Title of Proposal Salinization of critical groundwater reserves in coastal Mediterranean areas: Identification, Risk Assessment and Sustainable Management with the use of integrated modelling and smart ICT tools
MEDSAL

1. Excellence

1.1 Objectives

The MEDSAL Project aims to secure availability and quality of groundwater reserves in Mediterranean coastal areas, which are amongst the most vulnerable regions in the world to water scarcity and quality degradation, due to rapid changes occurring in non-climatic and climatic drivers[1,2]. This will be addressed by providing a novel holistic approach, towards the sustainable management of coastal aquifers which are affected by increased (single or multi-sourced) groundwater salinization (GWS) risk, especially under the variable meteo-climatic conditions of the Mediterranean[3] and the rapidly changing socio-economic context. The above goal will be achieved through the accomplishment of the following inter-connected specific objectives:

SO1: Deliver new aspects and tools for the identification of variable (multi-induced) and often cascading salinization sources and processes. **SO2:** Derive, build and integrate coherent and robust datasets of critical parameters related to GWS, especially in areas of insufficient and/or negligible availability. **SO3:** Couple physical models (hydrogeological and hydrogeochemical), environmental isotopes, advanced geostatistical methods and artificial intelligence (AI) techniques (shallow and deep learning) in order to develop novel approaches and methods in the simulation and forecasting of GWS. **SO4:** Identify new patterns and develop new proxies for monitoring, assessment and forecasting of GWS in areas with negligible data and/or limited financial and human resources. **SO5:** Elaborate tailor-made risk assessment and management plans by coupling GWS forecasts with climate change impacts and future scenarios. **SO6:** Develop a public domain web-GIS Observatory for monitoring, decision support and management of coastal groundwater reserves around Mediterranean. **SO7:** Facilitate public participation and enhance active engagement of local societies to dataset development and monitoring. **SO8:** Facilitate fusion of expertise among academia and stakeholders (national level) and transfer of technology and know-how among the participating countries (international level), including cross-training on methods, tools and services. **SO9:** Establish networks and synergies between interested parties (scientists, stakeholders, and public services).

1.2 Relation to call and topic

MEDSAL responds to **Call Section 2** and specifically to **Topic 1.1.1** “Water resources availability and quality within catchments and aquifers” of **Thematic Area 1** “Management of Water”. MEDSAL approach is strongly collaborative and is carefully designed to have an impact and contribute to demand and policy driven research, as dictated by the list of **KPIs** in **annex 3**. Corresponding to Topic’s **challenge**, MEDSAL is envisaged to provide a different insight for the identification, assessment and management of GWS risk in coastal aquifer systems (SO1, SO5); thus, clearly contributing to the development of innovative integrated approaches and tools (SO3) to ensure the availability of groundwater resources and, in particular to deal with seawater intrusion and GWS risks (SO5). In addition, according to requirements of **Thematic Area 1**, MEDSAL aims to secure water availability as to quality and quantity and enhance sustainable water resources management of arid and semi-arid areas through innovative tools and techniques (SO3, SO4), thus providing integrated solutions to improve resilience to water scarcity conditions (SO5). Furthermore, MEDSAL’s goals

[1] Intergovernmental Panel on Climate Change (2013). Annex I: Atlas of Global and Regional Climate Projections. In *Climate Change 2013: The Physical Science Basis*; Stocker, T.F. et al., Eds.; Cambridge University Press: Cambridge, UK; New York, NY, USA, 2013; pp. 1311–1393.
[2] United Nations Environment Programme/Mediterranean Action Plan (UNEP/MAP). *Mediterranean Strategy for Sustainable Development 2016-2025*; Plan Bleu, Regional Activity Centre: Valbonne, France, 2016
[3] Cook, et al. (2016). Spatiotemporal drought variability in the Mediterranean over the last 900 years. *J. Geophys. Res. Atmos.*, *121*, 2060–2074.

and expected outcomes underpin the understanding of system's (saline-freshwater) complexity under present and future climatic conditions (SO5), a goal acknowledged as crucial for ensuring the long-term availability of water resources in **Topic 1.1.1** and **Thematic Area 1**.

