Project deliverables

Deliverable #D4.2

Technical case study briefs on the specification of selected MAR infrastructure by implementation sites

Funded by

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AGREEMAR

Adaptive agreements on benefits sharing for managed aquifer recharge in the Mediterranean region

Deliverable #D4.2

Technical case study briefs on the specification of selected MAR infrastructure by implementation sites

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Executive summary

Deliverable D4.2 provides Technical Case Study Briefs with the main numerical modelling outcomes for each of the four demonstration sites, addressing the main questions and concerns raised by stakeholders during project meetings. These findings offer valuable insights into the effects of various water management scenarios, helping to support future decision-making considering new water resources and alternative management strategies.

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Deliverable number & title	D4.2 Technical case study briefs on the specification of selected MAR infrastructure by implementation sites
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Dissemination level	PU (public)

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Version	Date	Author	Remarks
0.1	13.11.2024	Teresa E. Leitão	First draft version with input from partners
0.2	27.11.2024	Teresa E. Leitão	With contributions from the project coordinator TUD
1.0	29.11.2024	Catalin Stefan	Final layout and editorial works

Abstract

Deliverable 4.2 aims to provide stakeholders with key insights from numerical groundwater modelling of current and projected Managed Aquifer Recharge (MAR) scenarios, developed through a participatory approach. It summarizes the main modelling outcomes, including regional water budgets, groundwater level increases due to MAR, primary flow directions, and areas influenced by MAR systems. Furthermore, it assesses environmental benefits, such as mitigating seawater intrusion, across the four demonstration sites.

This collaborative approach seeks to foster capacity building and support the effective implementation of optimized MAR scenarios, promoting long-term water supply security and environmental sustainability, by adopting new adaptive and innovative water management MAR strategies within River Basin Management Plans (RBMP).

This preliminary version of the deliverable may be updated to incorporate additional stakeholder requests, addressing further MAR scenarios within the framework of RBMP.

Table of contents

Abbreviations

AGREEMAR	Adaptive Agreements on Benefits Sharing for Managed Aquifer Recharge in the Mediterranean Region
BWRS	Basin Water Resources System
ECoE	ERATOSTHENES Centre of Excellence
INAT	Institut National Agronomique de Tunisie (National Agronomic Institute of Tunisia)
LNEC	Laboratório Nacional de Engenharia Civil (National Laboratory for Civil Engineering, Portugal)
MAR	Managed Aquifer Recharge
PRIMA	Partnership for Research and Innovation in the Mediterranean Area
RBMP	River Basin Management Plans
SAT	Soil-Aquifer Treatment
TUD	Technische Universität Dresden
UPV	Universitat Politècnica de València (Polytechnic University of Valencia)
WWTP	Wastewater Treatment Plant

Technical case study briefs

1. Introduction

The AGREEMAR project aims to support decision-makers in the safe and optimized use, sustainable planning, and management of Managed Aquifer Recharge (MAR) systems within the EU River Basins Management Plans (RBMP). This was technically supported by two main tools developed in different work packages (WPs) of the AGREEMAR project: the MAR feasibility maps (WP2) to identify the most feasible MAR areas (for more details see AGREEMAR deliverable D3.2) and the numerical groundwater models (WP4) to study specific sites in more detail (see deliverable D4.1).

Within WP4, Deliverable 4.1 conducted a detailed analysis of existing MAR sites using numerical groundwater modelling, with a focus on the most promising areas identified in the WP2 feasibility maps. Deliverable 4.2 is now designed to present key outcomes for stakeholders, including the impacts of the current situation, projected long-term impacts under a business-as-usual scenario, and the evaluation of alternative operational and management strategies.

The groundwater models served as a foundation for quantifying MAR water budgets, assessing groundwater level rises due to MAR, identifying main groundwater flow directions and areas of influence of MAR systems, and evaluating environmental benefits, such as mitigation of seawater intrusion. Additionally, simulations of current and optimized MAR systems integrated general models of the entire Basin Water Resources System (BWRS). This approach enabled an assessment of the enhancements in reliability, vulnerability, and resilience offered by MAR schemes within the BWRS and RBMP under both current conditions and optimized scenarios.

This work was conducted collaboratively, incorporating feedback from stakeholder consultations to address their specific needs and concerns. The modelling tools developed through this process are intended to support informed decision-making during the project and into the future. These findings offer valuable insights into the effects of various water management scenarios.

2. Methodology

For each of the four demonstration regions, a Technical Case Study Brief was prepared to address the primary questions and concerns raised by stakeholders during project meetings and needs assessment interviews.

Each Technical Brief outlines the outcomes of the technical feasibility assessment, beginning with the overarching project aims and the specific objectives of each demonstration site. It then presents the model outcomes related to the key questions about current and projected MAR scenarios and concludes with the research needs identified for each region.

3. References

- Chekirbane et al., 2023. AGREEMAR Deliverable D2.3: MAR feasibility maps validated for each demo region. Available online at https://www.agreemar.inowas.com/deliverables.
- Glass, J. et al., 2024. AGREEMAR Deliverable 4.1: Models for MAR scenarios and validation. Available online at https://www.agreemar.inowas.com/deliverables.

4. Acknowledgement

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Annex. AGREEMAR Technical Case Study Briefs

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Technical Brief
Case Study in Portugal

AGREEMAR
Adaptive agreements on benefits sharing for managed aquifer recharge (MAR) in the Mediterranean region
PRIMA

AGREEMAR overall goal

To optimise the hydrological balance in Mediterranean countries by developing governance models, management strategies, costs-benefits analyses, technical specifications and simulation tools to **optimise the water storage in aquifers**, enabling increased **resilience to climate change**.

AGREEMAR case study in Portugal

The goal is to use SAT-MAR (soil-aquifer treatment managed aquifer recharge) as a technology to **increase the groundwater availability in Alentejo region**, smoothen the gap between water demand and availability, and help **mitigating the effects of climate change** while supporting water-related environmental services.

The AGREEMAR case study in Portugal is Comporta Wastewater Treatment Plant (WWTP), whose **secondary treated effluent (110 to 190 m^3/day is being discharged into a SAT-MAR system composed of four infiltration basins**.

The system aims to improve the water quality during the infiltration of secondary treated wastewater, mainly through filtration, biodegradation and adsorption processes, avoiding direct discharge into a sensitive area.

Comporta WWTP is located in Alentejo region (Figure 1), located in the vicinity of the Sado estuarine ecosystem, a **Nature Reserve sensitive area**, lying over the Left-Margin Tejo-Sado aquifer (the largest aquifer of the Iberian Peninsula with 6,875 km^2).

Main questions addressed by the AGREEMAR project in Comporta SAT-MAR system

- What is the effect of SAT-MAR at the Comporta site?
- What is the impact of MAR on environmentally sensitive areas?
- What are the benefits of replicating such SAT-MAR practices in the region?
- Where is it possible to replicate MAR in the Alentejo region?

