NEXUS-NESS

NEXUS NATURE ECOSYSTEM SOCIETY SOLUTION

Fair and sustainable resource allocation demonstrator of the multiple WEFE Nexus economic, social and environmental benefits for Mediterranean regions

GRANT AGREEMENT NUMBER 2042

Deliverable D3.1
The NEXUS Ecosystem Labs: depicting the WEFE resources and challenges
V1.1 30 May 2022

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WP3 Leader and Task 3.1 Leader: SSSA, Rudy Rossetto

NEXUS-NESS - NEXUS NATURE ECOSYSTEM SOCIETY SOLUTION: FAIR AND SUSTAINABLE RESOURCE ALLOCATION DEMONSTRATOR OF THE MULTIPLE WEFE NEXUS ECONOMIC, SOCIAL AND ENVIRONMENTAL BENEFITS FOR MEDITERRANEAN REGIONS

GRANT AGREEMENT NUMBER 2042

Deliverable D3.1

The NEXUS Ecosystem Labs: depicting the WEFE resources and challenges

30 May 2022

WP3 Leader and Task 3.1 Leader: SSSA, Rudy Rossetto

Cite as: Rudy Rossetto, Laura Ercoli, Alessandra Francini, Nora Annesi, Enrica Caporali, Elena Bresci, Giulio Castelli, Tommaso Pacetti, Jerome El Jeitany, Leonor Rodriguez Sinobas, Illiasou Naroua, F. Abdell, M. Fetoui, M. Ben Zaied, S. M'hemdi, R. Belayadi, M. Ouessar, Mohamed Bahnassy, Osama Rady Mohamed, Rasha Badr El-Din, Basma Hassan Saad, Abdel-Wahab Shalaby, Sendiana Hamdy Shahin, The NEXUS Ecosystem Labs: depicting the WEFE resources and challenges, PRIMA NEXUS-NESS Innovation Action (PRIMA H2020 GA 2042), Project Deliverable 3.1, 30 May 2022

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Deliverable Identification

Deliverable No and Title	**D3.1 The NEXUS Ecosystem Labs: depicting the WEFE resources and challenges**		
Grant Agreement No	2042	**Acronym**	NEXUS-NESS
Project Full title	Fair and Sustainable Resource Allocation Demonstrator of the Multiple WEFE Nexus Economic, Social and Environmental Benefits for Mediterranean Regions NEXUS Nature Ecosystem Society Solution (NESS)		
Funding Instrument	PRIMA: To achieve, support and promote integration, alignment and joint implementation of national R&I programmes under a common research and innovation strategy to address the diverse challenges in water scarcity, agriculture, food security.		
Call	PRIMA SECTION 1 (IA) Demonstrating benefits of the Water-Ecosystem-Food Nexus approach in delivering optimal economic development, achieving high level of environmental protection and ensuring fair access to natural resources		
Work-Package No and Title	Work Package 3: Nexus Ecosystem Labs for NEXUS-NESS Service operationalisation		
WP- Main Beneficiary	SSSA		
WP-Leader	Rudy Rossetto, rudy.rossetto@santannapisa.it		
Task No and Title	Task 3.1 – Nexus Ecosystem Labs		
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Status	Draft ☐ Final ☒		
Dissemination Level	Internal ☐ Public ☒		
Reviewed by	Fernando Nardi (UNISTRAPG), Xenia Schneider (XPRO)		
Abstract	Report describing the major specifications of the 4 NELs with specific focus on WEFE Nexus resources, risks and policies. The NEL mapping provides a full picture of the "as it is" setting of the NELs. An initial presentation of the NELs Grand Challenges is provided.		
Key words	WEFE Nexus, NEXUS Ecosystem Lab, Water Resources Management, Natural resources, Energy, Climate change, Irrigated agriculture, Governance		
DOCUMENT HISTORY			
Planned Release Date	30 May 2022	**Actual Release Date**	30 May 2022
Version	V1.1	**Released Version No**	V1

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1. Purpose of the Deliverable

In Work Package 3 "***Nexus Ecosystem Labs for Nexus Ness Service operationalization***" of the **PRIMA NEXUS-NESS project**, following the work done in Work Package 2 "***WEFE Nexus transition through Innovation Ecosystem Approach***", four **NEXUS Ecosystem Labs** (NELs; Figure 1) are established: i) one in **Italy** (coordinated by SSSA with participation of all Italian partners); ii) one in **Spain** (coordinated by UPM supported by UNIFI); iii) one in **Tunisia** (co-coordinated by IRA and CRDA), and iv) one in **Egypt** (coordinated by UA). It is worth noticing that work to be done in Work Package 3 lies on top of that done in Work Package 2 where the collaboration/innovation framework and methodology based on Responsible Research Innovation Roadmap is set.

Building on **existing literature and data** and **background knowledge**, this Deliverable aims at mapping the NEL's WEFE Nexus **resources**, **challenges** as well as the **stakeholders** and **policies** in the 4 investigated areas. The NEL mapping provides a full picture of the "as it is" setting of the NELs. Moreover, the NEXUS **Grand Challenges** are provided for each NEL in order to present some of the main themes and topics that are discussed and researched.

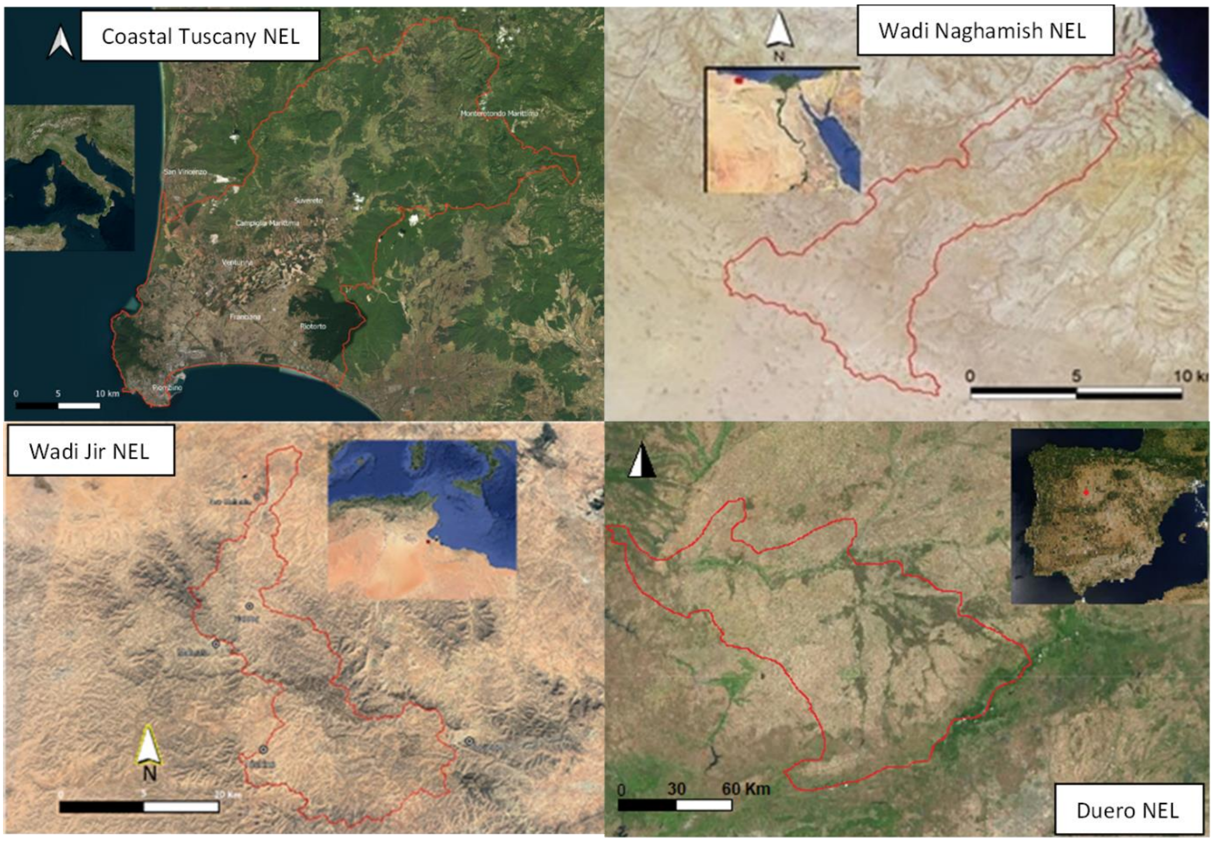

Figure 1. The four NELs areas testing and demonstrating the NEXUS-NESS approach.

2. Introduction

This deliverable is structured in the form of a **synthetic short document** presenting the work done in Task 3.1 "***Nexus Ecosystem Lab***" and four annexes in English (**four booklets**), one for each NEL, presenting the main characteristics of the NEL, their present position within the WEFE context, and the main Grand Challenges to be researched during the NEXUS-NESS PRIMA project.

Each booklet has a cover page with a nice photo of the NEL, the NEL's name and a significant title addressing the main issues in the NEL, the project logo, and an index. The content of each booklet is divided into Sections.

Section 1 consists of a **short introduction to the NEXUS approach and the NEXUS-NESS project** (this has been provided for all the NELs by the Work Package 3 coordinating team).
Section 2 details the **geographic and socio-economic situation**. In this section a general description of the NEL context is provided. This section includes information on (in the following order):

- Geographical setting and administrative borders settlements, and population;
- Geological, geomorphological and pedological setting;
- Climate setting and extremes;
- Socio-economic and technological situation.

Section 3 presents an **overview of the natural resources**. In this section a description of the current resources situation in the NEL context is provided. The section includes, when available, information on (in the following order):

- **Water resources, uses, infrastructures and impacts**
  - surface and subsurface hydrology, information on the hydrochemistry,
  - uses of the water resources,
  - relevant water infrastructures/works,
  - forecast on climate change impact,
  - environmental impacts or conflicts among stakeholders
  - information on main projects foreseen or in progress addressing this resource.

- **Land resources, uses, infrastructures and impacts**, including exploitation, related infrastructures, and impacts (if any). Information on agriculture and on any other relevant land use making use of resources are given. In addition, information on how irrigated agriculture is deployed (source of water, irrigation methods, energy to power the irrigation system) are provided.

- **Energy resources, uses, infrastructures and impacts**, including information on relevant energy sources in the NEL area, its exploitation, related infrastructures, and impacts (if any) or information on how energy and electricity is provided in the area.

- **Environment and Ecosystems**, including peculiar ecosystems existing in the NEL and how these are impacted or have been impacted by the land use and the use of the different resources.

Section 4 summarises the **governance framework** and presents the **stakeholders**, **as a whole**, highlighting the most relevant and why they are so relevant, providing information on the National/Regional governance context, the Local Institutional setting, Nexus-relevant policies and Cross-sectoral governance, citizen, government and stakeholders relationships.

Section 5 introduces the NEXUS Grand Challenges starting from the challenges identified in the project proposal for each NEL.

References are listed to provide a sounding background to all the information presented in each of the booklet. A final last page shortly presents the three other NELs booklets and invites the reader to consider deepening the issue by reading them. These booklets exploit also the work done in Work Package 2 - Sub-Task 2.2.1.

2.1 The original NELs Grand Challenges

In this section, for each NEL, we report the initial Grand Challenges foreseen in the project proposal. They may be differently presented in the Booklets for two main reasons: i) as the work at each NEL started more information were available to guide the analyses to be performed; ii) those described in the project proposal and in the booklets are initial exploratory challenges to be deepened and defined during the Responsible Research Innovation (RRI) approach (see work done in Work Package 2 and related deliverables). In the first months of the NEXUS-NESS project with the kick-off of at all the NELs an initiation WP3-driven (also WP2-based) pre-investigation of the specific co-definition of the NEL challenges was developed, coordinate by NEL reference partners. While initiating the RRI-based NEL local workshop organization where the above/following challenges will be discussed, refined, added, two core challenges have been confirmed, as proposed in the workplan. One more challenge may be expected to be co-identified and raised by Month 12 after the NELs workshops with all selected stakeholders will take place.

In the following sub-sections the original Challenges as foreseen in the project proposal are listed.

1) ***The Coastal Tuscany NEL (Italy)***

The workplan indicated the following three Grand Challenges for the Italian NEL:
1) Fair use of water resources. Concurrent water uses for drinking water agricultural production and industrial production (C-W-E-F) leading to unsustainable exploitation vs. innovative shared and sustainable use of resources.
2) Non-conventional use of water for agricultural production. Treated wastewater reuse and agricultural production for reducing groundwater exploitation and energy consumption (C-W-E-F) vs. release of secondary treated wastewater in the environment.
3) Boosting the value of ecosystem services for a sustainable management of resources. Integrated use of rural areas to provide services to the whole plain. Services to be foreseen are climate mitigation/adaptation, water purification, water supply, food production, soil conservation.

2) ***The Duero hydrological management units Cega-Eresma-Adaja and Tordesillas-Toro NEL (Spain)***

The workplan indicated the following three Grand Challenges for the Spanish NEL:

1) Adapt irrigation strategies to changing climatic conditions. Identify optimal irrigation technology to mitigate water stress and find shared solution with overlapping needs/issues among different stakeholders.

2) Manage water needs and optimize energy costs. Identify WEFE Nexus trade-offs and best compromises for improving water/energy use in the irrigation district to further improve the agroecosystem and rural life.

3) Solar, wind renewable energy sources preserving land and ecosystem functions. Increased energy production by renewable energy is challenging land and ecosystem services.

3) ***The Wadi Jir NEL (Tunisia).***

The workplan indicated the following three Grand Challenges for the Tunisian NEL:

1) Sustainable Food production and water stress. Investigate the increasing demand for water while accounting for the space and time imbalance of water quantity and quality makes water scarcity one of the most urgent problems of the region.

2) Water technology and policy innovations. Investigate the linkages between the new technologies (gabion units, ground water recharge wells, etc.) introduced by the government (novel policies and subsidize investments) and traditional systems under a WEFE Nexus approach

3) Use of renewable energy. Investigate the ability to collect underground water using solar energy. E.g. photovoltaic films to become self-sufficient in water and energy needed.

4) ***The Wadi Naghamish NEL (Egypt)***

The workplan indicated the following three grand challenges for the Egypt NEL:

1) Optimal and fair allocation of resources. Domestic, agricultural, and industrial water utilizations put a threat to water resources sustainability in a dryland agroecosystem.

2) Innovative utilization of water for agricultural production. The presence of a huge wastewater plant makes it easy to re-use large amounts of water for irrigation and industry.

3) Green economy for sustainable production. Introducing renewable wind and solar energy to the Bedouin community will boost the agricultural and industrial production as well as keep the environment safe from pollution and deterioration.

3. Work done

In order to achieve the completion of this deliverable several steps were taken. They are sum up below:

a) Conceptualisation of the work to be done (Task Leader);

b) Presentation to the Project Coordinator for revision and approval of the work to be done;

c) Discussion of the work concept with UNIFI colleagues and with leading partners from the NELs;

d) Sharing of a 5 pages booklet concept (.pdf file) to be followed by the NELs leaders for drafting the booklet in an initial form;

e) Booklet drafting at each NEL: data, pictures and information retrieval, map productions, text drafting;

f) Setting cooperation between UNIFI team and AU (for the Egyptian booklet) and UNIFI and IRA (for the Tunisian booklet) to support text drafting;

g) Exchange of a number of draft documents for at least four revision rounds between the Task leader and the NELs leaders;

h) Interactions and exchanges between the Tunisian and Egyptian teams and the UNIFI team, editing of the Tunisian and Egyptian documents;

i) Delivering of a final draft form of the booklets by the NELs leader to the Task leader for approval;

j) Upload in the NEXUS-NESS shared folder for revision by the Project Coordinator and partner XPRO;

k) Drafting of the deliverable document text;

l) Drafting and editing of the four booklets in the final form;

m) Final editing of the Deliverable text and of the four Booklets;

n) Submission of the deliverable.

3.1 Delays respect to the work plan

This deliverable is submitted with a four months delay due to the COVID emergency and slow data gathering at the NELs. Nonetheless, this delay did not affect work done in other Work Packages and it is produced to be used in the first NEL Workshops to be run in April/May 2022.

4. Results

Four booklets have been prepared in English language, one for each NEL. They are titled:

Booklet 1 – ***The Coastal Tuscany NEL (Italy).*** *Exploring innovative ways for conjunctive use of surface water groundwater and non-conventional waters to boost agricultural production, improve environmental quality, reduce energy consumption, and adapt to and mitigate climate changes.*

Booklet 2 – ***The Duero hydrological management units Cega-Eresma-Adaja and Tordesillas-Toro NEL.*** *Looking forward to water and food security based on RRI approaches on WEFE nexus*

Booklet 3 - ***The Wadi Jir NEL (Tunisia).*** *Towards an efficient allocation of scarce natural resources in arid environments of south-eastern Tunisia through adopting Nexus approach.*

Booklet 4 – ***The Wadi Naghamish NEL (Egypt).*** *Fair and Sustainable Resource Allocation Demonstrator*

of the Multiple WEFE Nexus Economic, Social and Environmental Benefits for Mediterranean Regions.

The four Booklets are attached to this Deliverable document.

Table 4.1 presents synthetic information on the four NELs as derived by the four booklets.

The work performed in Task 3.1 allowed a comprehensive review of the status of the resources, impacts, current criticalities, and of the WEFE approach at each NEL. It also allows incorporating the social dimension into a resources-dominated set of problems. Data gathering, useful for undertaking work in other Work Packages, such as Work Package 4, started.

NEL	Country	Investigated area (Km^2)	Major Cities	N. of Inhabitants	Major water source	Most relevant crops	Irrigated area (ha)	Major energy source
Coastal Tuscany	Italy	600	Piombino, Campiglia Marittima, Suvereto	50000 (plus about 200000 tourist arrivals per year)	Groundwater, Harvested rainwater, Reclaimed wastewater	Vineyards, Olive trees, Winter cereals, Artichokes, Horticultural crops	1400	Fossil fuels, Geothermal, Solar and Wind
Duero (two units, CEA and T)	Spain	CEA: 5000 T: 7500	CEA: Segovia/Ávila T: Zamora	CEA: 288000 T: 138420	Surface water (reservoirs) and groundwater	Cereals, Horticultural crops	CEA: 8822 T: 9106	Fossil fuels, Solar, Hydroelectric
Wadi Jir	Tunisia	155	Matmata, New Matmata	18000	Surface water, Harvested rainwater	Olive/Fig/Almond trees, Legumes, Barley, Wheat	900	Fossil fuels
Wadi Nagamish	Egypt	105	El-Garawla Village	3000	Harvested rainwater, Groundwater, Reclaimed wastewater	Fig, Olive, Almonds trees, Barley, Wheat, Tomatoes, Woody crops	210	Fossil fuels

Table 4.1. Major information from the NEXUS-NESS NELs.

Booklet 1

The Coastal Tuscany NEL (Italy)

Exploring innovative ways for conjunctive use of surface water groundwater and non-conventional waters to boost agricultural production, improve environmental quality, reduce energy consumption, and adapt to and mitigate climate changes

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1. The Water Food Energy Ecosystems NEXUS

Natural resources scarcity is a major environmental issue since the middle of the twentieth century. Many factors like population growth, climate change, land exploitation (or land use change) contributed to the depletion and deterioration of ecosystems and the shortage of resources like water, soil quality and raw materials (Cramer et al., 2018). Each one of these resources impacts different sectors, but these challenges are commonly dealt with separated policies and strategy, or what can be dubbed as "Silo thinking" (Salleh, 2016): a mindset where governing authorities and sectors do not share the same vision whilst operating without proper collaboration. Silo thinking can be found in several government policies for example, when an agricultural department aims at ensuring food security by increasing irrigation demand, while the water department calls for reduction in water usage based on available volumes. The connection among these sectors and departments is missing while several connections are easily identifiable (Figure 1.1). Energy is needed for crop irrigation and food processing, water is needed for growing food, land use impacts water availability and water quality, energy is needed to pump/divert, treat, and distribute water, etc.

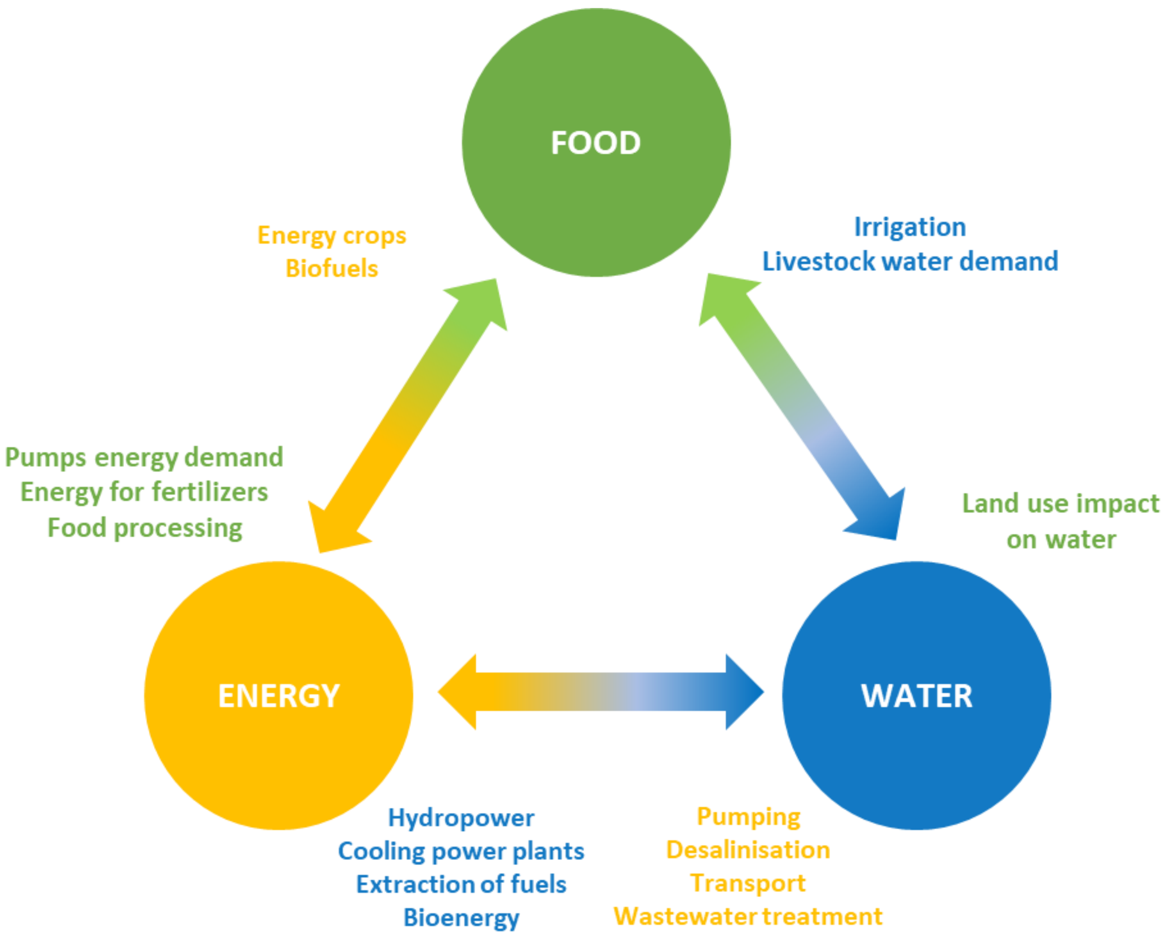

Figure 1.1. Typical Nexus connection diagram.

Cambridge dictionary defines the term NEXUS as an "*important connection between the parts of a system or a group of things*". Through the NEXUS thinking, resources are looked upon as being connected parts of a bigger system with synergies and trade-offs. The power of such a concept lies in its integrative capabilities, forming an umbrella under which multiple stakeholders can act (Simpson and Jewitt 2019). The resulting NEXUS system evaluation emerges consequently as a holistic analytical method driven by participation, research and science, with the final aim to provide adequate governance directions and policies for integrated and sustainable resource planning and management.

Several approaches may be implemented to avoid this silo-thinking that still characterizes the different sectors and actors of the WEFE components. Top-down (from policy to operations) or bottom-up (from the ground where people represent the main driver for mainstreaming the NEXUS) actions may be adopted with pros and cons of both

approaches. NEXUS-NESS recognises the core importance of bottom-up citizen-centred technological and behavioural change to favour the uptake of NEXUS approaches.

An opportunity for collaboration

Within the methodologies presented by the NEXUS, a critical factor of collaboration and dialogue through science lies. Because of this, the NEXUS approach is being adopted by major stakeholders and policy makers like the United Nations, European Commission, NGOs, and important academic institutes. Its compatibility with the Sustainable Development Goals, with the existence of the applied cases incorporating societal and economical aspects, despite limitations, allows the development of further studies and connections between the water, energy, food, and ecosystems, whether exploring their internal relationship or finding their response to the several drivers. Hence, a framework for dialogue and collaboration can be set, through NEXUS thinking, between businesses, NGOs, and the public sector.

NEXUS-NESS - Nexus Nature Ecosystem Society Solution. A HORIZON 2020 PRIMA project

The NEXUS-NESS PRIMA project implements the Innovation Ecosystem Approach (IEA) at four selected areas, called Nexus Ecosystem Labs (NELs). The approach focuses on stakeholder engagement and actionable information, and integration within a 'NEXUS' framework, to ensure fair and sustainable resource allocation. Each NEL has its own challenges and benefits obtained from the NEXUS approach. The geographical variability between the NELs helps in demonstrating the capability of NEXUS thinking in overcoming the different challenges. The IEA is supported by the implementation of the Responsible Research Innovation Roadmap (refer to Deliverable 2.1 of the NEXUS-NESS project for more information; Schneider 2021).

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2. Geographic and socio-economic context

The Italian NEL Coastal Tuscany is located in Val di Cornia (Fig. 2.1), a coastal alluvial plain in the Province of Livorno. Val di Cornia takes its name from the river crossing the plain: the Cornia River. While in the plain the bulk of human activities occur, the upstream part of the basin is relevant as there forms the river flow. This flow recharges the aquifer that is, in turn, the main source of water for all the human activities in the plain. Hilly areas sides the Val di Cornia plain. The activities run in the NEL will then include work to be done on the alluvial plain and in the upper part of the basin, where energy from geothermal sources is produced. The NEL area is about 600 Km^2.

Figure 2.1. Geographical setting of the Coastal Tuscany NEL. The north-western part of the area can be referred to the headwater catchment of the Cornia River, while south of Suvereto down to the sea extends the alluvial plain.

In the Cornia plain, the main sedimentary deposits refer to alluvial, marsh, lagoon and dune cordons, Holocene in age (Fig. 2.2; Boschian et al., 2006). The pre-Neogenic bedrock consists of tectonic units involved in the structuring phases of the Apennine chain of the upper-Oligocene. These units mainly belong to the Ligurian domain along the eastern edge, while along the north-western side mainly outcrop units belonging to the Tuscan domain. Figure 2.3 presents the distribution of soil hydrologic groups in the Cornia plain and adjoining hilly areas. The area is geothermally active and geothermal springs give rise to some well-known SPA plants.

The area is classified as "Csa" climate type (Köppen-Geiger; Beck et al., 2018), that is temperate-warm rainy climate with dry season in the summer and average temperature of the hottest month higher than 22 °C". As several other Mediterranean areas, the NEL area is considered by several authors as vulnerable to climate change and drought events (Vörösmarty et al. 2000). Concerning meteo-climatic data, Figure 2.4 and 2.5 show the distribution of rainfall for a hydrologic year for two raingauges of the Servizio Idrologico e Geologico della Regione Toscana: Monterotondo (average yearly, hydrologic, rainfall 2004-2021: 965 mm) and Venturina (average yearly, hydrologic, rainfall 1990-2021: 650 mm). The first one provides information on rainfall in the headwater catchment, while the second one provides data on rainfall on the Cornia plain. For each hydrologic year (1st October- 31st September) data are divided in two periods:

October-May to show data on the aquifer recharge season, and June- September for data on the aquifer discharge season.

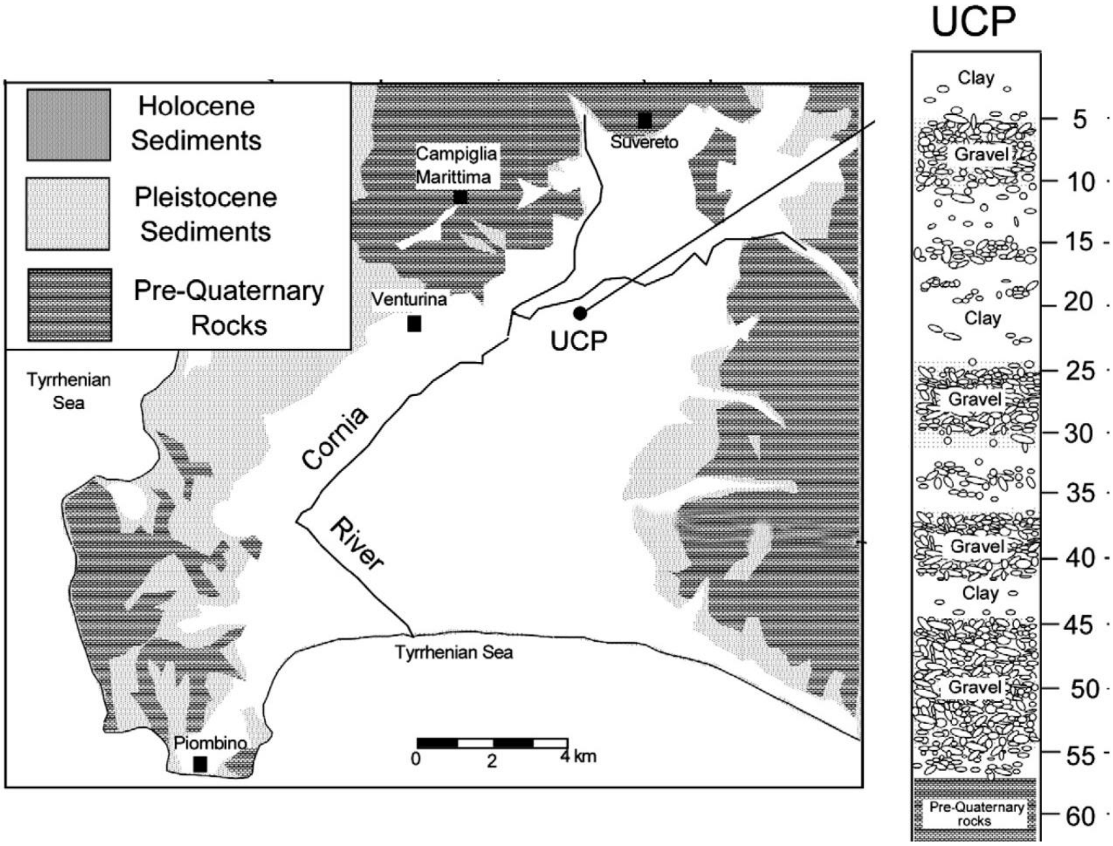

Figure 2.2. Synthetic geological map of the Cornia River plain with stratigraphic column (from Pennisi et al., 2009).

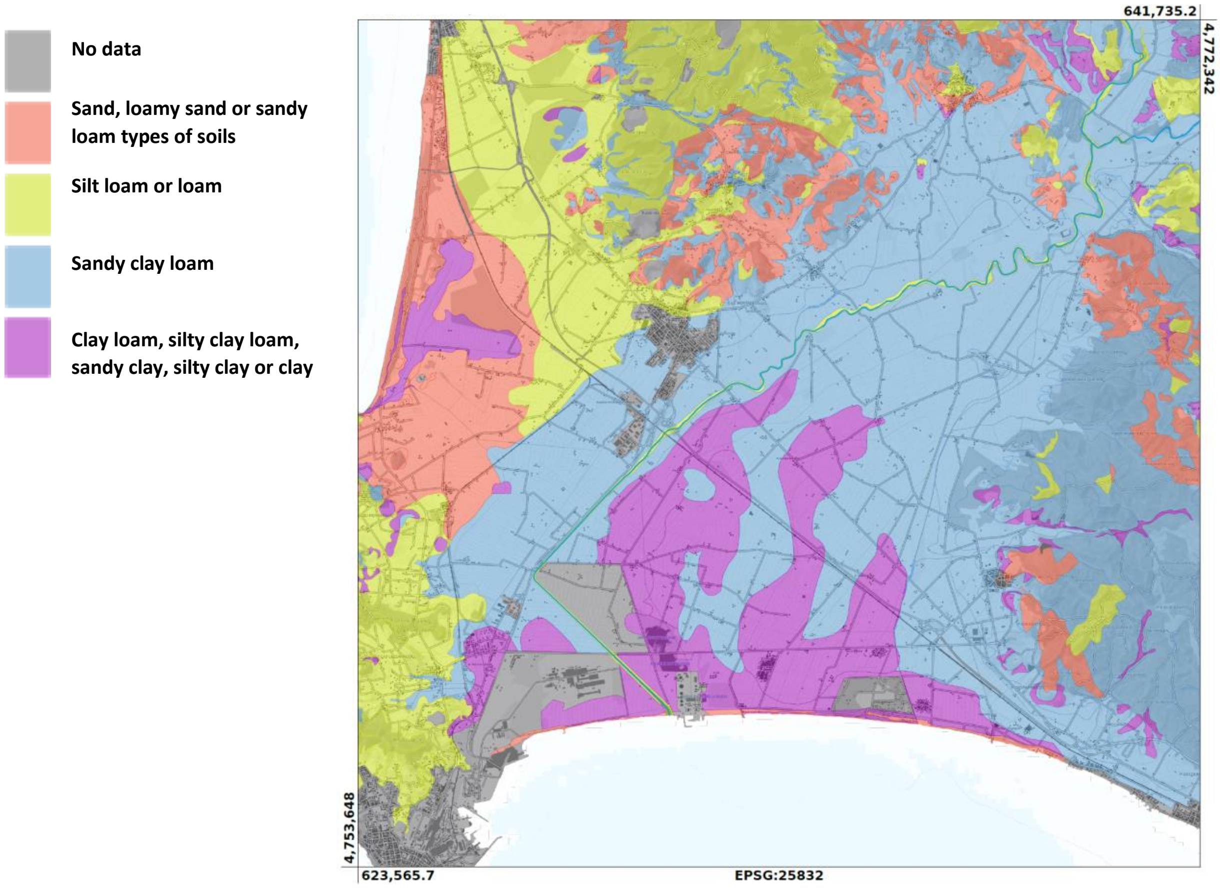

Figure 2.3. USDA hydrologic soil group map (from Regione Toscana, 2022).

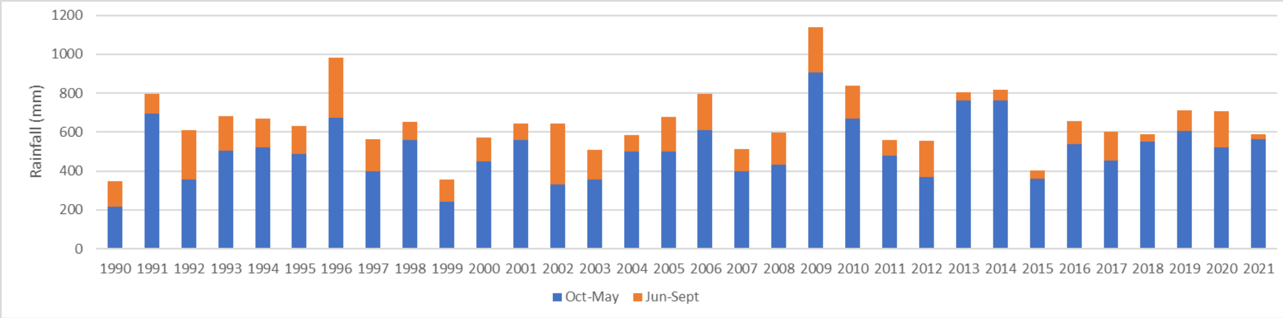

Figure 2.4. Hydrologic year (1990-2021) cumulate rainfall at the Venturina raingauge station (Servizio Idrologico e Geologico Regione Toscana).