The overall methodological approach and envisaged outcomes of MEDSAL Project, points to the achievement of **Topic 1.1.1 scopes**, as it aims to:

- Apply, test and evaluate adequate modelling methods (SO3), as well as effective monitoring tools (SO4, SO6, SO7) and research on new methodologies (SO4, SO6) to decipher GWS and facilitate its risk management (SO5).
- Develop and demonstrate effective monitoring (SO4, SO6, SO7) and modelling tools (SO3); gather appropriate data (SO2, SO7); and provide forecasting capabilities (SO4, SO5).
- Elaborate efficient simulation models which are necessary to analyse future scenarios at variable spatial-temporal scales for natural resource planning and management (SO5, SO6).
- Identify cost-effective strategies and techniques for a rational use of groundwater and its protection (SO5).

The above will be elaborated through the integration and fusion of different techniques and tools, such as benchmark studies, environmental isotope methods, numerical modelling of the physical system, advanced geostatistical and artificial intelligence (AI) methods, in order to deliver forecasting scenarios according to climatic stresses; the MEDSAL web-GIS Observatory (SO6) will allow to achieve these targets and safeguard Project's success during and beyond its lifetime. MEDSAL is in line with **Topic 1.1.1** as to the addressed **expected impacts:** it targets to deliver a more efficient water management linked to studies, models and methods devoted to understand, simulate and forecast the processes of GWS. Specifically, it focuses on designing new modelling routines for monitoring and forecasting, to ultimately facilitate the reduction in the risk of saline intrusion and salt accumulation in overexploited groundwater bodies.

1.3 Concept and methodology

1.3.1 Concept

1.3.1.1 Problem identification and background

The Mediterranean regions, and especially the coastal zones, suffer from water scarcity and over-exploitation of groundwater reserves to satisfy the increasing water demands for variable uses. As a result, researchers report increasing groundwater depletion and progressive deterioration of groundwater quality in Mediterranean coastal aquifers[4]. GWS worsens the problem of water availability, which is further impacted by climate change effects. Because of the arid or semi-arid climate and the expected water scarcity stresses of variable severity[5], the availability of freshwater resources in the Mediterranean countries is becoming highly important. A potential "water crisis" due to lack of water availability is alarming and likely to occur[6]. For the Mediterranean, GWS is a long-term and serious threat for maintaining sustainable access to fresh water, as : (a) it is a slow process taking many years to many decades to develop and even longer to revert; restoration of freshwater quality may require three times longer than the residence time, with some effects even persisting after this timespan, (b) affects the most productive and vulnerable aquifers of the Mediterranean coastal areas and, (c) may cause significant risk to environment, socio-economic development and human well-being.

Coastal aquifers, being under the influence of both marine and terrestrial environments, are dynamic and complex systems typified by transient water levels, variable 3D water density distributions, and heterogeneous/anisotropic hydraulic properties[7]. Climate variations, groundwater pumping and fluctuating sea levels result in dynamic hydrologic conditions, where groundwater flow is density-dependent and GWS is mainly related to present seawater

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[4] Leduc, M., Matthews, D.H., de Elia., R. (2016). Regional climate response to cumulative CO_2 emissions. *Nature Climate Change 6,474-478*

[5] United Nations Environment Programme/Mediterranean Action Plan (UNEP/MAP). *Mediterranean Strategy for Sustainable Development 2016-2025*; Plan Bleu, Regional Activity Centre: Valbonne, France, 2016

[6] IPCC, 2014: Climate Change 2014: Impacts, Adaptation, and Vulnerability. A Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C.B. et al. (eds.)]. *World Meteorological Organization, Geneva, Switzerland, 190 pp.*