1

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Technical Brief
Case Study in Cyprus

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AGREEMAR case study in Cyprus

The overall goal of the AGREEMAR project in Cyprus is to promote the use SAT-MAR (soil-aquifer treatment managed aquifer recharge) as an environmentally sustainable technology to **increase the groundwater availability in Akrotiri region for later use, while mitigating/preventing the seawater intrusion**. The integration of the modelling tools and results, together with the stakeholders' engagement during different stages of the implementation process, are expected to support the policymakers towards the design of efficient strategies to satisfy the water demand based on available water resources. The applicability of the proposed methodology is demonstrated in the non-occupied area of Cyprus (large-scale), and Akrotiri MAR site (small-scale), which uses tertiary-treated wastewater from the urban waste.

In Cyprus, the primary objective of the water authorities is the usage of recycled water to satisfy at least 40% of the agricultural needs, which consumes most of the water supply volumes (59 %), followed by the domestic (30 %) and tourism (5 %).

Akrotiri MAR site is one of the two SAT-MAR sites in Cyprus, located in the southern part of the island (Figure 1). It consists of seventeen infiltration ponds, which are recharged based on tertiary-treated wastewater from the urban Wastewater Treatment Plant (WWTP) during the winter period (1-4 Mm^3 in annual basis). **The recharge objective is primarily to mitigate the intrusion of seawater into the coastal aquifer while storing water amounts for later use, mainly for irrigation purposes.**

Main questions addressed by the AGREEMAR project in the Akrotiri MAR system

- Which regions in Cyprus are suitable for replicating MAR systems?
- What is the effect of SAT-MAR at the drinking wells, located upstream of Akrotiri site?

1

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Technical Brief
Case Study in Spain

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PRIMA

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AGREEMAR case study in Spain

The goal of the AGREEMAR project in Spain is to promote the use of **MAR** (Managed Aquifer Recharge) as a tool/technique to **restore groundwater levels**, mitigate local aquifer overdraft, **reduce the vulnerability of water demands** and mitigate seawater intrusion in the **Mijares** and **Palancia** river basins.

The Mijares and Palancia river basins are located within the Júcar River Basin District (JRBD) in eastern Spain (Figure 1). These basins face significant challenges, including groundwater overexploitation, seawater intrusion, and water scarcity due to agricultural demand, urban supply, and climate change impacts.

Mijares River Basin: Covers 4,818 km^2, originating in the Sierra de Gúdar and flowing into the Mediterranean Sea. Key features in the water resources system include the Belcaire Pond and aquifers such as Plana de Castellón and Azuébar-Vall d'Uixó.

Palancia River Basin: Covers 1,086 km^2, rising in the Sierra del Toro and flowing into the municipality of Sagunto. In the medium and lower part of the basin, we can find the Algar reservoir and aquifers like Medio Palancia and Plana de Sagunto.

Main questions addressed by the AGREEMAR project in the Mijares and Palancia river basins

- What is the effect of MAR on the quantitative changes in aquifer storage over time?
- How does MAR influence other water uses within the river basin?
- What are the most effective management strategies to optimize the implementation of MAR at the river basin scale?
- What are the key benefits of implementing MAR?

1

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Technical Brief
Case Study in Tunisia

AGREEMAR
Adaptive agreements on benefits sharing for managed aquifer recharge (MAR) in the Mediterranean region
PRIMA

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AGREEMAR case study in Tunisia

The goal of the AGREEMAR project in Tunisia is to promote the use of SAT-MAR (Soil-Aquifer Treatment in Managed Aquifer Recharge) **as an innovative approach** to enhance groundwater availability in the Chiba watershed, to address the **imbalance between water demand and supply, support water-related environmental services, and prevent seawater intrusion,** thereby mitigating the impacts of global change. Korba Wastewater Treatment Plant (WWTP) is the recharge water source of the Tunisian case study.

Secondary treated effluent from Korba WWTP is being discharged into a SAT-MAR system composed of three infiltration basins. They target to improve the water quality during the infiltration of secondary treated wastewater, mainly through filtration, biodegradation and adsorption processes, avoiding direct recharge into a sensitive area.

The SAT-MAR site is in Korba region (Figure 1), in the Cap-Bon peninsula at the north-eastern part of Tunisia.

Main questions addressed by the AGREEMAR project in Korba SAT-MAR system:

- What is the local impact of the SAT-MAR system on groundwater restoration at the Korba and Diar Hojjej sites?
- How does treated wastewater infiltration influence the long-term sustainability of groundwater levels in the area? What are the potential effects of MAR system on preventing seawater intrusion in the local aquifers?
- How can optimizing SAT-MAR operations contribute to improving groundwater availability and restoring water balance in the Korba region?

1

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- What is the impact of MAR on environmentally sensitive areas?
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- Where is it possible to replicate MAR in the Alentejo region?

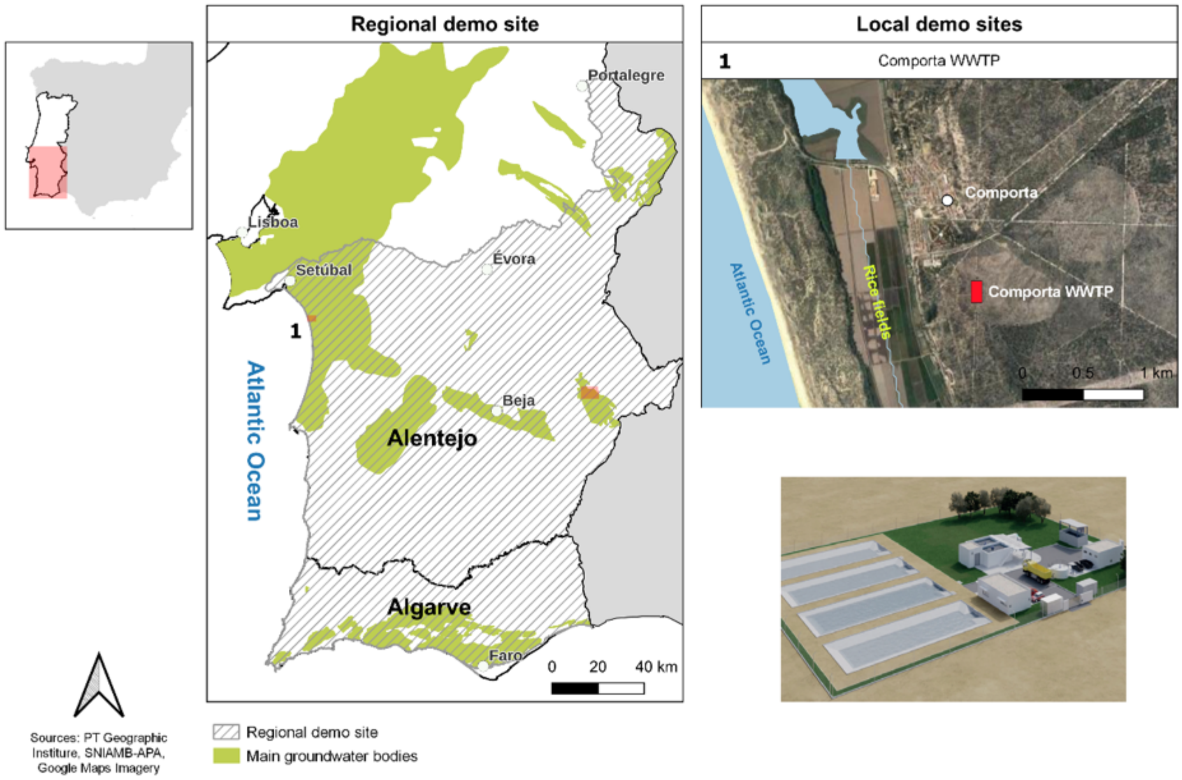

Figure 1. Comporta case-study site and existing aquifer systems in Alentejo and Algarve region

What is the effect of SAT-MAR at the Comporta site?

