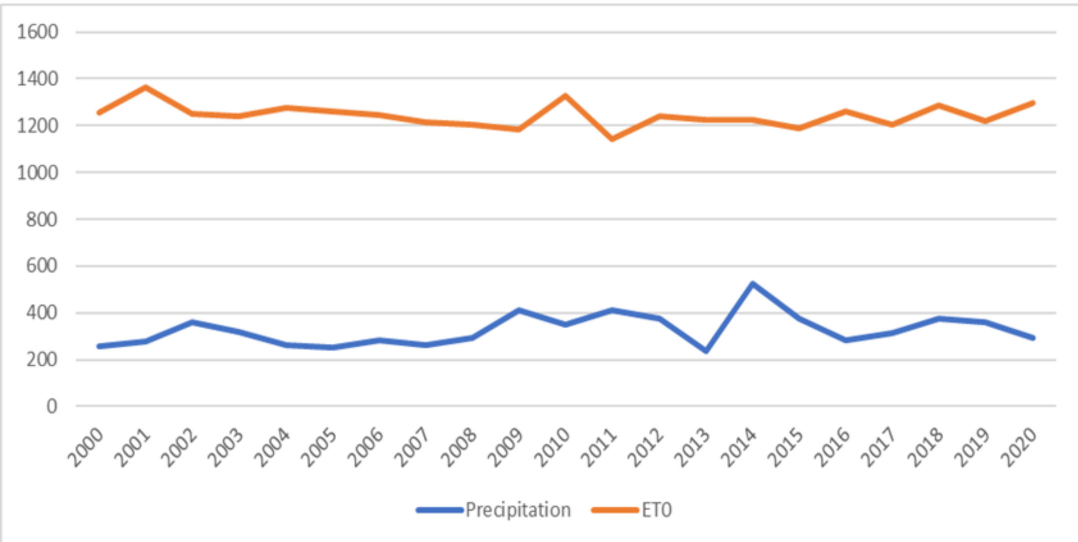

Figure 92 Annual precipitation (mm) and reference evapotranspiration (mm).

2.8.1.2. Hydrological/hydrogeological context

The basin is characterized by a semi-arid climate and minimal precipitation, resulting in water scarcity issues. The basin contains two prominent lakes: Lake Tuz and Lake Beyşehir (Figure 91). Lake Tuz is the second largest lake in Turkey and is also considered one of the largest hypersaline lakes globally (Aydoğdu et al., 2014). The SRTM Water Body Data indicates that Lake Tuz covers a vast area of 1725.9 km^2. Lake Beyşehir, located in the western half of the basin, is the largest freshwater lake in Turkey. The hydrological system of the KCB does not have a dominant stream. Groundwater is essential for water storage and for fulfilling the water requirements in the basin. Nevertheless, the imprudent exploitation of groundwater in recent decades has resulted in a decline in groundwater levels. The shift towards cultivating more water-intensive crops like maize throughout the summer is a contributing factor to the drop. As a result of the imbalance between water demand and surface water, reliance on groundwater has increased leading to a significant growth in both permitted and unregistered wells. It is estimated that more than 100,000 wells are present in the basin with more than two-thirds unregistered. The reduction in groundwater levels is a significant factor in the creation of sinkholes, as it leads to land subsidence (Özyurt et al., 2017).

A simplified hydrogeological cross-section of the basin is presented in Figure 93. The baisn and comprises the Tauride-Anatolide Block (TAB), Sakarya Zone Block (SZB), Neogene (N), and Paleogene (P). The basin primarily consists of two aquifer systems: an upper layer (Neogene) consisting of productive freshwater aquifers, and a lower layer (TAB) consisting of deep aquifers with saline water. Surface water and groundwater from the Taurus Mountains flow through the Paleozoic and Mesozoic karstic carbonates of the TAB lithospheric plate to feed the aquifer systems.

