Innovative and Sustainable Groundwater Management in the Mediterranean

D 2.1. Report on the Integrated and Innovative High-Resolution Monitoring Strategies in the Case Studies

VERSION 1.1

Acknowledgment: This project is part of the PRIMA Programme supported by the European Union's Horizon 2020 Research and Innovation Programme under Grant Agreement No 1923.

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DOI: 10.5281/zenodo.5464303.

Project Information

Project Title	Innovative and sustainable groundwater management in the Mediterranean		
Project Acronym	InTheMED	Grant Agreement Number	1923
Program	Horizon 2020		
Type of Action	Water RIA – Research and innovation Action		
Start Data	March 1, 2020	Duration	36 months
Project Coordinator	Universitat Politècnica de València (UPV), Spain		
Consortium	Universitat Politècnica de València (UPV), Spain Helmholtz-Zentrum für Umweltforschung (UFZ), Germany Università degli Studi di Parma (UNIPR), Italy Boğaziçi Üniversitesi (BU), Turkey Centre de Recherches et des Technologies des Eaux (CERTE), Tunisie Technical University of Crete (TUC), Greece Associação do Instituto Superior Técnico para a Investigação e Desenvolvimento (IST-ID), Portugal		

Document Information

Deliverable Number	D2.1	Deliverable Name			Report on the integrated and innovative high-resolution monitoring strategies in the case studies
Work Package number	WP2	Work Package Title			Innovative Monitoring and Data Analyses in the MED
Due Date	Contractual	February 28, 2021	Actual		August 31, 2021
Version Number	1.1				
Deliverable Type	Other	Dissemination Level			Public (PU)
Authors	Seifeddine Jomaa, Rafael Chavez and Leonardo Azevedo				
Reviewer(s)	Janire Uribe-Asarta and J. Jaime Gómez-Hernández				

Document History

Version	Date	Stage	Reviewed by
1.0	31.08.2021	Final	Janire Uribe-Asarta and J. Jaime Gómez-Hernández
1.1	06.09.2021	Updated	Seifeddine Jomaa, Janire Uribe-Asarta and Leonardo Azevedo

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Executive Summary

The overall objective of the InTheMED project is to implement innovative and sustainable management tools and remediation strategies for MED aquifers (inland and coastal) in order to mitigate anthropogenic and climate-change threats by creating new long-lasting spaces of social learning among different interdependent stakeholders, NGOs, and scientific researchers in five field case studies. These are located at the two shores of the MED basin, namely in Spain, Greece, Portugal, Tunisia, and Turkey.

InTheMED will develop an inclusive process that will establish an ensemble of innovative assessment and management tools and methodologies including a high-resolution monitoring approach, smart modelling, a socio-economic assessment, web-based decision support systems (DSS) and new configurations for governance to validate efficient and sustainable integrated groundwater management in the MED considering both the quantitative and qualitative aspects.

This deliverable synthesises the progress of Task 2.1 entitled "**Implementation of an innovative high-resolution monitoring**" (**Lead IST-ID**/ participants: UPV, UFZ, TUC, UNIPR, CERTE and BU), (Month 1–Month 12) during the first year of InTheMED project duration. InTheMED project considers implementing advanced technology to monitor groundwater level and quality as an ultimate priority since the beginning of the project. The different case studies have benefited from these emerging monitoring technologies, even though the covid-19 has considerably delayed the monitoring design, purchase, and installation of the new devices in the five case studies. The design and implementation of high-resolution monitoring strategies were conducted closely with Task 4.1 "**Systems characterisation, stakeholder mapping and governance analysis**". A first impression of the specific groundwater problems in the five case studies was developed among the local coordinator of each case study and key stakeholder groups. Then, the alignment between the main problems of each groundwater system, stakeholder objectives and existing monitoring network was conducted. Finally, different innovative monitoring strategies and their implementation requirements using the high-resolution monitoring approach were listed and discussed. It is worth mentioning that the implementation of the high-resolution monitoring approach was affected for all case studies

by the covid-19 pandemic lockdown and the consequent restrictions regarding travelling and remote work.