The effects of SAT-MAR infiltrations at Comporta were studied using a numerical groundwater flow model. Model results are estimates due to incomplete knowledge of the parameters that represent the groundwater system. Details can be consulted in AGREEMAR deliverable D4.1.

The numerical model shows that hydrogeological conditions in Comporta would allow **infiltration rates** 16x higher (2188 m^3/d) than the **current average infiltration rate** (137 m^3/d).

The water infiltrated at Comporta could help **increase the groundwater level** locally by 6.5 m for the maximum infiltration rate compared to the current average infiltration rate, therefore contributing locally to alleviating water stress. Concerning the area of influence, the water level rise would be approx. 1 m at about 500 m from the infiltration basins.

What is the possible impact of MAR on environmentally sensitive areas?

Comporta is in a sensitive area, classified as a Nature Reserve. To understand the main **groundwater flow directions**, particle tracking modelling showed that a **minimum travel time** of 10 years is needed to reach the Vala Real stream, set at the rice fields west of Comporta MAR site, considering the current average infiltration rate.

Figure shows the time needed to reach the rice fields for the current situation scenario and the maximum infiltration scenario. The time varies between approx. 3 and 10 years.

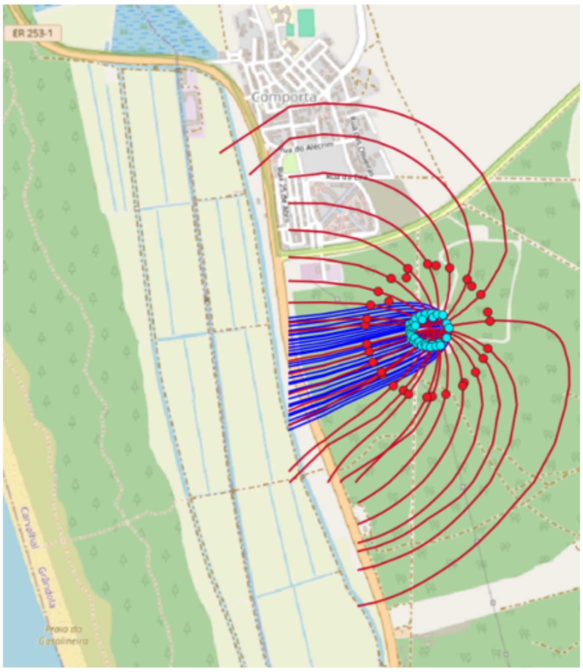

Figure 2. *Pathlines originating in the infiltration basins towards Vala Real and particles for 1 year travel time (blues = current average infiltration rate, reds = maximum infiltration rate)*

What are the benefits of replicating such SAT-MAR practices in the region?

In Alentejo and Algarve regions, the discharge of TWW is frequently done into streams that are dry most of the year, and where water slowly infiltrates mostly unmonitored deeper into the soil. In these situations, SAT-MAR basins can provide an advantage as water is intentionally and monitored infiltrated. Processes such as filtration, sorption, and biodegradation produce significant improvements in the water quality, therefore reducing subsequent impacts to the environment.

SAT-MAR systems are considered nature-based solutions and cost-effective approaches due to the natural treatment provided by e.g., reactive organic layer filters (sand / carbon).

The evidence of benefits from SAT-MAR systems are to:

- Reduce turbidity in a cost-efficient manner.
- Remove biological contaminants and biodegradable compounds.
- Improve microbiological, physical and chemical water quality.
- Bring a more consistent water quality and temperature.
- Reduce the need/cost for disinfection.
- Decrease construction and operation costs compared to conventional tertiary treatment.
- Generate less sludge.
- Be easily maintained.

Where is it possible to replicate MAR in the Alentejo region?

The areas more feasible for MAR were mapped for Alentejo Region using a methodology that has integrated a GIS-based multi-criteria decision analysis for selecting sites with good characteristics for MAR considering:

- Conventional and unconventional water availability for MAR.
- Water demand.
- Physical criteria (permeability, soil type, etc.).
- Non-physical criteria (social, cultural, economic).

Figure 3 presents areas potentially feasible for MAR (highlighted in green), that include Comporta (for more details see AGREEMAR Deliverable D2.3).

Further research needs

Though SAT-MAR diminishes the loads of contaminants present in source water, there is still a need for future research / investment in some of the following aspects:

- The occurrence of physical, chemical, or biological clogging, mainly due to suspended solids in the water, biofilm growth, or mineral precipitation.
- The mobilization of water and/or soil contaminants during recharge into the aquifer.
- The production of undesirable transformation products into the aquifer.

- The seasonal dynamics of temperature and redox conditions temporally establishing separate zones where certain compounds can modify their reactivity, their capacity to produce metabolites, and/or their redox behaviour (e.g., a shift to more anaerobic conditions retards some pharmaceuticals degradation).
- The need for regulatory framework concerning water for MAR, namely water quality standards.

The use of treated wastewater for aquifer recharge still faces resistance from stakeholders and possibly local communities due to concerns over environmental impacts and health risks. An interdisciplinary and transdisciplinary methodology to interconnect different perceptions of MAR innovations, technology, and sustainability is undergoing.