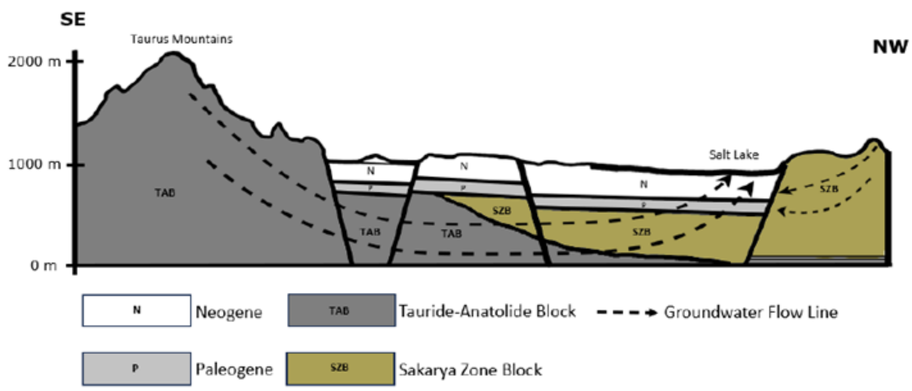

Figure 93 Simplified groundwater flow system in the basin, modified from Bayari et al. (2009).

2.8.1.3. Water resources infrastuctures

The State Hydraulic Works (DSI) has constructed a number of channels and tunnels as well as unnatural water storages to transport and distribute water from Lake Beysehir to the basin's center for use in agricultural and domestic demand sites. The most important channel is the Beysehir-Sugla-Apa (BSA) channel, while the largest unnatural water storage is Sugla, with 277.5 Mm^3 of storage and a 4000 hectare area, which is on the west side of the basin (Figure 94). The BSA channel provides water supply to agricultural regions in the Beysehir and Konya-Cumra subbasins. The second part of the BSA channel connects to the Apa dam. This dam is used for agricultural regions in Cumra district, in the center of the basin. The Apa-Hotamis Iletim (AHI) channel also connects BSA to the

Hotamis storage area, which is another water storage in the basin that is currently dry. There is another important dam in the south of the basin, named Bagbasi on the Goksu River, which is connected to the BSA channel by the Blue (Mavi) tunnel and is the main source of drinking water for Konya city, where more than 3 million people live. Water flowing through the Blue tunnel is used for irrigation of the southeastern part of the basin. Bagbasi dam located in the south of the basin collects water from Afsar and Bozkir dams by using the Hadimi tunnel. The drinking water from Bagbasi Dam directly goes to the Secme water treatment plant, which has a treatment capacity of 366850 m^3/day. Another dam that is being used for drinking water supply is Altinapa Dam, which has a 32 million m^3 capacity and directly gets water to Akyokus treatment plant. This dam is responsible for 13% of the drinking water supply in Konya city.