[7] Werner et al., (2013) Seawater intrusion processes, investigation and management: Recent advances and future challenges. *Advances in Water Research 51, 3-26*

intrusion/saltwater upconing[8]; however, additional factors may be potential sources[9] which despite causing similar adverse impacts are often underestimated or even non-identified, being obscured by the dominant concept of seawater intrusion[10]. The lowering of groundwater levels in coastal aquifers can induce lateral seawater intrusion (GWS type I) or up-coning of saline waters from the freshwater-saltwater interface (GWS type II). Once the natural subsurface outflow to the sea ceases due to over-exploitation, also solute transport to the sea interrupts, causing internal salinization of the system: coastal aquifers become a solute trap (GWS type III). Application of fertilizers and soil improving agents in agriculture and irrigation water return flow produce GWS especially in case of bad subsurface drainage (GWS type IV). Solution of entrapped salts or bedrock weathering (e.g. evaporites), release of brines from tectonic structures, or interconnection with deep aquifers holding synsedimentary saline waters/brines represent specific processes in some Mediterranean regions (GWS type V). A decisive factor in the correct assessment of coastal aquifer status, besides the reliable identification of GWS sources and processes, is the spatial and temporal availability of monitoring data. The lack of continuous records and measurements or their uneven distribution in space and time, give ambiguous information and pose limitations for the reliable forecasting and the subsequent risk assessment and management of coastal aquifers. As a result, stakeholders become unable of conceiving and applying appropriate management plans, and the decision making procedure is jeopardized, thus having significant adverse impacts to the available freshwater resources and to the overall environment and socio-economic development of coastal Mediterranean areas.

1.3.1.2 Envisaged solution and proposed MEDSAL Framework

MEDSAL aims to develop an integrated Framework for monitoring, protection and management of coastal groundwater reserves subject to increased salinization risks, due to overexploitation and rapid changes occurring from relevant climatic/non-climatic drivers. This new integrated approach not only targets to detect and identify GWS in a fast and more effective way, but it also proposes a solid and novel methodology for identifying type or combination of types of GWS I-V in coastal aquifers for facilitating reliable GWS forecasting, risk assessment and management. The proposed framework also endeavours to propose adequate measures based on a process and cause analysis and schedules, targets and indicators for the restoration of groundwater quality based on new analytical tools.

The proposed **MEDSAL Framework** is envisaged to integrate and fuse different tools, techniques and methods in order to: a) identify GWS sources (single or multi-sourced) and decipher their governing processes, b) assess the potential interactions with other compartments (small scale) and with other systems at catchment (large) scale, c) forecast the spatiotemporal evolution of primary (salinization) and secondary cascading effects and impacts, d) perform a risk assessment under variable climatic projections and stresses, and e) develop a public web-GIS Observatory to support monitoring, management, decision making, and increase of resilience to GWS risk. The described Framework would develop through a three-fold of interrelated and multi-disciplinary pillars, including: i) field studies, data collection and innovative application of environmental isotopes; b) coupling of advanced hydrogeological (e.g. FEFLOW, SEAWAT) and hydrogeochemical modelling (e.g. PHREEQC, compartment modelling) to decipher and simulate flow and transport processes along with the potential cascading interactions within involved aquifer systems; c) application of advanced geostatistical and machine learning techniques for the optimization of data processing and modelling outcomes, also accounting for the inherent uncertainty of each model and reduction of the overall computational burden and time. The **vision** of MEDSAL Framework is to provide novel integrated approaches (e.g. tools, proxy indicators, methodologies) for the accurate assessment and management of GWS risk in Mediterranean coastal aquifers, having as key priority the transferability of the envisaged methodological results to regions of limited resources (technical, funding, personnel), in order to increase the capacity building and efficacy of coastal groundwater management plans.

The overall MEDSAL's concept summarized in the risk assessment and management of coastal aquifers has a clear **interdisciplinary approach**, which involves: a) in-depth knowledge of the physical environment and the chief processes that drive and control GWS; b) identification of GWS sources by the joint compilation of diverse tools and methods,

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[8] Klassen, J., Allen, D.M. (2017) Assessing the risk of saltwater intrusion in coastal aquifers. *J Hydrology 551,730-745*

[9] Guler et al. (2012) Assessment of the impact of anthropogenic activities on the groundwater hydrology and chemistry in Tarsus coastal plain (Mersin, SE Turkey) using fuzzy clustering, multivariate statistics and GIS techniques. *J Hydrology 414-415, 435-451*