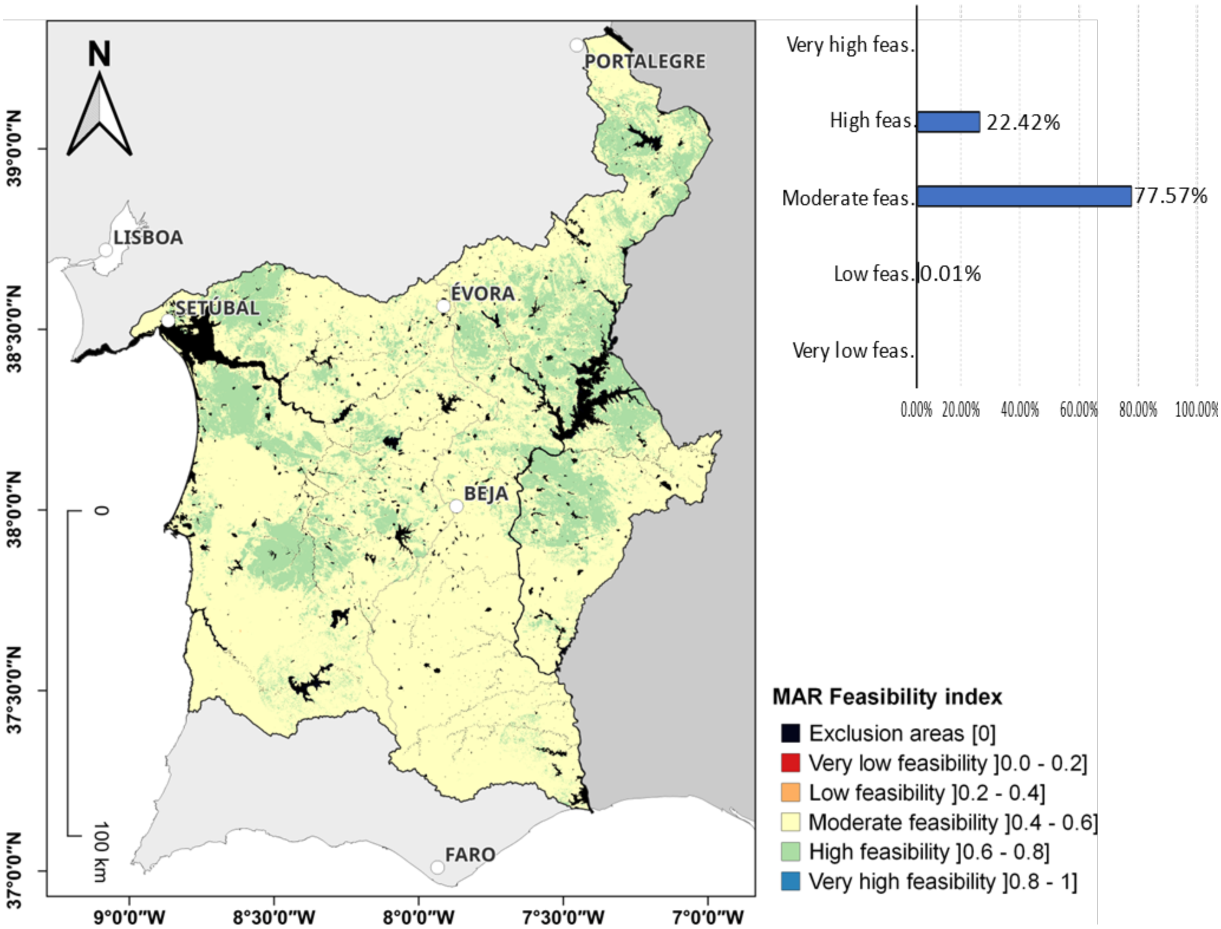

Figure 3. MAR feasibility map for Alentejo region

Acknowledgments

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Technical Brief
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Akrotiri MAR site is one of the two SAT-MAR sites in Cyprus, located in the southern part of the island (Figure 1). It consists of seventeen infiltration ponds, which are recharged based on tertiary-treated wastewater from the urban Wastewater Treatment Plant (WWTP) during the winter period (1-4 Mm^3 in annual basis). **The recharge objective is primarily to mitigate the intrusion of seawater into the coastal aquifer while storing water amounts for later use, mainly for irrigation purposes.**

Main questions addressed by the AGREEMAR project in the Akrotiri MAR system

- Which regions in Cyprus are suitable for replicating MAR systems?
- What is the effect of SAT-MAR at the drinking wells, located upstream of Akrotiri site?

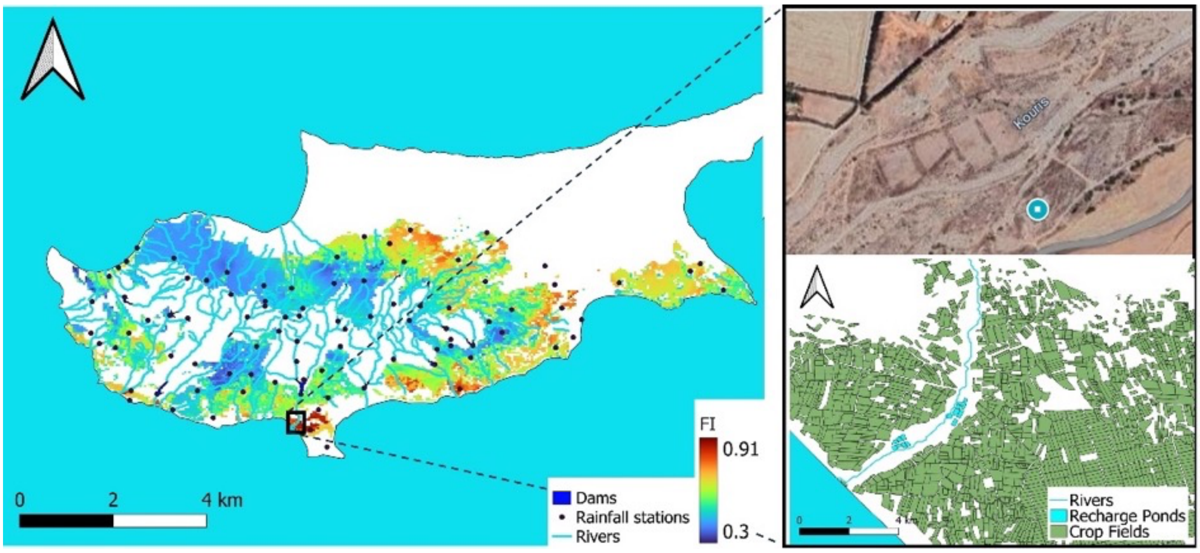

Figure 1. *Cypriot demo region (non-occupied part of the island) and Akrotiri MAR site. Shaded regions (left figure) denote MAR feasibility levels*

Which regions in Cyprus are suitable for replicating MAR systems?

The regions identified as more favourable, within the non-occupied area of Cyprus, for the installation of SAT-MAR systems have considered three thematic layers, namely intrinsic properties (topography, hydrogeology), water demand and availability of water resources for MAR.

Multiple criteria-factors have been selected via the active engagement of relevant stakeholders, primarily Water Development Department and Department of Geological Survey, and used to compile spatial maps for each thematic layer via multi-criteria decision analysis (MCDA).

The results reveal that **most of the favourable regions for MAR are distributed close to the southern-eastern and southern coastline**, supplemented by large-scale areas in the central part of the island, close to Nicosia urban area. The central part of Cyprus is dominated by low suitability levels, attributed to several factors, such as the sparse presence of agriculture land and the presence of intense and frequent precipitation events, steep terrain slopes, low proximity to relevant infrastructures, limited availability of treated wastewater, etc. In addition, the results validated the choice of Akrotiri site as a favourable region for MAR.