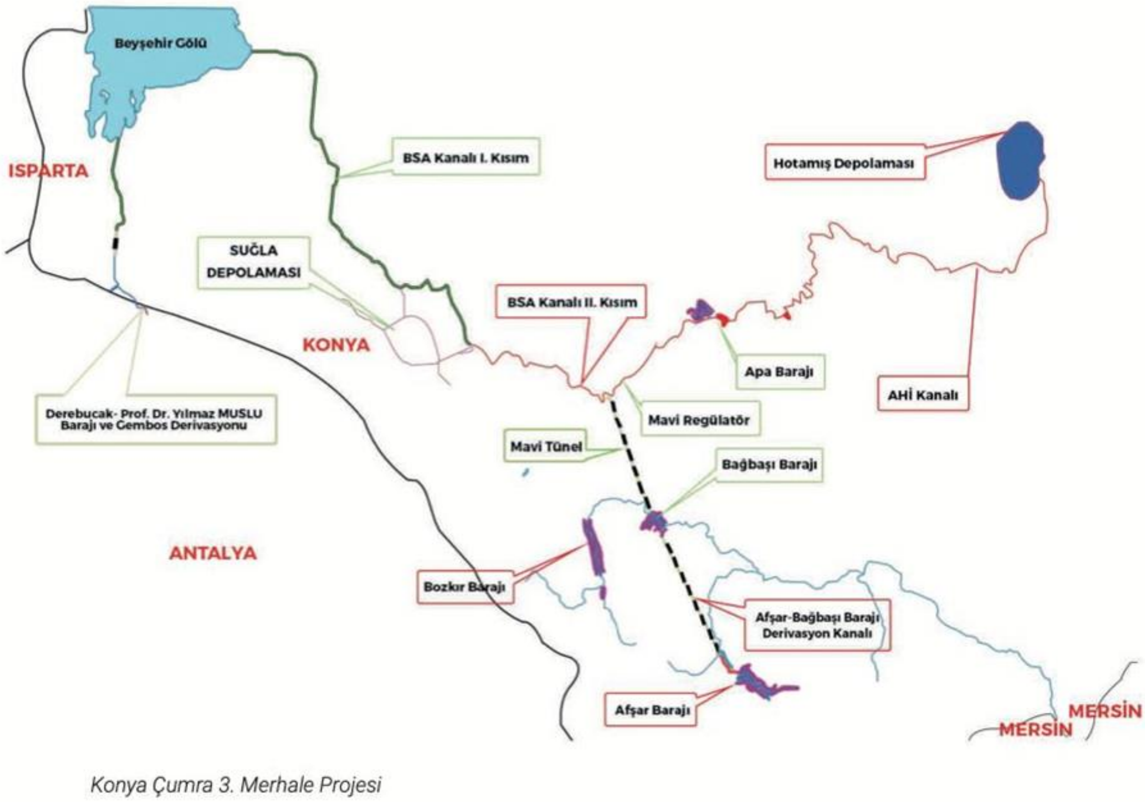

Figure 94 Surface water distribution map of west side of the KCB (Bildirici, 2020).

2.8.1.4. Ecological and ecosystes context and footprint

Konya Closed Basin is home to an array of different ecosystems, with freshwater and saline lakes, vast plains, and high mountains the basin is recognized as one of the 200 significant sites globally identified by the World Wildlife Fund (WWF) due to its abundant biodiversity (Uzun et al., 2011). In the south-western part of the basin lies the Beyşehir Lake, the largest freshwater lake in Turkey, with great ecological significance. Surrounded by fertile agricultural lands and fed by numerous streams, Beyşehir is a critical haven for biodiversity, with 12 important fish species, 7 of which are critically endangered according to IUCN Red List criteria (Doğa Derneği, 2018). The lake is also in the migratory route of several migratory bird species. In the north of the basis, Tuz Lake is a vast hypersaline lake, playing a critical role regulating the basin's hydrology. It is home for some halophytic plants, and is also one of the largest flamingo breeding spots in the world (Eken, et al, 2006).

2.8.1.5. Soil and Land use

Land use in the basin has been significantly impacted by a wide variety of human activities. The region has a significant agricultural activity, with extensive cultivation of grains, corn, and sugar beets. The fertile soils of the basin sustain a flourishing agriculture industry. Another substantial land use component in the region is livestock farming, which involves the rearing of sheep, cattle, and poultry and plays a significant role in the local economy. The presence of industrial zones and urban districts, which reflect the growth and development of the commercial and residential sectors, is what distinguishes the basin in addition to agriculture.

The land use changes in the Konya Closed Basin exemplify the intricate socio-economic and ecological facets of the area. Figure 95 shows the land use classification of KCB based on the Corine land cover database (generated using European Union's Copernicus Land Monitoring Service information) for the 2000, 2006, 2012, and 2018 years. Over the 18-year comparison of land use changes in the basin, significant development in artificial surfaces can be observed, which is primarily due to the expansion of urban centers (Kaya et al., 2022). A slight increase in forest areas can be seen in the southeast part of the basin in 2018, which has reduced agricultural areas in that part. Wetlands have had the most significant increase in land use. The drought periods in the basin have led to a notable increase in wetlands in the area as a result of water source depletion (Kaya et al., 2022).