[10] Zhao et al. (2017) A hydrogeochemistry and multi-isotope (Sr, O, H, and C) study of groundwater salinity origin and hydrogeochemical processes in the shallow confined aquifer of northern Yangtze River downstream coastal plain, China. *Applied Geochemistry 86,49-58*

especially in complex hydrogeological environments and under variable cascading effects; c) inter-engagement of hydrogeological and hydrogeochemical modelling by coupling physically based models of flow and transport with geochemical processes, within a spatiotemporal context; d) application of advanced geostatistical and machine learning techniques towards model optimization and GWS forecasting, under variable site characteristics and with adverse conditions (e.g. fragmented or insufficient datasets); e) coupling of climate changes stresses and projections along with physical-based assessments, models and simulations, f) elaboration of tailor-made management plans for Mediterranean test sites of diverse physical and socio-economic characteristics, legislative frameworks and regulatory issues.

Stakeholders are expected to have an important role in MEDSAL Project. MEDSAL incorporates as potential end-users several stakeholders from the participating countries (e.g. Decentralized Administration of Thrace-Macedonia, Greece; Tarsus Coastal Irrigation Association, Turkey; Acquedotto Pugliese S.p.A, Italy; Water Resources Directorate of El Tarf Province, Algeria; Office of Hydraulic Inventory and Research, Ministry of Agriculture and Hydraulic Resources and Fisheries, Tunisia). The above end-users have expressed their interest to Project's results and aim to capitalize them in their domain, as the relevant administrative authorities for water resources in their region. Moreover, they are willing to provide any means (e.g. knowledge, data, conveniences, etc.) for the smooth implementation of the Project, and actively collaborate with the PPs to raising awareness and dissemination activities. Finally, their critical role to Project's goals is proven by the training of their selected personnel to MEDSAL web-GIS Observatory tools and capabilities for monitoring and decision-making, in order to exchange know-how and expand their capacity.

Public participation and **societal engagement** is strongly encouraged by MEDSAL, through their active involvement to real-time monitoring and data-base building. Specifically, the envisaged MEDSAL mobile app will constitute a robust tool for volunteers (e.g. owners of boreholes, farmers, etc.) through which they may give their input (e.g. groundwater level, individual groundwater analyses) for alerting and information gathering of critical parameters. In addition, raising awareness and information activities are an integral part of the Project: they aim at shifting stakeholders, farmers and water-users towards a more sustainable use of groundwater reserves according to the customized and site-specific risk assessment and management plans.

1.3.1.3 Positioning of Project and Technology Readiness Levels

MEDSAL activities aim at setting up new knowledge and exploring the feasibility of novel methodological approaches, leading to integrated solutions for the sustainable management of coastal groundwater resources under GWS risk. For this purpose, it includes basic and applied research, technology development and integration, as well as testing and validation on selected pilot sites of the Mediterranean. The overall outcome foresees to embrace closely connected demonstration activities aiming at showing technical feasibility in a near operational environment. Thus, the overall outcome at the end of the Project is expected to achieve TRL6-7. Some of the individual tools and methods that compile the basic components of MEDSAL approach have already proven their capabilities through successful mission operations (e.g. physically based models). Other tools and methods are tested for the very first time and/or at initial stages, however with positive expectations and potential, such as the coupling of flow and transport along with hydrogeochemical modelling (from TRL4 to expected 6-7), shallow and deep learning methodologies in Project's domain (from TRL3 to TRL5), integrations of tools and methods for GWS forecasting (from TRL2 to TRL6-7) and web-GIS Observatory and responsive tools for GWS monitoring and decision support (from TRL2 to TRL6).