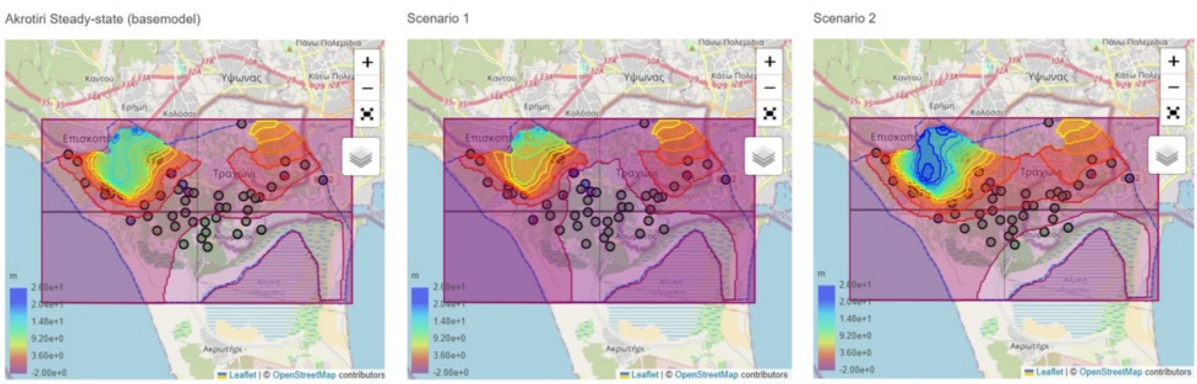

Figure 2. *Spatial distribution of head levels for the three scenarios (base, Scenarios 1 & 2). Screenshots are taken by INOWAS platform (www.inowas.com)*

What is the effect of SAT-MAR at the drinking water wells, located upstream of Akrotiri MAR site?

Akrotiri aquifer is partitioned into two zones based on the usage of the abstracted groundwater from extraction wells, particularly: a) irrigation/domestic and b) drinking purposes. Most of the area is covered by irrigation wells, whereas drinking water wells are present upstream of the MAR infiltration ponds. **The key question posed is how likely it is that the groundwater affected by the infiltration ponds – linked to treated wastewater - will reach these upstream areas?**

For that reason, a numerical steady-state model has been developed and calibrated for January 2019 (Base Scenario, BS), that considers both the hydrological complexity of the study area and the plethora of recharges/extractions from the local aquifer due to different processes (see Deliverable 4.1).

In close consultation with the national water authorities, two additional steady-state simulations were conducted for the following hypothetical scenarios: a) 50 % reduction in recharge amounts in the infiltration basins (Scenario 1, S1) and b) 50 % increase in recharge amounts in the infiltration basins (Scenario 2, S2). Figure 2 shows the spatial distribution of the groundwater heads for all scenarios. According to the BS, the highest head levels are observed around the infiltration bons and the Kouris delta, whereas the maximum values is 24 meters above sea level (m.a.s.l.). The head levels are decreasing towards the coast and the Salt Lake, dropping to -2 m.a.s.l. Those areas are especially prone to saltwater intrusion and abstraction needs to be managed carefully. S1 comprises the reduction of recharge rates in the infiltration basins by 50 % due to less water availability. As a result, the groundwater mound around the infiltration basins in the Kouris delta is increasing by 7.6 m, causing a decrease in head levels around the drinking wells. The results show the evolution of a depression cone which reaches -4.3 m compared to 0.2 m in the BS. Hence, a higher risk of seawater intrusion occurs for this scenario. For S2, the groundwater mound around the infiltration basins in the Kouris delta is further increasing by 7.4 m. Also, the depression cones in some drinking water wells are rising to 4.6 m above sea level compared to 0.2 m in the BS, indicating that the drinking wells are protected from seawater intrusion and treated wastewater when the extraction rates are kept constant.

Regarding the water budgets (Figure 3), keeping the extraction rates constant, the outflow through the constant head boundaries towards the sea fluctuates because of the direction of the head gradients in the study area. The leakage to the sea is reduced by 27 % for S1, compared to the BS (50 % decrease of infiltration rates), whereas the leakage to the sea is increasing by 27% for S2 (50% increase of infiltration rates) compared to the BS.

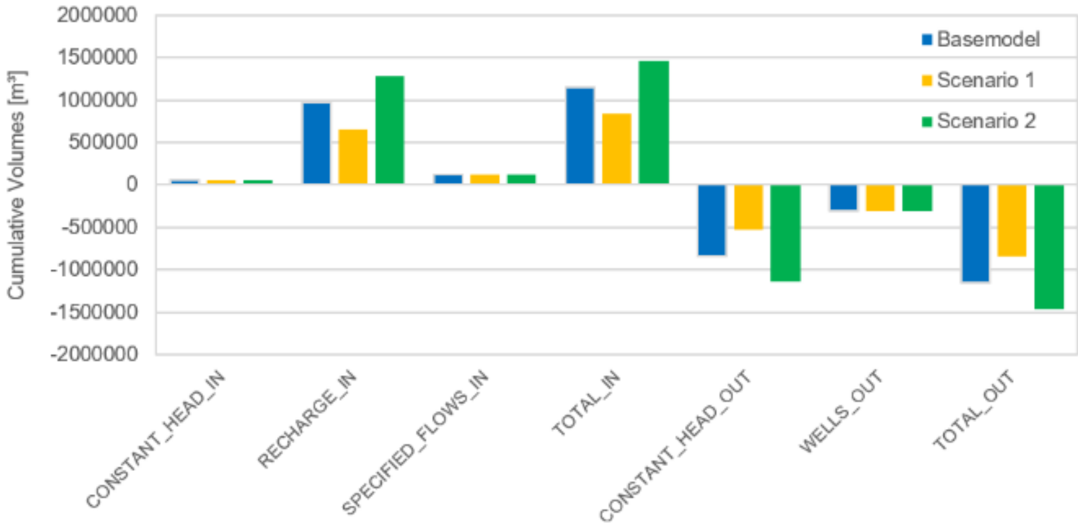

Figure 3. Groundwater budget for the three steady-state solutions of the model

The other water budget components such as the inflow through the constant head or specified flow boundaries are not influenced by the change of infiltration rates.

The **evidence of benefits from SAT-MAR systems** are to:

- Contribute to the water allocation management in a local, regional (watershed), even national level (e.g., affect the allocation of water from Kouris dam).
- Increase the effective portion of the aquifer from which groundwater can be extracted for either irrigation or drinking purposes (e.g., considering the control of the seawater front).
- Filter the treated wastewater during the soil-aquifer passage to reduce the concentrations of pathogenic micro-organisms (among others).
- Improve the quality status of the aquifer systems in terms of microbiological, physical and chemical elements.
- Satisfy the water demand, especially for irrigation purposes, and contribute to the mitigation of conflicts among multiple actors.
- Be easily maintained.

Further research needs

Though SAT-MAR diminishes the loads of contaminants present in source water, there is still a need for future research / investment in some of the following aspects:

- The occurrence of physical, chemical, or biological clogging, mainly due to suspended solids in the water, biofilm growth, or mineral precipitation.
- The mobilization of water and/or soil contaminants during recharge into the aquifer.
- The production of undesirable transformation products into the aquifer.
- The seasonal dynamics of temperature and redox conditions temporally establishing separate zones where certain compounds can modify their reactivity, their capacity to produce metabolites, and/or their redox behaviour (e.g., a shift to more anaerobic conditions retards some pharmaceuticals degradation).
- The need for regulatory framework concerning water for MAR, namely water quality standards.