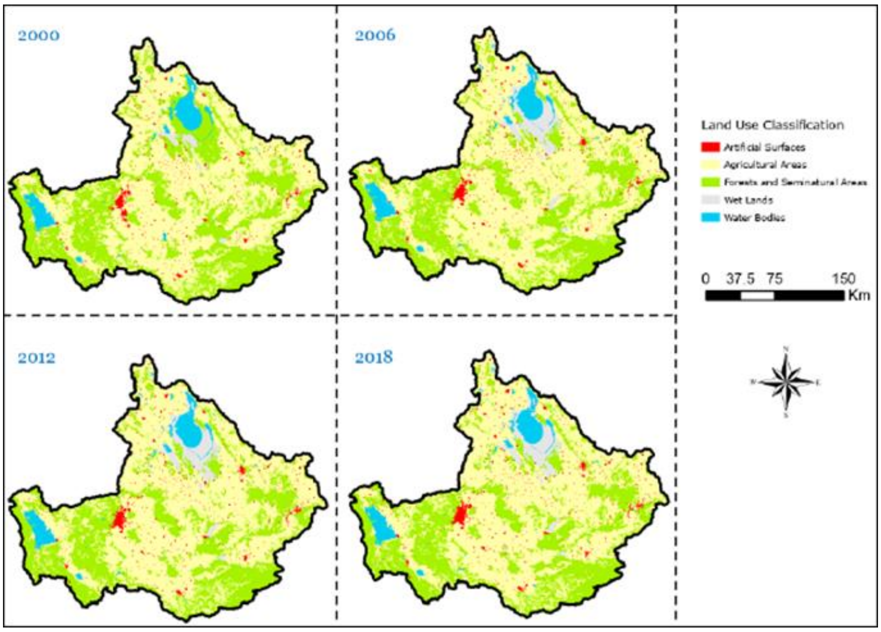

Figure 95 Land use classification of the Konya Closed Basin (Yoloğlu, 2023).

2.8.2. Water development and management

As previously mentioned, many vital factors such as low annual precipitation levels, pivotal role of agricultural production in the area and depleting ground water levels alongside limited surface water resources in Konya Closed Basin make it imperative to understand the physical attributes of the basin along with the socioeconomic factors that are at play. This is of great importance for successfully and sustainably managing water resources in the Konya Closed Basin.

2.8.2.1. Water supply, water storage and distribution

The aquifer system beneath the basin serves as the main reservoir and conduit for water storage and transportation. Due to the water-limited nature of the basin and its high evaporation potential, groundwater is a more dependable water source compared to surface water. Most regions of the basin except the central part use groundwater wells for drinking water.

Nevertheless, due to the unauthorized extraction of groundwater through excessive expansion of wells, the region has experienced a decline in groundwater levels.

Surface water irrigates 230,000 hectares of the basin, and 130,000 of those hectares are in the Cumra agricultural regions. The primary source of water supply for the Cumra agricultural regions is Apa Dam, which is connected to Beysehir Lake by the BSA channel. Another source of Apa Dam is Sugla, an unnatural water storage area. The Beysehir lake, one of the most important surface waters supplies in the basin, which has functioned as a primary water resource located upstream of the basin, provides water for agriculture and residential use in the basin (Bucak et al., 2018; Croitoru et al., 2016; Yılmaz et al., 2021b). This lake is 11.2 m deep, 26 km wide, 50 km long, and 1100 m surface altitude.

There is a water treatment plant near Beysehir Lake to bring drinking water to the Beysehir district, and groundwater is not predominantly used in this region. Dry farming is practiced in the vicinity of Beysehir Lake, where crops such as wheat, barley, and lentils are cultivated. Beysehir Lake is replenished from, surface runoff and groundwater in addition to receiving precipitation in the Beysehir district. Derebucak Dam (Figure 94), which has a total capacity of 130 million m^3 and current storage of 80 million m^3, is another source that feeds the Beysehir lake in the off-season. In the irrigation season, this dam irrigates 3000 hectares in the Yesildag and Derebucak areas.