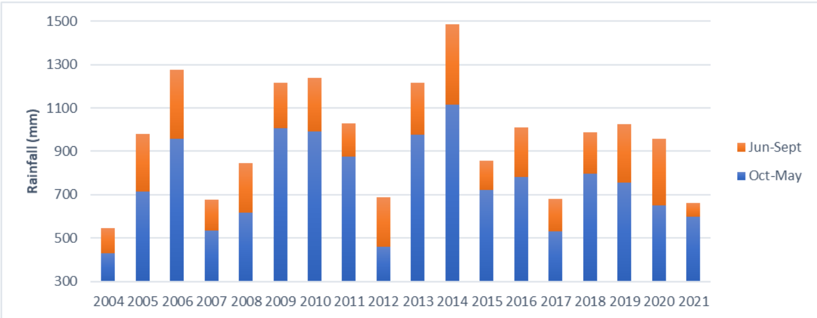

Figure 2.5. Hydrologic year (2004-2021) cumulate rainfall at the Monterotondo raingauge station (Servizio Idrologico e Geologico Regione Toscana).

For the coastal part of the NEL, Bartolini et al. (2021) report the presence of positive trend in dry spells (defined as a sequence of at least two consecutive days with a daily precipitation amount below a certain threshold) considering the period December- May for 1 mm threshold. Less significant trends are identified for higher thresholds. Longer periods without precipitation during the winter and spring seasons could lead to restrictions on irrigation in the hottest months, an increased potential for forest fires, and put important Mediterranean rain-fed crops at risk (Bartolini et al., 2021).

In the area, Campiglia Marittima, Piombino and Suvereto are the most important municipalities. The Municipality of Piombino seats in the coastal strip, while in the inner area there are the Municipalities of Campiglia Marittima and Suvereto. At 2020 Campiglia Marittima has an area of 8,328 hectares with 12,719 inhabitants; Piombino has an area of 12,900 hectares and 32,725 inhabitants; Suvereto has an area of 9,290 hectares and 3,073 inhabitants (ISTAT, 2022). The population density is 159 inhabitants per km^2, slightly lower than the Tuscany region average of 161 inhabitants per km^2 (ISTAT, 2022). In 2020, the population was made up of 52% of women and 48% of men. The old-age index, measuring the number of elderly people (65 years and over) present in a population every 100 young people (from 0 to 14 years), increased from 2002 to 2019 by 12.11% and always had higher values than the regional average. The observed data explain that the resident population in the cluster is mainly composed of an adult population between 50 and 80 years old, while the population in the 0-40 age group has much lower values. There is a greater amount of inactive population than the active population compared to the regional average. The inactive population is mainly made up of the elderly.

The NEL area has been for long time characterized by metallurgical and steel production which dates back to 2,700 years ago. The ancient Etruscan city Pupluna (Populonia) marked the fortunes of these areas thanks to the presence of rich deposits of iron, copper and silver. The iron steel production, after being one of the largest in Italy, practically ceased due to the economic crisis occurred at the end of 2010.

The economic landscape is dominated by agricultural activities (Figure 2.6), specialized in the cultivation of cereals, vegetables, wines and olive trees. The latter give nourishment to a thriving processing industry, which is responsible for the production of a precious oil and the renowned Val di Cornia Doc wine. The most important wine denominations are three: Suvereto DOCG, Val di Cornia Rosso DOCG and Val di Cornia DOC.

Per capita income in the area in 2019 was € 14,823.29, lower than the regional average of € 16,316.44. The population is increasingly dependent on public transfers, given aging, and a level of employment that is lower than the regional average. These elements highlight a reality at high risk of depression, where growth prospects seem low (Dipartimento delle Finanze, 2022). The unemployment level in 2011 was 26% higher than the regional average (Il Sole 24 Ore, 2019).

The steel sector, although in a depressive economic period, is still a relevant industrial one: Nobilcut srl is in Suvereto, while the companies Dalmine Spa, JSW Steel Spa, Etrusca Profilati Spa and Liberty Magona srl are in Piombino. Dalmine S.r.l. has about 1,900 employees, Liberty Magona S.r.l has about 452 employees and JSW Steel S.p.a. has about 400 employees at work and 1,500 employees on redundancy fund, with the incoming risk of new layoffs. In the area, there is also an industrial port, a commercial port and two tourist ports. The port system is administered by a Port Authority.

Tourism increased over time due to well-known seaside resorts and farmhouse tourism. Arrivals in Campiglia Marittima went from 26,254 in 2009 to 29,776 in 2019; in Suvereto they went from 4,623 in 2009 to 13,300 in 2019; in Piombino they went from 129,387 in 2009 to 156,637 in 2019. In 2020, due to the COVID emergency, tourism decreased. From 2019 to 2020 there was a reduction in arrivals to Campiglia Marittima by -35.04%, in Piombino by -28.47% and in Suvereto by -25.8% (Regione Toscana, 2022).

The availability of health facilities per capita shows a value of 0.000412, while the regional average is 0.0019, showing a lack of health-facilities compared to the regional average and missing capacity in meeting citizen's health needs (Azienda USL Toscana Nord-Ovest, 2022). The same applies to education facilities (for resident population aged between 3 and 19), which is well below the regional average of 0.70%. This shows a lack of educational services to be offered to the young population. Finally, NEETs, the percentage of the population aged 15-29 not working and not studying or training in 2011, was equal to 9.8%, a percentage lower than the regional average at 16.9% (Open Polis, 2020).

Following the coronavirus emergency, the development of a digital agenda has become crucial in combating educational poverty. In the months of online teaching in schools, all the differences emerged between those who were able to actively participate in the lessons and those with more difficulties. This kind of digital divide, dictated for example by the slowness of the connection or the absence of a device for each member of the family, risks deepening the pre-existing social and educational inequalities.

Figure 2.6. Aerial view of the Cornia plain rural landscape.

3. Overview of the natural resources

3.1 Water resources, uses, infrastructures and impacts

Water is a distinctive element in the Coastal Tuscany NEL. It is the main engine for the local rural economy. However, the area is set in potentially scarcity conditions, and geogenic alteration of groundwater quality complicates water resources management – giving rise to conflicts for water use. A wide range of waterworks were built in the last 50 years, and recently, to achieve sustainable water management.

Starting a process aiming at rebalancing the water budget of the hydrologic system was the main objective of the LIFE REWAT project (2015-2021, *sustainable WATer management in the lower Cornia valley through demand REduction, aquifer Recharge and river REstoration*; http://www.liferewat.eu). Five demonstration measures (river restoration; Managed Aquifer Recharge; reuse of treated wastewater for irrigation; high irrigation efficiency scheme; leakage management in water distribution systems) were set in place for promoting water resources management, along with capacity building and participatory actions. The latter closed with the signature of *The Cornia River Contract*, a voluntary agreement among the main stakeholders to achieve and to promote a shared vision on next 50 years priorities for water resources management.

3.1.1 Surface water

The NEL domain may also be divided in two areas by the hydrological point of view. The first one is related to the headwater catchment of the Cornia River, less inhabited, higher in yearly rainfall amount and largely forested (orange area in Figure 3.1). The second area is related to the coastal plain (purple area in Figure 3.1), mainly devoted to agricultural activities, where the Cornia River flows embanked and rectified. In the plain area, a dense network of drainage and secondary channels is present, with most of them dry for large part of the year.

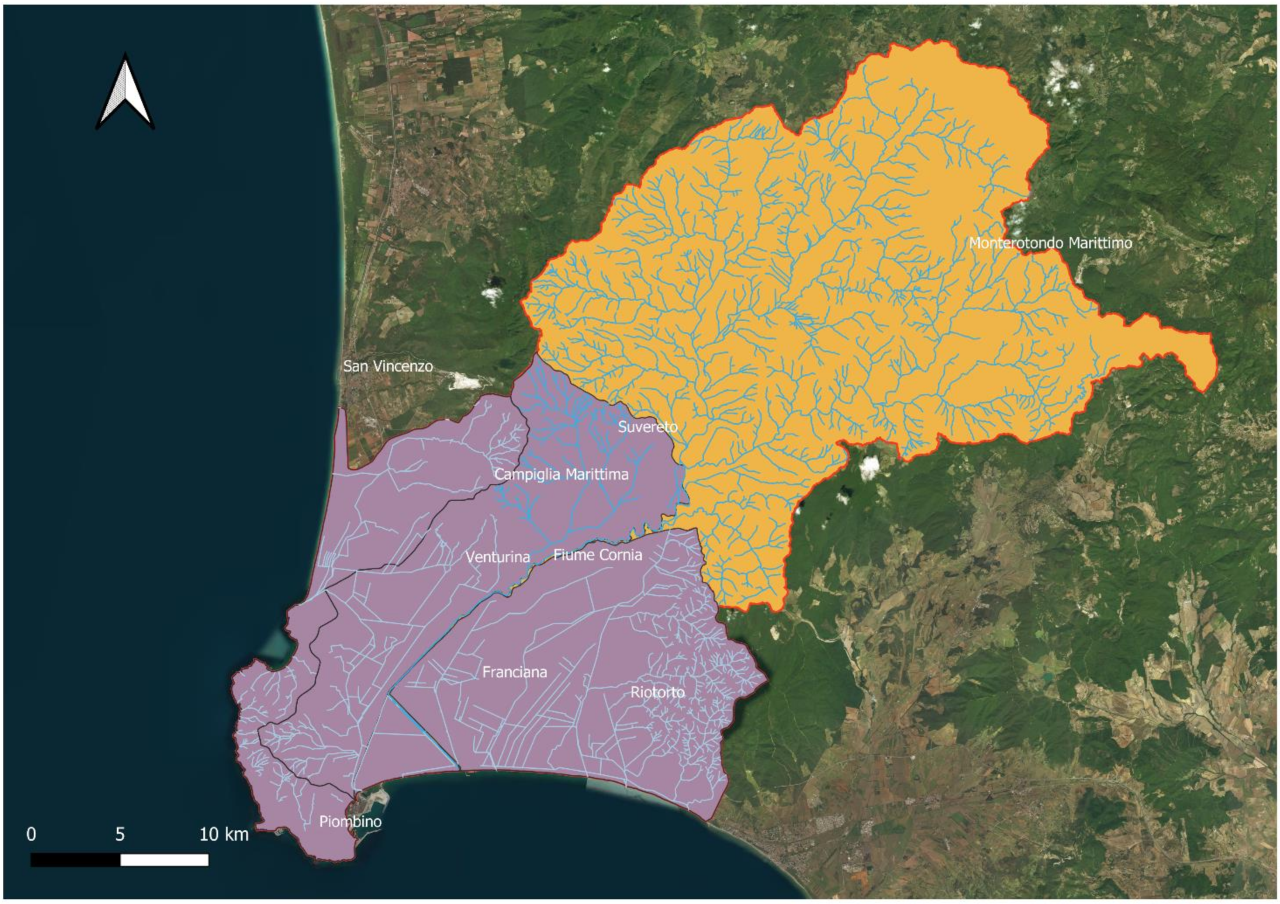

Figure 3.1. Hydrographic network in the Coastal Tuscany NEL. In orange, the headwater catchment, in purple the coastal plain area.

The Cornia River is about 50 km long, with a catchment of 365 km^2 (Figure 3.2), largely developed in the upper part of the basin. Baseflow is present usually between end of October and June each year, then the river runs dry for about 3-4 months in a year. The hydrologic regime alternates wet and dry phases in the channel and highly dynamic lateral, vertical, and longitudinal connections with adjoining ecosystems. While the river level is monitored at a number of stations of the Servizio Idrologico and Geologico of Regione Toscana, not so is discharge. Peak flow discharge monitored values date back to the '90 of the last century. Maximum estimated values are in the order of 100 m^3/s (return period of 5 years). Higher discharges, in the order of few hundreds of m^3/s may occur with return periods larger than 10 years.

Concerning the environmental status (WFD *sensu*), the Cornia River, divided in three reaches (one from the sea to approximately south of Venturina, *Fiume Cornia valle*; one up to the confluence with the Milia Stream, *Fiume Cornia medio*; and a final upper one, *Fiume Cornia monte*) qualified in good environmental status for both the ecological and the chemical one (DIAS, 2016). By the water quality point of view, anomalous concentrations values were noticed for mercury in the upper part of the River. Seawater encroaches the last part of the river reach in baseflow conditions.

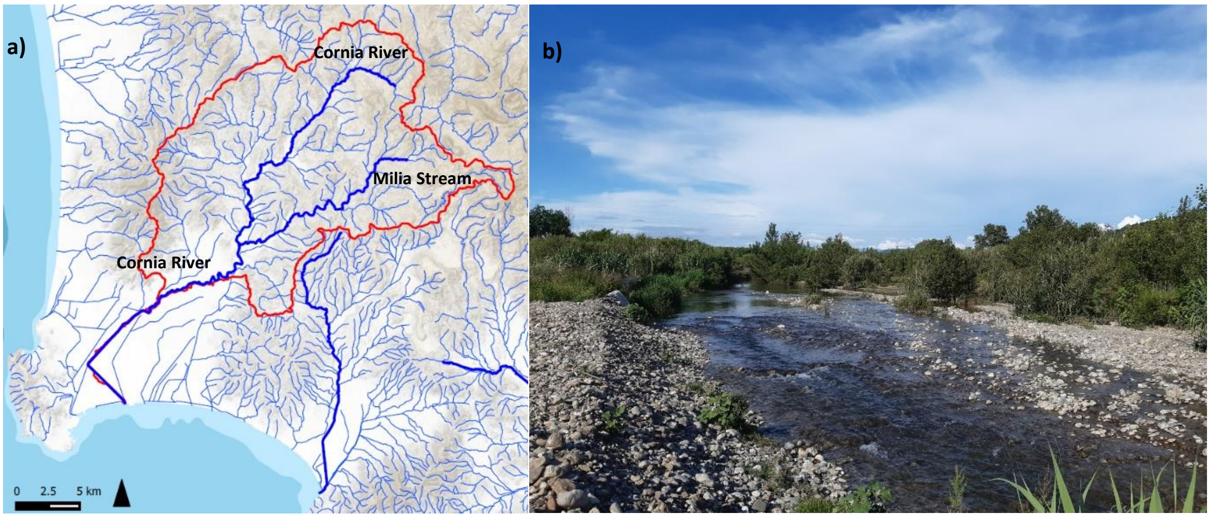

Figure 3.2. a) Cornia River basin (in red); b) Cornia River in Suvereto.

The evolution of the active riverbed is noticeable (Fig. 3.3). Narrowing started between 1800 and 1900 due to increase in forested areas. An increasing narrowing trend happened after the second world war. Up to the 80's of the last century riverbed excavation for construction materials is thought to be the primary causes for the deepening and narrowing of the riverbed. This in turn caused losses of ecological connection with the floodplain and local inversion of river/aquifer hydraulic relationship (i.e. river moving from losing to gaining conditions). A small part of the river body (approximately 1000 m) undergone morphological restoration works in the course of the LIFE REWAT (www.liferewat.eu) project in 2017. These works included removal of river weirs and widening of the river reach by raising the riverbed. After four years, in 2021 the monitoring activities allowed to highlight a trend towards the recovery of a new equilibrium of the system. A clear improvement, both in the vegetation and in the morphological elements was noticed in the waterwork areas. Despite the significant re-widening of the river section, the rest of the riverbed is still confined within an eroded section and disconnected by the fluvial plain, thus not allowing a full recovery of the river processes and habitats (LIFE REWAT 2021).

Flood risk has been managed in the long run by building (mostly) earth levees along all the Cornia river reach. From Venturina, the Cornia River flows in artificially channelized form, with levees running few ten of meters away from the riverbed. Flood risk from the secondary hydraulic network is managed by means of detention basins. In particular, a new detention basin is under construction West of the Venturina village to mitigate flood risk due to the Corniaccia ditch.

Because of the discharge seasonality, surface water resources may not be considered as a reliable source of water, with specific references to agricultural water uses. In the past decades, projects for constructing reservoirs in the upper part of the basin, and in particular on the Milia stream, were prepared, evaluated and then discarded.

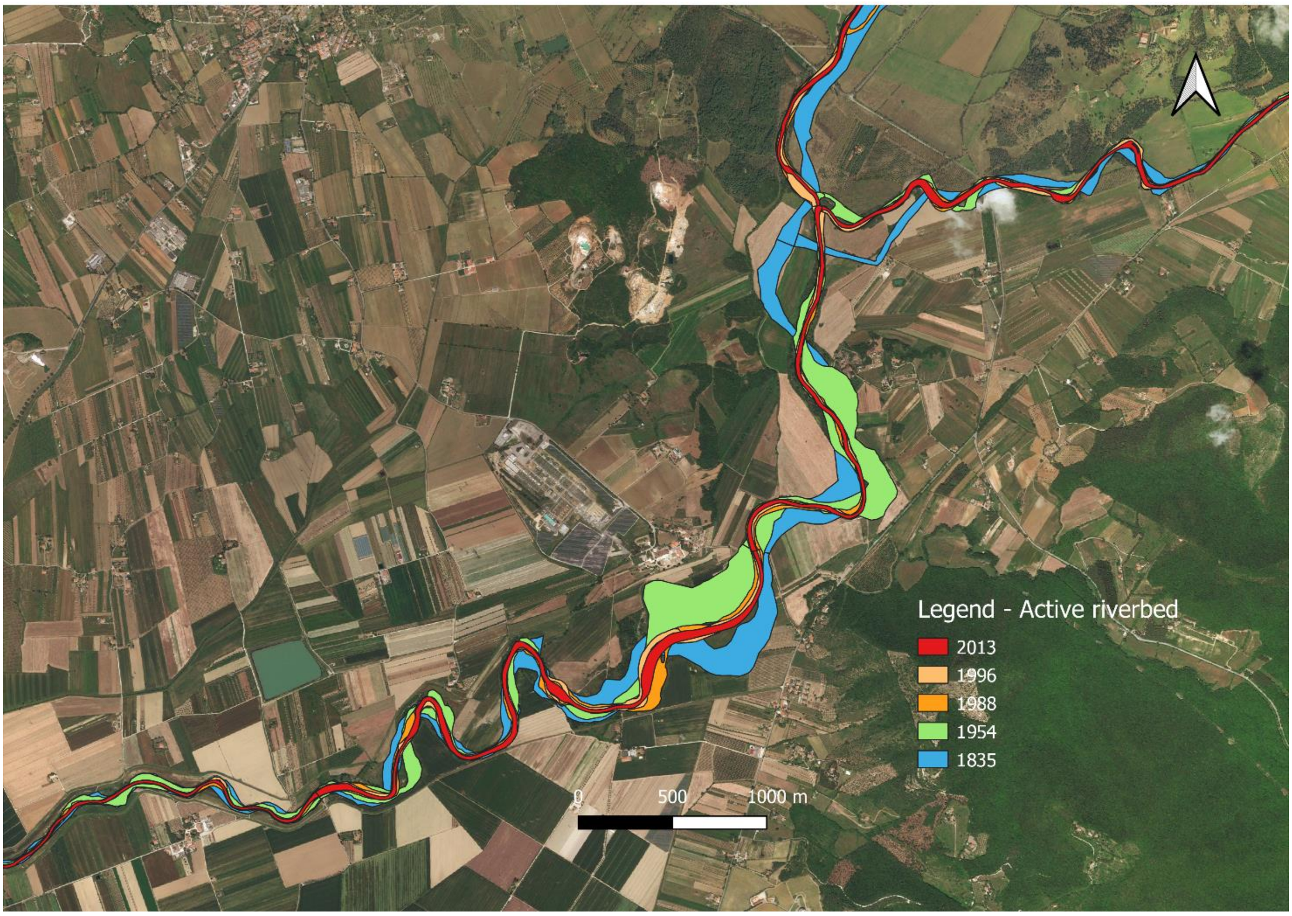

Figure 3.3. Evolution of the active riverbed of the Cornia River from 1835 to 2013 in the Suvereto area.

3.1.2 Groundwater

Groundwater is the most important resource in the area both by the human well-being and the economic point of view. The lower Cornia valley aquifer system provides the only source of water for drinking, irrigation, industrial purposes and it also contributes to the water needs of the nearby Elba island. Groundwater is hosted in an alluvial aquifer, named 32CT020 under the Groundwater Directive by Regione Toscana. The aquifer extends in the alluvial valley and it is mainly made of gravels in sandy-silty matrix, interlayered in clayey-silty deposits (Fig. 3.4 and 3.5). Groundwater head ranges in the Cornia plain from about 30 m above mean sea level (a.s.m.l.) to few meters below the mean sea level (Fig. 3.6). Roughly, between 12 to 13 hm^3/year are used for the drinking water services, 12 to 15 hm^3/y are used for irrigation, that are, the main water consumers (industrial use account for less than 1 hm^3/year). Industrial uses roughly withdrawn about 1 hm^3 of groundwater. These volumes of water are provided by Cornia River recharge of the aquifer (in values between 14 and 11 hm^3/year), inflows from the hilly areas bordering the plain (about 10/11 hm^3/y), and direct rainfall recharge (3 to 6 hm^3/y).

As in the area seawater intrusion phenomena are widespread, seawater contributes to the groundwater budget along the coast. Figure 3.7 presents the extension of groundwater salinization as derived by the values of electrical conductivities from 2018 to 2020. Two main salinized areas may be identified – caused on the southern side by the joint use of groundwater by the drinking and agricultural sector, and on the western side by the competing withdrawal of groundwater for drinking and industrial uses. Up to the end of the first decade of this century, the Piombino steel industrial hub was another major water consumer. At present, following the economic crises, as said, this production sector is practically closed. Plans to restart the steel production are being discussed since the last 10 years.

Groundwater chemistry shows a high variability in hydrochemical facies, ranging from Calcium-Carbonate in the upper part of the plain to Sodium-Chloride along the coastline and including a wide range of mixing terms (Fig. 3.6). Arsenic and Boron contamination in large part of the aquifer south of Suvereto required the construction and set-up of large treatment schemes for these two elements (Fig. 3.8). Research is ongoing under the EU H2020 ITN MARSOLUT project (https://www.marsolut-itn.eu/) to improve the understanding of groundwater geogenic contamination and to devise options to mitigate it.

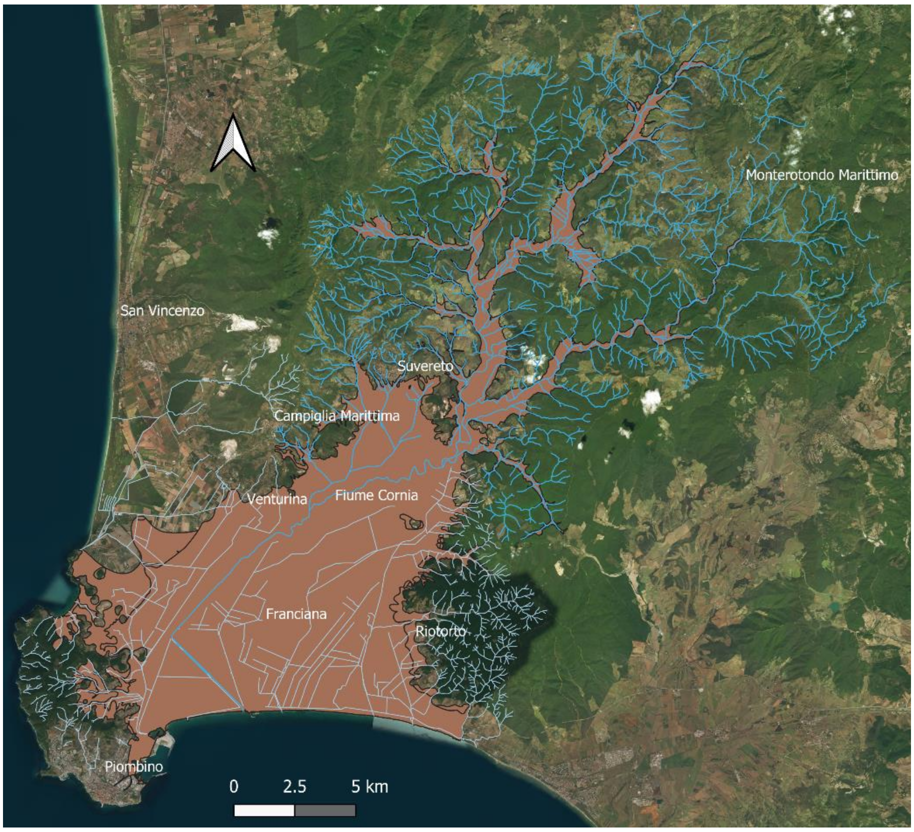

Figure 3.4. Extent of the 32CT020 aquifer.

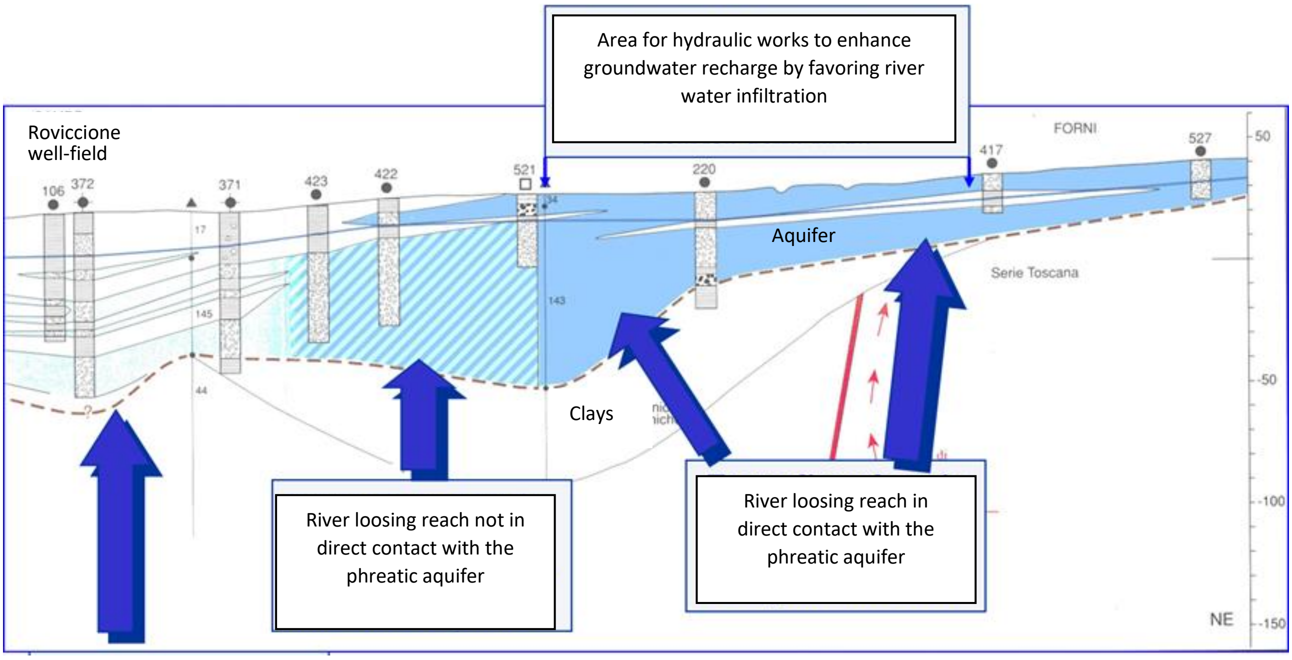

Figure 3.5. Hydrostratigraphic cross-section across the Cornia plain from Forni to Roviccione well-field (the cross section-line is displayed in Fig. 3.6; modified from Regione Toscana, 2003).

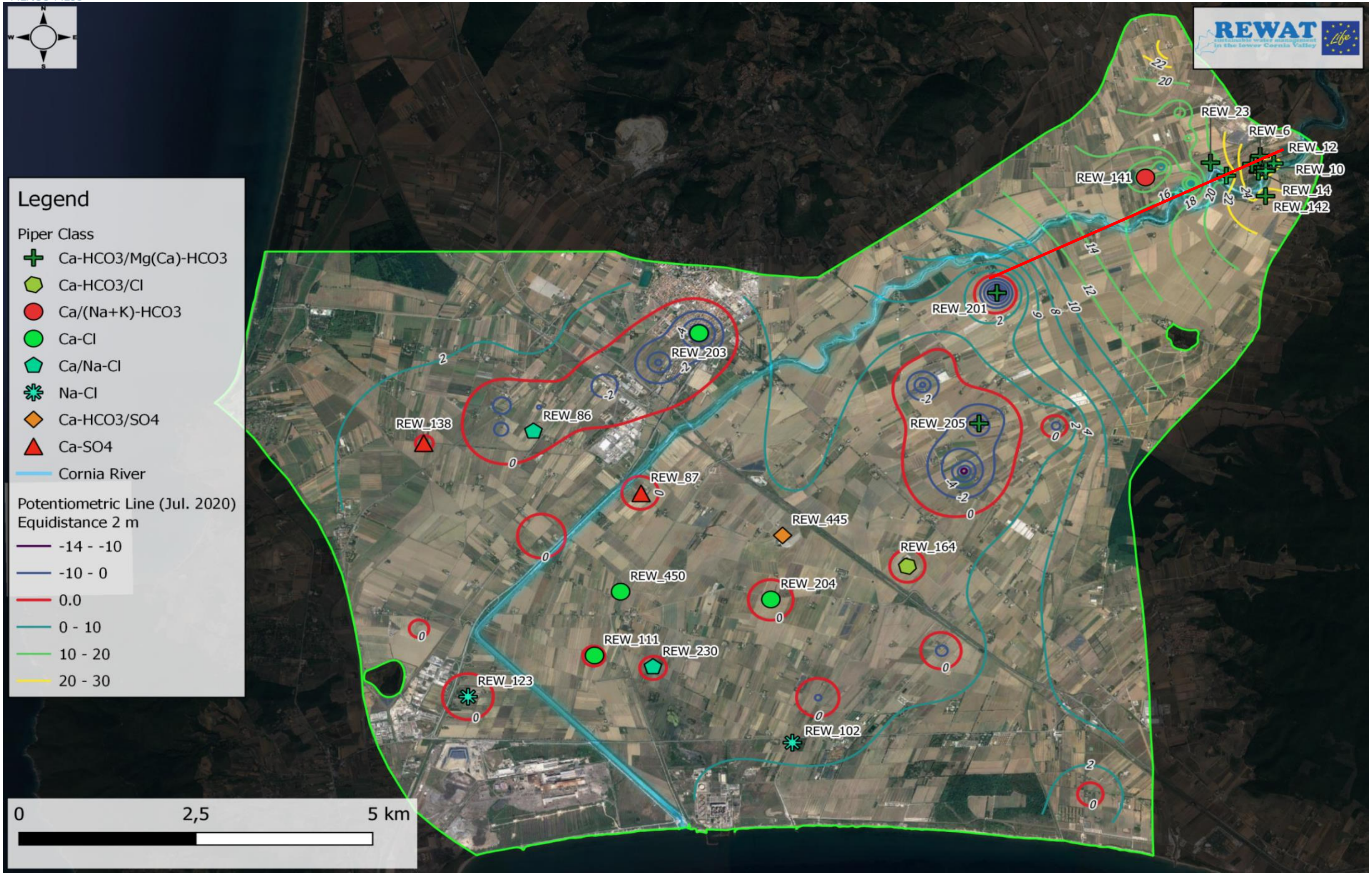

Figure 3.6. Groundwater head/hydrochem. facies across the Cornia plain. Red line REW_12/REW_201: cross section line for the hydrostrat. section in Fig. 3.5.

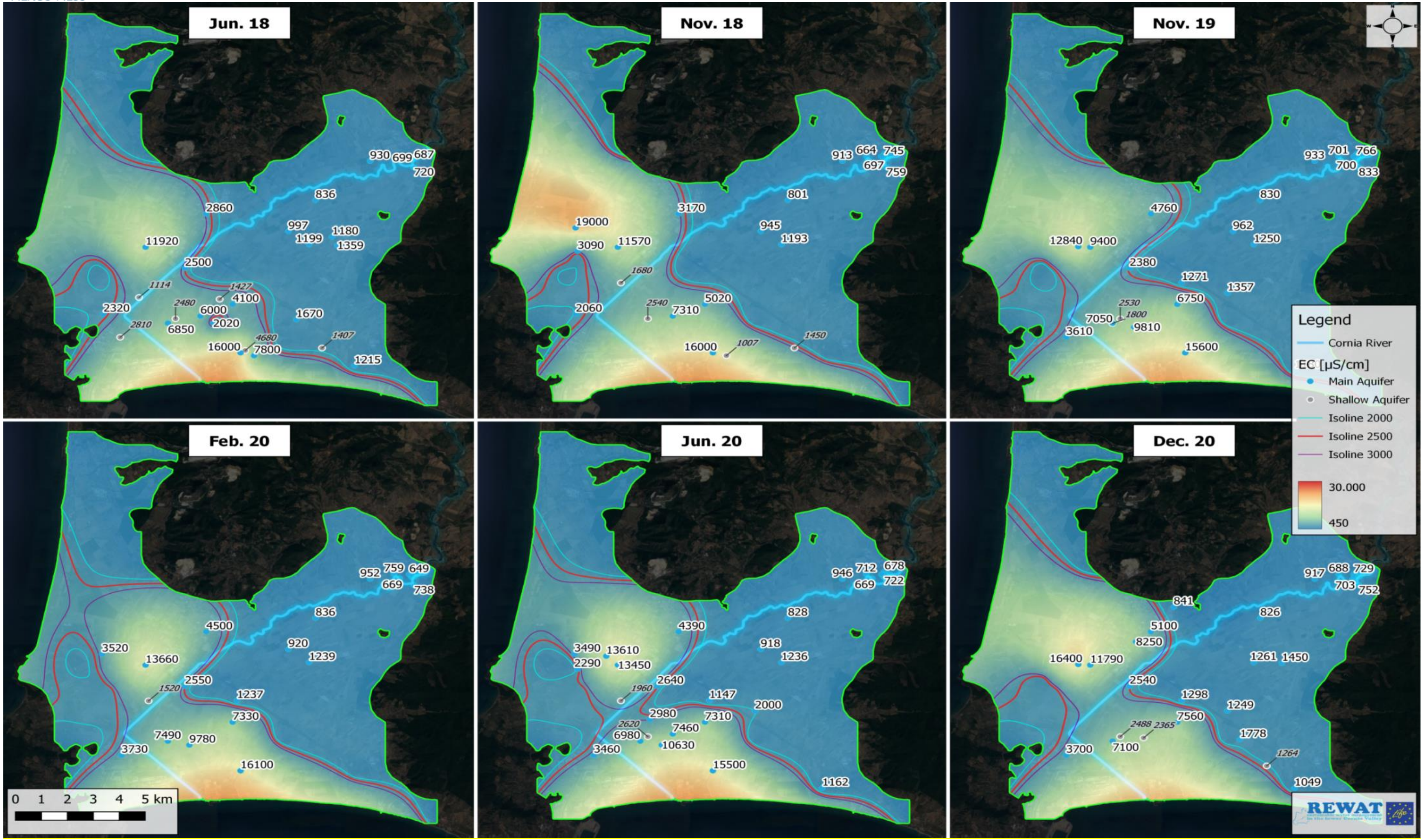

Figure 3.7. Distribution of electrical conductivities values in the groundwater of the Cornia plain.