An interdisciplinary and transdisciplinary methodology to interconnect different perceptions of MAR innovations, technology, and sustainability is undergoing.

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The goal of the AGREEMAR project in Spain is to promote the use of **MAR** (Managed Aquifer Recharge) as a tool/technique to **restore groundwater levels**, mitigate local aquifer overdraft, **reduce the vulnerability of water demands** and mitigate seawater intrusion in the **Mijares** and **Palancia** river basins.

The Mijares and Palancia river basins are located within the Júcar River Basin District (JRBD) in eastern Spain (Figure 1). These basins face significant challenges, including groundwater overexploitation, seawater intrusion, and water scarcity due to agricultural demand, urban supply, and climate change impacts.

Mijares River Basin: Covers 4,818 km², originating in the Sierra de Gúdar and flowing into the Mediterranean Sea. Key features in the water resources system include the Belcaire Pond and aquifers such as Plana de Castellón and Azuébar-Vall d'Uixó.

Palancia River Basin: Covers 1,086 km², rising in the Sierra del Toro and flowing into the municipality of Sagunto. In the medium and lower part of the basin, we can find the Algar reservoir and aquifers like Medio Palancia and Plana de Sagunto.

Main questions addressed by the AGREEMAR project in the Mijares and Palancia river basins

- What is the effect of MAR on the quantitative changes in aquifer storage over time?
- How does MAR influence other water uses within the river basin?
- What are the most effective management strategies to optimize the implementation of MAR at the river basin scale?
- What are the key benefits of implementing MAR?

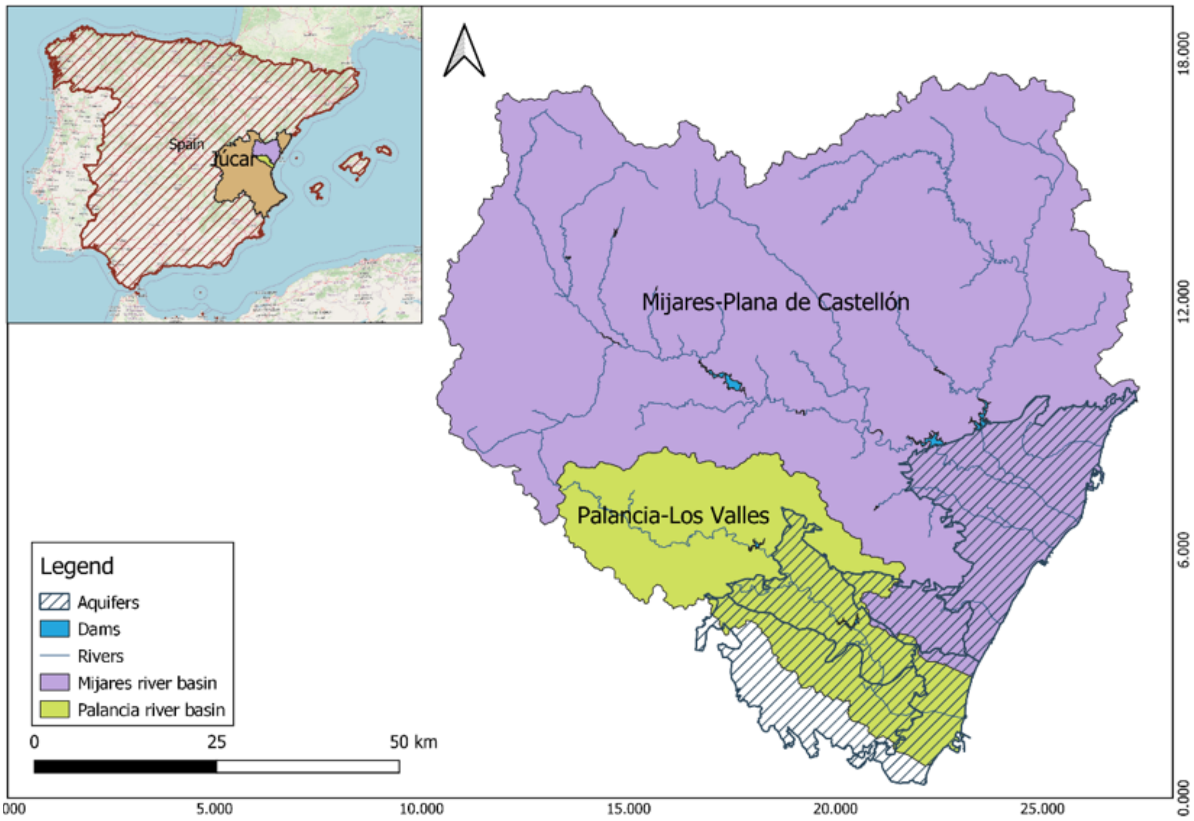

Figure 1. Mijares and Palancia case-studies sites and existing aquifer systems

What is the effect of MAR on the quantitative changes in aquifer storage over time?

The effects of MAR in the Mijares and Palancia river basins were analysed using the aquifer models included in the AQUATOOL DSS. The models aim to study the effect of water distribution on aquifer evolution.

In the Mijares river basin, the **MAR scenarios analysed demonstrate improvements in aquifer storage**. For instance, the Azuébar-Vall de Uixó aquifer, which is the aquifer recharged by the Belcaire pond, shows a **reduction in averaged annual pumping volumes up to 3.47 hm³**. The reduction in pumping has resulted in an average monthly increase in the net recharge (recharge minus pumping). More details can be consulted in AGREEMAR deliverable D4.1.

In the Palancia river basin, scenarios studying the effect of MAR using water from WWTP and desalination plants show positive impacts in aquifer volumes. Over the simulation period, improvements in net recharge were obtained. For example, the annual aquifer storage increased by up to **0.29 hm³ in the medio Palancia aquifer** and up to **0.28 hm³ in the Plana de Sagunto aquifer**. More details can be consulted in D4.1.

How does MAR influence other water uses within the river basin?

In the Mijares river basin, the use of treated wastewater within a conjunctive water management approach of other water sources enhances the water demand security, namely those in Vall d'Uixó and Moncófar Agricultural Demand units (ADUs). This strategy improves water security during droughts. The integration of water from Moncófar desalination plant further reduces groundwater extraction for irrigation, helping to stabilize aquifer levels and ensuring sustainable water supplies.

In the Palancia river basin, conjunctive use of water resources for MAR significantly reduces groundwater extraction for agricultural irrigation, helping in aquifer preservation and increasing water availability for urban and industrial purposes, especially in the Sagunto area. Moreover, the incorporation of treated wastewater from the Segorbe WWTP helps mitigate water deficits for key agricultural units, such as Segorbe ADU.

What are the most effective management strategies to optimize the implementation of MAR at the river basin scale?