2.8.2.2. Water uses

The basin's average annual water budget is 4.3 billion m^3 (both surface and ground water resources combined), but the consumption in the region exceeds around 6.5 billion m^3 creating an approximately 2 billion m^3 deficit. Compensating for the deficit through extensive groundwater extraction has led to an alarming depletion of underground water sources, raising concerns about the sustainability of current practices (Yoloğlu et al., 2023). To reduce the stress on ground water resources, a number of large-scale surface water projects, such as an inter-basin water transfer project, have been completed and more projects are either in the phase of construction or in the phase of planning.

In the basin, surface water resources are vital for multiple sectors, and the overall consumption is increasing as the population increases according to the "Sectoral Water Allocation Plan in Konya Closed Basin 2019-2014" developed by the Ministry of Agriculture and Forestry (2018). In the same report, the Ministry of Agriculture and Forestry has analysed water uses in the basin across five main sectors, namely, irrigation, drinking and domestic utility, environmental runoff, industry and energy. In recent years, the water demand distribution in the Konya Closed Basin was analysed across various sectors mentioned above. The predominant sector driving water demand is irrigation, accounting for approximately 90% of the total water usage. Drinking water constitutes around 4%, while environmental water usage represents 4.86% of the overall demand. The industrial and energy sectors contribute modestly to the water demand, with 1% and 0.14%, respectively. These figures are siginificantly different from national and global water demands. According to the "Agricultural Irrigation Sector Policy Document" report developed by TAGEM (2021), the global average water demand for agriculture was 70%, the industrial demand was taking up approximately 20% of the total water demand while drinking and utility water demand was approximately 10%. The same document reported that the annual water demand in the agriculture sector in Turkey in 2021 took up only 77% of the total water demand among different sectors. In comparison to these findings, the agricultural water demand in the Konya Closed Basin surpasses both the national and the global average water demand in the agricultural sector. Consequently, the magnitude of water demand of agricultural activities featuring crop patterns that demand excessive water, such as corn, alfalfa, sugar beet, potatoes, and sunflower, further exacerbate the overall water stress in the Konya Closed Basin considering that the total water demand clearly exceeds the capacity of available water resources. Inefficient irrigation practices compound the issue, hindering efforts to achieve optimal water use (TBMM, 2021). As a result, both surface and groundwater resources in the basin are under severe stress, becoming the epicentre of various environmental challenges.

2.8.2.3. Water management strategies

Turkey's Water Code which was adopted in 1926, almost a century ago, however, it has not been updated since then. There have been recent attempts to update the code in the last two decades, however they are unsuccessful so far. In the meantime, there have clearly been many changes, developments and sectoral growths that have changed the amount and nature of water use in the country, which necessitates a comprehensive update of the water code in line with today's dynamics and future scenarios. The basin's water resources are being managed closely and utilised for sustaining water supply and addressing challenges related to water scarcity. An overview of the key aspects of water management and usage in the basin are discussed below:

- River Basin Management Plan

A National River Basin Management Plan alongside basin-specific management plans based on the former has been crafted by the General Directorate of Water Management which operates under the Ministry of Agriculture and Forestry. The plan includes specific measures and actions that are monitored through the National Water Information System to guide water resource management. It aims to ensure the sustainable management of river basins in Turkey in accordance with the EU environmental and water management standards due to the country's candidacy.

The KCB Management Plan underscores the urgent need for holistic basin management to address environmental challenges, emphasising compliance with EU Water Framework Directive and the formulation of effective measures to safeguard water quality and biodiversity in the Konya Closed Basin. However, when examining the ecological, chemical, and environmental conditions of various surface water reserves, a significant majority is at moderate or high risk, with most unable to meet expected criteria. Factors such as high agricultural demand, inefficient irrigation techniques, increased evaporation due to rising temperatures, and reduced rainfall contribute to the exacerbated condition. Holistic basin management is deemed necessary to address these critical challenges according to the KCB Management Plan.