During this period, it was planned the development and implementation of innovative methods for aquifer modelling and characterization using geostatistical geophysical inversion methods. These methods were planned to be deployed at the Portuguese case study in the first 12 months, but due to the abovementioned restrictions, there were considerable delays related to data transmittal and visits to the site. Nevertheless, preliminary work shows the potential of these methodologies and advances the current knowledge about the groundwater system.

1. Introduction and Objectives

An effective evaluation of groundwater and surface water quality depends on the number of assessed parameters and their sampling frequencies and spatial coverage. Low-resolution and irregular (limited in time) grab sampling cannot capture fine dynamics of water quantity and quality status, resulting in large uncertainties in groundwater budget and its functioning. The recent development of high-frequency optical sensors (Rode et al., 2016) has enabled monitoring solute concentrations at sub-hourly time scales, relevant for process understanding and guiding efficient management practices. Here, an innovative monitoring scheme will be used to control groundwater quantity and quality for each case study. This new monitoring strategy was designed combining grab-sampling (biweekly) and High-Resolution Monitoring Approach (HRMA, very tight measures: sampling interval lower than one hour). To complement the information provided by the traditionally and spatially sparse grab sampling measurements, an innovative monitoring and characterisation approach using the HRMA and geophysical methods was considered. Geophysical data serve to deduce the spatial distribution of the aquifer properties, and corresponding uncertainty, for locations far from the available direct measurements, both for the solid and fluid phases, through geostatistical geophysical inversion procedure (Azevedo and Soares, 2017). The result will be a better understanding of groundwater system dynamics that will contribute critical information for the smart models of WP3. The geophysical inversion method will be first implemented in the Portuguese case study, where conventional sampling and resistivity data exists, and later extended to other sites. The hotspots in each case study, which was (for some case studies) and will (for other case studies) be defined with close interaction with stakeholders and simultaneously with Task 5.1 in WP5, will be prioritised considering stakeholders inputs. Hotspot locations are defined as gauging stations (wells or surface water bodies) with the highest groundwater depletion records and largest concentration of some water quality parameters (such as salinity and nitrate concentration). The real-time data will be synchronised with the decision-supporting system (DSS) tool (WP6) and used for the early-warning system. HRMA will be made available almost in real-time to the community through the InTheMED portal and other public domain databases (Task 2.4).

2.1. Objectives

Either grab-sampling or HRMA or combined methods will be implemented at the real sites to assess specific parameters of interest in terms of spatial and temporal dynamics. This information will be complemented by numerical models of aquifer properties predicted by geophysical data. The hotspots in each case study will be prioritised in this task depending on the specificity of each site and the suggestion of stakeholders. The specific objectives of Task 2.1 are:

1. To present the beneficial aspects and consideration of using HRMA,
2. To give some hints on budget calculation and distribution,
3. To list potential companies and sensors that can be considered on the implementation of HRMA in the case studies,
4. To list the potential benefits of coupling innovative sampling (HRMA) with geophysical data for aquifer modelling and characterization.

2. Beneficial Aspects and Consideration of Using HRMA

There are numerous beneficial aspects of using HRMA. However, several considerations should be followed before the monitoring design to ensure sustainability. Both aspects and considerations of using HRMA are detailed below.

2.1. Beneficial Aspects of Using HRMA

Testing the set of specific high-resolution optical sensors (Dupas et al. 2016, Rode et al. 2016) at laboratory and field scales during the project will provide recommendations for the combination of proximal and remote monitoring devices for effective water resource management. Recently, it has been proven the HRMA to be a sound technique to monitor water quantity and quality parameters, on-time and remotely, especially under rapidly changing environmental conditions such as the Mediterranean region. So far, the Mediterranean region is known as a relative data scare region due to the lack of systematic monitoring and data sharing policy. Also, rare high-resolution monitoring networks have been established in the Mediterranean basin, serving as a reference and long-term Terrestrial Observatory Network. The InTheMED team, together with partners from other PRIMA funded projects, will provide a significant step forward in that direction, where a continuous and HRMA will be developed in some typical case studies covering complementary groundwater problems in the Mediterranean region (Table 1 and Figure 1), known with serious water-related problems being already affected by climate change.