Figure 3.8. Treatment scheme for Boron in groundwater in Franciana (run by ASA spa).

Since 60 years, intensive exploitation of groundwater resulted in consistent head lowering (Fig. 3.9) and water balance deficit, causing subsidence (Sbrilli, 2004), reduction of groundwater dependent ecosystems, and salinization of freshwater resources (causing in the last 20 years abandonment of three drinking water well-fields and turning irrigated agriculture to rainfed along the coastline). Meteorological drought periods occur in single year-drought events since the 2000 every 4 to 5 years (i.e. 2007, 2012, 2017, 2021), posing under stress the whole hydrologic and socio-economic sectors. However, the natural system demonstrated resilience. Because of all this the 32CT020 groundwater body is classified in Scarce environmental status (for heads and chemistry) according to the WFD.

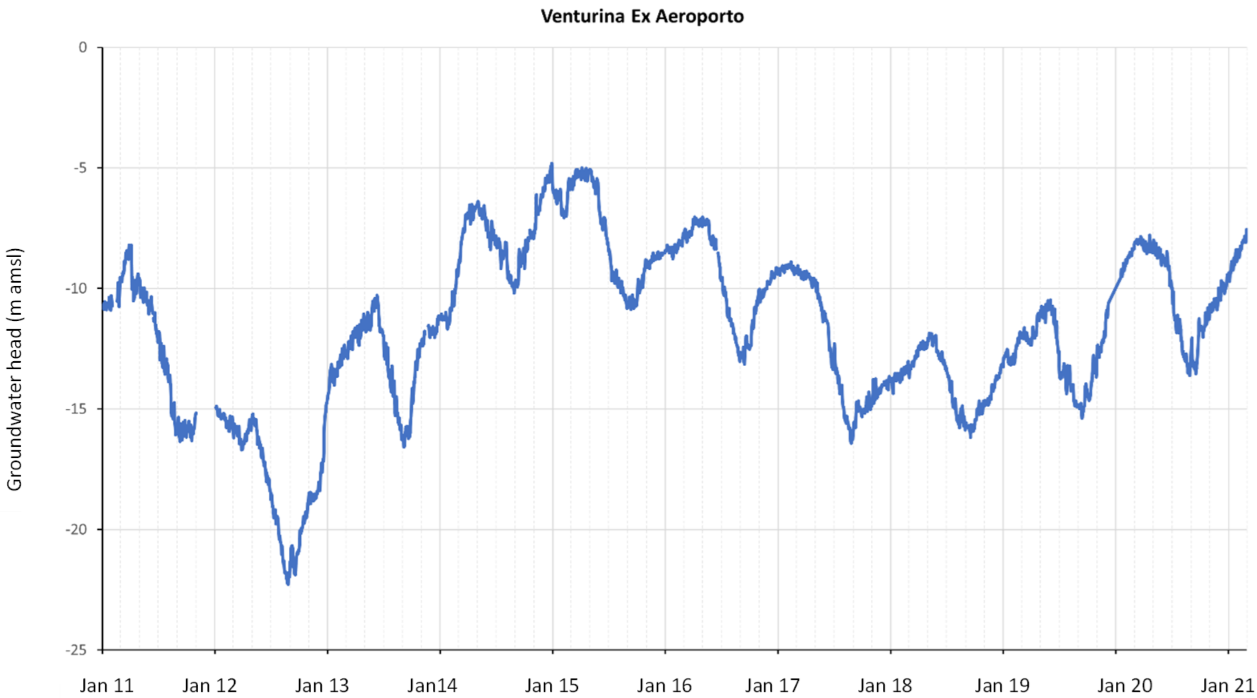

Figure 3.9. Temporal variation of groundwater head at the monitoring well Venturina ex-Aeroporto.

Besides river restoration works, a pilot Managed Aquifer Recharge (MAR) infiltration basin was designed and set in operation testing the new-issued Italian regulation on artificial recharge of aquifers (DM 100/2016) in 2018 (Figure 3.10; LIFE REWAT, 2020). The infiltration basin, built within the LIFE REWAT project activities, is located at a pre-existing topographical low near the Cornia River. The river, having intermittent flow, provides the recharge water during high flow periods, including floods, and when discharge is above the minimum ecological flow. The infiltration basin is set in a groundwater recharge area where the aquifer is constituted by gravel and sands.

The facility consists of the following elements: i) intake work on the River Cornia; ii) the inlet structure control system, managed by quality (mass spectrometer defining surface water spectral signature) and level probes, and allowing pumping into the facility at predefined head and chemical quality thresholds; iii) a sedimentation basin; iv) the infiltration area (less than 1 ha large); v) the operational monitoring system, based on a network of piezometers where both continuous data (head, T, EC, DO) are gathered and discrete measurements/sampling performed. The cost of construction of the plant is about 300000 €, well below the cost of a surface water reservoir for a similar storage. Depending on the climatic conditions, it is estimated that the volume of diverted surface water may vary between 300000 m^3/year and 1.2 hm^3/year. Minimal site development and modification was required, resulting in a no-impact waterwork, while providing ecosystem benefits by reconnecting and inundating former abandoned riverbeds.

Figure 3.10. The LIFE REWAT Managed Aquifer Recharge scheme in Suvereto.

All in all, the river restoration works and the Managed Aquifer Recharge scheme contributed to enhance aquifer recharge for a total estimated amount of about 2 hm^3/year, being 0.5 hm^3/year the average amount of recharged water by means of the MAR scheme in the three first experimental years of operations.

3.1.3 Water works

Besides what was already mentioned, other waterworks are present. In particular, being palustrine part of the coastal area, land reclamation is needed. Four land reclamation areas are then dominated by related pumping stations (Fig. 3.11). In lower-than the sea level reclamation areas, water is conveyed by means of a dense drainage network to a pumping system, and then lifted up into higher elevation channels or water bodies (usually at mean sea level elevation). To maintain the agricultural land a yearly average of 60000 KW is consumed.

Wastewater is treated by means of six treatment plants (WWTP; Fig. 3.11). All of them perform secondary treatment, but one (the small Campo di Gallio WWTP), which was upgraded (during LIFE REWAT project) to tertiary treatment in order to produce water suitable to the irrigation of the sport fields of Campiglia Marittima. At the wastewater treatment plant of Guardamare, northern of the area, wastewater is treated at tertiary level in order to be used for irrigation.

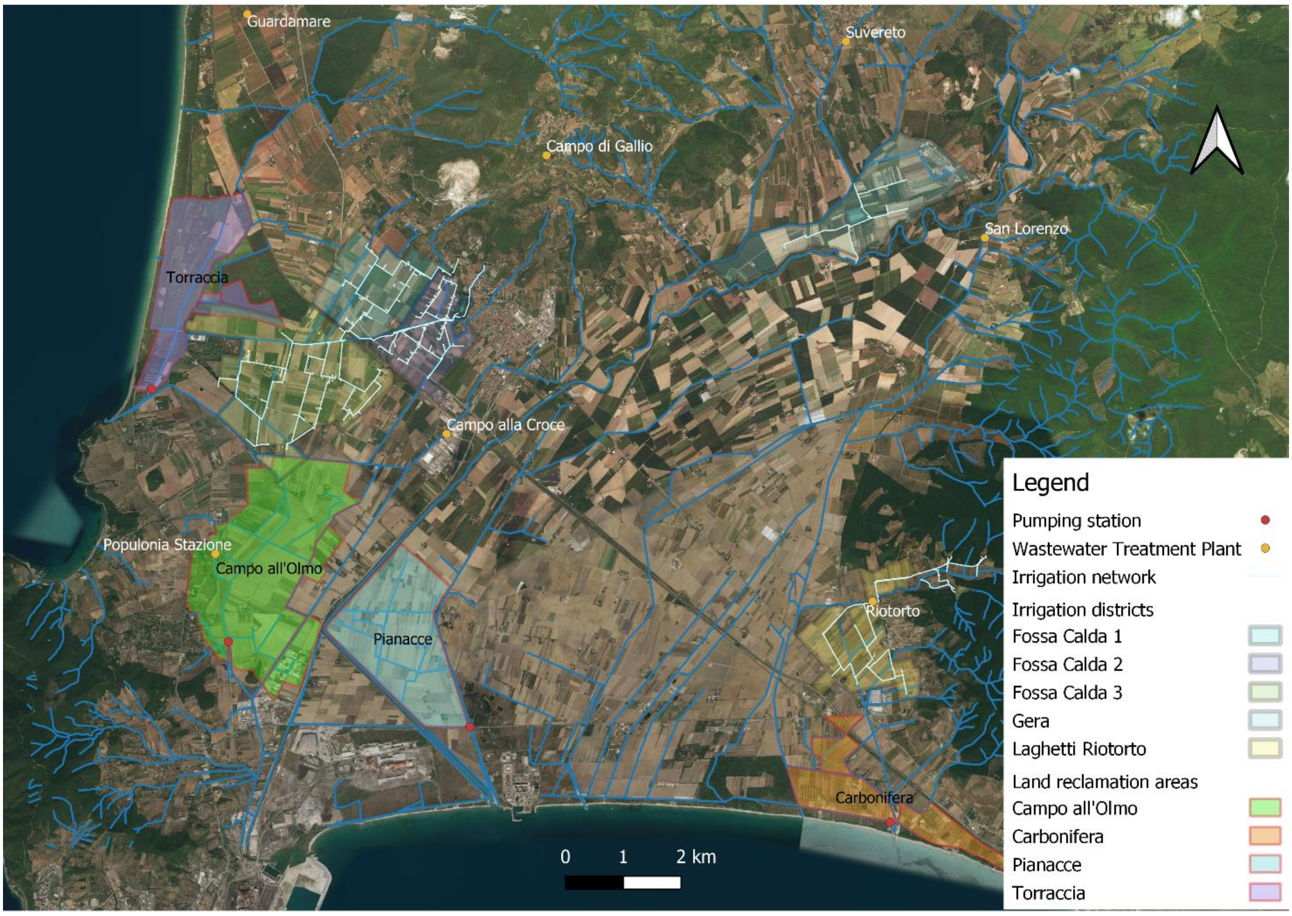

Figure 3.11. The LIFE REWAT Managed Aquifer Recharge scheme in Suvereto.

This last innovation was built and set in operation in recent years (since 2018), employing important investments, for tackling water needs following the last water crisis of 2017, in order to preserve the economy based on tomato crops and the related-industry. Regione Toscana financed the works, following the successful implementation of the Campo di Gallio pilot scheme for the reuse of treated wastewater. This innovation enhance the concept of sustainable water consumption, from a circular economy perspective, in an area where the use of water is essential for economic activities.

Drinking water is abstracted by means of a number of well fields from the local aquifer. A so-called ring-pipeline is used to collect the Boron and Arsenic rich groundwater, to treat it in dedicated plants (Figure 3.8), and then send it back for civil uses.

3.2 Land/Agricultural resources, uses, infrastructures and impacts

The agricultural sector of the Val di Cornia hosts a thriving specialized business and it is one of the main sources of income and employment in the area. The total agricultural area with respect to the total area is equal to 40.81%, a figure lower than the regional average, equal to 56.35% (this figure is related to the fact that large part of the municipal boundaries include forests in the hilly areas). The ratio between Utilized Agricultural Area (UAA) and Total Agricultural Area (TAA) in the cluster is 78.67%, higher than the regional average, equal to 58.25%, demonstrating the agricultural economic vocation of the area.

About rainfed crops, wheat is cultivated on about 15% of the UAA, while sunflower on 10%. Horticultural crops requiring irrigation are relevant, in particular, honey melon and watermelon, tomato crops (supporting a large local food transformation industry, ITALFOOD spa), and artichokes. The irrigation area of the Val di Cornia is estimated to a total area of 3500 ha. Irrigation water requirements strongly depend on meteo-climatic conditions (spring and summer temperatures and rainfall regime) and on the type of crops grown. The Consorzio di Bonifica 5 Toscana Costa manages the collective irrigation for 5 districts (Fig. 3.11), for an irrigated area of 700 ha, distributing a volume of water of about 7-800,000 m^3/year to a number of about 200 users. Table 3.1 provides synthetic information on these irrigation districts.

Irrigation schemes Consorzio 5 Toscana Costa		Springs			Reservoirs		
Irrigation scheme	-	Fossa Calda 1	Fossa Calda 2	Fossa Calda 3 - 4	Gera	Laghetti Riotorto	Total
Since	-	1985	1985	1990	2010	1985	-
Irrigable land	*ha*	222	195	490	295	237	**1439**
Yearly irrigated land	*ha*	107	110	252	125	95	**689**
Storage	*m^3*	2250	2250	75000	350000	98000	**527500**
Users	-	32	71	60	15	47	**225**
Lenght of the irrigation network	*Km*	6	10	15	4	11	**46**
Power (pumps)	*Kw*	45/22	45/22	80/80	44/44	-	-
Licenced water	*L/s*	60	60	120	900	60	-
Water price 2020	*€/m^3*	0,25	0,25	0,16		0,17	-
Average yearly water (2013 - 2020)	*m^3*	157437	102670	382665	31096	38271	**712139**
Periodo irriguo	-	Marzo - Ottobre					

Table 3.1. Basic data on the irrigation districts managed by Consorzio di Bonifica Toscana 5.

These irrigation schemes uses surface water coming from thermal springs or diverted into artificial reservoirs during the rainy seasons (Figure 3.12). Small on-farm reservoir are scattered around the plain.

Figure 3.12. The Gera reservoir near the town of Suvereto, supplying the Gera irrigation district.

However, besides the irrigation districts, large part of the plain is irrigated by means of private wells. Sprinkler irrigation is the most widespread irrigation method being used for artichokes, onions, and other vegetable crops. Drip irrigation is used for honey melon and watermelon, olive trees and vineyards (Figure 3.13). The LIFE REWAT project set in operation a demonstrative subsurface irrigation scheme for irrigation of artichokes (multi-annual crop, Figure 3.14) to favour the adoption of this technique. Several farmers started rainwater harvesting works (storing water in small in-farm lakes) for diluting groundwater salinity and the local high concentrations of Boron especially along the coastline.

Not licensed, and abstractions often performed without proper advices, along with the use of inefficient irrigation methods and timing (often producing runoff and subject to high evapotranspiration rates), generate conflicts because of the ongoing aquifer overexploitation and salinisation. The profitability of the horticultural production and requirement of water for not-traditionally irrigated crops (olive trees and vineyards) is going to increase these conflicts in the next few years.

Figure 3.13. Drip irrigation of olive trees generating runoff.

Figure 3.14. The sub-surface drip irrigation scheme for artichokes built within the LIFE REWAT project.

3.3 Energy resources, uses, infrastructures and impacts

At present, there are no data for the energy consumption in the NEL area. Energy consumption in the Province of Livorno is equal to 26.3 GWh for agriculture, 1,258.6 GWh for the industrial sector, 481.3 GWh for services and 379 GWh for domestic use. Industries consume 58.67% of the total energy of the Province of Livorno. The total energy used in the Province of Livorno is equal to 2,145.1 GWh, that is 12.19% of the total consumption in the Tuscany Region.

The Costal Tuscany NEL is already exploiting renewable energies, in terms of wind, solar and geothermal sources. In the Tuscany Region, 5,867 GWh of geothermal energy per year are produced. In the area of Monterotondo Marittimo, headwater part of the catchment, geothermal energy is exploited by ENEL Green Power to produce electricity and power some farms and food-production activities.

In 2019 the Foce del Cornia wind farm was inaugurated, in the Municipality of Piombino, with 6 wind turbines The annual wind energy production is equal to 52000 MWh.

In the area about 40 ha of agricultural land are used for solar electricity panel plants. Anyway, at present, the agricultural sector is largely relying on the use of fossil fuels for agricultural works.

Until 2015, a fossil fuel thermal power station (1280 MW) was in operation in Piombino (Fig. 3.15). Decommissioning is now ongoing due to non-profitability of the operations. The station occupies 40 ha out of 140 ha premises. Nowadays, the environmental restoration of the area is under discussion.

The grid for transferring electricity from the mainland to the Corsica Island (France) is under construction in the Val di Cornia area.

Figure 3.15. The thermal power station in Piombino (source: https://corporate.enel.it/it/futur-e/impianti/piombino).

3.4 Environment and Ecosystems

The main environmental issue in the Coastal Tuscany NEL is related to the overexploitation of the water resources, which is deeply linked to the economic exploitation of agricultural land, industrial activities and tourism, already discussed in the previous sections of this document.

The Orti Bottagone area is a WWF Oasis on the Follonica Gulf, a precious legacy of the past extensive coastal swamps of the lower Val di Cornia, which most disappeared as a result of land reclamation. The Oasis, 126 ha, is a Special Conservation Area (IT5160010), Special Protection Area (SPA IT5160010), and RAMSAR area in the Municipality of Piombino. The Oasis is home for a large variety of birds among which flamingos. Maintenance of surface water and groundwater-dependent ecosystems and biodiversity losses is an issue.

Pesticides are extensively used in the area as well as fertilizers. At some deep wells high nitrates concentration of presumably agricultural origin have been noticed in the last years. Pollution of surface water in the drainage network is associated to release of nutrients, untreated/poorly treated non-collected wastewater, and release of industrial wastewater.

In the area there is an emergency regarding the waste disposal plant in Piombino, because on 21 May 2021 the Rimateria service company, which disposed an average of 400 tons of waste per day, was declared bankrupt. This led to worrying environmental and employment implications. The landfill was subject to ARPA sanctions for unpleasant odors and it is at the center of a heated debate with local environmental associations and citizens. Legambiente spoke about this issue, describing the health emergency caused by the illegal and uncontrolled landfills near Colmata. The WWF also expressed itself on this issue, asking for the cancellation of the current permissions and the return to public services.

4. Governance framework

The Municipalities (*Comuni*) are the main authorities in the area. In the Coastal Tuscany NEL, the municipalities of Piombino and Campiglia Marittima are trying to carry out an integrated strategic planning, through the drafting of a single framework plan for the area (*Piano Strutturale Intercomunale*). Besides national and municipal regulations, the Regione Toscana is regulating and overlooking several sectors such as the environmental and the agricultural one. NEXUS policies at present are not perceived and cross-sectoral initiatives are in their infancy.

All water related issues are regulated by the Water Framework Directive, the Groundwater Directive, the Flood Directive, the Nitrates Directive and overlooked by Regione Toscana. Of particular importance for the area is the Common Agricultural Policy of the European Union and its declination in the local Rural Development Plans (*Piani di Sviluppo Rurale*). Reuse of treated wastewater is at present regulated by the DM 185/2003 – which is quite a strict regulation concerning the concentration values the reclaimed water must have in order to be reusable.

NEXUS-NESS takes advantages of several years of work of the NEL reference partner for the Italian NEL (SSSA) in this study domain with specific regard to the H2020 FREEWAT and LIFE REWAT EU-funded projects. Thanks to the LIFE REWAT project, all of the water-relevant stakeholders in the NEL were mobilized since 2016 in order to achieve agreement on a shared vision on water resources management. The EU LIFE REWAT project created a collaborative environment among the main stakeholders thanks to the activities run. Consorzio di Bonifica 5 Toscana Costa (CBTC), the land reclamation and irrigation institution, coordinated the project. CBTC aims at controlling the functionality of the secondary drainage network, providing for the necessary maintenance and works, for the design and construction of public reclamation works, and delivering irrigation at the five irrigation districts. ASA spa, the water utility, manages the abstraction, treatment and distribution of the water resource and then the treatment of wastewater, before release into the environment. While Regione Toscana is regulating and overlooking the energy sector, ENEL and TERNA are the main stakeholders and energy producers in the area.

The LIFE REWAT project aimed at the signature of The Cornia River Contract, a voluntary act of commitment by various public and private entities in various capacities for defining shared and medium to long term sustainable water resources management. From an administrative point of view, it is configured as a negotiated planning process and, in line with current planning and in compliance with the specific skills of the various territorial actors. It allows the various instances around the river system to be brought into a single vision.

CIA, COLDIRETTI and CONFAGRICOLTURA are the main farmer's associations. These associations bring the instances of farmers, such as discussions on the price of water, perceived as a barrier and as unfair, the length in time of authorization processes, low-salaries in agriculture. They also face criticisms for inefficient water uses (Figure 4.1) and the unauthorized groundwater exploitation in the agricultural sector.

Besides decreasing population and the lack of water resources, main weaknesses for the NEL may be listed as: i) low-paid jobs in the agricultural sector; ii) the demand of the large distribution for products with certain standards poses the farmers in the position for pushing for intensive agriculture; iii) missing up-to-date managerial skills in many farms; iv) basic/lack of knowledge on the WEFE nexus issues. Main strength of the area may be listed as: i) a recognized role on technological innovation; ii) stakeholders willing to explore new options; iii) spreading of renewable energy is on the way; iv) a running and strong agricultural product chain along with the development of cooperatives to guarantee larger rewards for the agricultural production (i.e. Terre d'Etruria).

Figure 4.1. Inefficient irrigation at onion crops during mid-day in August 2017.

5. NEXUS Grand Challenges

5.1 Water-Energy-Food-Ecosystem Current Status and the Grand NEL Challenges

At the Coastal Tuscany NEL, discussions on the WEFE NEXUS already started thanks to the activities run in the EU LIFE REWAT project. The main actors are already aware at an initial stage of the whole interrelation among the use of resources. The following NEXUS Grand Challenges will be dealt:

1) **Non-conventional use of water for agricultural production**. Treated wastewater reuse and agricultural production for reducing groundwater exploitation and energy consumption (C-W-E-F) vs. release of secondary treated wastewater in the environment.

Currently, the lack of fresh water resources due to climate change, population growth, and the degradation of water quality is becoming a big challenge for agricultural practices. The water demand for industries and agriculture are being met at the expense of the ecological requirements. The use of treated wastewater in irrigated agriculture is one of the strategies for mitigating water scarcity and nutrient deficiency in agricultural systems. Treated wastewater can be considered as a renewable and sustainable source of water as it is produced constantly. Furthermore, treated wastewater provides farmers with renewable fertilizers, reduce pollution of the environment, and ease demand for freshwater. It is well demonstrated that farmers may save on artificial fertilizers using treated wastewater for irrigation.

However, not all the synergistic effects of the reuse of treated wastewater have been evaluated and quantified, and evidences and data are needed, in the light of the NEXUS approach. In particular, the energy consumption and greenhouse gas emissions of treated wastewater reuse has not been holistically considered so far against:

a) the BaU behavior of releasing secondary treated effluents in the environment;
b) the groundwater pumping costs and the related depletion of aquifers;

c) the reduction of costs and greenhouse gas emissions due to the reduced use of fertilizers;

d) the impact on soil (unsaturated zone) and groundwater of the reuse of tertiary treated wastewater, with specific reference to the fate of contaminants of emerging concern (i.e. pharmaceuticals);

e) cost of reusing treated wastewater to farmers compared to private abstraction;

f) the risk associated to indirect reuse of secondary treated wastewater discharged into surface water bodies;

g) overall environmental benefits (i.e. quality of the ecosystems).

In the a) case, in example, energy and chemicals (and associated energy consumption for production) are used to release in the environment secondary treated wastewater that, although with contaminants concentrations below defined limits, is far from being native/good quality water. This will then reflect in poor quality aquatic ecosystems and in loss of potentially usable resources (such as nitrate and phosphates in wastewater).

Expected results will allow a thorough evaluation of the whole energy consumption and emission framework considering pumping of good quality groundwater vs reuse of treated wastewater vs release of secondary treated wastewater in the environment. Results will also aim at providing an answer to the question whether environmental benefits have to be invoked in order to consider the reuse of treated wastewater economically sustainable or reuse itself is economically sustainable.

2) **Boosting the value of ecosystem services for a sustainable management of resources**. Integrated use of rural areas to provide services relying on nature-based solutions to the whole plain. Services to be foreseen are climate mitigation/adaptation, water purification, water supply, food production, soil conservation.

As deeply interlinked challenges to water, energy, and food security appear to accelerate in the coming decades, interest has grown in landscape-based approaches to manage the WEFE NEXUS risks and trade-offs. Both engineered and "natural infrastructure" approaches are needed to increase productivity and resilience in WEFE systems and to meet pressures of a growing global population and changing climate. Nature-based solutions (NBS) have been identified as key concepts to defuse the expected tensions within the WEFE NEXUS due to their multiple benefits. Anyway, relevant data from real environment are lacking, making it difficult to quantify the contribution of NBS to the WEFE nexus.

Research questions in the NEL will address:

a) investigating the potential for real (with specific references to river restoration measures) and simulated applications of nature-based solutions in addressing the WEFE Nexus at real scale;

b) analyse the integration of single site-specific NBSs into an interlinked green infrastructure framework by means of spatially-distributed simulations tools;

c) assess and quantify the interlinkages between nature-based solution and the NEXUS providing empiric evidences, with particular reference to food production issues;

d) identify existing indicators and suggesting new ones (Nika et al. 2020), especially related to food production, helping in highlighting productivity or resource-saving;

e) awareness of potential funders, and ability to implement nature-based strategies to address nexus-related challenges, and appropriateness of current investments in matching the scale of risk or dependency of our WEFE systems.

Research activities will allow to provide:

i. real examples with specific technical and societal challenges on linking NBS to the WEFE system;
ii. information on feedback loops and trade-offs among technological, environmental, political and social dimensions;
iii. the use of effective participatory schemes to promote the use of nature-based solutions.

The Coastal Tuscany NEL's Grand Challenges will then provide answers , in a participatory framework, to the above-mentioned themes by means of distributed modelling analyses, analyses of time series and dedicated lab and fields experiments. Technical issues will also be dealt with along with farmers associations and the most relevant stakeholders.

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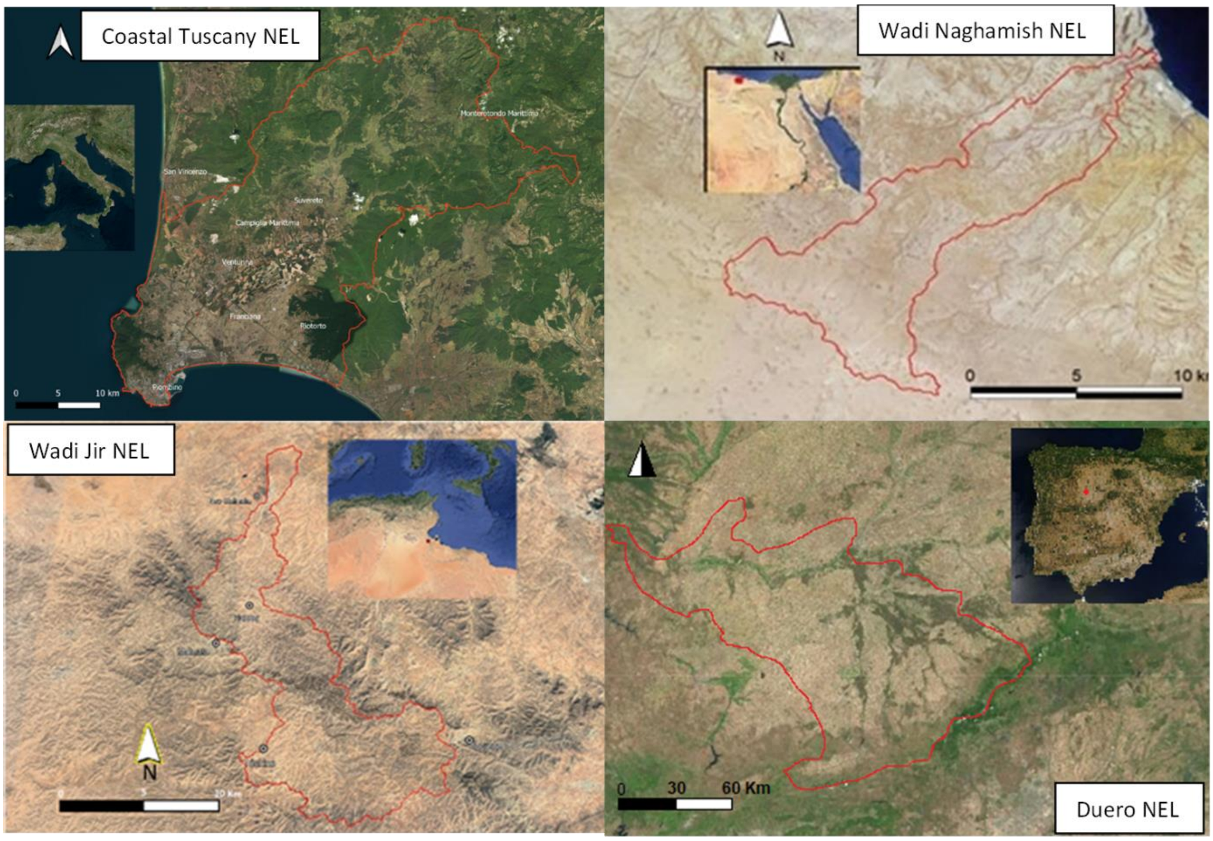
The Four NEXUS-NESS NEXUS Ecosystem Labs

Within the PRIMA NEXUS- NESS project four NEXUS Ecosystem Labs will be testing and demonstrating the outcomes of the project. They are located in Italy, Spain, Tunisia and Egypt. NEXUS-NESS NELs (considering actual and future demand and socio-economic conditions) demonstrates and assesses, in economic terms, the social and environmental importance of the optimization and sharing of economic benefits maintaining in high consideration the importance of preserving and considering also the services provided by ecosystems.



The four NELs areas testing and demonstrating the NEXUSS-NESS approach.

This document is one of the four Booklets produced as **Deliverable D3.1 The NEXUS Ecosystem Labs** of the NEXUS-NESS PRIMA project. Check for the other three booklets presenting the Spanish, Tunisian, and Egyptian NELs.

Booklet 1 – **The Coastal Tuscany NEL (Italy)**. Exploring innovative ways for conjunctive use of surface water groundwater and non-conventional waters to boost agricultural production, improve environmental quality, reduce energy consumption, and adapt to and mitigate climate changes.

Booklet 2 – **The Duero hydrological management units Cega-Eresma-Adaja and Tordesillas-Toro NEL**. Looking forward to water and food security based on RRI approaches on WEFE nexus

Booklet 3 - **The Wadi Jir NEL (Tunisia)**. Towards an efficient allocation of scarce natural resources in arid environments of south-eastern Tunisia through adopting Nexus approach.

Booklet 4 – **The Wadi Naghamish NEL (Egypt)**. Fair and Sustainable Resource Allocation Demonstrator of the Multiple WEFE Nexus Economic, Social and Environmental Benefits for Mediterranean Regions.

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Booklet 2

The Duero hydrological management units Cega-Eresma-Adaja and Tordesillas-Toro (Spain)

Looking forward to water and food security based on RRI approaches on WEFE NEXUS.

<u>**H2020 PRIMA NEXUS-NESS – Deliverable 3.1**</u>

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1. The Water Food Energy Ecosystems NEXUS

Natural resources scarcity is a major environmental issue since the middle of the twentieth century. Many factors like population growth, climate change, land exploitation (or land use change) contributed to the depletion and deterioration of ecosystems and the shortage of resources like water, soil quality and raw materials (Cramer et al., 2018). Each one of these resources impacts different sectors, but these challenges are commonly dealt with separated policies and strategy, or what can be dubbed as "Silo thinking" (Salleh, 2016): a mindset where governing authorities and sectors do not share the same vision whilst operating without proper collaboration. Silo thinking can be found in several government policies for example, when an agricultural department aims at ensuring food security by increasing irrigation demand, while the water department calls for reduction in water usage based on available volumes. The connection among these sectors and departments is missing while several connections are easily identifiable (Figure 1.1). Energy is needed for crop irrigation and food processing, water is needed for growing food, land use impacts water availability and water quality, energy is needed to pump/divert, treat, and distribute water, etc.

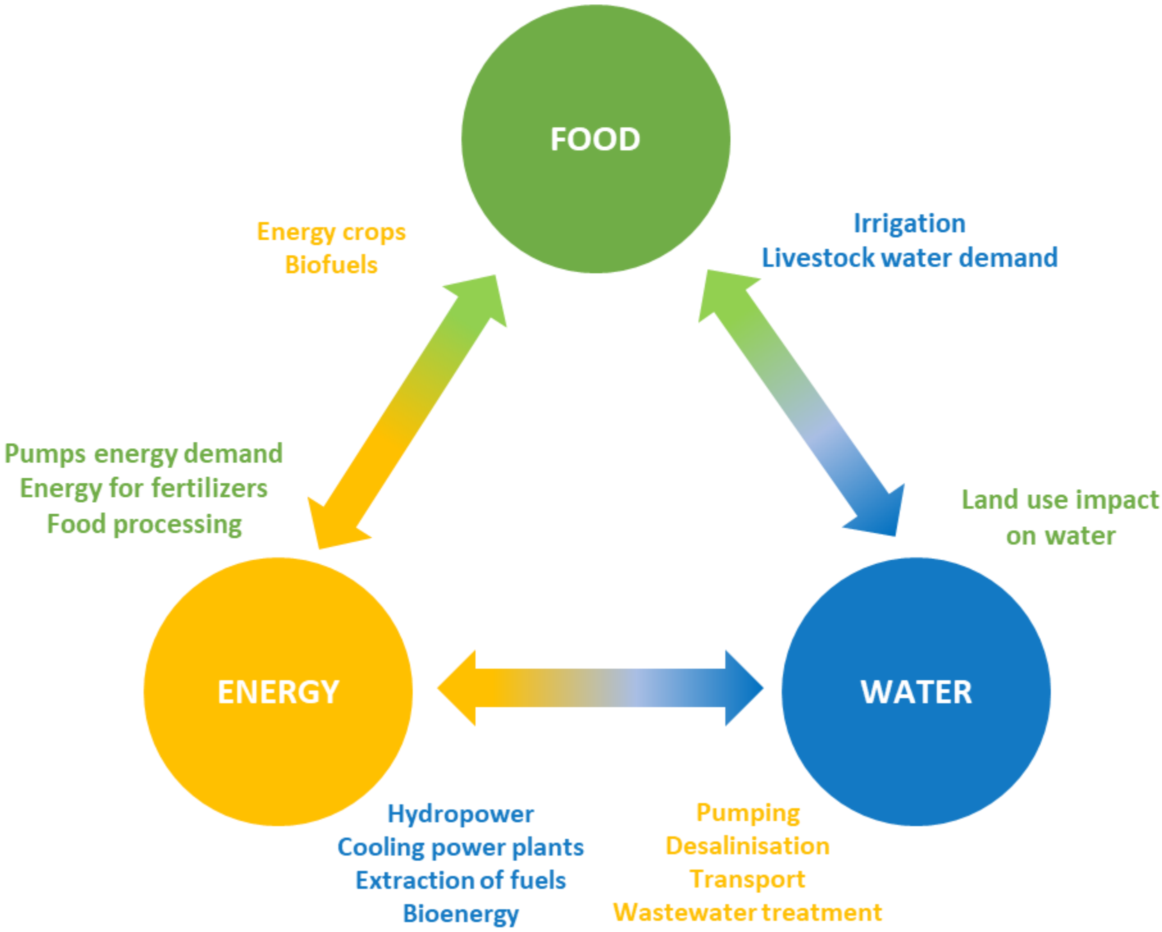


Figure 1.1. Typical Nexus connection diagram.