- Sectoral Water Allocation Plans

To ensure efficient and sustainable use of water resources, Sectoral Water Allocation Plans have been developed for the Konya Closed Basin (Ministry of Agriculture and Forestry, 2018). These plans prioritise the allocation of water based on the basin's hydrological structure, climatic conditions, drought severity, and socioeconomic factors. However, the highest priority is always given to drinking and domestic water supply as well as environmental water needs. One of the significant efforts within the Sectoral Water Allocation Plans is the optimization of crop patterns, particularly in the agricultural sector. By determining water requirements in advance and predicting potential drought conditions, optimal crop patterns are established to allow continuous production and increase the net income of farmers, even in the face of decreasing water resources. The economic benefits of water allocation and the potential social impacts are evaluated in the Sectoral Water Allocation Plans. Action Plans have been prepared, specifying the responsible institutions and organisations. These plans are to be regularly monitored to ensure the implementation of the defined measures. The Sectoral Water Allocation Plan and Action Plan for the Konya Closed Basin are currently in effect.

However, these plans are not implemented well enough or they fail to observe important factors. As it is mentioned in the Grand National Assembly of Turkey Research Commission Report (2021), the water scarcity and distribution issues are not to be solved unless the crops which are high in water demand are opted out from the agricultural production in the basin.

- Drought Management Plan

A drought management plan, deemed necessary in the National River Basin Management Plan (2014), was developed for Konya Closed Basin to address potential water scarcity issues. The plan was initially published in 2015 and updated in 2023 to incorporate changing climatic conditions and their impacts of water resources. The Konya Closed Basin Drought Management Plan adopts an integrated watershed management approach to mitigate the adverse impacts of drought on production resources and socio-economic activities in the Konya Closed Basin. The plan considers the basin's water budget, sensitivity to drought, and employs drought indices, indicators, threshold values, and sectoral impact analyses.

2.8.2.4. Main issues

A comprehensive monitoring program, introduced as part of the measures specified in the river basin management plan, has been implemented in the basin to assess the ecological quality of water resources (Ministry of Agriculture and Forestry, 2018). This includes biological, physicochemical, and hydromorphological monitoring at 62 monitoring points, which have identified 41 reference (unpolluted) water sources. These monitoring efforts have provided valuable insights into the ecological conditions of water bodies in the Konya Closed Basin. When assessing the ecological condition of these water bodies, it is observed that none of them are in a high-level condition. Approximately 18% are in good condition, 34% in moderate condition, 3% in poor condition, and 12% in a weak condition. The ecological condition of 25% of the water bodies is unknown. Notably, Beyşehir Lake, the largest freshwater lake in Turkey, has a moderate ecological condition. Regarding the chemical status, around 56.5% of the water bodies do not meet the required criteria, while only 5% pass the chemical status analysis. The chemical status of 38% of the water bodies is unknown, highlighting the need for improvement in water quality monitoring.

It has been determined that the water demand of the agricultural sector cannot be met 100% in the Konya Closed basin and in its sub-basins in different drought scenarios examined in the Sectoral Water Allocation Plan prepared by the General Directorate of Water Management and that significant deficits have occurred. As a solution to this situation, inter-basin water transfer projects have been planned and implemented. Approximately 90% of the water potential in all sub-basins is used in the agricultural sector. Again, according to the action plan of SYGM, despite this very high allocation rate reserved to the agricultural sector, it is predicted that the rate of meeting the water demand will further decrease significantly in today's conditions and especially in severe and very severe drought scenarios. Even in sub-basins such as Beyşehir and Konya Çumra, where important surface water resources are located or transferred, it is stated that the rate of meeting agricultural water demand in severe and very severe drought scenarios will decrease from around 90% under normal conditions to around 75%.

2.8.3. Water resources governance system

The surface water governance in Konya Closed Basin takes a multilevel governance form. The governance organization mainly falls under the scope of three ministries which are namely the Ministry of Agriculture and Forestry, the Ministry of Environment, Urbanisation and Climate Change, and the Ministry of Industry and Technology. Authorities responsible for surface water governance mainly operate under these three ministries. The policymaking bodies are centrally organized mainly in Ankara and have representative regional offices in the basin.