Table 1. Summary of the five case studies and their key groundwater problems considered in InTheMED project. P and T refer to Precipitation and Temperature, respectively.

Characteristics	Requena-Utiel, Spain	Tympaki, Greece	Castro Verde, Portugal	Grombalia, Tunisia	Konya, Turkey
Size (km^2)	1360	55	30	363	62000
Population	30,000	25,000	7,276	201,836	~3,000,000
Location	Inland	Coastal	Inland	Coastal	Inland
Mean P & T (mm y^{-1}/ °C)	440/13	500/15	567/16	356/20	387/12
Principal groundwater users	Agriculture, urban	Agriculture	Urban, mining	Agriculture, industry, tourism	Agriculture, urban
Overexploited	Yes	Yes	No	Yes	Yes
Groundwater pollution	No	Nitrate, salinity	Mine wastes	Nitrate, salinity	Nitrate, salinity

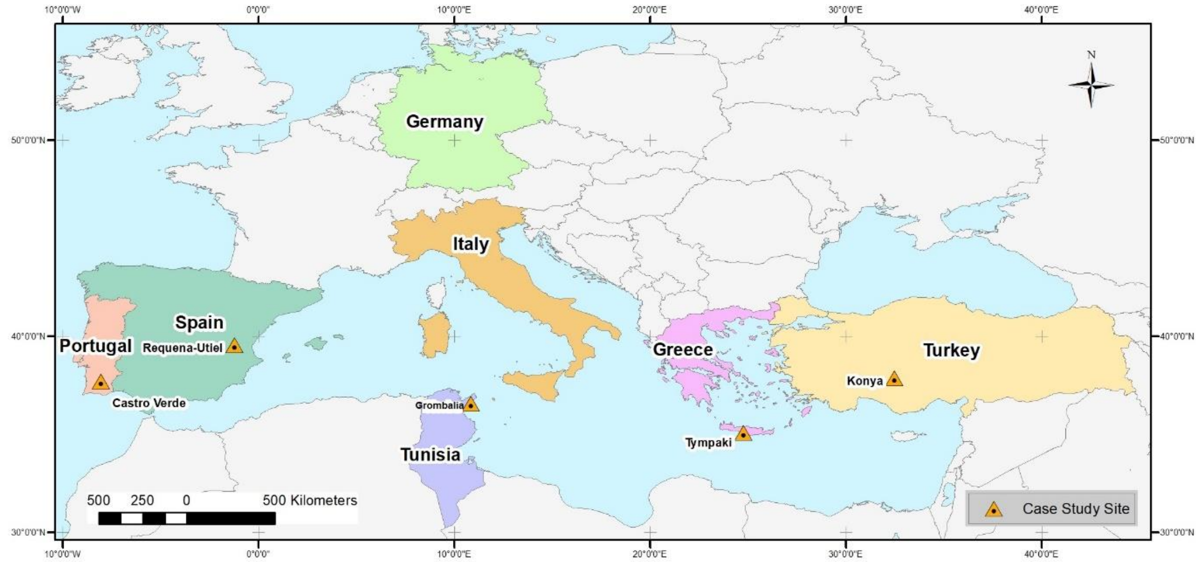

Figure 1. Geographical Location of the five case study areas of InTheMED project. The five case studies represent typical inland and coastal groundwater problems in the Mediterranean region, as listed in Table 1.