Cambridge dictionary defines the term NEXUS as an "*important connection between the parts of a system or a group of things*". Through the NEXUS thinking, resources are looked upon as being connected parts of a bigger system with synergies and trade-offs. The power of such a concept lies in its integrative capabilities, forming an umbrella under which multiple stakeholders can act (Simpson and Jewitt 2019). The resulting NEXUS system evaluation emerges consequently as a holistic analytical method driven by participation, research and science, with the final aim to provide adequate governance directions and policies for integrated and sustainable resource planning and management.

Several approaches may be implemented to avoid this silo-thinking that still characterizes the different sectors and actors of the WEFE components. Top-down (from policy to operations) or bottom-up (from the ground where people represent the main driver for mainstreaming the NEXUS) actions may be adopted with pros and cons of both

approaches. NEXUS-NESS recognises the core importance of bottom-up citizen-centred technological and behavioural change to favour the uptake of NEXUS approaches.

An opportunity for collaboration

Within the methodologies presented by the NEXUS, a critical factor of collaboration and dialogue through science lies. Because of this, the NEXUS approach is being adopted by major stakeholders and policy makers like the United Nations, European Commission, NGOs, and important academic institutes. Its compatibility with the Sustainable Development Goals, with the existence of the applied cases incorporating societal and economical aspects, despite limitations, allows the development of further studies and connections between the water, energy, food, and ecosystems, whether exploring their internal relationship or finding their response to the several drivers. Hence, a framework for dialogue and collaboration can be set, through NEXUS thinking, between businesses, NGOs, and the public sector.

NEXUS-NESS - Nexus Nature Ecosystem Society Solution. A HORIZON 2020 PRIMA project

The NEXUS-NESS PRIMA project implements the Innovation Ecosystem Approach (IEA) at four selected areas, called Nexus Ecosystem Labs (NELs). The approach focuses on stakeholder engagement and actionable information, and integration within a 'NEXUS' framework, to ensure fair and sustainable resource allocation. Each NEL has its own challenges and benefits obtained from the NEXUS approach. The geographical variability between the NELs helps in demonstrating the capability of NEXUS thinking in overcoming the different challenges. The IEA is supported by the implementation of the Responsible Research Innovation Roadmap (refer to Deliverable 2.1 of the NEXUS-NESS project for more information; Schneider 2021).

2. Geographic and socio-economic situation

The Duero Basin Authority (CHD) is the Institution responsible for the planning and management of water in the river Douro basin following the measurement hold in the so-called A.G.U.A. program (Actions for the Management and Use of Water; www.chd.es). The Spanish NEL comprises the Duero hydrological management units Cega-Eresma-Adaja (**CEA**) and Tordesillas-Toro (**T**; Low Duero) extended across 4986 km^2 and 7488 km^2, respectively. It is located in central north of the Iberian Peninsula and belongs to the Castilla y Leon autonomous community, comprising the provinces of Ávila, Segovia, Valladolid and Zamora. Each of them includes between 10 to 30 municipalities (see Figure 2.1). The CEA name stands for the three major rivers and is composed of two adjacent sub-basins: the network of streams defined by the Eresma and Adaja sub-basin represents 67% of the total area, while the one defined by the Cega comprises 33%. The former is regulated in the upper river network (reservoir of Las Cogotas), but the Cega is not yet regulated.

The climate is dominated by a sub-arid Mediterranean regime, with 12.6 ± 7.3 °C (arithmetic mean ± standard deviation) temperature and 387.8 ± 84.3 mm annual precipitation (www.chd.es). Severe drought periods in the summer months have been frequent during the last decade, decreasing water resources within 10.1% and 25% and raising the concern on water availability (CHD, 2021).

The rural area is depopulated (less than 10 people/km^2); people has moved to nearby cities or to the Spanish coast since 1960's although the Plan for modernization of irrigation systems (in the XXI century) has decreased this trend (INE, 2020). The average farmers' age is over 50's but the Rural Development Plan (RDP) (2014-2020) has settled young population with the incorporation of young farmers. Currently, average villages' population ranges between 200-400 persons. Therefore, some issues regarding rural health care centers and primary children's schools arise. Moreover, the chance to settle down new inhabitants is reduced by the poor internet access.

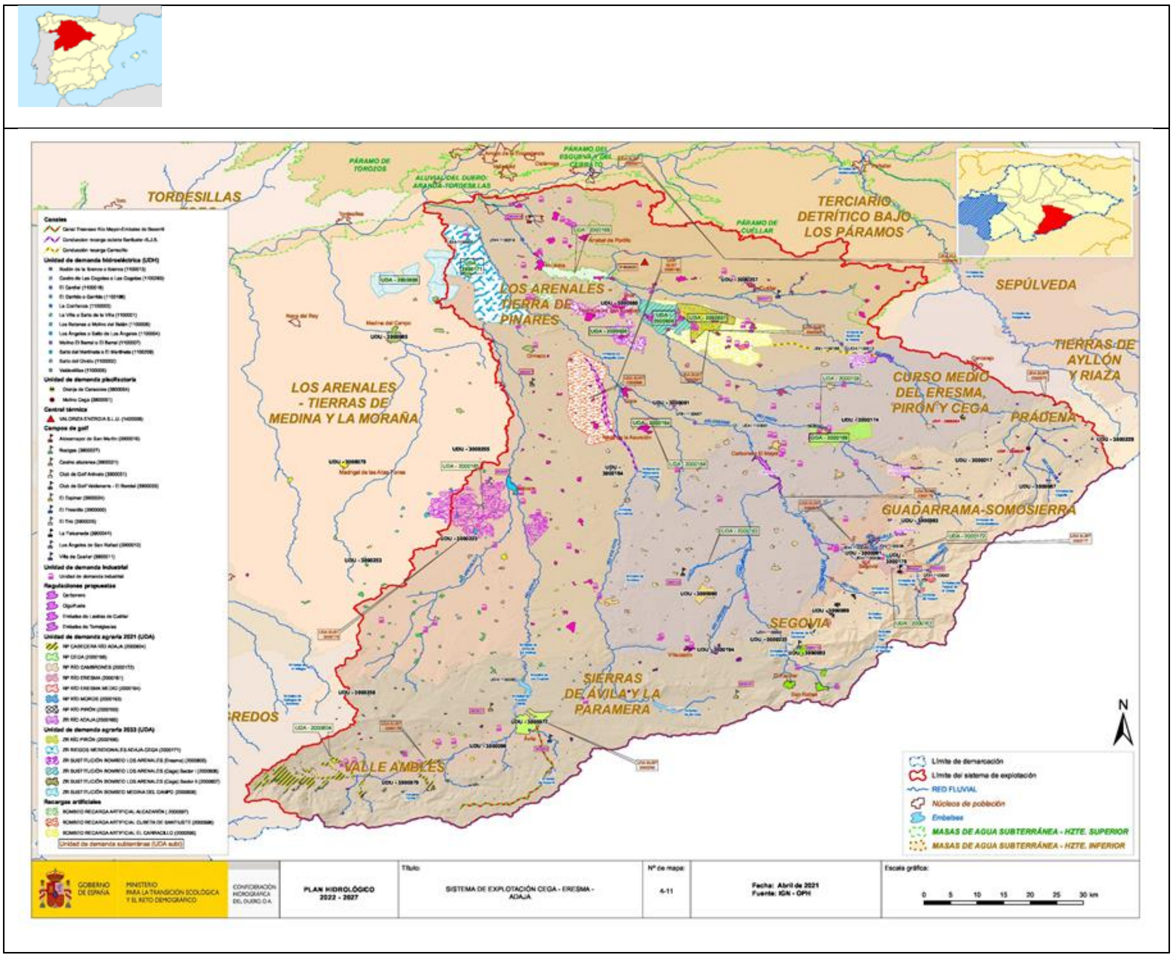


Figure 2.1a. Location of the Duero basin in the Iberian Peninsula and details of the river hydrological management units: (a) Cega-Eresma-Adaja (source www.chduero.es).

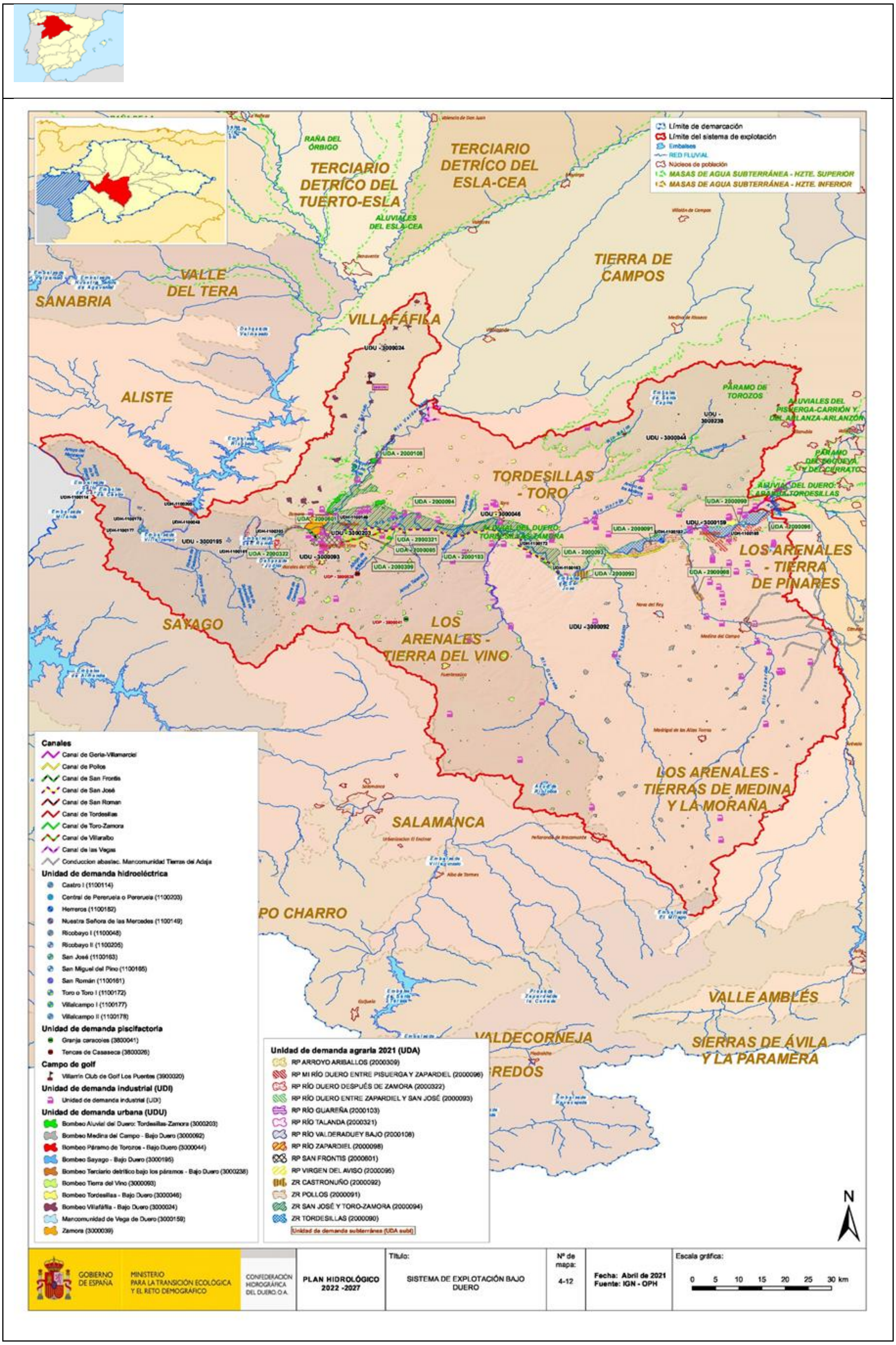


Figure 2.1b. Location of the Duero basin in the Iberian Peninsula and details of the river hydrological management units: (b) Bajo Duero (Tordesillas-Toro; source www.chduero.es).

The subsequent RDPs have increased the role of rural women and nowadays, at least one Rural Women Association can be found in each province. The modern farmers' generation has secondary education and few of them also have agricultural knowledge from University degrees or Professional courses. However, the land owners are the old generation who, frequently, limits decisions from the youngest regarding innovate agricultural practices.

The RDP of Castilla y León (2014-2020) has strengthen: the agricultural sector and its processing industry, sustainable agriculture and forestry, and economic activities in the villages. The Program has created new small enterprises such as: cooperatives for onion, sugar beet, horticultural products (carrots, potatoes, turnips, parsnips, nabicoles, scallions and leeks); cooperatives for fodder, meet and genetics for pigs; small factories for strawberry plant production, strawberries, raspberries, blackberries, cranberries, and currants; marketing of sheep and goat milk; strawberry plant nurseries.

The average gross domestic product in T is about 24000 €/year and in CEA, the profitability has an average of 300 €/ha. Agricultural cooperatives are a key productive sector, with a turnover of 2.566 million € generating more than 3.500 jobs in the whole Duero basin. Farmers rely on funds from the Europe Agriculture Policy (PAC), which is renewed every 5 years. The PAC establishes a basic rights payment (historical rights) which is aimed at complete the farmers' income and thus, settle down the population in rural areas. Likewise, there are other funds to cultivate legumes and stone fruits (almond, pistachio) and funds for preserving ecosystems (Política Agraria Común PAC | Política Agrícola Común | Junta de Castilla y León (jcyl.es)). Thus in total, all funds account for 150 €/ha and 370 €/ha, in rainfed and irrigation agriculture, respectively. The PAC is going to be modified in 2022. In addition, there are funds from the Autonomous Castilla y León and the Spanish Agricultural Ministry such as: for the sugar beet crop (1000 €/ha), which pursue to subsidize its cultivation to save the sugar industry; 26 €/kg to maintain fallow lads; for almond, pistachio and other stone crops as well as for organic products. Likewise, there is an incipient activity in rural tourism.

The sugar beet is a major crop in the area although it is not profitable and its water requirements are very high almost twice as much as corn. Its price is fixed every year by Regulatory Laws. There are two major and powerful sugar beet associations (AIMCRA and ACOR) that received European funds to maintain the crop and the subsidiary sugar factories. The other major crops are corn and cereals (wheat and barley).

Within a global economy, the extensive crops in the area are not competitive. The cost of fertilizers is high as well as the seeds. In 2021 fertilizers have raised 200% and most of them are not manufactured in Spanish factories, which increases the cost and, sometimes, decreases the availability of specific products. The big company FERTIBERIA supplies most of fertilizers and nowadays, since the global situation, some of the fertilizers are lacking. The farmers cannot choose transgenic seeds (corn) while other competitors can (Americans), thus, their products cannot make a fair completion in the market causing a general dislike.

The rural population seeks for a short-term profit. Most of them are against environmental policies such as control in fertilizers' doses and stubble burning, since it implies an increase in their expenses.

Nine major soil groups: Cambisols (34%), Luvisol (26%), Arenosols (19%), Leptosol (11.5%), Fluvisols (4%), Regosol (3%), Solonetz (1%), Solonchak (1%) and Gleysol (0.5%) are the predominant in both hydrological units. In CEA, sandy soils characterize more than 54% of the area and a medium-high infiltration rates of subsurface flow to streams and recharge of groundwater. In T, loamy clay sand and sandy loam soils are predominant.

3. Overview of the natural resources

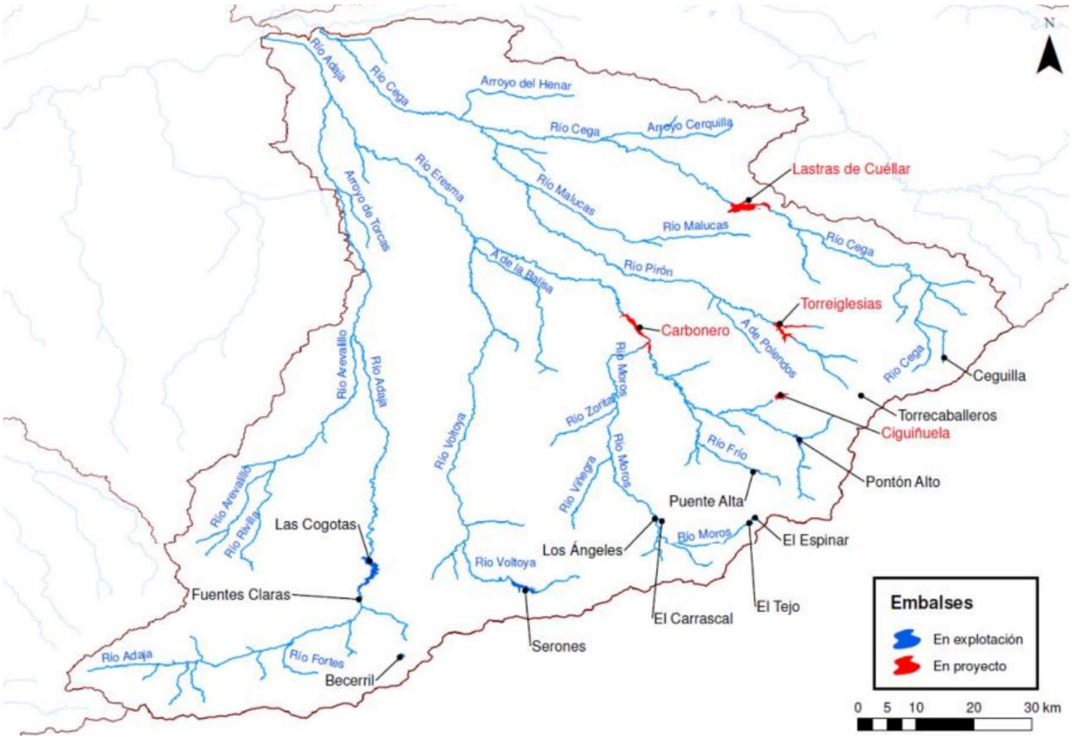
3.1 Water resources, uses, infrastructures and impacts

The own natural water resources estimated by the CHD (2021) for CEA and T (1940-2005) are 644.6 hm^3/year and 1000.8 hm^3/year, respectively. Water is scarcely mineralized with a predominance of calcium bicarbonate facies.

The CEA units counts on 12 water reservoirs (see location in Figure 3.1a); the main one is “Las Cogotas” in the Adaja river, which supplies water to close irrigation area, municipalities and industries. Then, the second one is “Pontón Alto”, which supply water to the population of the main cities Segovia and Ávila. In 2027 , it is foreseen to use the reservoirs “Ciguiñuela” and “Carboneros” in the Eresma river and “Lastras” in the Cega river for the allocation of water to the new irrigation areas aimed at replacing the the use of subsurface water in “Los Arenales” for surface water.

The T unit encompasses four water reservoirs: San Román, Villalcampo, Castro and San José (see location in Figure 3.2b). The first three are devoted to hydroelectric production (San Román y Pereruela); the second allocates water to the irrigation areas San José y Toro-Zamora.

The quantity and quality of water in the reservoirs are monitored through several discharge control and quality control points. The surface and the subsurface water bodies are presented in Figure 3.2a and 3.2b.



Figures 3.1. Regulation reservoirs: (a) Cega-Eresma-Adaja (source www.chduero.es).

In CEA most of the rivers are directly connected to aquifers, but groundwater depletion, due to overexploitation, sometimes has disconnected the flow between the riverbeds and the aquifers. This situation is aggravated in dry periods, where most rivers have very low flows. Water table in CEA is between 100-300 m depth. In T, the water table oscillates between 80-120 m and has decreased almost 16 m since 1975, not only because of dry hydrological years, but also of illegal abstractions (CHD, 2015).

In CEA, the irrigated area “El Carracillo” and the “Cubeta de Santiuste” uses subsurface water provided by means of managed aquifer recharge (MAR). In the first, water is diverted from the Cega river, 30 km far from the irrigable area and the second, it is diverted from the Voltoya River (intake of the Pinarejos dam). Both areas are associated to the subsurface water body “Los Arenales” in poor quantitative conditions according to the Water Framework Directive.

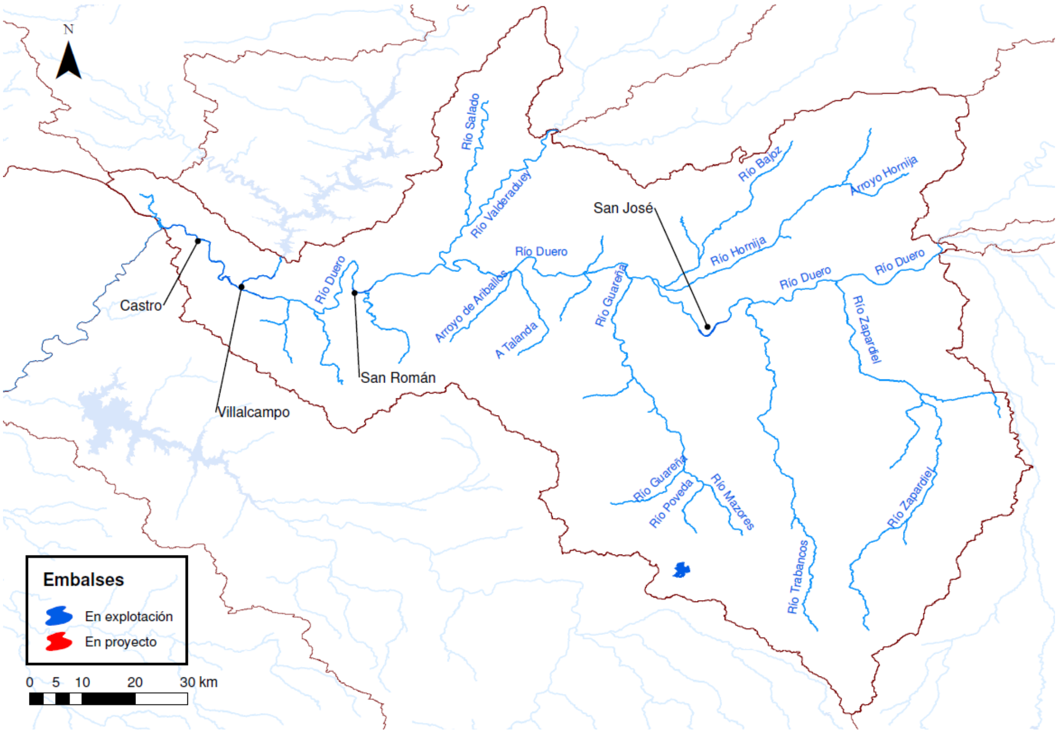


Figure 3.1b. Regulation reservoirs: (b) Bajo Duero (Tordesillas-Toro; source www.chduero.es).

The irrigation District " El Carracillo " can derive water from the Cega River between December 1st and April 30th up to a maximum of 14.2 hm^3/year; the maximum volume must not exceed 5 hm^3/month. The diversion of water from the Voltoya River is restricted from December to May with a maximum volume of 0.48 hm^3/year. In "El Carracilllo", the growing demand for water has deteriorated water quality and has threatened the basin's sustainability and its economic activities. This issue may be worsening, as the Duero River Basin Plan (2015–2021) has approved an increase of irrigated area (equivalent to 7000 ha) by 2027, despite the existing water gap (Rivas-Tabares et al., 2019).

In 1998, the hydraulic infrastructures for water supply, flood control, wastewater treatment and irrigation for the MAR project was designed and this was declared of general interest by Royal Decree (R.D. Law of 9/1998). The decree aims at recovering and preserving the aquifer as well as it provides water to fulfil the agricultural needs in the area (3000 ha). The technology includes ponds infiltrating the water at various points (see Figure 3.3). The EU FP7 Project MARSOL (2013-2016) funded the studies in the area aiming at demonstrating that Managed Aquifer Recharge techniques are able to secure 'excess' water and store it in the soil.

The main water user is irrigation (96%, T and 79 %, CEA) followed by human consumption (3 %, T and 18 %, CEA) and industry (0.5 %, T and 1.9 %, CEA).

The CEA is a surface water body showing a low IPS (Pollution Specific Sensitivity Index), a biological indicator of water quality related to benthic organisms.

The economic development of the region of El Carracillo (CEA) is caused overexploitation of the aquifer which has triggered the action of the CHD to address the associated water management problems. It is foreseen that the actual water consumption from crops causes a significant or severe level of water stress during two to five months per year. The expected expansion of irrigation in the coming years could make water management difficult.

In CEA, the area "Los Arenales" the quantitative and qualitative water state qualifies as "bad"; its exploitation index above 0.8 (0.86), mainly due to the water table decrease caused by agricultural activities. Currently this is stabilized, although the cumulative decline remains significant. The water body is in poor chemical condition; the average concentration in nitrate content is above 50 mg/l in 10 out the 31 control stations. In addition, the ammonium content has also showed high although currently it qualifies good status (CHD, 2015). Likewise, the results from a participatory approach in the area provide an interesting insight into ecosystem services trade-off (Laurita et al. 2021).

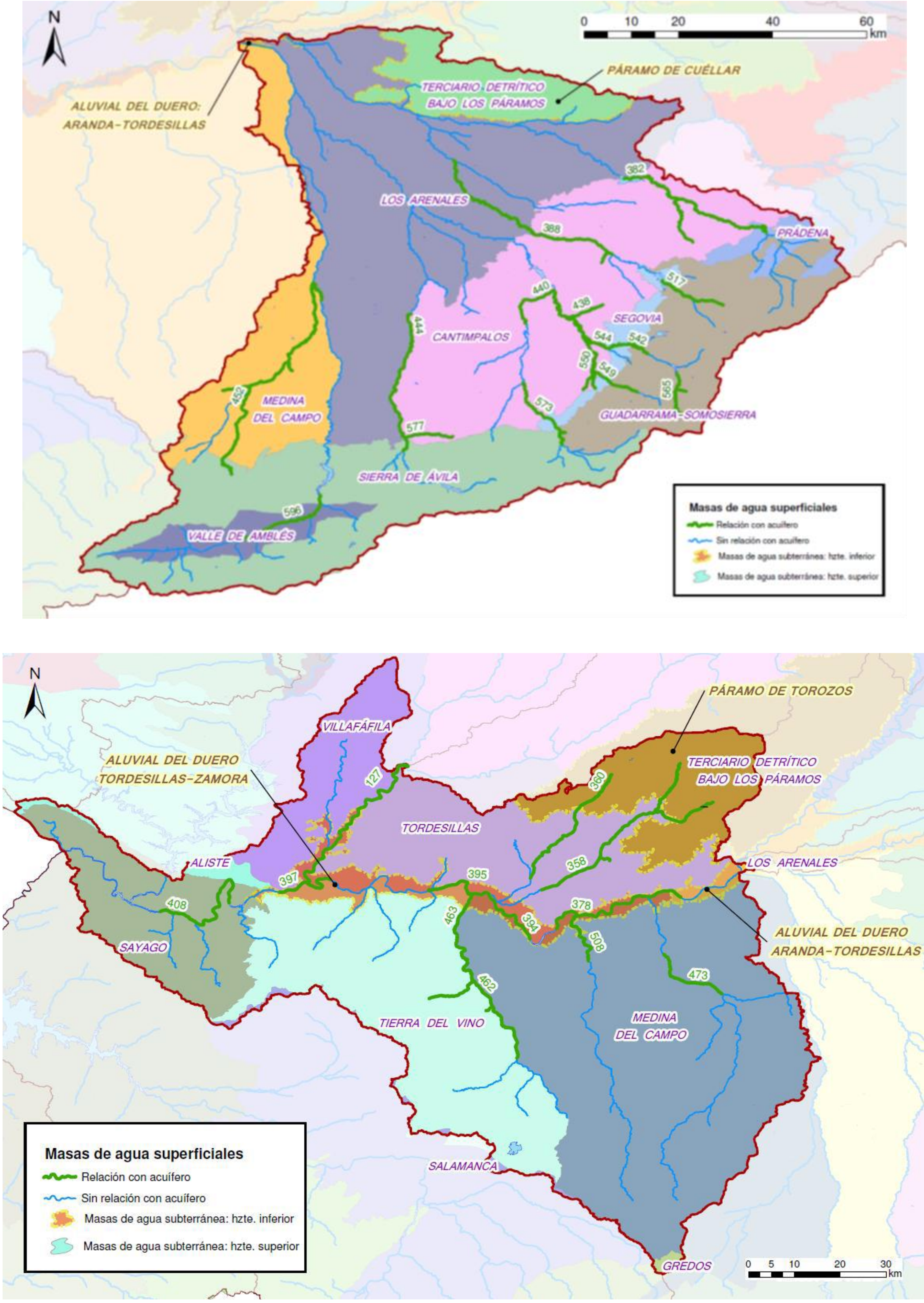


Figure 3.2. Surface and subsurface waters: (a) Cega-Eresma-Adaja and (b) Bajo Duero (Tordesillas-Toro; source www.chduero.es.

In T, the area “Tordesillas” the quantitative and qualitative water state qualifies as “bad” (explotaition index =1.03) similar as in CEA and caused by the same factors. Likewise, its bad quality conditions are also associated to the high ammonium content detected in two out nine control stations. Likewise, the diversity in birds’ species has decreased and thus, there is a reduction in insects’ control.

(a)	(b)	(c)

Figures 3.3. Managed artificial aquifer recharge in “El Carracillo” (CEA): (a) control head; (b): settling pond and (c): infiltration channel.

3.2 Land/Agricultural resources, uses, infrastructures and impacts

Agriculture is the main land use, representing 54.1% of the total area, followed by forestry (27%), urban areas (12%), scrub and pastures (6.7%) and water’s bodies (0.1%; CHD, 2021). Rainfed crops account for 63% of total agricultural land, while fallow land accounts for 31%, irrigated agriculture accounts for the reminder 6%. The area has long been characterized by subsistence agriculture, extensive sheep breeding and pine management (in sandy soils), the latter being one of the oldest economic activities. It has a long history of dependency upon governmental agencies, both by subsidies for agricultural inputs and by the supply of agricultural infrastructure to individual household and communities. Figure 3.4 shows the land use in CEA.

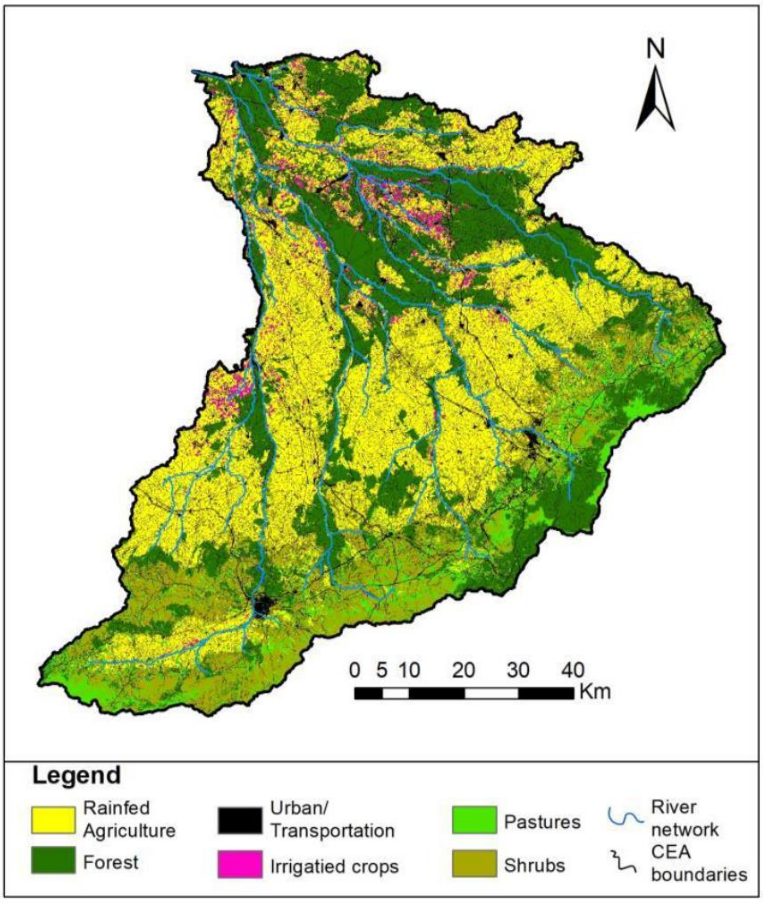


Figure 3.4. Land use of CEA system (source www.chduero.es).

Since the 1960s, a new model of rural development has produced a transformation and intensification of rural activities and a change in the management of natural resources, in cultivation patterns and the horticultural production expansion. The adoption of irrigation has shifted the crops from less water requirements (cereals) to more water demanding (horticultural crops). Table 3.1 shows the water productivity of major crops in the last decade.

	Water productivity (€/m³)								CV
	2011	2013	2014	2015	2016	2017	2018	Average	%
Sunflower	0.66	0.71	0.32	0.65	0.32	0.38	0.33	0.48	35.03
Potato	0.93	1.54	0.44	1.52	2.13	0.69	2.35	1.37	48.60
Clover	0.45	0.47	0.35	0.42	0.32	0.50	0.55	0.44	16.84
Sugarbeet	1.27	1.17	1.31	1.29	0.86	1.03	0.76	1.10	18.65
Corn	0.52	0.42	0.42	0.48	0.42	0.47	0.48	0.46	7.84
Barley	1.04	0.50	0.57	0.42	0.75	0.71	0.37	0.62	34.32
Wheat	0.82	0.59	0.43	0.98	0.62	0.50	0.47	0.63	29.66

Table 3.1. Annual water productivity in the major crops from 2011 to 2018 (Naroua and Rodriguez-Sinobas, 2022).

In CEA, traditional crops such as sugar beet and chicory were replaced by horticultural crops with higher irrigation requirements, such as strawberries. In addition, numerous seedbeds and nurseries were established to produce both propagation material plants and plants to export. This new economic model led El Carracillo to become an example of productivity and agricultural development. Today, the irrigable area is about 7600 ha, of which approximately 3000 ha are already irrigated.

The regional Advisory Board (ITACYL) developed the platform InfoRiego (Inforiego) to support farmers in irrigation management (crop water requirements, fertilizer`s doses and best agricultural practices). The information can be consulted "on-line", either in a WEB page or in a mobile phone. However, farmers did not determine the crop water requirement properly, causing underestimation of water requirements in some cases and overestimation in others (Segovia-Cardozo el al. 2019).

Irrigation in CEA comes mostly from surface water bodies while in T (4000 ha) comes from subsurface water bodies (Vicente et al. 2016). Fig. 6 shows the distribution of surface and subsurface waters for irrigation. In CEA 17 agrarian units uses surface water and 12 subsurface water while in T the values are 14 and seven, respectively (CHD, 2015).

Table 3.2 shows the water demand for irrigation in the three IDs studied in NEXUS-NESS during the last decade.

Irrigation water demands varied from 4000 to 7800 m³/ha in the last decade. In the last 40 years, the effects of climate changes have caused an increase in drought periods. Summers are hotter with extreme temperatures and lack of rainfall. A recent assessment of water resources (CHD, 2015) showed a decrease in discharge and overall rainfall: 38% and 11 %, respectively, in CEA; and 37 % and 3 %, respectively, in T. The River Duero basin management Plan (2022-2027) analyzed water availability under climate change, considering both temperature and precipitation forecasts, for three time periods: 2010-2040, 2040-2070 and 2070-2100; 12 climatic projections for six emission scenarios in RCP4.5 and RCP8.5 were carried out. The results showed that water availability in the climate change period is smaller than in the control period, meaning that water demand management will be required to adapt to climate change. The climate changes maps predicted the highest water reductions (in percentage) in the summer months and the lesser in the winter months: Daily mean air temperature is foreseen to increase severely to the end of the century in all seasons, but especially in summer. Therefore, water availability for irrigation will be affected.