The policymaking and implementation bodies are organized to make the coordination and implementation efforts across different scales possible. However, horizontal coordination and communication problems are prevalent due to factors such as overlapping terms of reference and lack of local engagement.

2.8.3.1. Water policy and current instrments of water regulation

- General Directorate of Water Management (SYGM)

SYGM (Su Yönetimi Genel Müdürlüğü) is a regulatory management body that operates at national scale, under the Ministry of Agriculture and Forestry. It has six departments working on basin management, water quality, monitoring and water information system department, flood and drought management, research and assessment, water law and policy, and therefore has a significant impact at local scale. Although planning and designing the necessary policies and regulations is the primary competence and expertise of SYGM, implementing the developed policies and management plans is not in the scope of SYGM's competence and area of primary interest.

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

The State Hydraulic Works General Directorate's mission involves the utilisation of the country's water resources in accordance with science and technology, focusing on the development of water and related soil resources in line with environmental sensitivity and sustainability principles. DSI is responsible for planning, managing, developing, and operating all water resources in the country, operating within the Central Government Budget and under the Ministry of Agriculture and Forestry. As a public institution, it effectively fulfils objectives such as flood protection, widespread irrigation, hydroelectric power generation, and supplying drinking water to major cities, as well as providing drinking water to settlement areas with municipal organisation. The Directorate prioritises its activities, particularly in dam construction, a common point of the four aforementioned purposes. Consequently, it is recognized as an organisation that constructs dams in the country and is an authoritative institution in the allocation of various uses for the country's water resources (Devlet Su İşleri Genel Müdürlüğü, n.d.).

- Central Basin Management Board and Provincial Basin Management Boards

The Central Basin Management Board is chaired by the Deputy Minister of Agriculture and Forestry, with members representing various relevant ministries and institutions such as the Ministry of Industry and Technology, Ministry of Environment, Urbanization and Climate Change. The board's main responsibilities include coordinating inter-agency efforts for the preparation and implementation of basin-scale management issues, and overseeing the execution of basin management decisions.

The Provincial Basin Management Boards are established by the governors of respective provinces and consist of representatives from various governmental bodies, local authorities, and stakeholders. The boards contribute to the implementation of basin-scale management plans within their provinces, ensuring the protection of drinking-water resources and coordinating with relevant institutions. They evaluate the work of Provincial Water Management Coordination Committees, report to the Central Basin Management Board, and actively engage the public in the development, review and updating of basin management plans. The boards can also establish sub-committees and working groups to address specific issues within their jurisdictions.

- Konya Plains Project Regional Development Administration (KOP BKI)

Konya Plains Project (KOP) Regional Development Administration (BKI), established in 2011, plays a pivotal role in accelerating the development of the KOP Region, comprising Konya which is the centre of KOP BKI, Aksaray, Karaman, and Niğde provinces. Operating under the Ministry of Industry and Technology, KOP BKI's primary responsibilities include preparing action plans to ensure the harmonious execution of projects and activities by relevant institutions, coordinating their implementation, monitoring, and evaluation.

- Provincial and District Directorates of Agriculture and Forestry

The Provincial Directorates of Agriculture and Forestry, along with the District Directorates of Agriculture and Forestry, play a crucial role in the development and enhancement of agricultural practices within their respective regions. The District Directorates are responsible for various tasks, including collecting and proposing necessary information for the preparation of programs and projects aimed at the development of the district and the improvement of farmers' income and living standards. They implement and evaluate relevant portions of programs and projects, conduct training programs for farmers, assist in the establishment of farms based on sample farm development plans, and identify and communicate agricultural input needs to the provincial directorate.