Representative aquifers were considered in InTheMED project: the Portuguese Castro Verde aquifer is under pressure by nearby mining activities, the Spanish Requena-Utiel aquifer has shown consistent water declines over the last ten years after the beginning of vineyard irrigation, a crop that has been dry farmed in the past; the Tunisian Grombalia aquifer suffers from salinization due to saltwater intrusion plus continuous groundwater depletion owed to agricultural, industrial and tourism activities; the Greek Tympaki aquifer on the island of Crete presents saltwater intrusion up to 2 km inland; and the Turkish Konya aquifer, a large aquifer underlying a closed basin in central Anatolia is suffering from high levels of salinity and nitrate contents and severe water decline due to intensive water use for irrigation (InTheMED project).

2.2. Consideration for Selecting Groundwater Monitoring Sensors

The main consideration prior to any implementation of HRMA is to clarify our monitoring targets, which mainly depend on the site characterisation, former knowledge, and emerging concerns. To better reshape this consideration, it is essential to answer the following three questions:

- **What do we measure?** The answer to this question depends on the system feature, concerns and available technology.

- **Where do we measure?** The answer to this question depends on the source and its spatial distribution, geology, secure site selection, ease of access, available power supply, and good connection with the site owner.

- **How often do we measure?** The answer to this question depends on the time response of the groundwater system (commonly, 1-hour is recommended for groundwater monitoring). Note that the more often we measure, the more efforts (installation, maintenance and data correction and quality) and costs should be dedicated.

2.3. Budget Calculation and Distribution

A successful and sustainable design of HRMA approach depends significantly on the budget calculation and distribution. Therefore, before any investment in new devices and methods, the budget should be well calculated and carefully distributed among the different components of the monitoring design. The different items that the original budget should consider are:

- Installation cost (which often require a private company to drill the well, resulting in additional costs such as recommendation and logistics etc.),

- A connection cable is costly (on average, 1-m of cable costs 10 euro) and should be considered from the beginning of the calculation. In some cases, it is possible the price of the cable can be close to the sensor price,

- Telemetry system (needed or not: often needed for deep well and not recommended for a sallow well),

- The number of parameters required for the monitoring (one port, 4-6 replaceable mobile ports).

- Required pressure range for the sensor. Always it is fixed and not replaceable. Each sensor has its unique pressure range. For instance, In-Situ Aqua Troll 200 is operating at 6-351 m range. While the In-Situ Aqua Troll 400 is operating in the range 1-76 m.

- Below is the list of companies and their list of parameters that were discussed with the project partners as potential sensors can be considered in the design of the monitoring strategies and implementation of HRMA in each case study (Table 2). Also, a short discussion on the advantage and price category of each option were briefly listed in Table 2.

Table 2. List of companies, parameters and characteristics of each category of sensors.

Company	Parameters	Advantage	Price category
YSI-EXO https://www.ysi.com/exo2 	Multi-parameter probes with seven sensors including: Water Depth, Temperature, Electrical Conductivity, Dissolved oxygen, pH, Total algae (blue-green algae and chlorophyll in one sensor), Turbidity	Very complete sets of parameters allowing a very detailed understanding of the system. Also, it permits developing good proxies, where high-resolution data can be used as indicators (proxies) to reconstruct continuous records of parameters, which are traditionally grab-sampled such as Phosphorus concentration	Expensive
In-Situ-AquaTroll http://www.in-situ-europe.com/ 	pH, water level, Dissolved Oxygen, Temperature and Electrical Conductivity	Has key set of parameters combination needed for good assessment of groundwater quality and quantity. Also, it is available with a different set of parameters and communication and data-transfer options such as: AquaTroll 200, 400, 500, 600 and 9500.	Moderate
Onset-Hobo https://www.onsetcomp.com/products/water  Vanessen-diver	2 Separate options: for groundwater Quantity (Water depth) or Quality (Electrical Conductivity and water temperature)	Usually, only one option is implemented depending on the specific problem of the groundwater system (either quantity or quality).	Relatively cheap

https://www.vanessen.com/products/water-level 			

2.4. Geophysical Data for Aquifer Modelling and Characterization

One of the fundamental aspects of numerical fluid flow models of aquifers is the characterization of the spatial distribution of relevant properties such as porosity and hydraulic conductivity. These properties depend on the geological characteristics (e.g., sedimentary facies) of the aquifer. The prediction of these properties by interpolating data measured at borehole locations is not suitable to describe complex geological settings as this approach result in smooth models unable to capture the true variability of the system. Geostatistical geophysical inversion methods allow to overcome this limitation (i.e., these methods predict subsurface models with high variability) and to assess the spatial uncertainty of the prediction, which is critical to identify areas associated with larger risks.