The Spanish Plan for the Modernization of Irrigation has transformed rainfed land into irrigated agriculture aimed, mainly, at settling down population and increasing rural development. The irrigated areas belong to Irrigation Districts; CEA has 10 (total 5822 ha) and T 10 (total 9106 ha). Sprinkler irrigation methods (center-pivot, moving lateral, solid set and guns) are predominant in the area. The farmers have increased their revenue since the first year of operation, and also, new agribusiness opportunities have arisen fostering the economic development of the rural area. Pressure irrigation systems are commanded by large pumping stations (fully automated and controlled by pump drives and other controllers) supply water to the irrigation districts. All irrigation districts are modernized and digitalized; their network and equipment have been installed between 2007-2009 to fulfill irrigation efficiency Standards (see Figure 3.6). They have a central control station to monitor: discharge and pressure in all irrigation inlet valves.

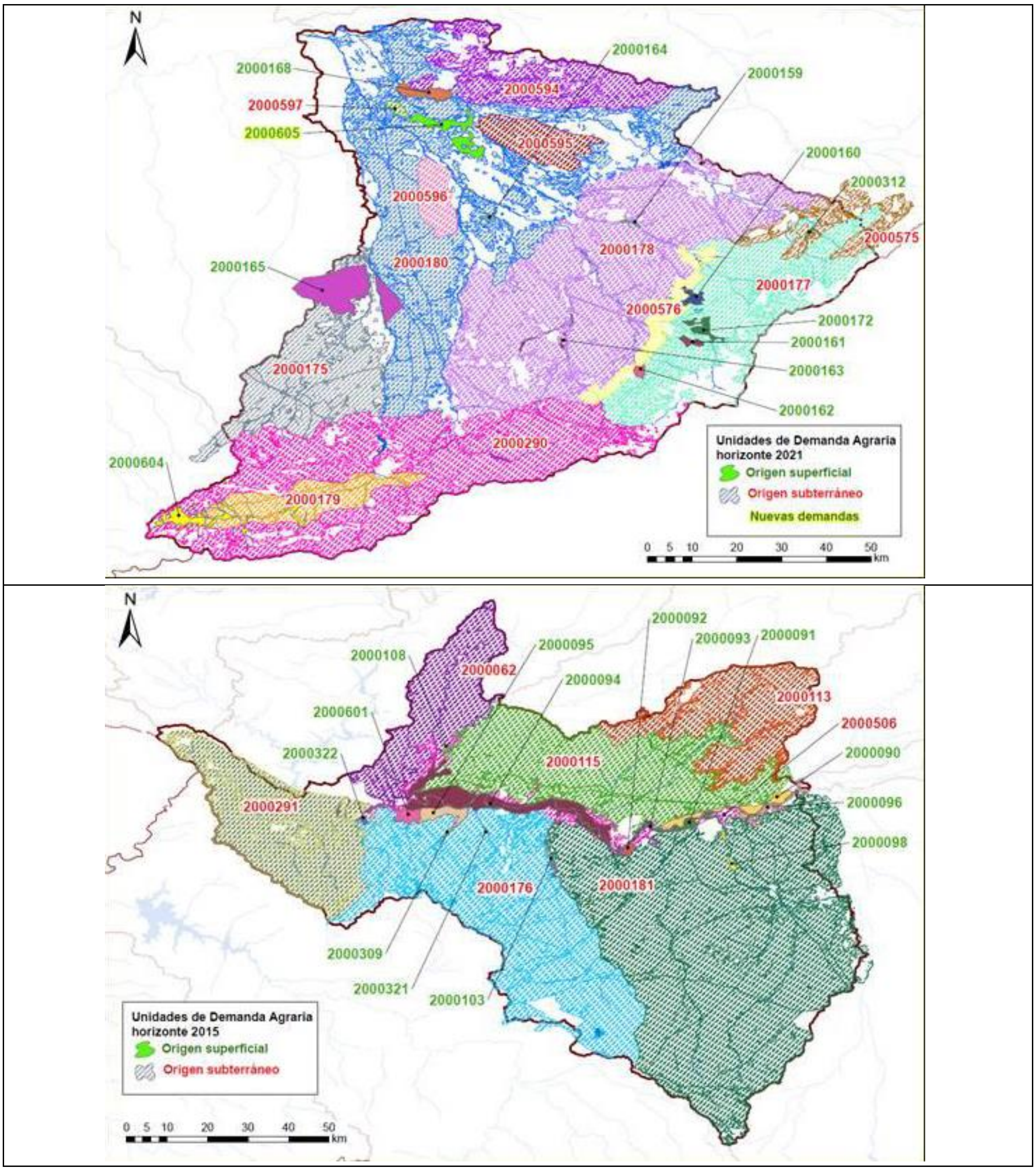


Figure 3.5. Origin of water for irrigation demands (2021): (a) Cega-Eresma-Adaja and (b) Bajo Duero (Tordesillas-Toro; source www.chduero.es).

	Water demand (hm^3)												CV
Irrigation District	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Average	%
Río Adaja (CEA)	0.17	0.01	20.97	33.53	43.51	47.94	43.04	49.23	33.59	42.79	42.56	32.49	52.45
Villalar de los Comuneros (Bajo Duero)	81.49	102.23	105.42	93.42	110.34	108.93	94.42	111.01	88.82	105.63	93.78	99.59	9.35
Carracillo (CEA)	14.81	16.33	19.97	16.46	16.64	17.2	17.58	13.48	13.95	14.11	14.05	15.87	11.95

Table 3.2. Annual water demand in the studied Irrigation Districts from 2010 to 2020 (Naroua and Rodriguez-Sinobas, 2022).

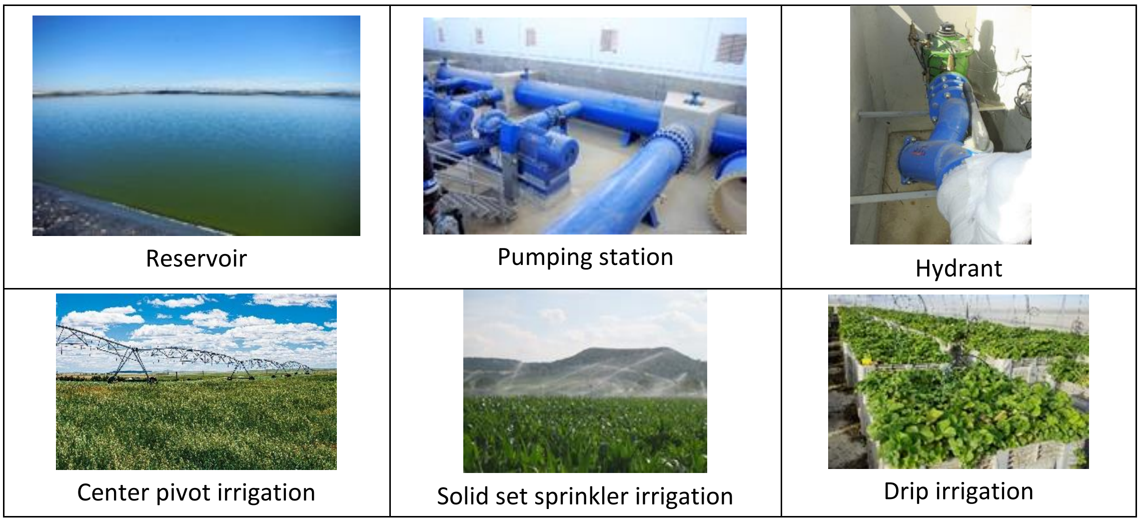


Figure 3.6. Components of the irrigation systems.

3.3 Energy resources, uses, infrastructures, and impacts

The energy consumption estimated for the pressure irrigation systems is between 0.3 and 0.4 KWh/m^3 (Omedas, 2020), depending on the efficiency in the irrigation systems as well as the increase in water table depths caused by aquifer over-exploitation. In the past decade, the energy demand for irrigation was between 1800 and 2800 kWh/ha in the area (CHD, 2021) see Table 3.3. Energy cost is a key issue since 2010; the electrical tariffs have increased about 700%.

	Annual energy demand (kWh/ha)											CV
Irrigation Districts	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Average	%
Río Adaja	1792.17	1320.75	2310.90	1860.32	2408.30	2654.36	2383.82	2773.49	1895.67	2411.24	2393.80	2200.44	18.66
Villalar Comuneros (Bajo Duero)	1939.18	1906.49	1951.37	1751.59	2016.74	1965.66	1688.98	2055.32	1623.95	1929.24	1720.68	1868.11	7.41
Carracillo (CEA)	1643.01	1666.39	1978.62	1676.94	1675.37	1752.89	1703.07	1705.56	1723.58	1764.20	1735.14	1729.52	5.00

Table 3.3 Annual energy demand in the studied irrigation districts from 2010 to 2020.

The electrical tariffs are set up by the electrical companies and sometimes, regulated by the Spanish Government. Average, farmers pay a minimum of € 1000 / month even in the months with no irrigation. Therefore, the energy cost has increases about 40% compared to last year.

A renewable solar panels has installed in T (2020) funded by a private international investment (Canada) and it is foreseen the installation of one hydrogen plant. Each solar plant covers about 150 ha, and the full installation will cover 1000 ha in the municipalities of Tordesillas, Toro and Medina del Campo. This will reduce the irrigated land and will increase the farmers' income.

There are 12 hydroelectric plants in operation in CEA and 10 in T and their location in the NEL is presented in Figure 3.7.

3.4 Environment and Ecosystems

Environmental Flows are considered an effective restoration measure for most Climate Change effects. However, they are a poor mitigation measure to recover the rivers good ecological status in the Duero River Basin. A practical response to climate change is River Restoration. However, using historic references for dangerous species or spatially fixed protected areas for restoration, targets may fail in the context of rapid Climate Change (DURERO, 2015).

Fluvial Ecosystems are especially sensible to climate change effects, as are greatly dependent on their watershed. Proportions in the fish community of Brown trout, Pyrenean gudgeon, Bermejuela and Common carp are sensitive and known to be affected by warming. On the basis of climate change forecasts, the thermal habitat is expected to induce decreases in brown trout range by the year 2100. Thus these species can be used as indicators of medium–term changes. In CEA the study conducted in DURERO (2015) showed that these reductions would affect up to 38% of the length of Cega stream that was occupied by brown trout and 11% of Pirón stream, as estimated from the 1997 and 1998 samplings. A thermal window detected at the piedmont zone could open increasing habitat loss up an additional 18%.

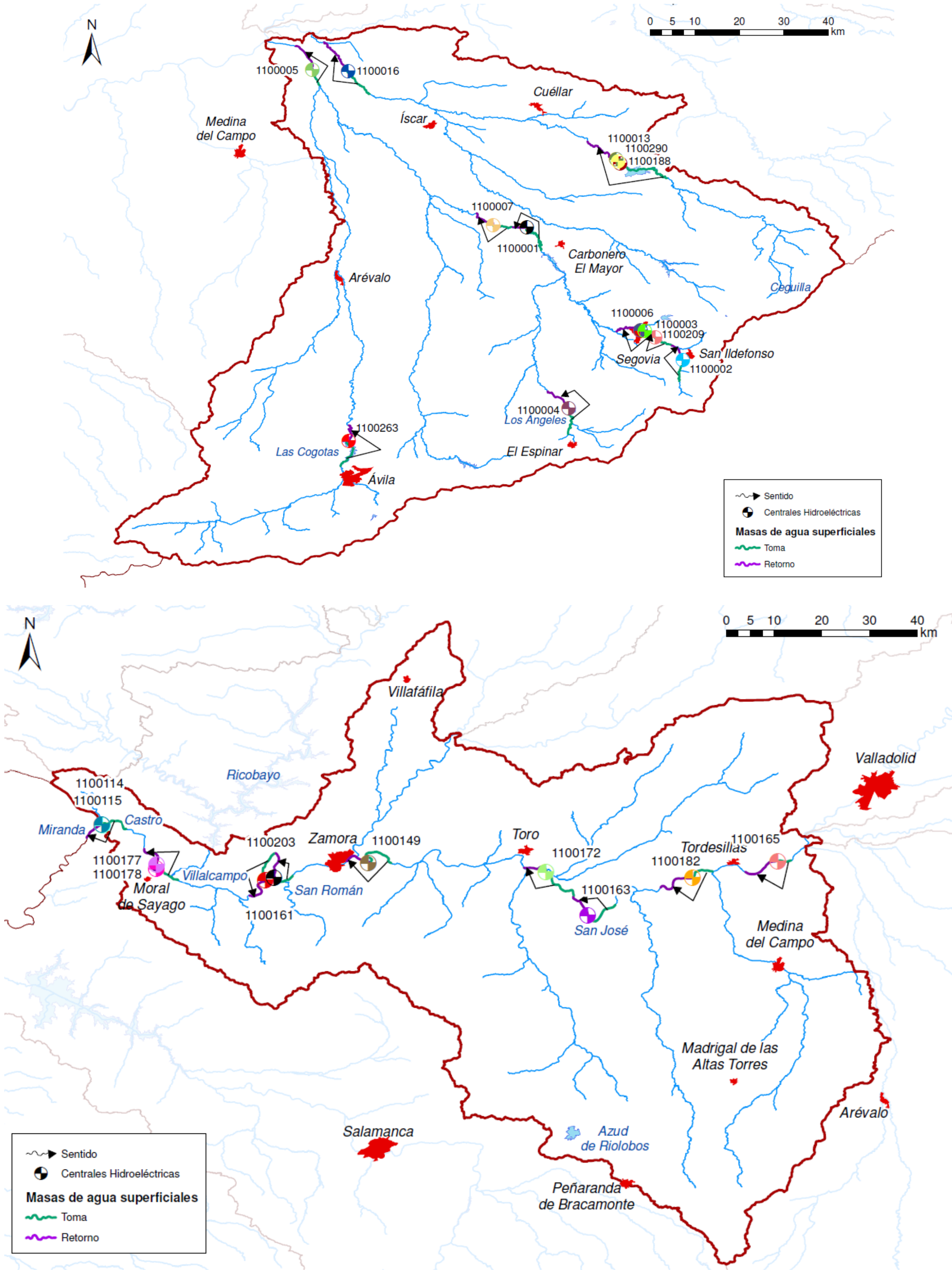


Figure 3.7. Hydroelectric plants (2021): (a) Cega-Eresma-Adaja and (b) Bajo Duero (Tordesillas-Toro; source www.chduero.es).

The NEL presents nitrate water contamination, especially T, caused by livestock and agricultural activities. Figure 3.8 shows an overall picture of nitrate problems in the Duero basin.

In the NEL, the CHD has carried out actions in various river realms such as: (i) recover river ecosystems by the National River Restoration Strategy for the improvement of the ecological status and connectivity of surface water bodies (2015 to 2018). (ii) development of guides for the development of river restoration projects;(iii) working groups on rivers' conservation and recovery and environmental volunteer programs. The II River Bank Restoration Plan is aimed at the environmental regeneration of rivers and riverbanks, the defense against floods and floods and the recovery of these riparian spaces. It was applied to the conditioning of the left bank of the Adaja River.

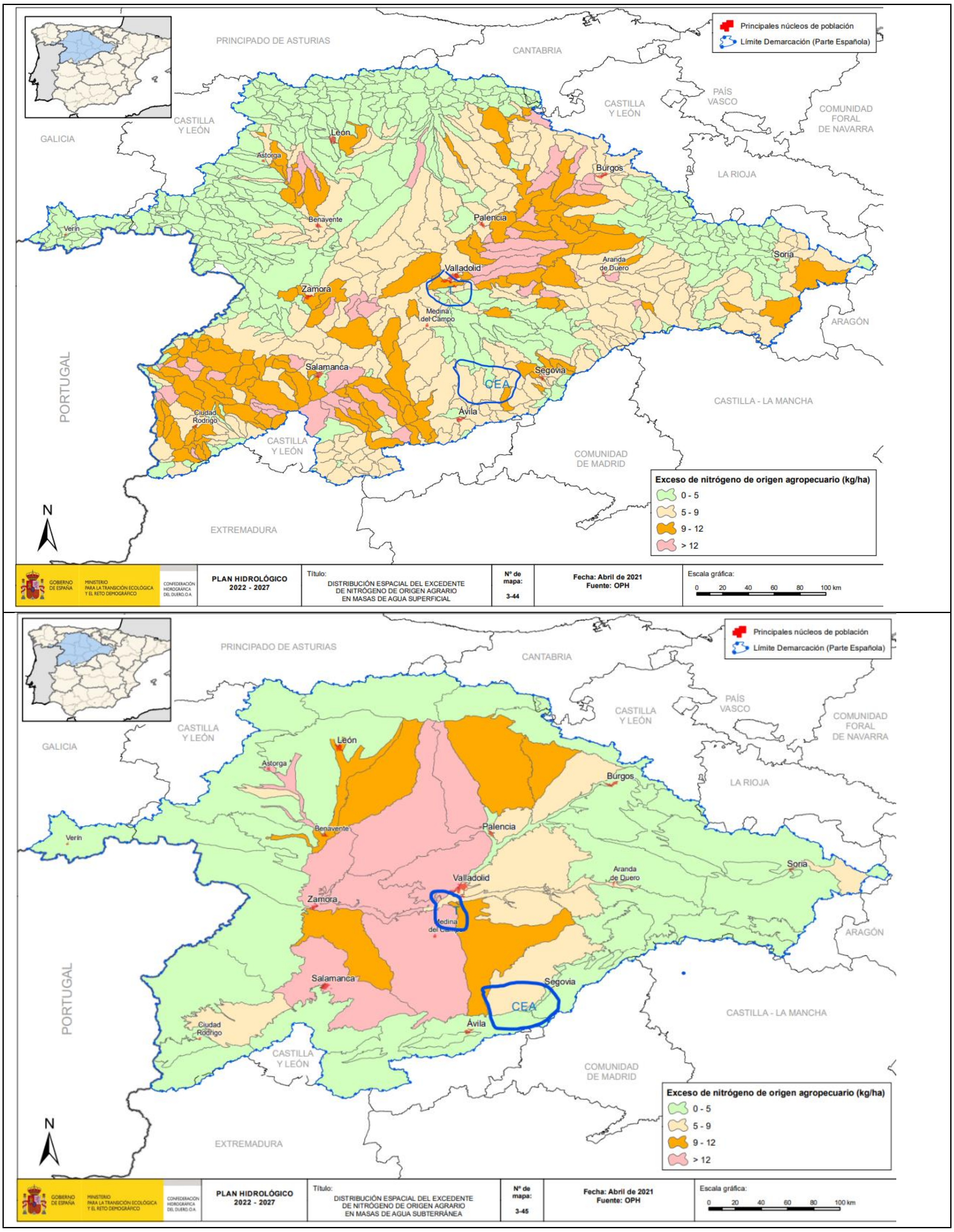


Figure 3.8. Contamination by nitrogen in the Duero basin: (a): surface water and (b): subsurface water (source www.chduero.es).

4. Governance framework

The CHD is under the superior direction of the Secretary of State for the Environment. to the Ministry for the Ecological Transition and the Demographic Challenge through the General Directorate of Water. They are Autonomous Bodies on the Organization and Operation of the General State Administration whose provisions were adapted in article 60 of the Accompanying Law of 2009 (Law 50/1998. of December 30). The Committee of Competent Authorities of the Duero river basin coordinates the complex scenario of competences around hydrological planning.

The CHD was set on the Spanish Royal Decree 125/2007 of February 2 and is located in the north central of the Iberian Peninsula. Subsequently, the Consolidated Text has undergone some modifications derived especially from the Accompanying Laws of 2002. 2003 and 2004 (Laws 24/2001. 53/2002 and 62/2003). Law 11/2005 on the reform of the National Hydrological Plan, Royal Decree Law 4/2007 and, finally, the so-called Omnibus Law (Law 25/2009). Of these. the reform introduced by the Accompanying Law of 2004 stands out for its importance. which meant the transposition into our legal system of the provisions contained in Directive 2000/60/EC of the European Parliament and of the Council. of 23 October 2000. establishing a Community framework for action in the field of water policy.

The Water public administration within the scope of State competence is regulated in Title II of the Consolidated Text of the Water Law (TRLAg), chapter III (arts. 21 and ff).

The CHD develops the Duero River Management Plans DRMP, according to the EU Water Framework Directive (WFD, Directive 200/60/CE European Parlament and EU Council. October 23rd. 2000) which applies in the area and is complemented by other more specific European legislation such as: the Environmental Quality Standards Directive (2008). the Floods Directive (2007), the Surface Water Directive (2006), the Nitrates Directive (1991). There is one Plan (adopted in March 2007) for the management of short-term drought and other for flood risk assessment and management (2015).

The WFD establishes the need to create a framework for action that guarantees the quality of water bodies and promotes sustainable use, ensuring the supply of water in adequate conditions, as well as the achievement of good ecological status of water. Water is a public domain and the CHD is in charge of its planning and management considering the water cycle and its interaction with ecosystems within a framework of public citizen participation as tools in water policy.

The River Basin Plans (RBP) are reviewed every six years and responds to the requirements of articles 5 of the WFD, incorporated into the Spanish legal system through articles 41.5 of the consolidated text of the Water Law, 76.1. 77.2 and 78 of the Regulation of Hydrological Planning. There is a yearly monitoring report on water demands. consumption and quality as well as ecosystem indicators. The Duero RBP for the period 2015 to 2021 has increased the irrigation area in more than 1000 ha and the next RBP (2022-2027) is going to be released in 2022.

CEA and T are depopulated rural areas which have been further developed after "the Spanish Modernization Irrigation Plan" developed from 2006-2010. Irrigators have collaborated with the governmental and regional organisms to monitor the efficiency of irrigation systems and look for best irrigation and agricultural practices.

The farmers are willing to collaborate with the Universities and other stakeholders in searching for integrated activities with the goal of reaching farmer's stable revenue and the maintenance of agroecosystems. Therefore, Nexus-Ness has selected the following representative sample of stakeholders to address WEFE nexus:

- ✓ Three major irrigation districts: "Río-Adaja" and "El Carracillo" in CEA and "Villalar de los Comuneros" in T, as well as their corresponding municipalities.
- ✓ The Duero Irrigation Association FERDUERO and the Spanish Irrigation Association FENACORE as representatives of the irrigators issues.
- ✓ The Duero Basin Authority CHD together with the Agriculture Technical Institute of Castilla ITACYL and León and the Ministry of Agriculture of Castilla and León, as technical and public organisms for rural development at regional scale and the National Institute of Agricultural Research and Ministry of Ecological Transition at National scale.

- ✓ Gesternova , Globaluz and Iberdrola as enterprises for renewable energy distribution.
- ✓ The sugarbeet cooperative ACOR and Azucarera EBRO Agrícola to address sugar beet issues.
- ✓ The Agricola Samboal S.L. and Forrajes y Proteinas as small enterprises for processed commodities.
- ✓ The Cooperativa ARION S.L. and Agralia Villalar de los Comuneros as successful enterprises on fertilizers' production.
- ✓ Universidad Católica de Ávila and Universidad de Valladolid as a private and public universities in the region.
- ✓ the Federation of Rural Women and Families AMFAR-AVILA as a gender association for rural women.
- ✓ Tragsa as a semi-public enterprise with expertise on hydraulic infrastructure design and operation.

5. NEXUS Grand Challenges

The following Grand Challenge will be addressed.

Can irrigated agriculture in the NEL be resilient under a scenario of water scarcity, prices for energy and fertilizers rises and reduction in food production revenues?

In order to answer this question, the study will consider three modernized irrigation districts (ID) which illustrates the WEFE issues in the NEL:

- ✓ ID “Río Adaja” (CEA) uses surface water. The CEA is a surface water body which shows a low IPS (Pollution Specific Sensitivity Index), a biological indicator of water quality related to benthic organisms. The CHD has developed the II River Bank Restoration aimed at the environmental regeneration of rivers and riverbanks which comprised the recovery of riparian spaces on the left bank of the Adaja river and also, the ecological status and connectivity of surface water bodies.
- ✓ ID “Villalar de los Comuneros” uses subsurface water and has installed solar panels for energy supply, and
- ✓ ID “El Carracillo” (CEA) uses subsurface water recharged from the nearby river. The area is an example of productivity and agricultural development. Today, the irrigable area is about 7600 ha, of which approximately 3000 ha are already irrigated. The economic development of the region has overexploitated the aquifer and the programmed expansion of irrigation in the coming years could make water management more difficult.

The questions preliminarily co-identified in the NEL will deal with:

1. Analysis of water and energy consumption together the expansion of irrigated agriculture in the three IDs since 2010. The CHD, ITACYL and IDs will provide the databases for water, food and energy, respectively. The data will be analyzed to observe trends and relation among variables. The results will present the evolution of water-energy and main crops (sugarbet, cereals, sunflower, potato, clover) area since the IDs were settled. Likewise, the added economic value in the irrigated area will be assessed by considering the food production chain. The information will be discussed within an RRI context to get feedback and make necessary change in current irrigation practice and cultivated crops.
2. Quantify Green and Blue water and energy consumption for the major agricultural crops: at local scale and daily temporal scale (during the irrigation season) and a monthly scale otherwise. Then, upscale this information to the Cega-Eresma-Adaja and Tordesillas-Toro hydrographic management systems. The agro-hydrological model for WEFE nexus Watneeds will be used to make the estimations and then, mapping the water-energy needs in the NEL in the current scenario. The model will be validated with the information from point 1. Thus, it will estimate WEFE Nexus needs at real scale and will include predictions of water-energy needs, within the climate change scenarios, in a short term as well to find critical targets for ecological services. The information will assess and quantify the interlinkages between nature-based solution and the NEXUS providing evidence on food production issues and the effect of river restoration measures.

The information from the above points will be discussed on effective participatory schemes to foreseen resilience alternative scenarios to promote the use of nature-based solutions among technological, environmental, political and social dimensions.

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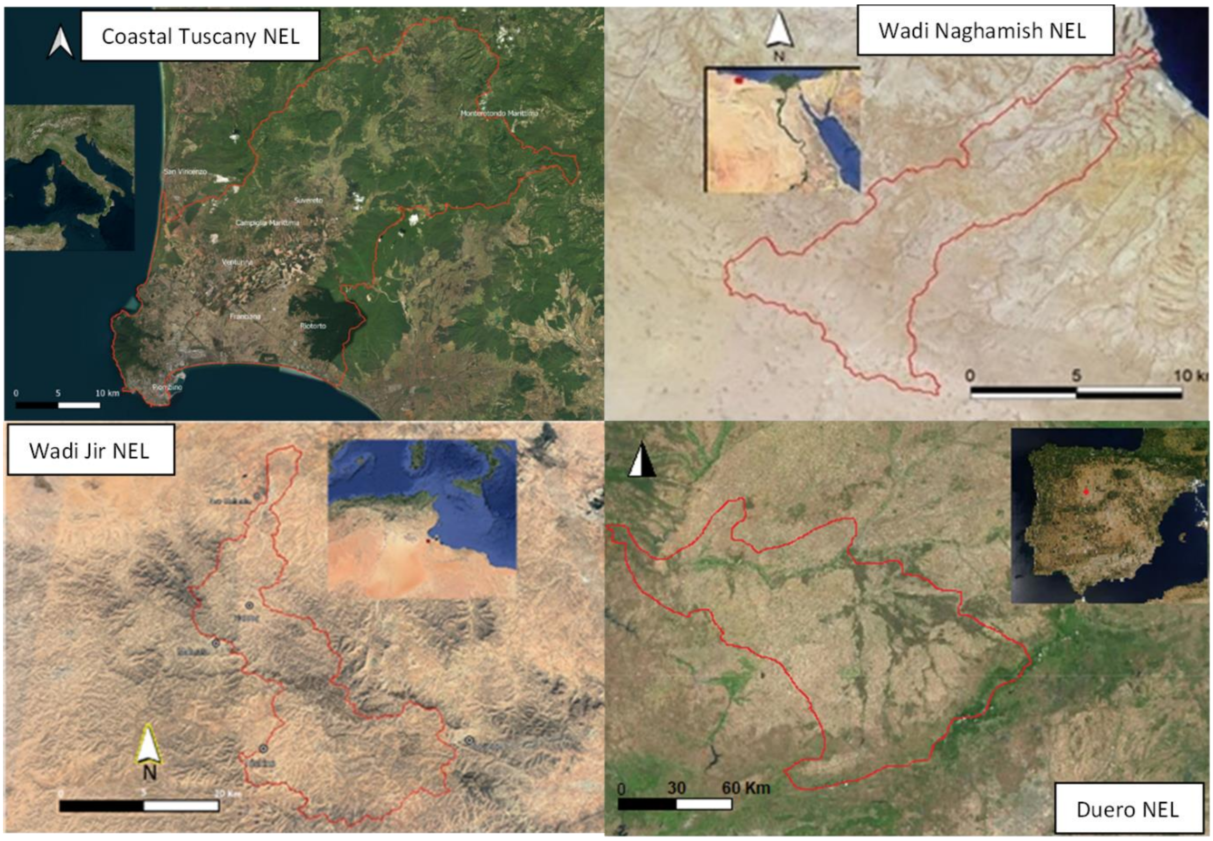
The Four NEXUS-NESS NEXUS Ecosystem Labs

Within the PRIMA NEXUS- NESS project four NEXUS Ecosystem Labs will be testing and demonstrating the outcomes of the project. They are located in Italy, Spain, Tunisia and Egypt. NEXUS-NESS NELs (considering actual and future demand and socio-economic conditions) demonstrates and assesses, in economic terms, the social and environmental importance of the optimization and sharing of economic benefits maintaining in high consideration the importance of preserving and considering also the services provided by ecosystems.



The four NELs areas testing and demonstrating the NEXUSS-NESS approach.

This document is one of the four Booklets produced as **Deliverable D3.1 The NEXUS Ecosystem Labs** of the NEXUS-NESS PRIMA project. Check for the other three booklets presenting the Italian, Tunisian, and Egyptian NELs.

Booklet 1 – **The Coastal Tuscany NEL (Italy)**. Exploring innovative ways for conjunctive use of surface water groundwater and non-conventional waters to boost agricultural production, improve environmental quality, reduce energy consumption, and adapt to and mitigate climate changes.

Booklet 2 – **The Duero hydrological management units Cega-Eresma-Adaja and Tordesillas-Toro NEL**. Looking forward to water and food security based on RRI approaches on WEFE nexus

Booklet 3 - **The Wadi Jir NEL (Tunisia)**. Towards an efficient allocation of scarce natural resources in arid environments of south-eastern Tunisia through adopting Nexus approach.

Booklet 4 – **The Wadi Naghamish NEL (Egypt)**. Fair and Sustainable Resource Allocation Demonstrator of the Multiple WEFE Nexus Economic, Social and Environmental Benefits for Mediterranean Regions.

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Booklet 3

The Wadi Jir NEL (Tunisia)

Towards an efficient allocation of scarce natural resources in arid environments of southeastern Tunisia through adopting Nexus approach

H2020 PRIMA NEXUS-NESS – Deliverable 3.1

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1. The Water Food Energy Ecosystems (WEFE) NEXUS

Natural resources scarcity is a major environmental issue since the middle of the twentieth century. Many factors like population growth, climate change, land exploitation (or land use change) contributed to the depletion and deterioration of ecosystems and the shortage of resources like water, soil quality and raw materials (Cramer et al., 2018). Each one of these resources impacts different sectors, but these challenges are commonly dealt with separated policies and strategy, or what can be dubbed as "Silo thinking" (Salleh, 2016): a mindset where governing authorities and sectors do not share the same vision whilst operating without proper collaboration. Silo thinking can be found in several government policies for example, when an agricultural department aims at ensuring food security by increasing irrigation demand, while the water department calls for reduction in water usage based on available volumes. The connection among these sectors and departments is missing while several connections are easily identifiable (Figure 1.1). Energy is needed for crop irrigation and food processing, water is needed for growing food, land use impacts water availability and water quality, energy is needed to pump/divert, treat, and distribute water, etc.

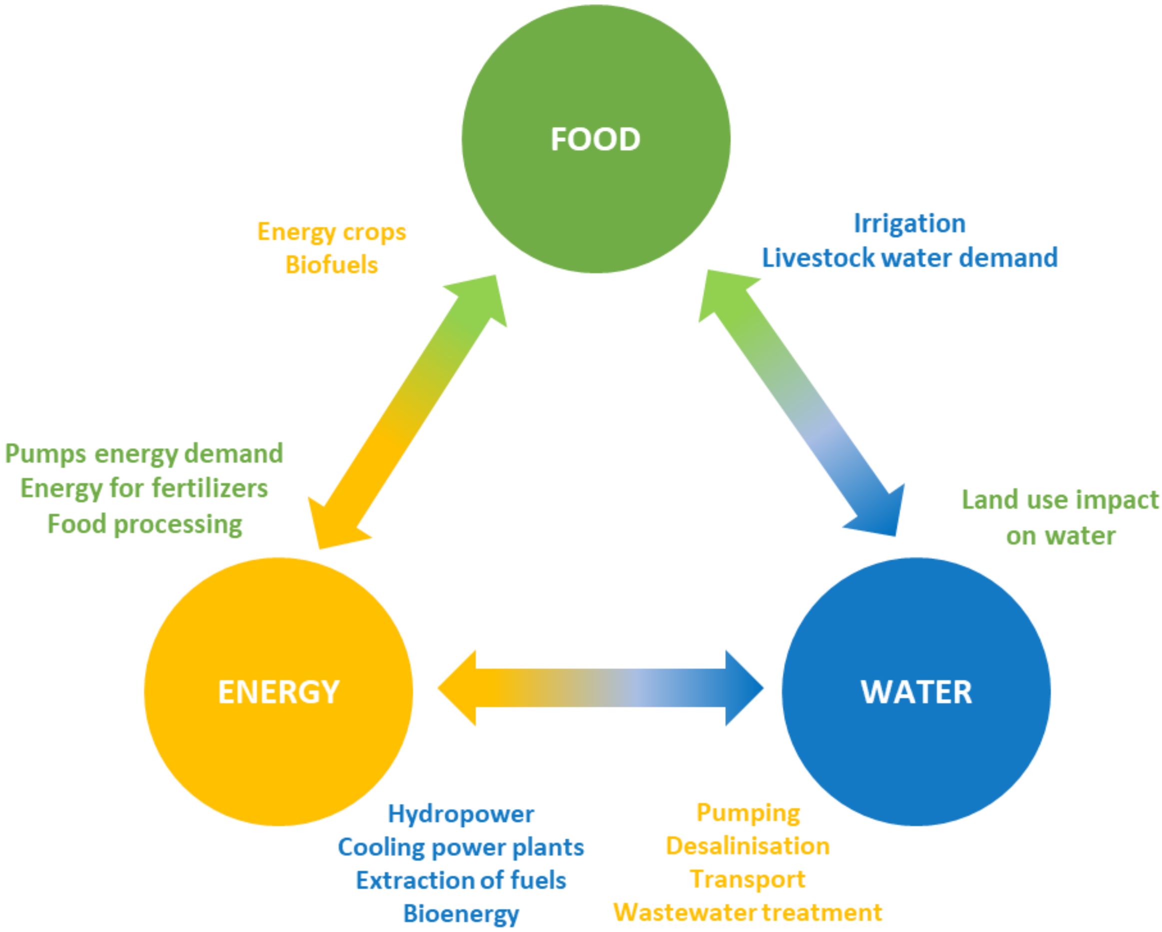

Figure 1.1. Typical Nexus connection diagram.

Cambridge dictionary defines the term NEXUS as an "*important connection between the parts of a system or a group of things*". Through the NEXUS thinking, resources are looked upon as being connected parts of a bigger system with synergies and trade-offs. The power of such a concept lies in its integrative capabilities, forming an umbrella under which multiple stakeholders can act (Simpson and Jewitt 2019). The resulting NEXUS system evaluation emerges consequently as a holistic analytical method driven by participation, research and science, with the final aim to provide adequate governance directions and policies for integrated and sustainable resource planning and management.