On a regional scale, MAR strategies should not only contribute to define the increase in the groundwater level in the aquifer, but also to identify new management strategies, e.g., which extra volumes of water are available for irrigation, drinking water supply, and environmental sustainability.

In the Mijares and Palancia river basins, the most effective strategies combine MAR with conjunctive use of conventional and non-conventional water sources, such as treated wastewater and desalinated water, so that resource efficiency is maximized, and aquifer stress is minimized.

Simulations of various water management strategies in these case studies highlight the effectiveness of implementing measures like WWTPs, desalination plants, and MAR infrastructures (e.g. the Belcaire pond and infiltration wells, Algar infiltration reservoir). These strategies together with MAR, significantly enhance water demand reliability, reduce aquifer pumping and increase aquifer recharge, thereby improving aquifer sustainability and improving the quantitative and qualitative state of the aquifers.

To optimize MAR in the Mijares and Palancia basins, the following key strategies were identified:

- Prioritize areas with high recharge potential, such as Belcaire Pond and Algar Reservoir regions, based on GIS-based multi-criteria decision analyses.
- Employ conjunctive water use strategies, integrating surface, groundwater, and non-conventional water resources like treated wastewater and desalination.
- Implement regional measures such as WWTP upgrades, desalination plants, and reservoir regulation to minimize aquifer stress and improve water demand reliability.

What are the key benefits of implementing MAR?

In the Mijares and Palancia river basins, direct and induced MAR strategies mitigate aquifer overdrafts, effectively preventing seawater intrusion, which is crucial for coastal aquifers such as Plana de Castellón and Plana de Sagunto. It also provides reliable water supplies during drought periods, ensuring that agricultural and urban water needs are met. Natural and MAR related recharge and filtration processes during wet periods improve water quality, reducing treatment costs for stakeholders, helping to cope with climate changes extreme events, storing water in times of surplus and using it in drought periods. Additionally, the reduced need for deep aquifer pumping leads to lower energy consumption and operational expenses. MAR also supports ecosystems by promoting aquifer sustainability (e.g. Quart spring).

The areas more feasible for MAR were mapped for Mijares and Palancia river basins using a methodology that has integrated a GIS-based multi-criteria decision analysis for selecting sites with good characteristics for MAR considering:

- Conventional and unconventional water availability for MAR.
- Water demand.
- Physical criteria (permeability, soil type, etc.).
- Non-physical criteria (social, cultural, economic).

Figure 2 presents the results obtained for the MAR feasibility maps and confirms the feasibility of MAR in the Belcaire pond and the Algar reservoir areas.

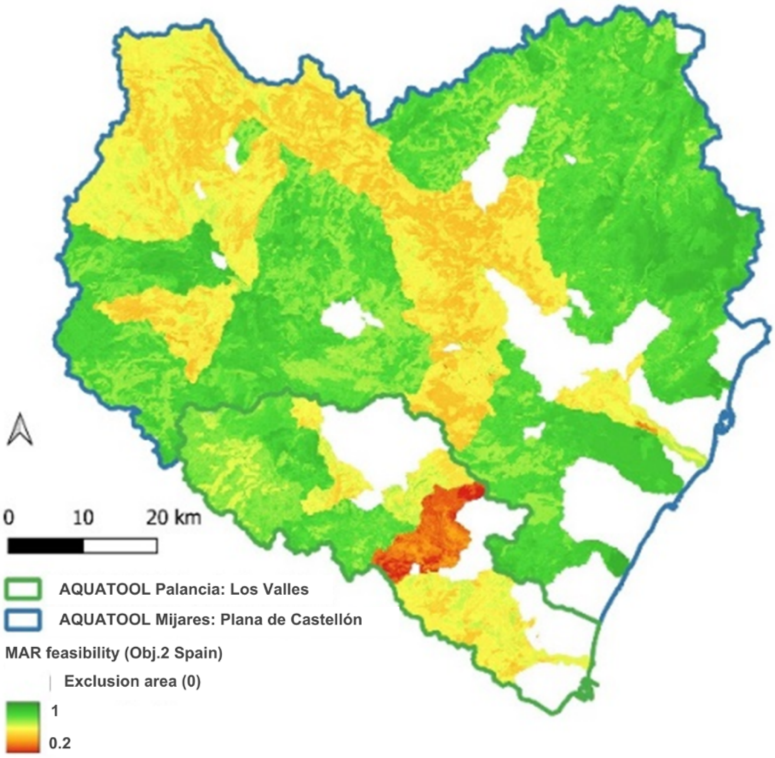

Figure 2. MAR feasibility map for Mijares and Palancia river basins

Further research needs

While MAR has demonstrated substantial benefits, there remain challenges requiring further investigation:

- Socioeconomic factors influencing stakeholder acceptance and the cost-effectiveness of MAR projects.
- Assessment of the effects of climate change on the feasibility and reliability of MAR.
- Enhancement of the modelling of MAR systems to include more detailed simulations of water flow, quality, and storage.
- Exploring the water quality aspects of MAR, focusing on contaminants, pathogens, and long-term water quality management.

Acknowledgments

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Technical Brief
Case Study in Tunisia

AGREEMAR overall goal

To optimise the hydrological balance in Mediterranean countries by developing governance models, management strategies, costs-benefits analyses, technical specifications and simulation tools to **optimise the water storage in aquifers**, enabling increased **resilience to climate change**.

AGREEMAR case study in Tunisia

The goal of the AGREEMAR project in Tunisia is to promote the use of SAT-MAR (Soil-Aquifer Treatment in Managed Aquifer Recharge) **as an innovative approach** to enhance groundwater availability in the Chiba watershed, to address the **imbalance between water demand and supply, support water-related environmental services, and prevent seawater intrusion,** thereby mitigating the impacts of global change. Korba Wastewater Treatment Plant (WWTP) is the recharge water source of the Tunisian case study.

Secondary treated effluent from Korba WWTP is being discharged into a SAT-MAR system composed of three infiltration basins. They target to improve the water quality during the infiltration of secondary treated wastewater, mainly through filtration, biodegradation and adsorption processes, avoiding direct recharge into a sensitive area.

The SAT-MAR site is in Korba region (Figure 1), in the Cap-Bon peninsula at the north-eastern part of Tunisia.

Main questions addressed by the AGREEMAR project in Korba SAT-MAR system:

- What is the local impact of the SAT-MAR system on groundwater restoration at the Korba and Diar Hojjej sites?
- How does treated wastewater infiltration influence the long-term sustainability of groundwater levels in the area? What are the potential effects of MAR system on preventing seawater intrusion in the local aquifers?
- How can optimizing SAT-MAR operations contribute to improving groundwater availability and restoring water balance in the Korba region?