We start by implementing these methods in Castro Verde site (Portugal). For this case study we have available a comprehensive data set composed of two-dimensional resistivity profiles (i.e., geophysical data) and borehole data (***Figure 2***). As an illustrative example of the models predicted by the methods developed, we show an inverted resistivity profile in ***Figure 3***. Resistivity is a subsurface property, which depends on the solid and liquid phases of the system. These models might be used to predict the spatial distribution of other geological variables of interest. The information provided by the inverted models will be relevant and integrated into the DSS.

The inverted profiles can be interpreted as a snapshot of the aquifer conditions at a given moment in time. Coupling the temporal information retrieved by the HRMA system with the inverted properties might allow the building of spatiotemporal models of the aquifer properties. This approach will be further explored under the scope of the project.

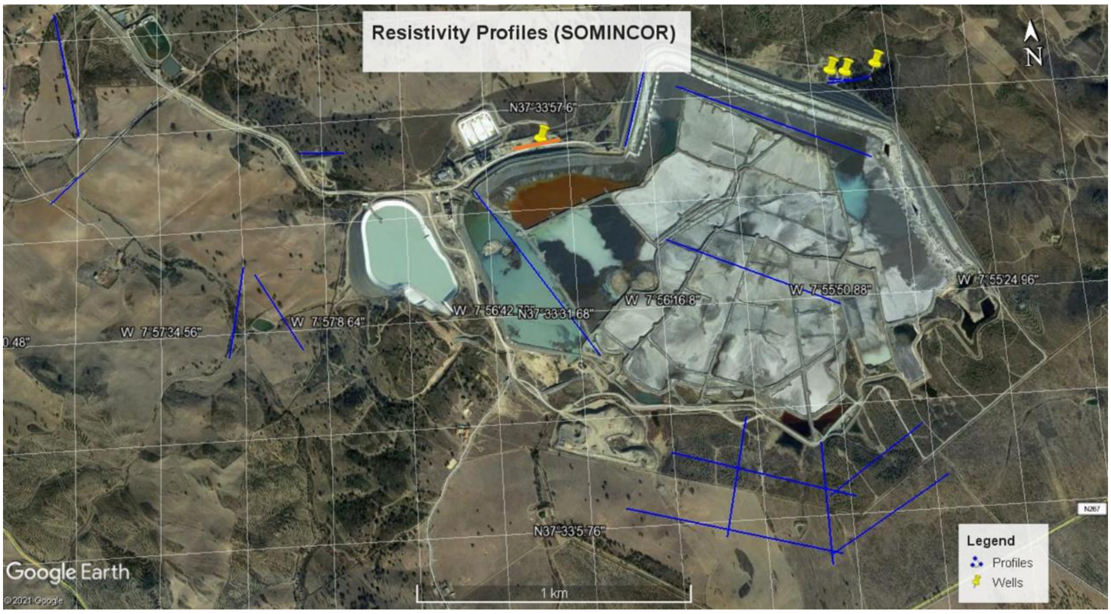

Figure 2. Location of the resistivity profiles (blue lines) and borehole data (yellow pins) within the Portuguese study area. The orange line represents the location of the inverted profile shown in Figure 3.