Several approaches may be implemented to avoid this silo-thinking that still characterizes the different sectors and actors of the WEFE components. Top-down (from policy to operations) or bottom-up (from the ground where people represent the main driver for mainstreaming the NEXUS) actions may be adopted with pros and cons of both

approaches. NEXUS-NESS recognises the core importance of bottom-up citizen-centred technological and behavioural change to favour the uptake of NEXUS approaches.

An opportunity for collaboration

Within the methodologies presented by the NEXUS, a critical factor of collaboration and dialogue through science lies. Because of this, the NEXUS approach is being adopted by major stakeholders and policy makers like the United Nations, European Commission, NGOs, and important academic institutes. Its compatibility with the Sustainable Development Goals, with the existence of the applied cases incorporating societal and economical aspects, despite limitations, allows the development of further studies and connections between the water, energy, food, and ecosystems, whether exploring their internal relationship or finding their response to the several drivers. Hence, a framework for dialogue and collaboration can be set, through NEXUS thinking, between businesses, NGOs, and the public sector.

NEXUS-NESS - Nexus Nature Ecosystem Society Solution. A HORIZON 2020 PRIMA project

The NEXUS-NESS PRIMA project implements the Innovation Ecosystem Approach (IEA) at four selected areas, called Nexus Ecosystem Labs (NELs). The approach focuses on stakeholder engagement and actionable information, and integration within a 'NEXUS' framework, to ensure fair and sustainable resource allocation. Each NEL has its own challenges and benefits obtained from the NEXUS approach. The geographical variability between the NELs helps in demonstrating the capability of NEXUS thinking in overcoming the different challenges. The IEA is supported by the implementation of the Responsible Research Innovation Roadmap (refer to Deliverable 2.1 of the NEXUS-NESS project for more information; Schneider 2021).

2. Geographic and socio-economic situation

The Tunisian NEL is located in the region of Matmata and it is represented by the Wadi Jir catchment and the spreading perimeter of new Matmata (Figure 2.1). The study area belongs to the region of southeastern Tunisia (*governorate* of Gabès). It is situated at the south of the city of Gabès. It covers administratively the d*elegations* of new Matmata and Matmata. It can be considered, from the ecological, hydrological as well as socio-economical point of view, as representative of the arid southeastern Tunisia. In addition, it contains a large water spreading structure, unique in the south of Tunisia (Abdelli, 2017).

The watershed of Wadi Jir, with a surface area of 146 km^2, is controlled at the outlet of new Matmata city by a floodwater diversion. This is a bypass dam that drains the floods from Wadi Jir to an irrigation command area where flood water area spread, namely the "spreading perimeter", with a size of around 9,21 km^2 (Figure 2.1). Recharge wells are also present, behind the flood diversion in the upstream of the spreading perimeter.

The main inhabitants of the region are the Berbers. In 2019, the total number of the population was estimated at 18167 inhabitants, 18668 inhabitants in 2014 (INS, 2014) and 21537 inhabitants in 2004 (INS, 2005) distributed as follows: 22% (4038) inhabitants reside in Matmata delegation and 78% (14,129) inhabitants in new Matmata delegation (ODS, 2020).

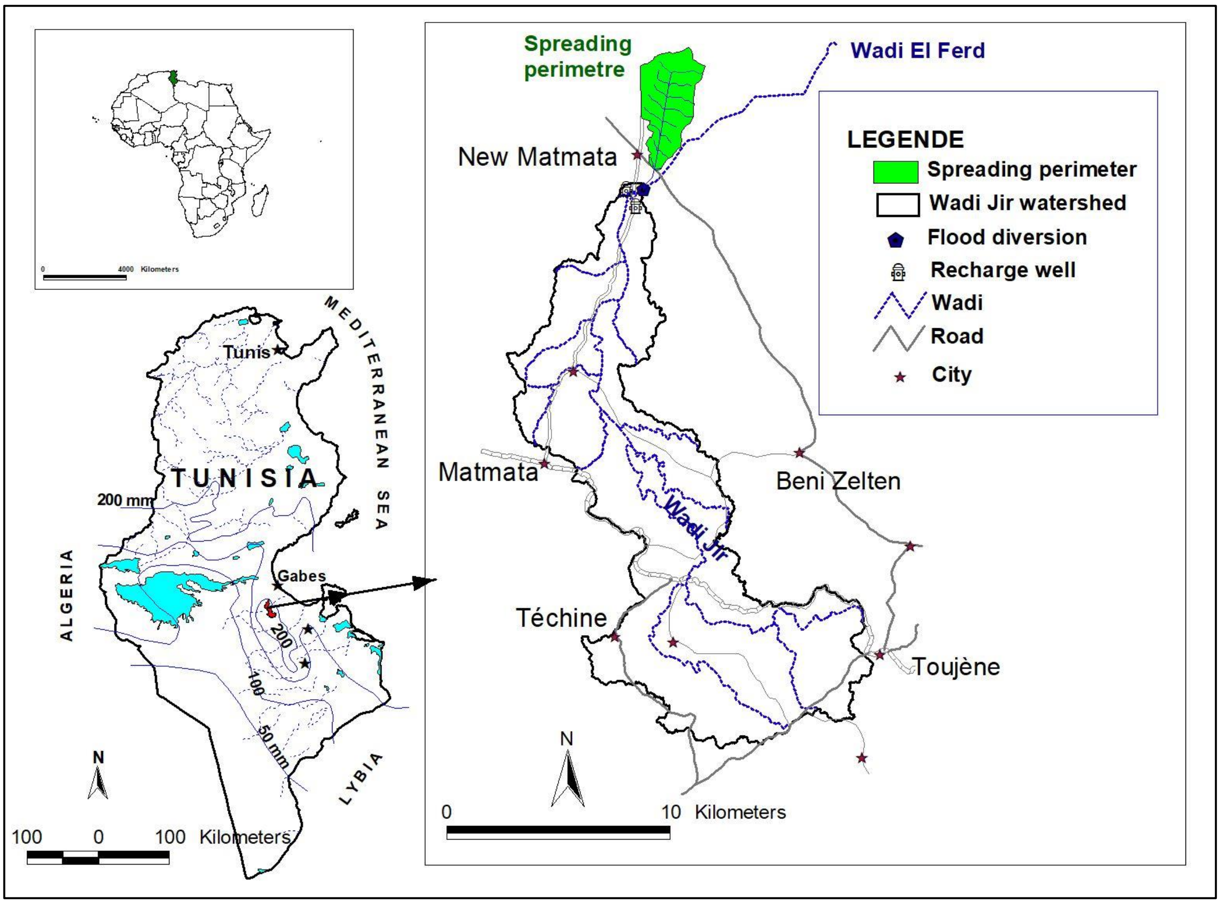

Figure 2.1. Location map of Wadi Jir watershed and the spreading area.

Large areas of the study zone are covered by Cretaceous terrain and Quaternary cover represented by the silts of Matmata (Ben Baccar, 1987). The stratigraphic series outcropping in the region extends from the Permian to the Quaternary with some gaps. The unique Permian outcroppings in Tunisia and Africa are encountered in Jebel Tébaga, 10 km southeast of the study area. The Triassic and Jurassic outcrop south of the Permian range.

The region is dominated by the Cretaceous series Busson (1967). The Quaternary is represented by the deposits: terraces found on the banks of the wadis, the silts or '*loess of Matmatas*' which are very fine detrital particles transported by the wind and accumulated in the deep valleys and wadi alluviums (Ouessar, 2007).

The soils are developed on a calcareous substratum in the upstream area and gypsum or gypsum to calcareous in the downstream area. The soil horizons are generally shallow, stony, unstructured with sandy to fine sandy texture. The main classes identified are Regosols, Lithosols, Fluvisols and Xerosols (Figure 2.2).

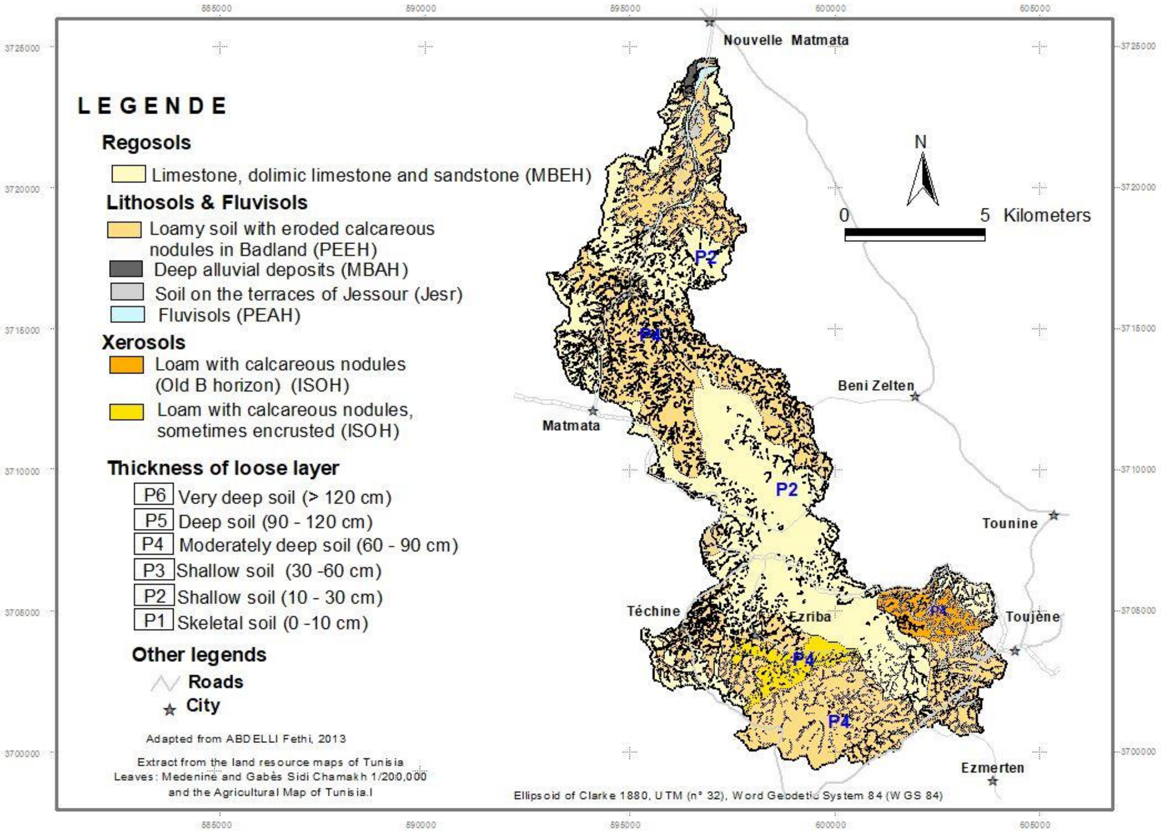

Figure 2.2. Soil map of Wadi Jir watershed (adapted from Abdelli, 2017).

The soil map of the study watershed was extracted from the land resource maps of Tunisia and "*la carte agricole de Tunisie*", adapted by Abdelli (2017) according to the French soil classification (CPCS, 1967).

Three main classes have been identified (Table 2.1):

- The Regosols made mainly of dolomites, limestone outcroppings and stony regs. They cover 42% of the watershed land area (mountains and hills);
- The Lithosols & Fluvisols:

The Fluvisols, soils in alluvial deposits, occupy a reduced area (0,6 %) and are found in the wadi fans (downstream part); The Lithosols; Loamy soil with eroded calcareous nodules in badland that cover 40 percent of the total study area, and the soil on the terraces of Jessour (12%).

- The Xerosols, moderately deep soil (60 -90 cm), occupy a reduced area (5,5 %) and are found in the upstream parts.

Soil	Code	French classification (FAO classification)	Area (ha)	Area (%)
Rigosols	MBEH	*Sols minéraux bruts d'érosion (Regosols)*	6114	41,7
Lithosols & Fluvisols	PEEH	*Sols peu évolués d'érosion (*Lithosols*)*	5884	40,1
	MBAH	*Sols Minéraux bruts d'apport (*Lithosols*)*	35	0,2
	JESR	*Soil on the terraces of Jessour (*Lithosols*)*	1742	11,9
	PEAH	*Peu évolués d'apport hydrique (Fluvisols)*	84	0,6
Xerosols	ISOH	*Sols isohumiques bruns calcaires tronqués (Xerosols)*	810	5,5

Table 2.1. Summary of soil types in the Wadi Jir watershed. French classification (CPCS, 1967); in English: FAO, 1989).

Rangelands are the dominant land use in the study area (88%, Table 2.2). They are divided into two classes, mountain and plain rangelands, because of their different phenology and grazing practices. In the mountain, the vegetation is mostly steppe made of *Stipa tenacissima.* In the plain, the vegetation differs from one site to another depending on soil type (Ouessar, 2007). The fruit trees are mainly olives and are found on Jessour only. The cereals (winter barley and wheat) are grown episodically during wet years on the Jessour (Ouessar, 2007). There are also a small degraded forest of Eucalyptus, located in Téchine (upstream part), and covering an area of 25 ha (0.05% of the total area) (figure 7)

Landuse	**Classes**	**Area (km^2)**	**Area (%)**
Mountain rangeland	Natural vegetation	60,2	41,5
Plain rangeland	Natural vegetation	67,6	46,5
Olives on jessour	Fruit trees	17,3	11,9
Forest of Eucalyptus	Trees	0,25	0,05

Table 2.2. Land use in the Wadi Jir watershed (adapted from Abdelli, 2017).

The region has an arid Mediterranean bioclimate (Köppen climate classification *BWh*). The hot and dry summer lasts four to five months, the winter is a mild and irregular rainy season, the autumn and spring are very variable. The coldest months are those of December, January, and February (up to 0 °C). June-August is the warmest period of the year during which the temperature could reach as high as 48° (Table 2.3).

Stations	Annual average	Average of the maxima	Average of the minima	Absolute maximum	Absolute minimum
Matmata	18,9	35,2	5,5	48	0

Table 2.3. Average and extreme temperature in Matmata station (°C). Source: Louhichi (2004).

In the study area, the average annual rainfall ranges between 175 mm (downstream area) and 200 mm (upstream) (Table 2.4). Rainfall is very irregular from one hydrological year to the next, with a maximum of 764 mm recorded at Téchine station in the upstream part (1975/76) and a minimum of 20 mm recorded during the year 2000/01 in the same site (Abdelli, 2017).

	Matmata Delegation*	Téchine **	New Matmata***
Average annual rainfall	197,6	199,9	175,1
Standard deviation	117,9	146,6	101,0
Median	181,9	151,2	168,8
Max	550,8	764,0	489,7
Min	27,7	20	29,3

Table 2.4. Statistical analysis of the average annual rainfall recorded at the rainfall stations of Wadi Jir watershed (mm; after Abdelli, 2017). Max: Maximum annual rainfall; Min: Minimum annual rainfall. *: period 1970/71 – 2014/2015; ** 1975/76 – 2014/2015; *** 1988/89 – 2014/2015.

The average annual rainfall recorded at the Matmata delegation station, during the observation period (1970/71-2014/15), is 197.6 mm. The interannual variability is very strong with a maximum of 550.8 mm (1975/76) and a minimum of 27.7 mm (2000/01). The average monthly rainfall can reach extreme values. It reaches 261 mm (January) as a maximum and 0 mm as a minimum (Table 2.5). The torrential rains and their seasonal variability are a frequent phenomenon. Most of the precipitation falls in winter (about 78.7% of the total), but summer is almost dry (4.9%).

Dominant winds of sectors W, NW and SW from November to April, very dry and cold violent ones; from May to October, winds of the sea sector (E, SE); and during the summer period, are the dry and hot winds of the sector SW (sirocco) which prevail (Ouessar, 2007).

Year	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	Jun	July	Aug.	Total
P_m Avg.	14,1	24,9	19,1	**28,5**	**25,9**	**24,3**	33,6	14,1	8,2	3,2	0,2	1,5	197,6
Ps Avg.		58			**78,7**			56			4,9		197,6
Std. dev.	27,9	45,3	28,1	35,0	47,0	28,0	38,5	16,9	16,1	11,3	1,0	5,0	117,9
Median	4,5	7,0	6,5	17,0	10,9	12,8	23,0	8,0	1,7	0,0	0,0	0,0	181,9
Max	162,8	209,5	87,1	165,6	261	113	158,1	67	83,5	64	6,2	23	**550,8**
Min	0	27	0	0	0	0	0	0	0	0	0	0	**27,7**

Table 2.5. Statistical analysis of average monthly and annual rainfall (mm) recorded at the Matmata delegation station (1970/71 -2014/15; after Abdelli, 2017). P_m Avg.: Average monthly rainfall; Ps Avg.: Average seasonal rainfall; Std. dev.: Standard deviation; Median: The median value; Max: The largest value among the monthly average rainfall data; Min: The smallest value among the monthly average rainfall data.

In the mountainous region, all families in the study area practice rainfed farming based on the Jessour water harvesting system, and animal production. In addition, some families practice tourist activities taking advantage of the troglodyte houses (Abdelli, 2017). Recently, in the flat area (plain of Jeffara), there has been the introduction of irrigated cultivation by the creation of several irrigated perimeters in the areas bordering the spreading perimeter. The farmers organized these areas through associations called the Agricultural Development Group. Generally, it is just a family production. Nevertheless, during the good years they sell the surplus product, mainly of olive, on the market of the village.

The labor market remains very limited in this area. The unemployment rate is around 20% (ODS, 2020). Most people of working age are forced to leave their area to seek employment (seasonal or permanent) in the construction sector or in the industrial sector (bakery and others). Agriculture only employs family labor. According to our observation (Abdelli, 2017), many farmers have an extra - agricultural income, mainly from the service sector or from their pension. The migratory movement in this area is determined by repelling factors (lack of wealth, climate difficulty, etc.) and by attractive factors (economic prosperity, ease life, etc.).

In general, there is a community and social behavior of the inhabitants of the area. The population is characterized by a spirit of solidarity and a predisposition to group work. This spirit is particularly evident during major events (parties, weddings, deaths).

3. Overview of the natural resources

3.1 Water resources, uses, infrastructures and impacts

Water sources in the region are represented by surface water and groundwater, where surface waters are typically managed with the flood diversion facilities of the spreading perimeter (downstream part of the watershed) and as runoff using water harvesting technologies (WHT). The main sources of surface water are the Wadi Jir and its tributaries. The watershed is the main sub-watershed of Wadi El Ferd (Figure 2.1) which then crosses the Jeffara plain (via Kettana city) and the little saline zones before ending in the Mediterranean (Gulf of Gabès). Wadi Jir's hydrographic network is temporary. It is made up of numerous talwegs with a high slope bordered by the Matmata mountains. The main stream length is 37 km. The upstream part is the rainiest, while the intermediate and downstream portions, with medium to low slopes, receive lower precipitation.

Domestic water is provided by SONEDE (National Company for the exploitation and distribution of water), under the supervision of the Ministry of Agriculture, Water Resources and Fisheries. Its mission is to supply the whole country with drinking water. It is responsible for the operation, maintenance and renewal of water collection, transport, treatment, and distribution facilities. In the study area, the SONEDE distribute only groundwater. Today, it has a brackish water desalination station located next to the study area, 11 km far from New Matmata. In addition to tap water, the inhabitants of the area use rainwater-harvesting (cisterns) for supply drinking water. In the study area, there is no collection of wastewater. It is directly discharged on the soil.

3.1.1 Spreading perimeter and artificial recharge of aquifers

The water of Wadi Jir watershed, diverted by the spreading water structure, is the main source of surface water in the region. The Wadi Jir is controlled at the outlet of new Matmata city by a floodwater diversion to irrigate the spreading perimeter (around 9,21 km^2). The main canal of the water distribution network in the spreading perimeter ensures the delivery of water to 16 secondary canals, which are almost perpendicular to it. These secondary canals ensure the distribution of water to the plots by means of head plates (Figure 3.1).

The spreading structure is equipped with two recharge wells. The first well was created in 2000 and the second in 2018. Both have a depth of 150 m, in order to inject water into the Senonian aquifer (deep aquifer). Since the permeability of the underlying bedrock is judged very low, those recharge wells are drilled in to enhance the infiltration of runoff water to the aquifer (Figure 3.2).

3.1.2 Surface water and water harvesting

The average annual flow of the Wadi at this outlet is equal to 0.36 m^3/s, which is equivalent to an average annual water of 11.4 hm^3. Large part of this water is used to irrigate the spreading perimeter of new Matmata. The most important floods recorded at this outlet are: the flood of March 1973, where the peak flow recorded was 360 m^3/s, i.e. a surface water supply of 7,1 10^6 m^3 (Ghiloufi, 1997) and the flood of January 1990 with a peak flow of 381 m^3/s (i.e. a surface water supply of 8,3 10^6 m^3). Within the systems there are two recharge wells in the upstream of the spreading perimeter, and before the diversion, where part of the water is directed for managed aquifer recharge.

In the study area, agriculture, despite being mainly rainfed, constitutes the main core of the region's economy because it helps to fight against food insecurity, unemployment, and environmental degradation. Traditional WHT (Jessour, singular Jesr) are present in all major tributaries of Wadi Jir. They are a variation of riverbed reclamation, consisting of three components: the catchment, the terrace and the dyke. The dyke (also called *tabia*) made from soil, rock, or gabions, is either built across seasonal stream channels or at the foot of slopes. Fertile sediments accumulate behind the dykes allowing the cropping of trees and annual crops such as olive trees (Figures 3.3 and 3.4).

Moreover, a comprehensive soil and water program has been implemented in the watershed since 1990 in the framework of the national strategy for water resources mobilization and soil conservation (Min. Agr., 1990 a, b). Check dams have been installed with the aim to mobilize additional resources for the aquifer through recharge with floodwater (Yahyaoui et al., 2002) and to protect people and infrastructures during flood events.

WHT structures realized in the upstream areas, and especially check dams, have generated an imbalance in the distribution of runoff water between the upstream part and the downstream part of Wadi Jir. As a consequence, farmers with cropping areas in the downstream part of the watershed, and within the spreading perimeter have less water for food production (Figure 3.5). The CRDA technicians, responsible for monitoring the effect of these new WHT, confirm this upstream-downstream disparity.

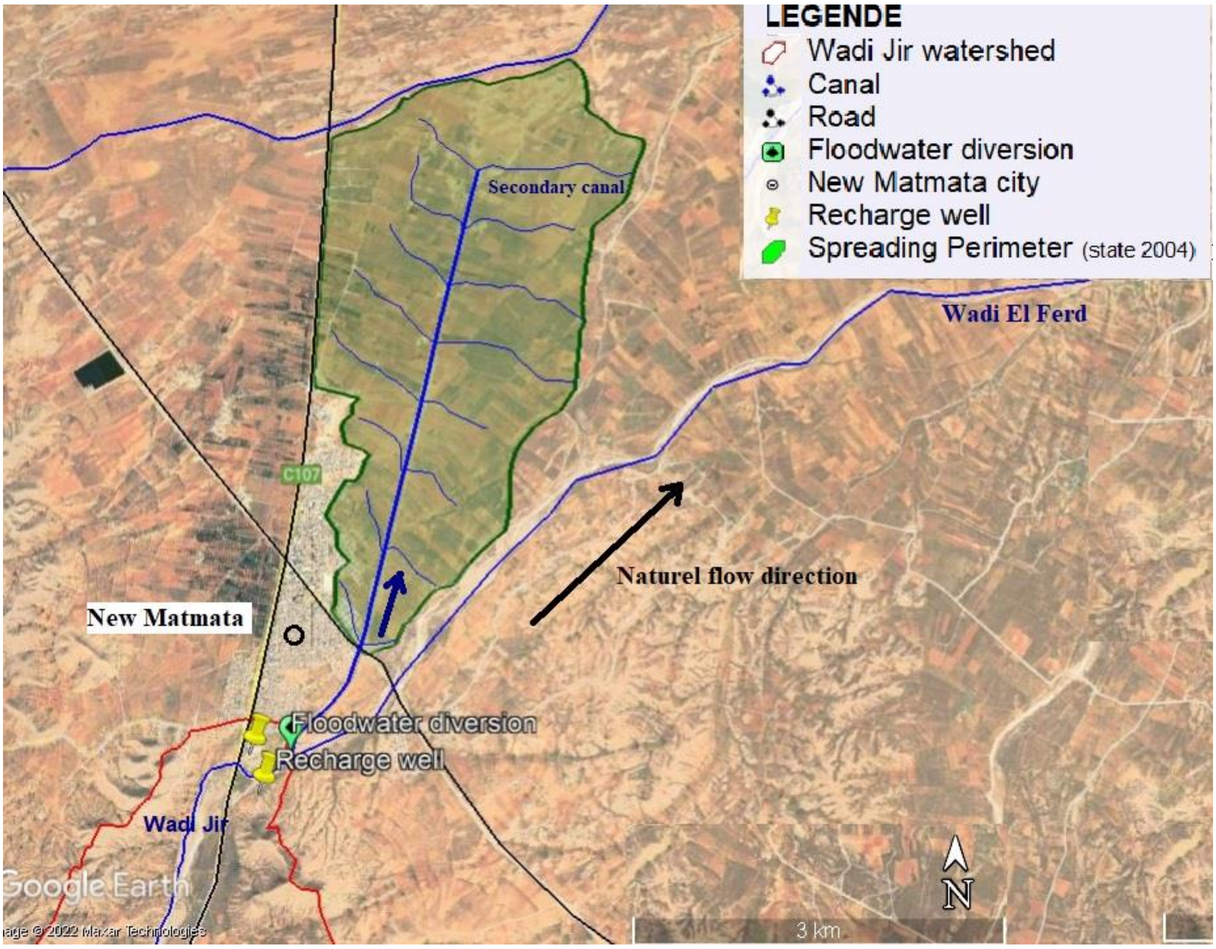

Figure 3.1. Floodwater diversion structures and spreading perimeter of new Matmata (Google earth image).

Figure 3.2. One of the recharge wells upstream of the spreading perimeter

Figure 3.3. Jesr water harvesting in Tunisia

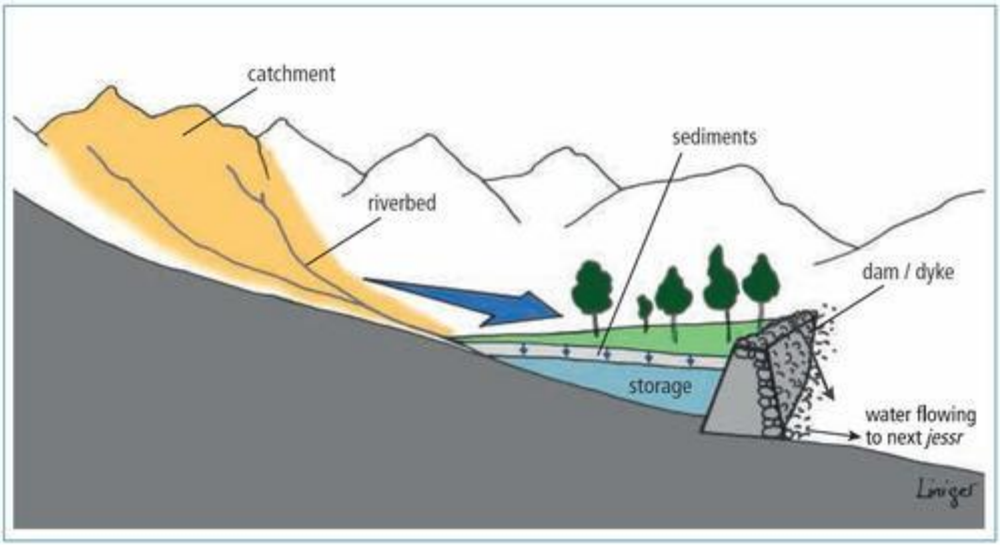

Figure 3.4. Scheme of a Jesr system (source: https://www.geo.fu-berlin.de/en/v/iwrm/Implementation/technical_measures/Water-harvesting-techniques/floodwater_harvesting/floodwater_harvesting_within_streambed/jessour/index.html)

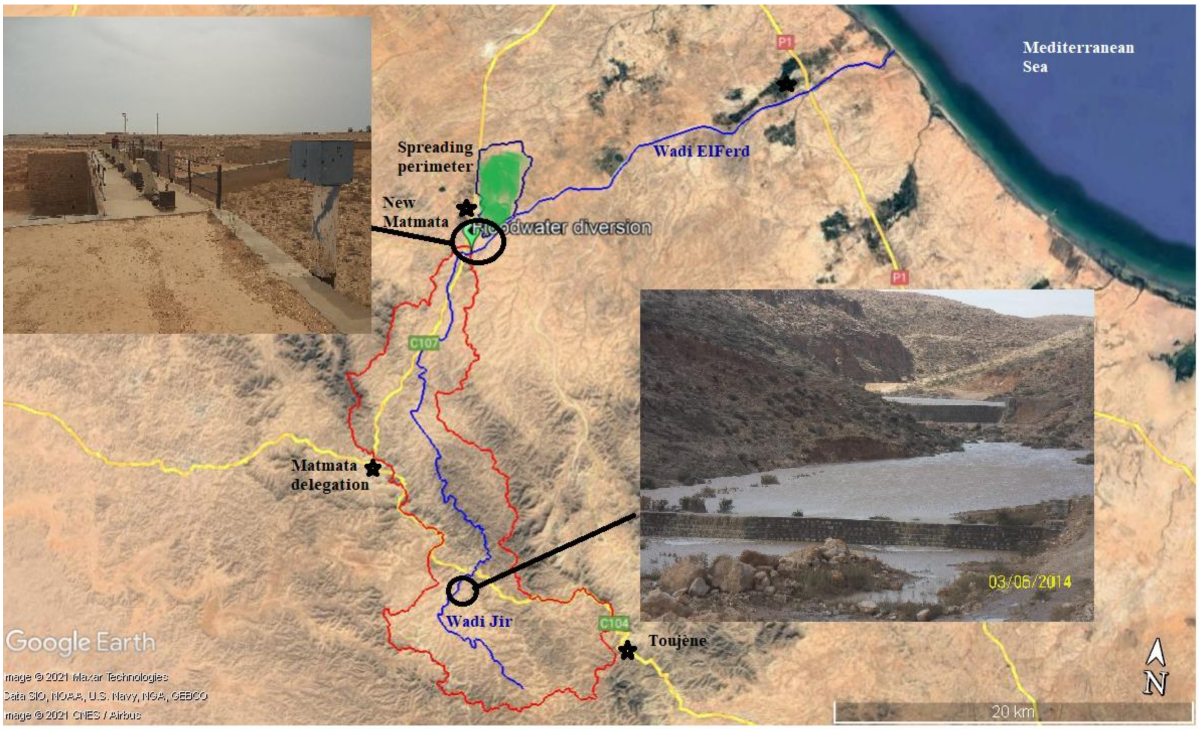

Figure 3.5. Upstream-downstream conflicts.

Other typical hydraulic infrastructures in the region are cisterns, which are used to provide drinking water. In the cistern system, runoff water is collected from roof-catchment then stored in stone-faced underground cisterns, of various sizes, called *Majel* (small cistern) and *Fesquia (large cistern)* (Ouessar, 2007). It is estimated that a tank with a capacity of 35 m^3 (Figure 3.6A) can meet the annual water needs of a family and its livestock (Ennabli, 1993). The water of cisterns is also used for watering livestock in rangelands (Figure, 3.6B). At the country level, it was estimated, during the 1990s, that 10 to 16 hm^3 of water per year could be mobilized using this type of hydraulic infrastructures (Ennabli, 1993).

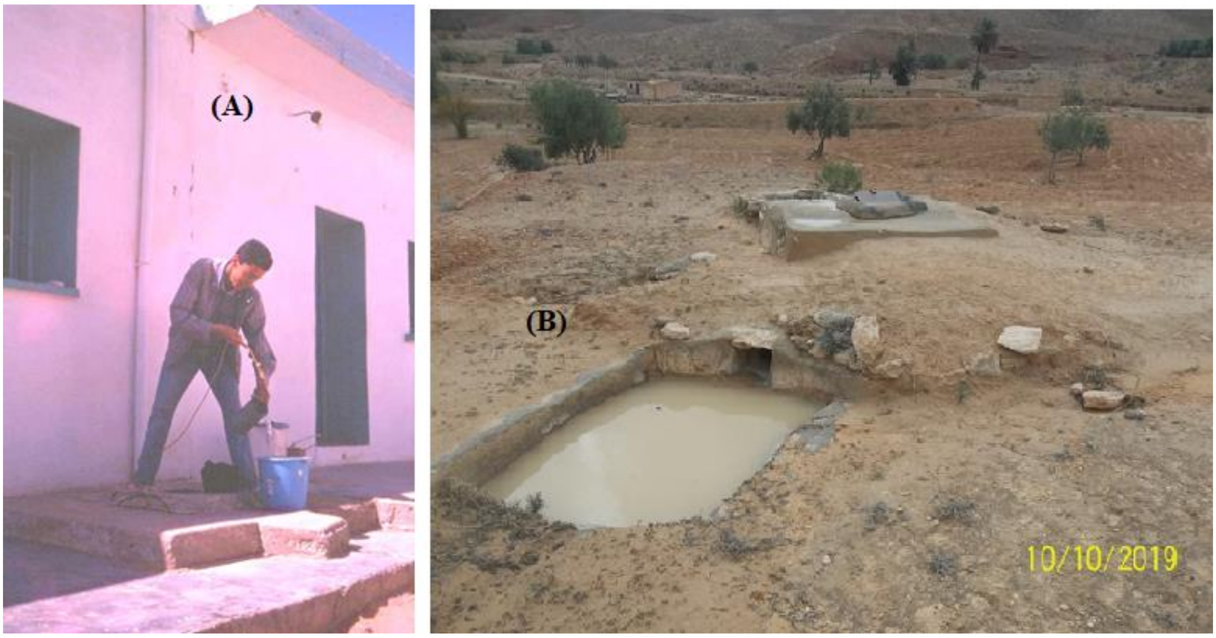

Figure 3.6. Underground cistern "Majel" (A: collected rooftop water used for dinking, (B) collected land runoff water used for supplemental irrigation and watering livestock).

3.1.3 Groundwater resources

The principal aquifers in the study area are the Cenomano-Turonian aquifer (deep aquifer), found in the mountainous area, and the Senonian aquifer (deep aquifer) present in the plain, to the North, East and West of the mountainous zone

(Figure 3.7). The Cenomano-Turonian extends over the entire mountainous area of Matmata to the extreme south (Ben Baccar, 1987). At the level of Wadi Jir, the depth to the water table varies from 90 to 110 m. It reaches 365 m in Tamezret (11 km west of Matmata city).

The deep Senonian aquifer, lodged in the calcareous fissures of the lower Senonian, is not detected at the mountainous zone of Matmata. However, it exists on the North, East and West foothills. It is the main source of water supply for the whole region, from the mountains area to the plain of Jeffara. It has a depth from 80 to 220 meters depending on the location (more than 100 m nearest the spreading perimeter). Its total mineralization varies from 2.5 to 2.8 g/l (Ben Baccar, 1987). Steady increase in the salinity of water resources and the decline in the groundwater level are the most widespread processes that degrade water-quantity and quality endangering future water exploitation.