On the other hand, the Provincial Directorates of Agriculture and Forestry have a broader set of responsibilities. They conduct agricultural inventories, prepare and disseminate agricultural extension programs, collaborate with stakeholders for program implementation, organise trials and demonstrations in collaboration with research institutions, address farmers' issues, facilitate processing and marketing of agricultural products, predict agricultural product yields, assess risk criteria in animal and plant health, and formulate plans to prevent the spread of infectious diseases. They also manage animal breeding activities, oversee quarantine services, monitor the production and distribution of agricultural products, and enforce regulations related to food safety.

- Irrigation Unions

The irrigation unions play a crucial role in the rational use of the country's surface water resources for irrigation purposes, in coordination with DSI. They are tasked with operating, maintaining, and managing irrigation facilities approved by DSI, as well as developing new projects to enhance these facilities. The unions are not to pursue profit in their activities related to the operation, maintenance, and management of transferred facilities. User service fees are designated every year accordingly. The law dictates that all revenues collected from water user service fees, penalties, donations, and other income sources should be entirely allocated to the operation, maintenance, and management responsibilities of the transferred facilities.

- Chambers of Agriculture

Chambers of agriculture aim to provide professional services and their objectives include meeting the common needs of farmers, facilitating their professional activities, promoting the development of the agricultural profession in line with public interests, fostering honesty and trust in the relationships among professionals and the public.

Primary responsibilities and powers of the Chambers include gathering agricultural-related news and information, conducting necessary studies and gathering key statistics, providing information and records upon request, making recommendations to public and private institutions, collaborating with trade and industry chambers, and engaging in educational, promotional, and advisory activities to support agricultural development. Other key functions involve maintaining farmer records, organising and participating in fairs and exhibitions related to agricultural production and development.

2.8.4.SWOT analysis of project actions

Strengths:	Weaknesses:
Physical Characteristics of basin: The Konya closed basin is a vast plain with fertile soil and natural subsurface storage (aquifer system) that is well suited for agricultural activities **Agricultural Production**: The region has a bigger than average farm size compared to the rest of the country, with farmers having access to modern agricultural technology, such as drip irrigation, machinery and remote-control technologies. **Awareness**: Farmers and policy-makers have strong awareness on groundwater depletion and potential impacts of climate change on groundwater resources **Monitoring:** Since 2019, the State Hydraulics works has high resolution spatial and temporal monitoring stations for groundwater level and selected water quality parameters across the basin	**Limited Precipitation: The average annual precipitation is** 380 mm/year about half the national average precipitation. The low precipitation rate necessitates some irrigation in the spring and summer months for most crops. **Scarce Surface Waters**: The basin does not have a dominant river and surface water bodies are severely dependent on precipitation. **Uncontrolled Groundwater Depletion:** Uncontrolled groundwater extraction, especially for agricultural purposes, has resulted in declining groundwater levels, exacerbating surface water scarcity issues. **Inefficient Water Use:** Cultivation of water-intensive crops contribute to the overconsumption of water resources, exacerbating the imbalance between supply and demand. **Governance**: Lack of coordination for implementation of rules and regulations. Redundancy between state institutions, for enforcement of rules and regulations. **Groundwater Management**: The basin has more than 100,000 groundwater wells, two thirds without permit which complicates the implementation of new policy or regulations

Opportunities:	Threats:
Potential Policy Reforms: Updating water management policies and regulations to address current challenges and promote sustainable water use practices could lead to more effective resource allocation and conservation. **Alternative Water Sources:** Exploring alternative water sources such as treated wastewater and rainwater harvesting could help alleviate pressure on surface and groundwater resources. **Stakeholders**: Willingness of stakeholders to act upon the problems and collaborate with researchers.	**Climate Change:** Increasing temperatures and changing precipitation patterns due to climate change pose a significant threat to water resources, exacerbating existing water scarcity issues. **Over-Exploitation and Biodiversity Loss:** Continued over-exploitation of both surface and groundwater resources without proper regulation and management could lead to irreversible environmental damage in rich biodiversity areas. **Sinkholes**: The rate of sinkhole occurrences in the central region of the basin has increased in recent years due to increased groundwater extraction threatening farmer security, agricultural lands, and structures

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