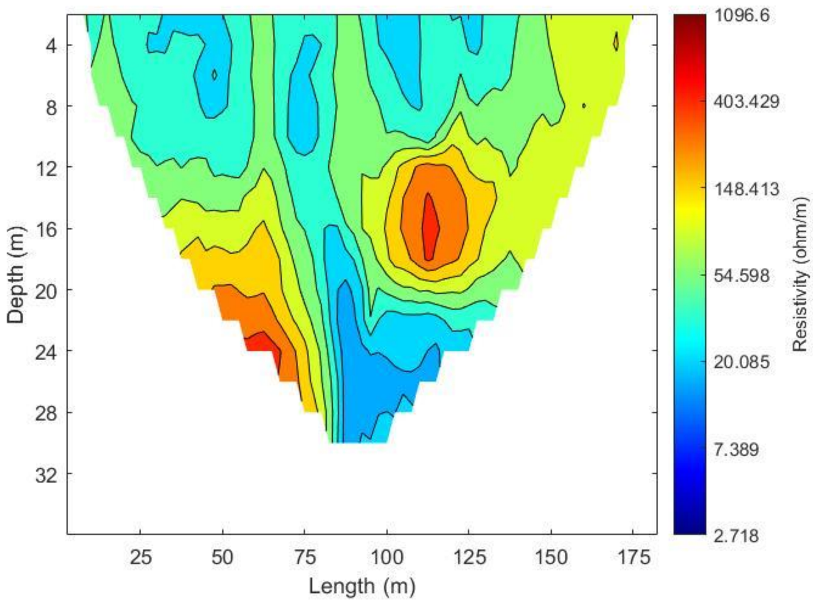

Figure 3. Inverted resistivity section for profile. For location, see Figure 2.

3. Conclusions

Adopting new high-resolution monitoring techniques for groundwater and surface water assessment considering both the quantitative and qualitative aspects and using specific sensors are valuable for processes understanding and scientific decision-making tools development. InTheMED aims to initiate continuous and high-resolution monitoring strategies at five case studies of the project. Together with other initiatives, our efforts can be considered as an initiation towards developing long-term Terrestrial Water Observatories in the Mediterranean region. The long-term objective of this project is to generate common and online hydrological, hydrogeological and water quality datasets between the different case studies and beyond in near real-time steps. Also, it is worth considering that the HRMA is expensive and laborious and needed additional maintenance and recalibration of the sensors from time to time and a cleaning system to ensure accurate measurement. Also, the specificity of each case study and objective of the monitoring should be aligned early with the decision-makers expectation to choose better the proper monitoring strategies and critical sets of parameters. The literature well reported (e.g., Jomaa et al. 2018) that the combination of continuous long-term grab sampling monitoring and the implementation of high-resolution monitoring approach for a given period can be an optimum solution. Measuring water bodies' detailed notes and fluctuations following hydrological extremes and anthropogenic perturbations is extremely important for systems characterisation and setting early interventions. However, long-term groundwater level records are also crucial to investigate groundwater trends and their controlling factors under changing anthropogenic and climate pressures. Both monitoring approaches are complimentary for sustainable management. They helped to gain further insights on physical processes understanding (thanks to HRMA) and the long-term responses of groundwater system due to varying inputs (thanks to continuous grab sampling).

While these data are extremely important, they provide information about the groundwater system at sparse locations (i.e., the borehole locations). When combined with geophysical data, the information provided by both types of direct measurements allows modelling the spatial distribution of the aquifer properties far from the borehole location. The predicted subsurface models, which describe the geological properties related to water flow and quality, provide invaluable information about critical regions where the predictions are more uncertain (and therefore associated with higher risk) and/or critical areas under larger pressure in terms of water quality/quantity.

As a next step, discussion of optimising monitoring strategies in each case study will be continued between project partners and key stakeholders until the full implementation of HRMA. This will be conducted considering the system boundaries of each case study and inputs from different stakeholders groups collected during the Living Labs. Also, the implementation of HRMA will be considered in the cost-benefit analysis to better guide decision-making and the role of accurate monitoring to achieve sustainability in each case study.

4. References

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