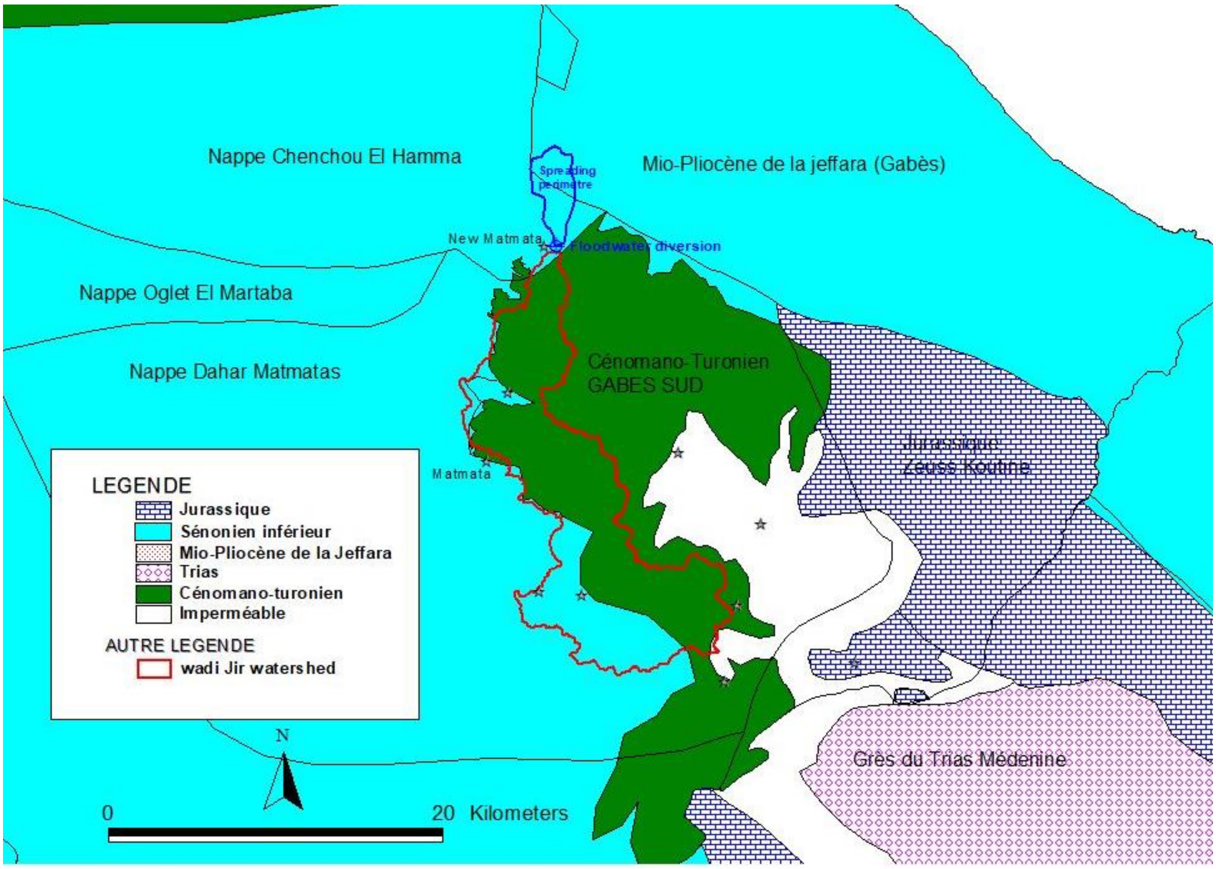

Figure 3.7. Deep aquifers system in the mountainous area of Matmata (after Abdelli, 2017).

At the level of the Wadi Jir watershed, shallow aquifers are almost absent. The only shallow aquifer in the study area is the given by the underflow of Wadi Jir (Ben Baccar, 1987). The underflow of Wadi Jir was detected since the beginning of the century by the discovering of the Spring of Jir (Figure 3.8). This was subsequently developed (1912) (Ben Baccar, 1987). In 1938 two wells were dug near the site of the spring, 15 to 17 meters deep. The wells were tested in 1977 and the groundwater flow at this location is calculated at 1 l/s (Mamou, 1977). This groundwater has a total mineralization varying from 0.6 to 1 g/l. This water, with a good quality, is used for human drinking and livestock watering. It is not clear how much check dams and the recharge wells are impacting on this latter surficial aquifer.

3.2 Land/Agricultural resources, uses, infrastructures and impacts

The region is poor in land or natural resources as water, oil, copper, natural gas, coal, and forests. The spreading perimeter is divided into small parcels not equal in size. Each plot is generally planted with fruit trees, mainly olive, fig and almond. During wet years, especially when there is a flood, legumes (e.g., pea, chickpeas, lentil, and faba bean) and barley and wheat are cultivated.

As land use, the study area is occupied by the steppe vegetation and mountain olives (olives in Jessour). Floristically, there are several groups, classified into 4 classes (Figure 3.9). They vary from a small, degraded forest of Eucalyptus, located in Téchine, and covering an area of 25 ha (0.05% of the total area), to steppe groups. Mountain Steppe covering 41.45% of total study area and plain Steppe covering 46.6%. The rest of the area (11.9%) is occupied by the Jessour. Each Jesr (singular of Jessour) is cultivated in arboriculture (on average 3 to 4 olive trees and 1 to 2 fig trees by Jesr).

Figure 3.8. The Spring of Jir in Matmata.

According to Le Houérou (1959), the mountain steppe is dominated by *Juniperus Phoenicea, Rosmarinus officinalis, Stipa tenacissima, Lygeum spartum,* etc. However, the plain steppe is dominated by *Artemisia herba alba, Hammada scoparia Gymnocarpos decander, Nitraria retusa, Ziziphus lotus, Ziziphus lotus, Retama raetam, Artemisia compestris, Rhanterium suaveolens*, etc.

3.3 Energy resources, uses, infrastructures and impacts

Fossil fuels (coal, natural gas, and petroleum) are absent in the region, so, the area is dependent from external sources. The state power utility company STEG controls 100% of the electricity in the study area. Renewable energy resources, especially, solar energy and wind, could be available, but they are not exploited with the exception of very limited use of photovoltaic panels for lighting. Approximately 97% of Tunisia's electricity is generated from fossil fuels, mainly natural gas. In 2020, nearly 57% of Tunisia's natural gas needs were met through imports (mainly from Algeria). Only 3% of Tunisia's electricity is generated from renewables, including hydroelectric, solar, and wind energy.

The Tunisian government has approved the implementation of five Independent solar Power Producer (IPP) projects with a total capacity of 500 MW. The government's approval is expected to encourage the construction of other Independent solar Power Producer (IPP) projects. Renewable energies can be a future asset to meet the electricity needs of rural houses and for pumping water from wells. We can also think of an independent solar Power Producer (IPP) project. The surplus energy of this project will be injected into the STEG network.

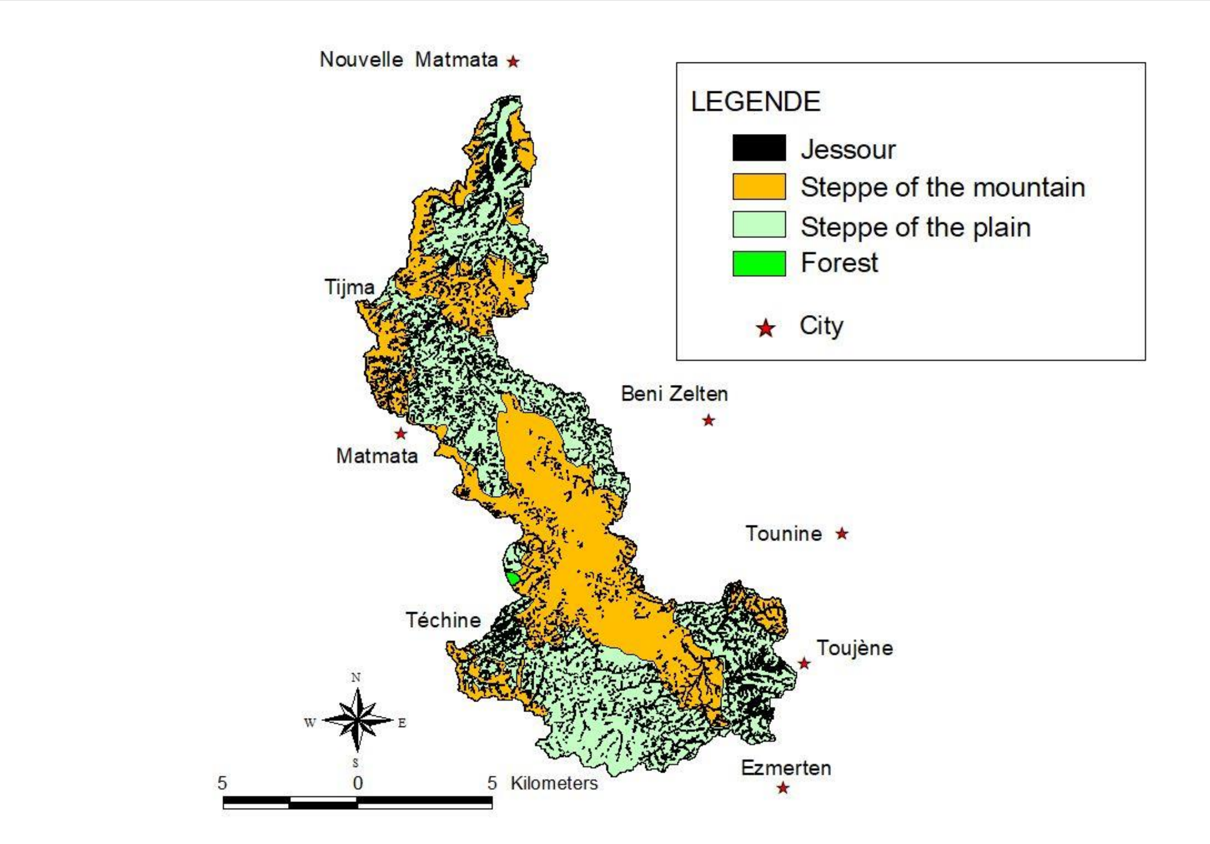

Figure 3.9. Landuse map of Wadi Jir watershed (Abdelli, 2017).

3.4 Environment and Ecosystems

Mountain region of Matmata provide particular landscapes and agro-ecosystems such Jessour, shrublands that provide medicinal plants and rangelands for livestock grazing. The vegetation cover is mostly made of *Stipa tenacissima*, *Artemisia herba alba*, *Reaumuria vermiculata* and *Gymnocarpos decander*. Such vegetation type results from the degradation of forest of *Pinus halepensis*, *Juniperus phoenica* and *Pistacia atlantica* which completely disappeared from the area due to long history of cuttings (Ouessar, 2007).

Many of these spontaneous plant species are considered as herbal, medicinal and aromatic plants (HMAP) and are used in traditional phytotherapy by mainly rural communities having developed broad local knowledge (Neffati et al. 2008). For nearly a decade, aromatic and medicinal plants (AMP) in Tunisia have enjoyed renewed interest at the various departments, especially in agriculture, health, environment, industry, and scientific research. Aromatic and medicinal plants in the Matmata mountains can used to combat natural resources degradation and improve the income of rural communities through rehabilitation, conservation and production diversification.

In addition, in the mountain region of Matmata, grazing is an important use of rangelands. Livestock grazing is used to manage rangelands by harvesting forage to produce livestock (Figure 3.10).

One of the specific features of the socio-ecological systems in the region is the troglodyte homes. They are dwellings dug in the mountains. The rooms are longitudinally hollowed out around the circular well constituting the courtyard of the house. This particular habitat makes it possible to maintain the freshness in the hottest of summer. This type of construction already existed 3000 years ago. The Sidi Driss hotel (Figure 3.11) is the setting for George Lucas' Star Wars; it is the residence of the Lars family where Luke Skywalker, Beru and Owen Lars live. On January 10, 2020, the Tunisian government proposed this habitat for future classification on the UNESCO World Heritage List.

Figure 3.10. Livestock grazing is an important use of rangelands in the mountain region of Matmata.

Figure 3.11. The troglodyte dwellings of Matmata; Courtyard of the Sidi Driss hotel. (https://fr.wikipedia.org/wiki/Matmata)

4. Governance framework

As shown in the figure below (Figure 4.1), the CRDA is a regional authority providing overall information at the Governorate level. The CTVs are the local representations of the CRDA in each delegation. They follow the agriculture of the delegation. The delegation is a public administration (local authority) depending on the governorate (regional authority) which represents the Ministry of the Interior in the region (national authority). A delegate heads the delegation. It is political, policy maker and implementer.

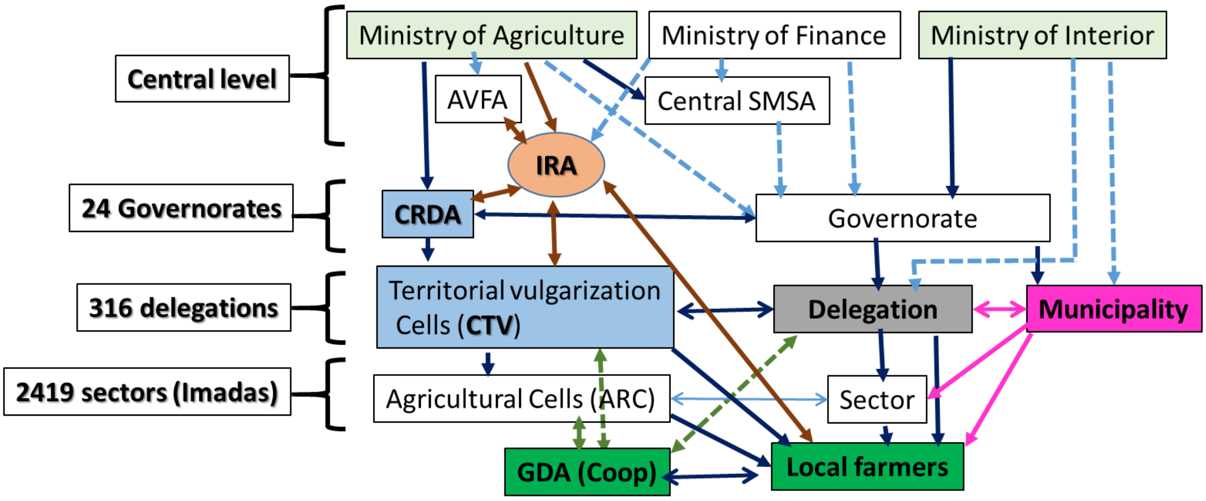

Figure 4.1. Governance framework: rough diagram of the relationships between the stakeholders.

The relationship between the CTV, the Municipality (local authority) and the delegation of new Matmata, in theory must be complementary. Therefore, the delegation has political powers and the authority that it exercises over the territory of the delegation. However, the municipality has the powers and the authority that it exercises over a limited territory comprising only the urban and neighboring parts as in the case of the spreading perimeter. However, the CTV intervenes throughout all the territory of the delegation, but interest only in agricultural and rural activities. Therefore, CTV New Matmata has all the authority, in harmony with the delegation and the Municipality, to manage the spreading perimeter. However, in reality, there is a lack of synergy and coordination between these institutions in the application of laws. Especially with Socio-political situation resulting from the Tunisian revolution (context of transition without clear perspectives).

We remind that in the study area, there are two CTVs; the CTV of New Matmata and the CTV of Matmata delegation. Each one has an independent administrative structure, thus, each CTV coordinate the agricultural activities within its own administrative limit. The CTV of New Matmata is best positioned to make the first contact with local communities, in particular the farmers. In the same context, it has more interest and more influence compared to CTV Matmata, since, the pilot zone (the spreading perimeter) is located within the administrative limit of the new Matmata. However, CTV Matmata has authority in the upstream part of Wadi Jir watershed.

The IRA (*Institut des Régions Arides of Médenine*) as a public research institution can play a crucial role in water management (WM) to improve the current local situation. It will give its scientific and technical support to all stakeholders interested by water management. The Coop ETTOUMOUH (Agricultural services cooperative ETTOUMOUH) of New Matmata is a farmers' Association/ an agricultural cooperative. This civil society can intervene in the study area by taking advantage of its relationship with several farmers.

The direct beneficiaries are the local farmers (Land owners and users). They are the end users of water management programs and interventions. Despite the strong social cohesion and religious affiliation, that can ensure better water governance (reduction of conflicts, equitable distribution of water, etc.), there are many social conflicts over land ownership and water allocation (rainwater sharing). This situation is due to several factors, such as demographic and climatic changes, increased needs of water and problems of fragmentation of land (privatization). If we add the lack of respect of laws and development actors, the situation becomes complicated.

5. NEXUS Grand Challenges

In southern Tunisia, especially for the last decade, ensuring enough water, food and energy while maintaining environmental sustainability is the main challenge due to the lack of political decision-making to improve the situation. A more detailed analysis of the situation shows that the most urgent WEFE Nexus-related challenges to be met in the Wadi Jir basin and the spreading perimeter are related to surface and groundwater allocation for multiple uses, including the environmental ones.

In this framework the main Nexus Grand Challenge in Wadi Jir watershed is related to the *identification of the best water and crop allocation strategy for sustainable food production and ecosystem conservation* carefully assessing the effect of upstream check dams and Jessour, and their optimal management, but also evaluating the potential impact of water saving technologies or of a shift of the cropping pattern in the downstream areas (**Water-Food-Ecosystems**).

As additional sub-challenge, the *impact of the overall groundwater recharge on local water resources should be assessed,* also considering that the potential use of the riverine shallow aquifer of Wadi Jir, and of the deep aquifer in the downstream area, which could request additional energy sources (**Water-Energy-Food**). Such analysis should take into account the potential impact of climate change in the area. Moreover, the *overall impact of water harvesting, Wadi riverbed cultivation and grazing should be evaluated, to detect potential environmental degradation within the study area, as well as different rural development strategies (tourism, AMP production)* (**Water-Food-Ecosystems**).

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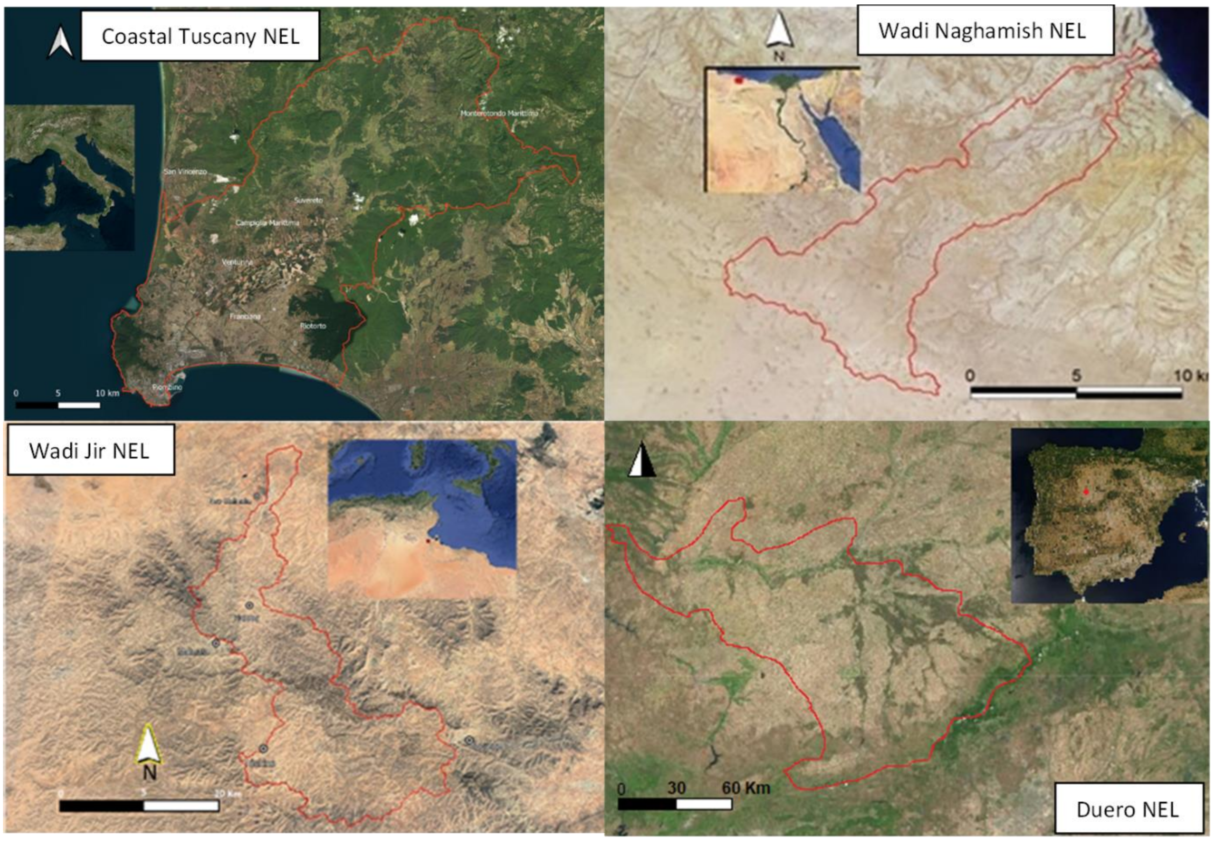
The Four NEXUS-NESS NEXUS Ecosystem Labs

Within the PRIMA NEXUS- NESS project four NEXUS Ecosystem Labs will be testing and demonstrating the outcomes of the project. They are located in Italy, Spain, Tunisia and Egypt. NEXUS-NESS NELs (considering actual and future demand and socio-economic conditions) demonstrates and assesses, in economic terms, the social and environmental importance of the optimization and sharing of economic benefits maintaining in high consideration the importance of preserving and considering also the services provided by ecosystems.



The four NELs areas testing and demonstrating the NEXUSS-NESS approach.

This document is one of the four Booklets produced as **Deliverable D3.1 The NEXUS Ecosystem Labs** of the NEXUS-NESS PRIMA project. Check for the other three booklets presenting the Italian, Spanish, and Egyptian NELs.

Booklet 1 – **The Coastal Tuscany NEL (Italy)**. Exploring innovative ways for conjunctive use of surface water groundwater and non-conventional waters to boost agricultural production, improve environmental quality, reduce energy consumption, and adapt to and mitigate climate changes.

Booklet 2 – **The Duero hydrological management units Cega-Eresma-Adaja and Tordesillas-Toro NEL**. Looking forward to water and food security based on RRI approaches on WEFE nexus

Booklet 3 - **The Wadi Jir NEL (Tunisia)**. Towards an efficient allocation of scarce natural resources in arid environments of south-eastern Tunisia through adopting Nexus approach.

Booklet 4 – **The Wadi Naghamish NEL (Egypt)**. Fair and Sustainable Resource Allocation Demonstrator of the Multiple WEFE Nexus Economic, Social and Environmental Benefits for Mediterranean Regions.

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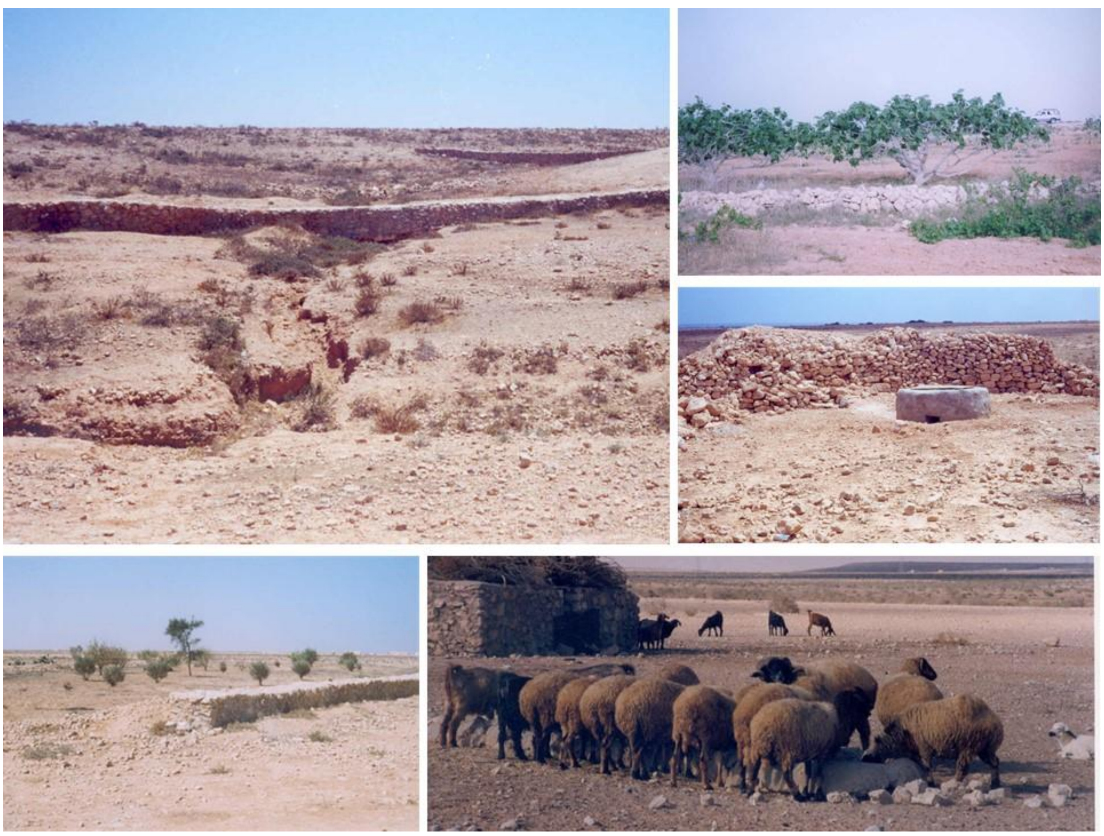
Booklet 4

The Wadi Naghamish NEL (Egypt)

Fair and Sustainable Resource Allocation Demonstrator of the Multiple WEFE Nexus Economic, Social and Environmental Benefits for Mediterranean Regions



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1 The Water Food Energy Ecosystem NEXUS

Natural resources scarcity is a major environmental issue since the middle of the twentieth century. Many factors like population growth, climate change, land exploitation (or land use change) contributed to the depletion and deterioration of ecosystems and the shortage of resources like water, soil quality and raw materials (Cramer et al., 2018). Each one of these resources impacts different sectors, but these challenges are commonly dealt with separated policies and strategy, or what can be dubbed as "Silo thinking" (Salleh, 2016): a mindset where governing authorities and sectors do not share the same vision whilst operating without proper collaboration. Silo thinking can be found in several government policies for example, when an agricultural department aims at ensuring food security by increasing irrigation demand, while the water department calls for reduction in water usage based on available volumes. The connection among these sectors and departments is missing while several connections are easily identifiable (Figure 1.1). Energy is needed for crop irrigation and food processing, water is needed for growing food, land use impacts water availability and water quality, energy is needed to pump/divert, treat, and distribute water, etc.

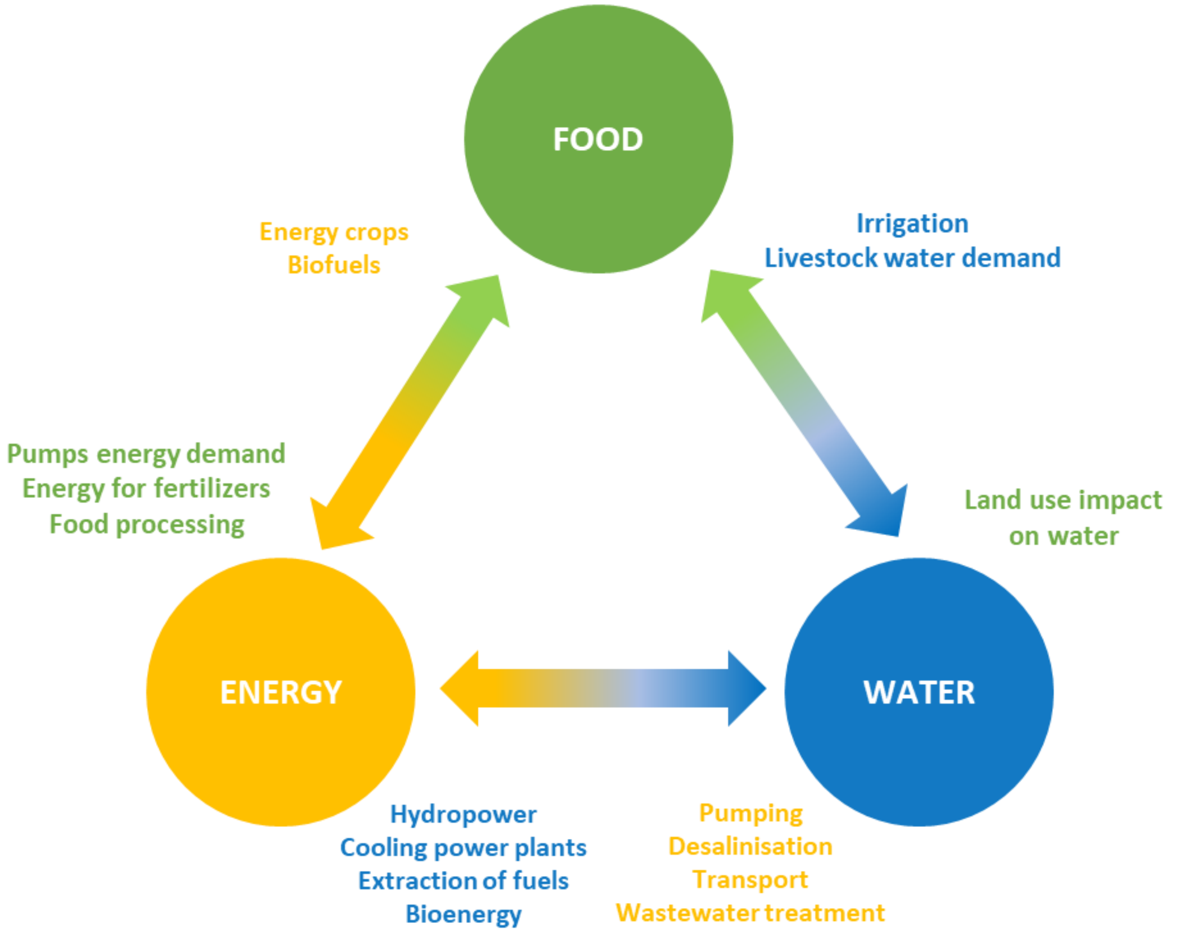

Figure 1.1. Typical Nexus connection diagram.

Cambridge dictionary defines the term NEXUS as an "*important connection between the parts of a system or a group of things*". Through the NEXUS thinking, resources are looked upon as being connected parts of a bigger system with synergies and trade-offs. The power of such a concept lies in its integrative capabilities, forming an umbrella under which multiple stakeholders can act (Simpson and Jewitt 2019). The resulting NEXUS system evaluation emerges consequently as a holistic analytical method driven by participation, research and science, with the final aim to provide adequate governance directions and policies for integrated and sustainable resource planning and management.

Several approaches may be implemented to avoid this silo-thinking that still characterizes the different sectors and actors of the WEFE components. Top-down (from policy to operations) or bottom-up (from the ground where people represent the main driver for mainstreaming the NEXUS) actions may be adopted with pros and cons of both approaches. NEXUS-NESS recognises the core importance of bottom-up citizen-centred technological and behavioural change to favour the uptake of NEXUS approaches.

An opportunity for collaboration

Within the methodologies presented by the NEXUS, a critical factor of collaboration and dialogue through science lies. Because of this, the NEXUS approach is being adopted by major stakeholders and policy makers like the United Nations, European Commission, NGOs, and important academic institutes. Its compatibility with the Sustainable Development Goals, with the existence of the applied cases incorporating societal and economical aspects, despite limitations, allows the development of further studies and connections between the water, energy, food, and ecosystems, whether exploring their internal relationship or finding their response to the several drivers. Hence, a framework for dialogue and collaboration can be set, through NEXUS thinking, between businesses, NGOs, and the public sector.

NEXUS-NESS - Nexus Nature Ecosystem Society Solution. A HORIZON 2020 PRIMA project

The NEXUS-NESS PRIMA project implements the Innovation Ecosystem Approach (IEA) at four selected areas, called Nexus Ecosystem Labs (NELs). The approach focuses on stakeholder engagement and actionable information, and integration within a 'NEXUS' framework, to ensure fair and sustainable resource allocation. Each NEL has its own challenges and benefits obtained from the NEXUS approach. The geographical variability between the NELs helps in demonstrating the capability of NEXUS thinking in overcoming the different challenges. The IEA is supported by the implementation of the Responsible Research Innovation Roadmap (refer to Deliverable 2.1 of the NEXUS-NESS project for more information; Schneider 2021).

2. Geographic and socio-economic context

Egypt's NEL (Wadi Naghamish) is located at around 15 km East of Marsa Matrouh city. The total area of the watershed is 105 km^2. The NEL is bounded by latitudes 31° 6′ 2′′ N to 31 ° 10′ 37′′ N and longitudes 27 ° 19′ 50′′ E to 27° 24′ 45′′ E. The watershed extends about 20 km inland to the southwest, the total length of the mainstream is around 15 km (Figure 2.1). Ten villages are found in the NEL with total population of about 3000 persons. The total number of houses is about 400 houses, 6 schools, 2 agricultural cooperatives, 1 gas station, 1 youth center, 10 mosques, 1 police station (IDSC, 2021).

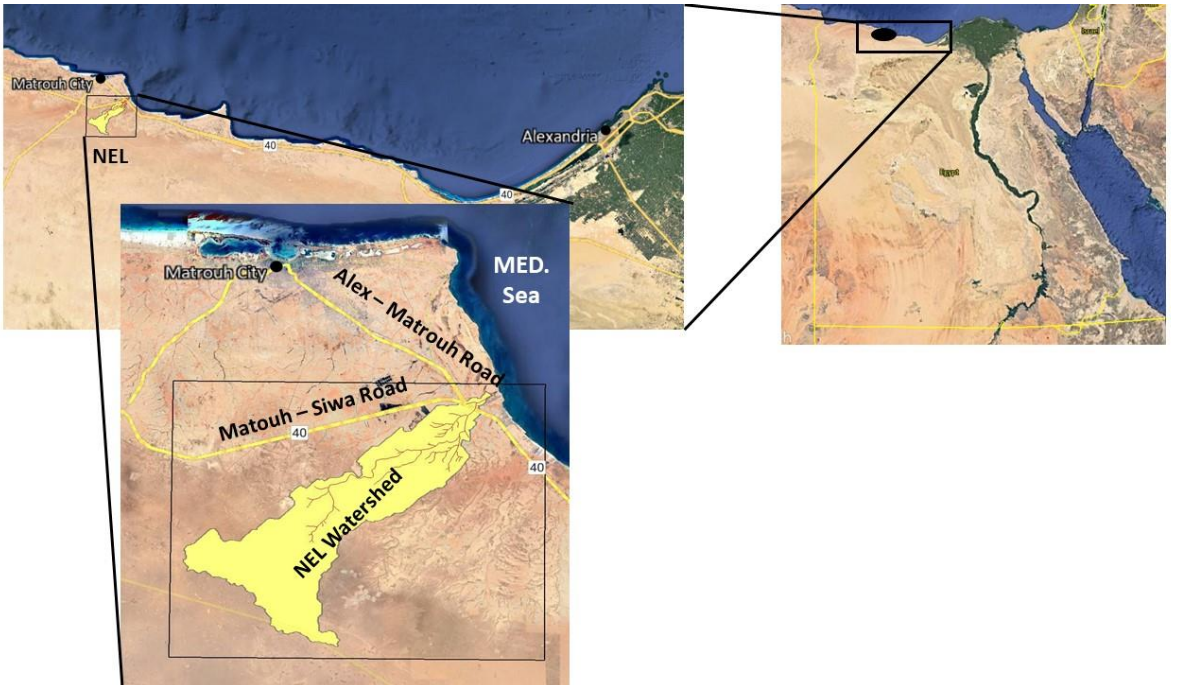

Figure 2.1. Geographical location of Egypt's NEL Wadi Naghamish.