1.3.1.4 Research and innovation activities linked with MEDSAL Project

MEDSAL will seek to valorise the existing knowledge capital from previous projects, as well as to create synergies and complementarities with on-going or potential new ones. Specifically, MEDSAL will capitalize the know-how and experiences gained from the participation of its partners to the following key projects, per scientific domain: (a) GWS and seawater intrusion: PRIMAC – Protection of coastal aquifers from seawater intrusion (INTERREG IIIA); WADIS MAR – Water harvesting and agricultural techniques in dry lands: an integrated and sustainable model in Maghreb Regions (SWIM); (b) Environmental isotopes: Environmental Isotope Techniques for Water Flow Accounting in the Mediterranean ISOMED (ERANET3), Groundwater Resources Re-evaluation of Cyprus (GRC), Groundwater Recharge in the Eastern Mediterranean (GREM, INCO-DC), Managed Aquifer Recharge MARSOL FP7, Assessing Flood Water Recharge of Alluvial Aquifers in Dryland Environments WADE (FP7) (c) Hydrogeological modelling: Protection and rehabilitation of water and forest resources of the Prefecture of Rodopi (EEA Grants); Geochemical modelling in Jeffara of Medenine aquifer (Tunisian funding); (d) Application of geostatistical methods: Advances in geostatistics for environmental characterization and natural resources management (ESF); (e) Web-GIS Observatories: web-GIS data visualization, Biodiversity Protection through Climate-adapted Agriculture (WWF Deutschland). In addition, MEDSAL will capitalize the know-how and tools from the "International virtual topic-network on modelling and management of catchments in Mediterranean basin", funded and supported by Forschungszentrum Jülich (HAO has an extensive research collaboration), as well as from the EURO-CORDEX Initiative, both dedicated to climate change domain. In respect to on-going projects, MEDSAL will seek to establish a synergy with SYDYWAMED Project (Socio-agro-hydro-systems dynamic facing Water Scarcity in the region) funded by ERANETMED 2017-2020.

1.3.2 Methodology

Based on the main goal and the specific objectives of MEDSAL Project, the methodological approach is structured in 7 discrete, yet inter-correlated, Work Packages (WPs). Each WP includes actions, which are the individual tasks needed for its completion. The accomplishment of each WP is a prerequisite for Project's success; hence, each one has equal importance. Each WP is assigned to a lead partner (LP), which coordinates and organizes the individual contribution of other Project Partners (PPs). MEDSAL's approach foresees the highest engagement of all PPs (if and whenever feasible, according to their expertise) to achieve the same consensus of contribution and know-how. Towards this goal and to ensure the equal contribution of all PPs, the LPs have been evenly distributed among the participating countries and according to their domain. The overall methodological approach of MEDSAL Project includes both research and pilot/demonstration actions. Fig. 1 shows the schematic overview of the methodological flow and of the dependencies and interactions among the envisaged WPs.