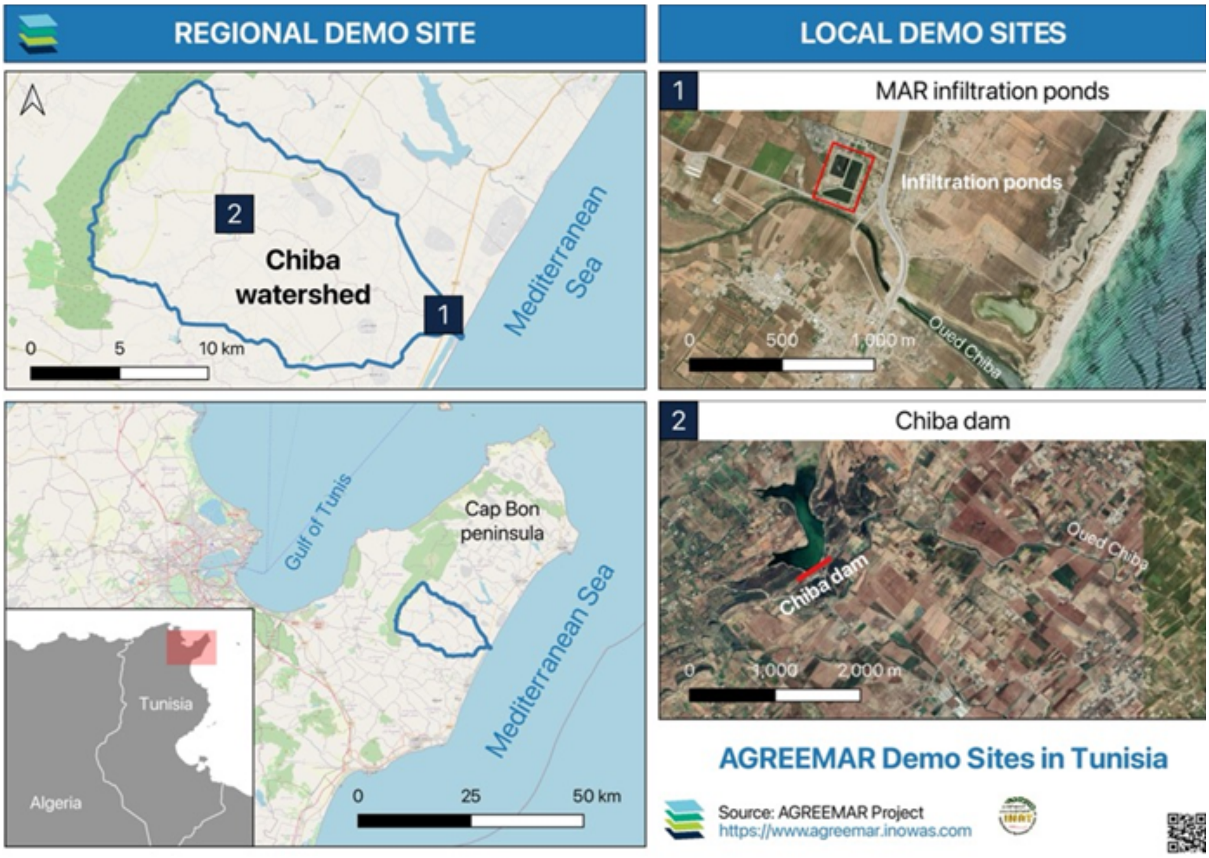

Figure 1. Location of the Tunisian case study site

What is the local impact of the SAT-MAR system on groundwater restoration at the Korba and Diar Hojjej sites?

The groundwater numerical modelling results from the Chiba watershed indicate that the current Managed Aquifer Recharge (MAR) volume at the Korba site is insufficient to fully recover the groundwater levels. The simulation shows that doubling the volume of treated wastewater (TWW) infiltration could increase the groundwater head locally by 5.8 meters, improving water table conditions within a 500-meter radius. At the Diar Hojjej site, replicating the MAR system could raise the water table by 3.9 meters, though more substantial interventions, such as tripling the infiltration, would be necessary to address the severe drawdown in this area.

How does treated wastewater infiltration influence the long-term sustainability of groundwater levels in these areas?

Treated wastewater infiltration plays a crucial role in the long-term sustainability of groundwater levels, as demonstrated by the simulation scenarios. The base scenario shows that the current TWW volumes are insufficient to significantly recover groundwater levels, particularly in regions like Diar Hojjej, where groundwater drawdown exceeds 20 meters over the last 20 years, since approximately 2000. By increasing the volume of TWW infiltration, the model predicts notable improvements in groundwater levels. This suggests that optimizing the SAT-MAR operations, with larger volumes of TWW, is the key to ensuring long-term sustainability, mitigating overextraction impacts, and managing seasonal groundwater fluctuations.

The **evidence of benefits from Korba SAT-MAR systems** are to:

- Gain improvement in microbial, physical and chemical water quality, ensuring compliance with irrigation and environment standards.
- Bring a more consistent water quality for agriculture and other aquifer dependent services.
- Reduce the need/cost for disinfection, leading to lower treatment costs and minimized chemical use.
- Be easily maintained, ensuring long-term sustainability and reliability of the system.

What are the potential effects of MAR system on preventing seawater intrusion in the local aquifers?

The MAR system at the Korba site shows potential to mitigate the risk of seawater intrusion by raising groundwater levels above sea level. Under a scenario considering doubling the current TWW infiltration rate in Korba SAT-MAR site, from 1500 m^3/d to 3000 m^3/d, and tripling it in a replicated site in Diar Hojjej, it can create a local increase of 5.8 meters in current groundwater levels withing influence radius reaching 500 m, therefore reducing the likelihood of seawater intrusion from the coastal area.

How can optimizing SAT-MAR operations contribute to improving groundwater management and restoring water balance in the Korba region by enhancing recharge rates?

Optimizing SAT-MAR operations, particularly by increasing TWW infiltration volumes, can significantly improve groundwater management in the Korba and Diar Hojjej regions. The modelling scenarios suggest that doubling or tripling the infiltration rates not only helps restore groundwater levels but also diminishes the impacts of overextraction (e.g., below sea level) from existing wells. In the Diar Hojjej region, where over-extraction has caused severe groundwater depletion, increasing the MAR system's capacity could elevate the water table, leading to improved productivity and reducing the pressure on groundwater resources in the long term, as well as pumping costs due to shallower piezometric levels.

Further research needs

While SAT-MAR systems help reduce contaminant loads in source water, further research and investment are needed, particularly in the context of the Chiba watershed. Further research needs can cover the following aspects:

- Performance of the SAT-MAR in pollution removal and possibilities of its amelioration throughout including purification enhancers like biochar.
- Modelling the unsaturated transfer of water and solutes to simulate the behaviour of the SAT-MAR system under the current situation and possible optimization measures.
- Develop water quality standards and regulations tailored for MAR in Tunisia.
- Enhance the use of sensors and IoT in monitoring the SAT-MAR operations and aquifer recharge.
- Include the economic aspect while optimizing the technical performance of the SAT-MAR.
- Efficient methods to rise the stakeholder’s awareness about the treated wastewater for aquifer recharge and to reduce/eliminate the resistance from stakeholders and local communities due to environmental and health concerns.

Acknowledgments

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