The geological setting of the Egypt's NEL consists of 3 main types of deposits (Egypt Geological Survey, 1981), namely, undivided quaternary (Q) consists of Wadi and playa deposits and raised beaches (Figure 2.2). The geomorphological setting of the NEL is shown in Figure 2.3. The NEL is set in a coastal plain with 3 escarpments at different heights, and the northern and southern plateau.

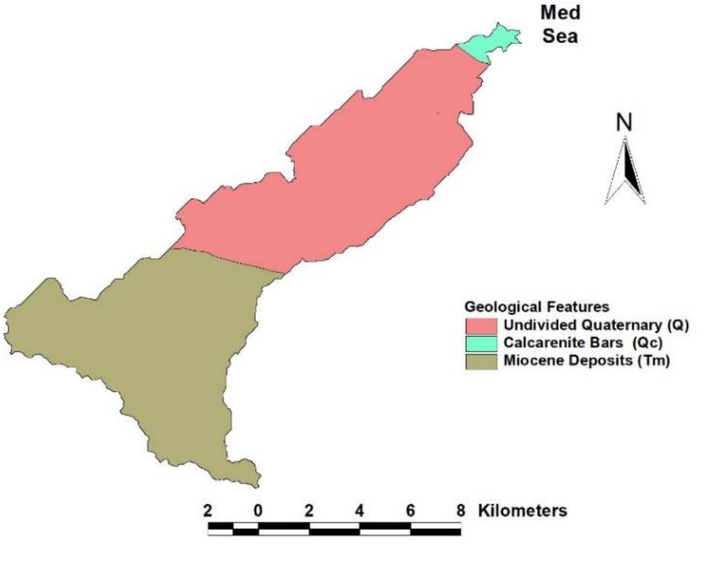

Figure 2.2. Simplified geology of Egypt's NEL Wadi Naghamish

Pedological characteristics are represented by the pedological map (Figure 2.4). The map was derived from soil sampling and analysis carried out at the Soil and Water Sciences Department, Alexandria University (Abdel-Kader et al., 2004). Four main soil units were identified in the study area based on the geomorphologic features by several studies including, FAO (1970), Hammad (1972), and El-Naggar & Perrier (1989). The four soil mapping units are: 1) the wind-blown soils, 2) the soils of the former beach plains and dune depressions, 3) the soils of the alluvial fans and outwash plains, and finally 4) the rock lands. Each soil unit has subdivisions according to the depth of the profiles and its soil texture. The subdivisions are important as they show different potentials for agriculture production, Abdel Kader at al., 2000.

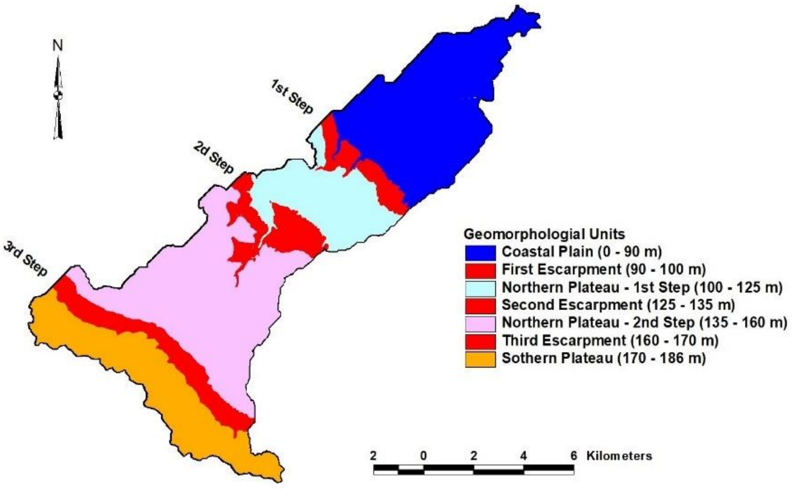

Figure 2.3. Geomorphological units of Egypt' NEL.

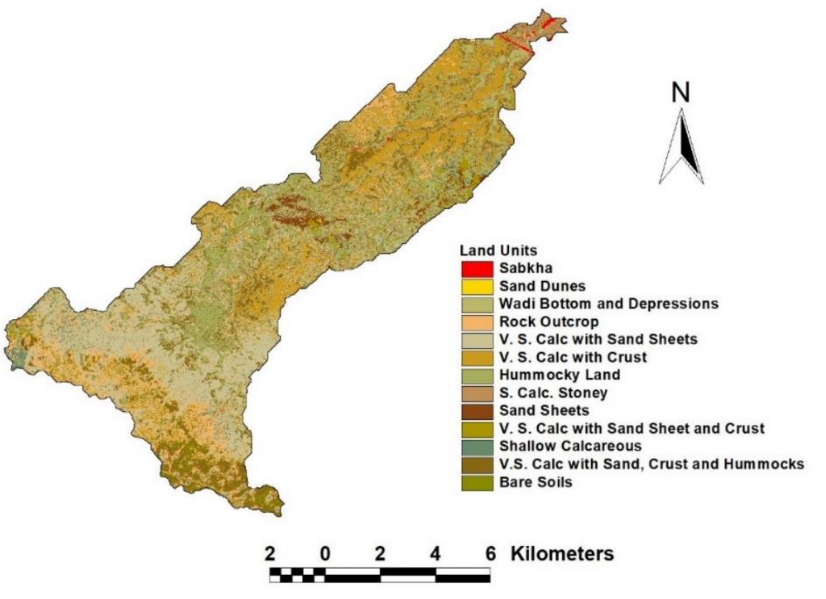

Figure 2.4: Pedological map of Egypt's NEL Wadi Naghamish (from Abdel Kader et al, 2000).

Wadi Naghamish is characterized by arid Mediterranean climate (BWh for Koppen classification, with hot dry summer and warm rainy winter), partially moderated by maritime influence in the northern part of the watershed. Table 1.1 shows the average climatic data for 30 years in Marsa Matrouh meteorological station. The maximum temperature is 29.7 ^{o}C, and was recorded in August, while the minimum temperature is 8.4 ^{o}C and was recorded in January. The amount of rainfall is concentrated in months October-March, where the maximum monthly rainfall is 33.2 mm in January. The average rainfall is around 150 mm/year. The maximum and the minimum values of relative humidity values were recorded from July to August and April, being 73 % and 61 %, respectively. Prevailing winds comes from the northwest in the most of year months. Surface wind velocity varies from 8.1 to 11.9 km/h. Evaporation data indicate that the lowest values of evaporation is 2.7 mm/day recorded in January, while the highest value is 5.9 mm/day recorded in July (Sayed, 2013).

Month	Temperature			Rainfall (mm)	Relative Humidity (%)	Wind Speed (km/h)	Average Evaporation (mm/day)
	Max.	Min.	Mean				
Jan.	18	8.4	12.8	33.2	66	11.5	2.7
Feb.	18.8	8.6	13	15	65	11.5	3
Mar.	20.4	10.2	15.1	12	63	11.9	3.8
Apr.	22.7	12.1	17.4	2.8	61	10.2	4.6
May.	25.4	14.7	20.1	2.6	64	9.3	5.2
Jun	28.1	18.4	23.3	2	68	9.7	5.9
Jul.	29.1	20.4	24.9	0	73	9.8	5.8
Aug.	29.7	21.1	25.5	0.6	73	8.9	5.6
Sep.	28.6	19.7	24.3	1.1	68	8.3	5.1
Oct.	26.9	16.9	21.6	15.6	67	8.1	4
Nov.	23.2	13.4	18.1	22.5	68	9.1	3.1
Dec.	19.5	10.1	14.1	30.2	66	11.1	2.8

Table 1.1. Climatic data for Marsa Matrouh City (source: Daoud, 2016).

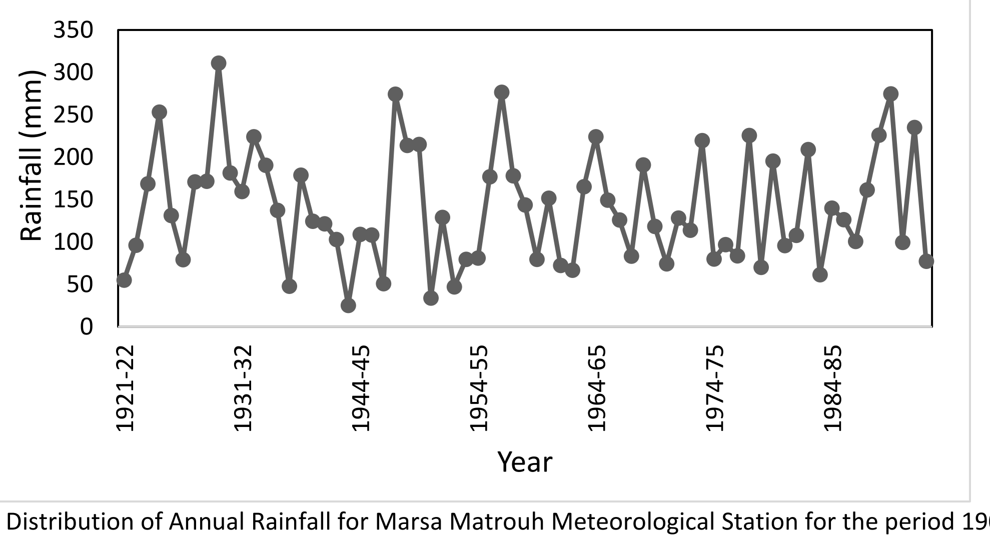

Figure 2.5. Distribution of Annual Rainfall for Marsa Matrouh Meteorological Station for the period 1905-1992.

The social setting of the NEL is based on traditional Bedouin tribes system, with five tribes found in the study area. Three of them, Mwalek, Menfa and Hafian have one clan each (Bait in Bedouin local language), named Mawalek, Sebak and Abu Gdida, respectively. The major tribes Gbihat and Gnashat have three clans each: Gbihat tribe has Maiof, Abu Khatra and Al borma clans; while Gnashat tribe has also 3 clans, namely, Abu Bakr, Abd Allah and Masarna. Overall, the average family size is around seven persons (Daoud, 2016). However, in the last 20 years, population statistics show a rapid increase of urbanization (people moving to Marsa Matrouh city) due to drought issues that caused migration of people looking for another civil job that could replace the pastoral Bedouin life (Bonnet et al., 2014). The level of education is mostly limited at the primary school (grade 9) due to the long distance the student walk from home to school and return. Dropouts tend to work to support the family.

Agriculture, organized around the wadi, is the main source of living in the watershed with figs and olives being the main productions. The area is also populated by diverse group of livestock species (mainly sheep and goats) that represent another important economic sector. Other potential economic activities can be envisioned: Wadi Nagamish is located in the Northwest Coast of Egypt that is a promising region for touristic development. This sector could provide great economic help to the local community and to the national economy, if it is properly managed, developed and sustained (Metwally Abdalla, 2005).

3. Overview of the natural resources

3.1 Water resources, uses, infrastructures and impacts

The main water resources in the Northwestern Coastal Zone of Egypt (NWCZ) are surface water and groundwater (Paver and Pretorius, 1954). Wadi Nagamish is not an exception, with the presence of a nearby urban wastewater treatment plant. The latter allows the reuse of treated effluent, with limitations imposed by the final water quality, limiting its use for agricultural purposes to crop such as timber plantations.

3.1.1 Surface Water

Surface water flows are collected in underground cisterns (called by Bedouin *Bir* for single, and *Abiar* for plural systems, Figure 3.1). In 2006, a survey revealed that 446 cisterns were present in the watershed (Daoud, 2016). These cisterns are excavated 1 to 2 m below the ground surface (rock outcrop), that constitute the ceiling of the cistern, then underground soil are dug and removed outside the pit. The walls and the bottom of the cistern are covered with cement. The capacity of storage ranges between 50 m^3 and 500 m^3 (El-Hariry, 1997). The more favorable locations for such cisterns are at the foot of limestone escarpments, which tend to funnel the runoff into the cisterns entrance. In the south of the NEL area, farmers lack the presence of owned cisterns due to poverty. In this regard, financial assistance for these farmers is crucial. The cost of digging 1 m^3 of land is 300-500 Egyptian Pounds.

Dykes are also used as water harvesting structures to with-hold runoff water (Figure 3.2). Dykes thickness, height, and typology vary from place to place. Concrete dykes (2-3 m height) are built at the mouth of the Wadi to prevent water from discharging to the sea. Stoney dykes or check dams (less than 1 m height) are built in the Wadi course to hold the rainwater for irrigating the fig and olive trees grown in the wadi course, and dirt dykes (less than 50 cm height) are built on the plateau around the local depression to keep rainwater and runoff for watering the trees and barley and wheat (Abdel Kader et al, 2000). No survey of the number of dykes has been carried out so far, despite their relevant role for local farmers.

Figure 3.1. Cisterns for rainwater harvesting.

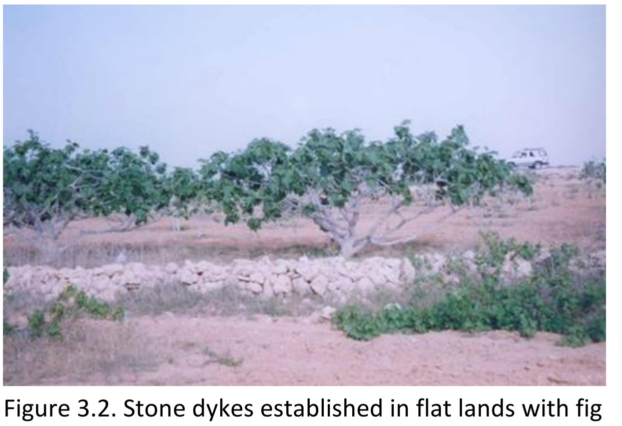

Figure 3.2. Stone dykes established in flat lands with fig plantations.

3.1.2 Groundwater

Shallow groundwater is the second source of water and it heavily depends on rainfall. The water depth of this source is proved to be at about 10 m below the land surface and is recharged by localized precipitation that percolates through the soil forming galleries. Deep groundwater is not utilized in Wadi Naghamish, due to high costs of digging and the presence of water at deep locations.

3.1.3 Reclaimed wastewater

The presence of a wastewater treatment plant of Marsa Matrouh (outside the NEL boundaries, Figure 3.3), designed to treat up to 25,000 m^3/day, makes available large amounts of water for irrigation and industry. However, in summer it often receives 60000–70000 m^3/day because of the increased water flows caused by the arrival of holidaymakers in the city. According to the operations staff, the treated wastewater is a burden for Holding Company for Water and Wastewater (HCWW, 2019) since there are no agricultural drains nearby, and the far distance of the treatment plant from the sea hinders the safe discharge of the treated effluent into this water body. Since 2015, the treated wastewater from HCWW-Matrouh is reused to irrigate two timber plantations on lands owned by the company (partially included within NEL boundaries). One plot is 63 ha (cultivation area 1); the other is 147 ha (cultivation area 2) as shown in Figure 3.3. The wastewater salinity is very high (3000 ppm) and it is used to irrigate tree planted on shallow soil depth (< 40 cm; Tawfik at al., 2021).

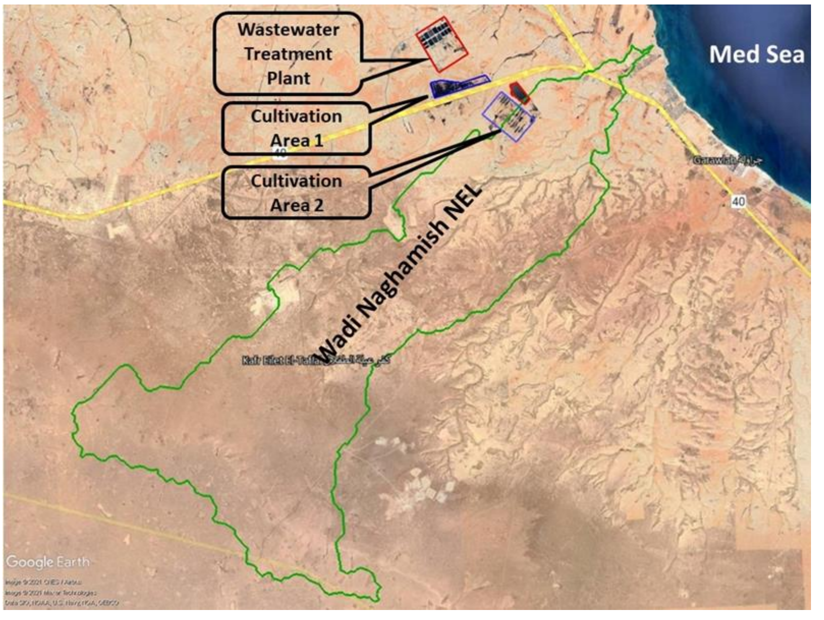

Figure 3.3. Location of Matrouh wastewater treatment plant in relation to Wadi Naghamish (image from Google Earth).

3.2 Land/Agricultural resources, uses, infrastructures and impacts

The main land uses (Figure 3.4) in the NEL are:

- agricultural land: fig and olive trees, as well as barley and wheat are grown in the area. Except from the input of water harvesting, no formal irrigation is used in the NEL, apart for the tree plantations which take advantage from the wastewater treatment plan. The total number of fig trees is about 4300, olive trees are around 1000, and about 800 feddans (1 feddan is 4200 m^2) planted with barley.
  Barley cultivation based on runoff farming is the dominant and traditional form of cereal cultivation in the study area. However, within the past 20 years, wheat has been introduced to the area in through subsidized seeds available through the government organized cooperatives.
- grazing areas: a vast area of the watershed is used for goats, sheep, and camels grazing.
- tourism: summer resorts are spreading on the Mediterranean coast, and the outlet of Wadi Naghamish to the sea was transformed to summer resort (Figure 3.5).

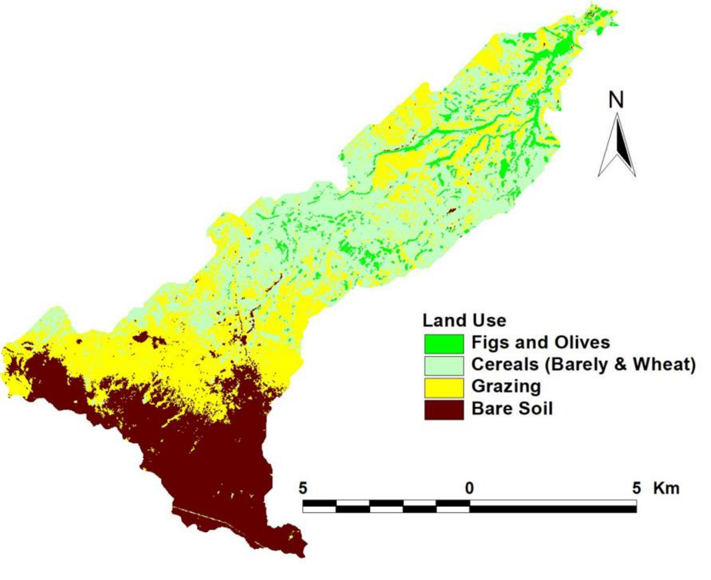

Figure 3.4. Land Use of Wadi Naghamish watershed

Abdel-Kader and FitzSimons, (2002) indicated that agropastoral livelihood system, combining the small ruminant (sheep and goat) rangelands system and cereal cropping is the core element of Bedouin agropastoral activity in the area. The study indicates that there is small ruminant feed gap, showing that, in overall terms, external feeds (maize and concentrates) would fill 40% of this feed gap in a good year, 75% in an average year and over 80% in a poor rainfall year. However, there are marked differences between zones within each year rainfall type, largely because of the relative contribution of barley grain to this feed group. Grazing process, however, is so destructive to local vegetation as ruminants consume all the edible species. Moreover, when land is cultivated with barley and wheat for producing feed, pesticides and herbicides are used with a negative impact on biodiversity.

Overall, the area of the NEL is facing multiple issues related to land degradation. The most important threats are represented by salinization, erosion by water and wind, overgrazing, and urbanization. Another factor that reduces the quality of land resources is shallow soil depth, which limits the use of land. Poor soil fertility is another important issue that deteriorate the land.

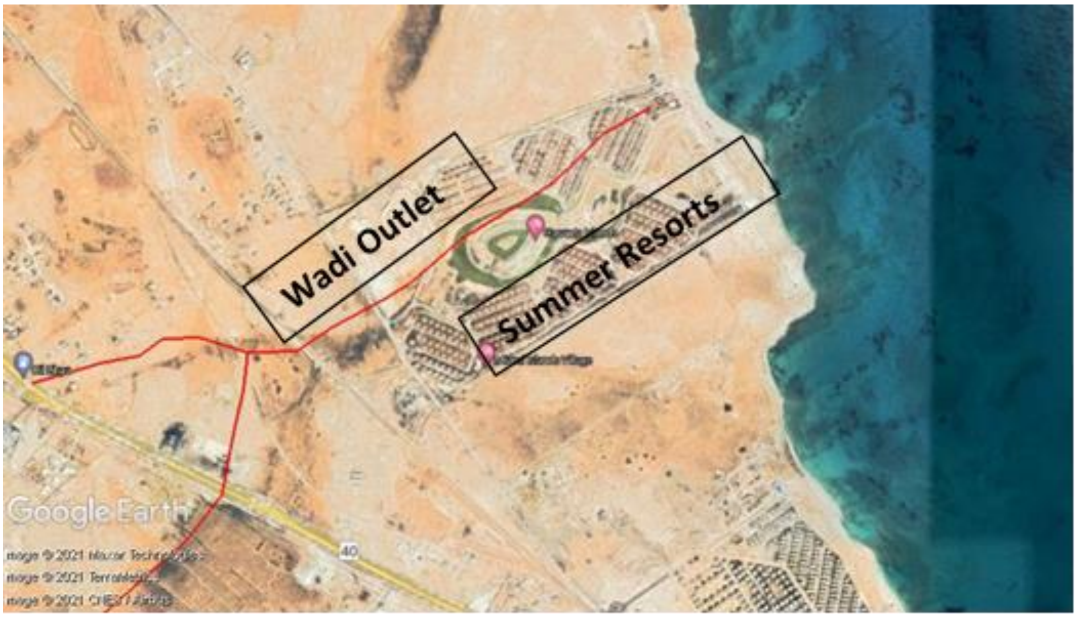

Figure 3.5. Map showing the outlet of Wadi Naghamish after transforming to summer resort (image from Google Earth).

3.3 Energy resources, uses, infrastructures

The main source of energy is gasoline. Electricity reaches about 400 houses with different types of generators and grids (IDSC, 2021). Despite the presence of solar and wind energy, they are not utilized due to the high cost of installation, as well as the lack of experience to maintain these systems.
The following infrastructures are present in the Egypt's NEL excluding the summer resort, according to IDSC (2021):

- there is 1 electricity network, 12 transformers, 2 generators, 1200 electricity poles, and the total number of subscribers (users) are 374 houses and 1 commercial one. All the community has electricity;
- regarding road network, the paved roads are 7.5 km length, the tracks are 10 km length, and the dirt roads are 35 km length;
- regarding drinking water: there is 1 network, 1 strategic tank (1000 m^3 capacity), 1 car with tank, 1 water nozzle to fill the tank of the car;
- for transportation, there is one rail station, no bus stations.

3.4 Environment and Ecosystems

Three main ecosystems are found in the Egypt's NEL (Wadi Naghamish), as follows (Figure 3.6):
a) Coastal cultivation strip. This strip extends from the seashore to 5 km inland, including the beach and the coastal plain. Annual rainfall is about 150 mm. Cultivation of orchards and vegetables predominate especially in the deltas of

wadis. The inhabitants are settled. It constitutes 5% of total land. Fig and olive trees are the main orchards, and in shallow soils, barley and wheat are cultivated on the plateau

b) Inland mixed production or grazing-cropping (barley) strip. This strip is located between 5-15 Km from the coast. Annual rainfall is 100-140 mm. Soils are mainly poor calcareous soils. Grazing (especially sheep and goats) and cropping are the main activities. Inhabitants are sedentary. This zone constitutes 22% of total land. With the development of dykes, we can see the extension of orchard plantation in this zone. Some authors speak about tree-crop-livestock system in this strip (MRMP II, 2000).

c) Inland grazing (Rangeland) strip. This strip lies between 15 and 50 km from the seashore. Annual rainfall is from 50-100 mm. Grazing predominates, with some barley cultivation. In the wadi Naghamish, due to the last drought period (lasting 15 years from 1995 to 2010, according to Daoud, 2016) and erosion issues, this zone is completely devoted to grazing now.

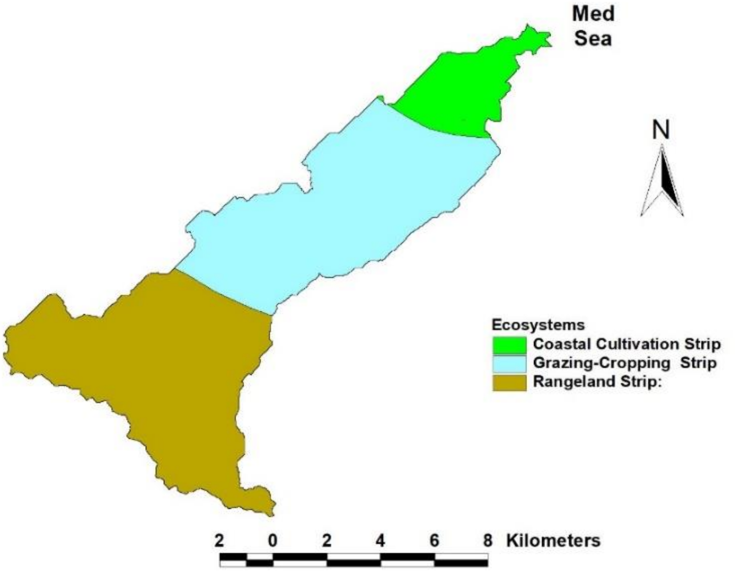

Figure 3.6. Ecosystems of Egypt's NEL Wadi Naghamish.

4. Governance framework

The NEL has one agricultural cooperative namely El-Garawla, which groups the farmers and is considered the link between the farmers and the Ministry of Agriculture. It provides the farmers with seeds for planting both wheat and barley, which are domestically consumed, and fed to the livestock. There are two associations namely, association of olive growers and association of fig growers. They help farmers solve their problems, related to marketing figs and olives. Power companies are located far from the NEL around Alexandria. Two authorities are working in Marsa Matrouh City. They are Matrouh Sanitary, and Matrouh Drinking Water. Other governmental bodies like Ministry of Agriculture, Ministry of Environment, Ministry of Water Resources and Irrigation, and Ministry of Electricity and Renewable Energy are located in Marsa Matrouh City for official communications between the farmers and the central Government in Cairo. There are many scientific bodies which are carrying out research related to different aspects of Agriculture, Environment, and Water resources represented by Egyptian Environmental Affairs Agency, National Water Research Center, Faculty of Desert and Environmental Agriculture at Fuka, and National Research Center.

5. NEXUS Grand Challenges

5.1 Water-Energy-Food-Ecosystem Current Status and the Three Grand NEL Challenges

As highlighted in the Sections 2 and 3, the Wadi Naghamish area economy is mainly based on agriculture and livestock, both strongly water dependent sectors. Therefore, the Grand Challenges for the Egyptian NEL are linked to maximizing the agricultural productivity (including livestock) without harming its fragile environment, considering different water and land allocation settings, and including the possibility of enhancing groundwater use and non-conventional water sources.

The **first Nexus Grand Challenge** is to *set a plan for the sustainable intensification of water infrastructures in the watershed for food production, without creating water allocation imbalances*. As said, water availability is based on rainfall that is affected by a strong variability inside the basin. Shallow groundwater is also totally rainfall dependent while deep groundwater extraction is limited due to the excessive depth of the aquifer. This leads to water scarcity issues, especially in the southern part of the basin where the rainfall input is generally lower. Rainfall needs to be stored by digging cisterns, building more check dams, and locating better soil for cultivation. In this essence, more water storing structures are needed in the southern part to compensate the less rainfall Bedouins receive. These structures (e.g. cisterns) could be also be combined with wind and solar energy. Shifting from fossil fuels (currently used for pumping) to renewables can boost the agricultural production as well as keep the environment safe. Such intensification should be however carefully evaluated, to avoid competition over water resources and groundwater depletion. As a result, the NEL will contribute to identify the more effective solutions to regulate and improve surface water and shallow aquifer storage aiming at supporting fair and sustainable agricultural water management in Wadi Naghamish.

The north-south dichotomy is exacerbated by the soil characteristics of the area. The highest quality of land resources are the soils of the Wadi bottom and depressions, which have deep soil profile and sandy texture. These soils are located at the Northern part of the NEL and represent about 8% of the total area of the NEL (105 km^2). Less quality soils are in the southern part of the NEL. The exact distribution of deep soils to cultivate and their conservation must be investigated to optimize agricultural siting and practices to store water in the soil profile. The unsustainability of the present nexus dynamics is reflected in the different income of the Bedouins living in the north of the NEL and Bedouin living in the south of NEL. This has caused people migration (urbanization) and the growth of alternative economic activities, replacing the traditional agricultural-based economy. In this sense, the expansion of the touristic sector is an evident signal of the economic system change that needs be understood also because of the potential drawback that it can have on the nexus itself, putting extra pressures on water resources and determining an increase in energy demand. In this sense, a **second Nexus Grand Challenge** can be evaluated, namely *introducing sustainable land and water management practices to revert land degradation and soil loss.* By doing so, the NEL will provide a comprehensive understanding of the risks connected to land degradation, assessing the effects of land use changes on water (and energy) resources and identifying appropriate management strategies.

The **third Nexus Grand Challenge** in the NEL (water-energy-food-ecosystem Nexus challenge) would be to *evaluate the introduction of the use of non-conventional waters such as desalinated water and treated wastewater.* This will allow to assess the potential of non-conventional waters as an additional source to mitigate the water scarcity issues, analyzing the implication they can have on food production and the impact on energy use. Indeed, the use of non-conventional water resources, such as wastewater reuse and desalinization, represents a promising option to be explored in Wadi Naghamish. In particular, the present wastewater reuse is limited to the cultivation of trees due to the low water quality. This water quality issue, besides having negative impacts on the environment (water-ecosystem nexus) is also limiting the potential use of this important alternative water source. Therefore, better wastewater treatment (tertiary treatment) could support multiple agricultural production and the introduction of more productive crop types. Desalinization is another applicable option, but it brings issues related to energy supply that need to be analyzed.

These two further potential NEL Grand Challenges will be discussed and co-identified in the upcoming NEL workshops.

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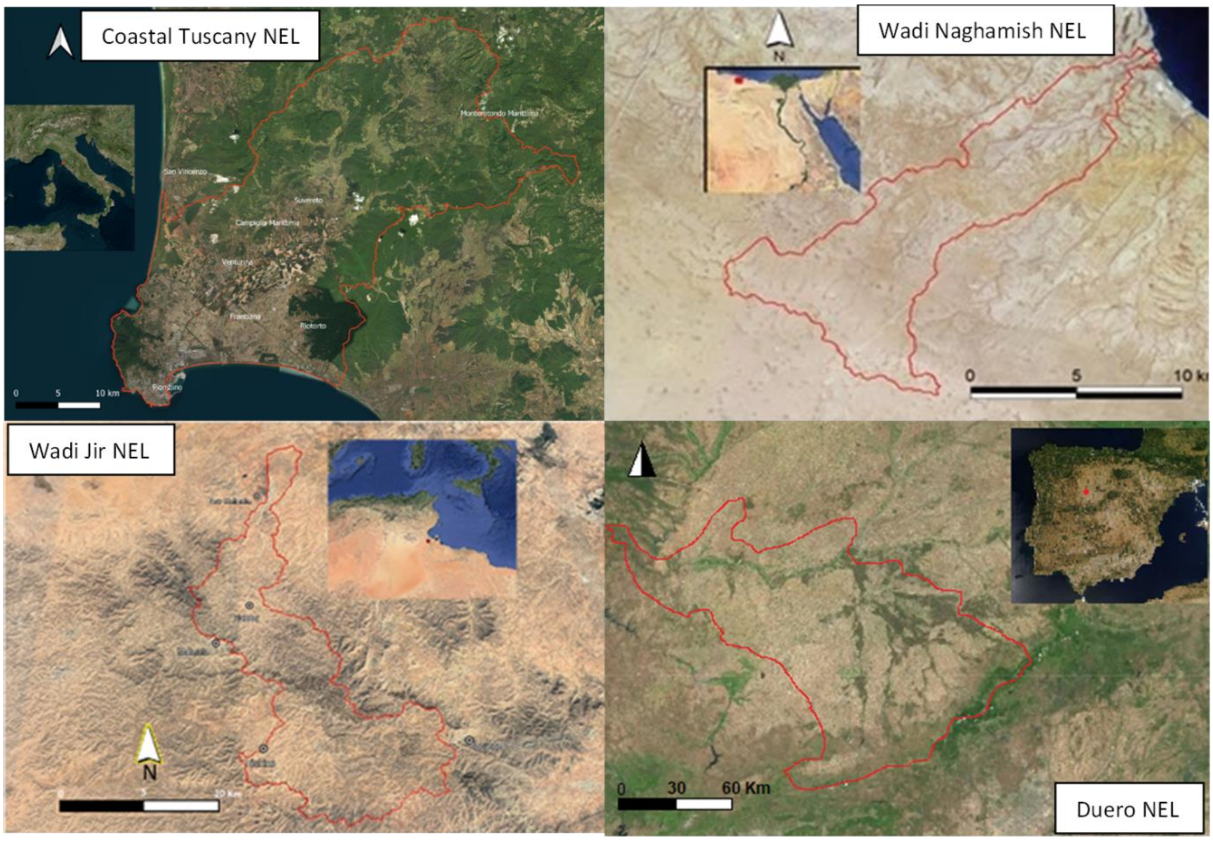
The Four NEXUS-NESS NEXUS Ecosystem Labs

Within the PRIMA NEXUS- NESS project four NEXUS Ecosystem Labs will be testing and demonstrating the outcomes of the project. They are located in Italy, Spain, Tunisia and Egypt. NEXUS-NESS NELs (considering actual and future demand and socio-economic conditions) demonstrates and assesses, in economic terms, the social and environmental importance of the optimization and sharing of economic benefits maintaining in high consideration the importance of preserving and considering also the services provided by ecosystems.



The four NELs areas testing and demonstrating the NEXUS-NESS approach.

This document is one of the four Booklets produced as **Deliverable D3.1 The NEXUS Ecosystem Labs** of the NEXUS-NESS PRIMA project. Check for the other three booklets presenting the Italian, Spanish, and Tunisian NELs.

Booklet 1 – **The Coastal Tuscany NEL (Italy)**. Exploring innovative ways for conjunctive use of surface water groundwater and non-conventional waters to boost agricultural production, improve environmental quality, reduce energy consumption, and adapt to and mitigate climate changes.

Booklet 2 – **The Duero hydrological management units Cega-Eresma-Adaja and Tordesillas-Toro NEL**. Looking forward to water and food security based on RRI approaches on WEFE nexus

Booklet 3 - **The Wadi Jir NEL (Tunisia)**. Towards an efficient allocation of scarce natural resources in arid environments of south-eastern Tunisia through adopting Nexus approach.

Booklet 4 – **The Wadi Naghamish NEL (Egypt)**. Fair and Sustainable Resource Allocation Demonstrator of the Multiple WEFE Nexus Economic, Social and Environmental Benefits for Mediterranean Regions.

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