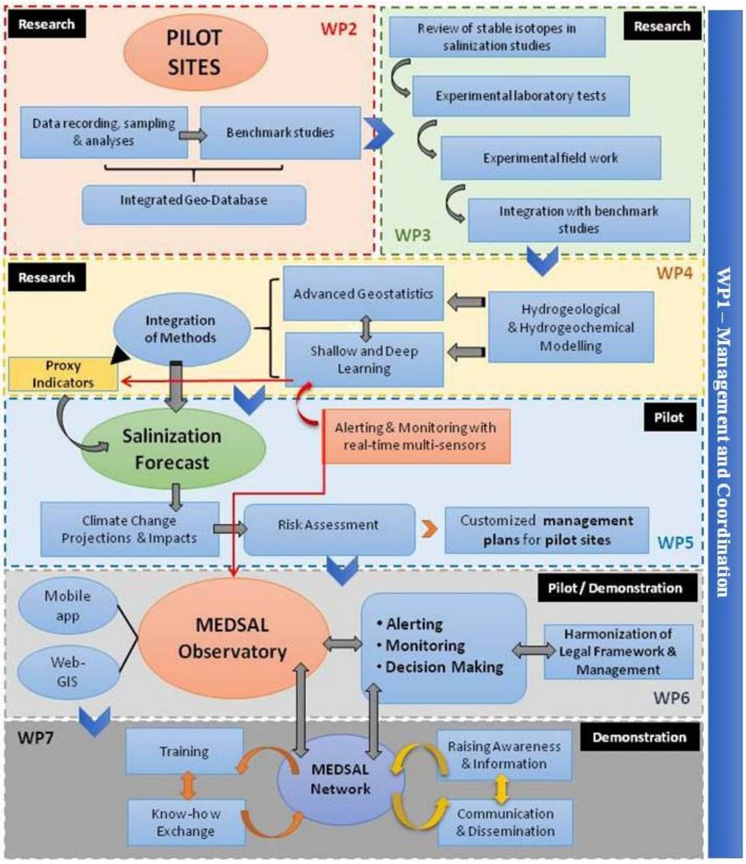

Figure 1: Methodological concept and workflow of MEDSAL Project

With respect to gender dimension: MEDSAL did not (during preparation) and shall not (during the implementation) discriminate on the basis of race, color, religion, gender, age, national origin, disability, marital status, sexual orientation, in any of its activities or operations, providing also equal opportunities in terms of employment, participation in project actions and the access of information, knowledge and events. It is well understood that successful implementation of the Project shall raise considerable potential for employment posts both in the scientific and primary sectors, especially in the non-EU countries, and the equal basis opportunities to cover these posts shall also be systematically promoted.

WP1 - Management and Coordination (LP: HAO, PPs: All): The major aim is to pursue all scientific, financial, and organizational management aspects of the Project to run smoothly, timely and successfully. WP1 actions include (i) the development of management's strategy (management plan, contingency plan, quality assurance manual, structure and regulation of steering committee, monitoring and quality control of deliverables) and, (ii) implementation and coordination activities (day-to-day coordination, financial monitoring, reports, etc.). WP1 is considered as the backbone of the Project and will critically interact with all WPs.

WP2 - Data recording, processing, and integration (LP: FST, PPs: HAO, POLIBA, LUAS, MEU, MGRE, UIZ): This WP includes collaborative research and provide the essential input data for the successful elaboration of the next WPs in terms of data analysis, simulations and models. Specifically, WP2 includes the elaboration of field studies, macroscopic investigations, and groundwater sampling campaigns for the collection of raw data; an extensive set of analyses including major ions, trace elements, physicochemical parameters, as well as environmental isotopes will be performed; additional data, such as existing literature and historical records (e.g. datasets; time-series, etc.) of each pilot site, will be integrated with the new records in a holistic dataset. Accordingly, a detailed hydrogeological and hydrogeochemical study will be performed for each test site, coupled with the essential geological (tectonic, stratigraphic, etc.), environmental (land uses, contamination sources, etc.) and climatic evidences. Both sampling/analyses and benchmark studies will be elaborated by local PPs that are HAO for Greece (Rhodope), FST for Tunisia, MGRE for Algeria, POLIBA for Italy, and MEU for Turkey, whilst LUAS will operate in the second Greek site (Samos Island) due to its previous experience. Special attention will be given to the interaction of the studied aquifers with other compartments (small scale) and with other water systems at catchment (large) scale, as well as with groundwater-dependent ecosystems of high environmental significance. The final outcome of WP2 will be an integrated Geo-database in G.I.S environment with all the available information (spatial or not) for the pilot sites. Efforts will focus on building a general and comprehensive platform for data management and decision support about GWS problems in the Mediterranean region.

WP3 – Application of environmental isotopes to the identification of GWS sources and processes: (LP: LUAS, PPs: HAO, FST, MEU, MGRE, POLIBA): This WP includes research activities and aims to give a different insight to application of environmental isotopes in GWS problems, ultimately targeting to provide new tools and proxy indicators. The WP includes a thorough review of existing knowledge and theoretical background of different environmental isotopes that have been applied to identify sources, processes, degree and history of salinization. The objective of the WP is to develop fast track **indicators** for salinization source, status and trend. Indicators are based on an innovative multi-isotope approach for a sound and comprehensive analysis of salinization processes. Sea-water intrusion, up-coning, internal solute trapping, addition of salts from different anthropogenic sources (agriculture, sewage, waste dumps) or geochemical sources each produce an environmental isotope fingerprint that is specific for the source and often more distinctive and indicative of the process[11]. The use of selected isotopes $\delta^{18}O$, $\delta\,^{2}H$, $\delta^{13}C$, $\delta^{15}N$, $\delta^{34}S$, $\delta^{7}B$ and $^{87}Sr/^{86}Sr$ has been proposed[12] to study individual aspects of GWS. Their systematic and combined use in detecting and characterizing GWS will be studied. As ^{228}Ra, ^{226}Ra have different solubility in fresh and saline water, their ratio provides information on the time salinization started and about changes in flow regimes of coastal aquifers[13]. These tracers will be evaluated in terms of their suitability to detect sources, past and historic changes, status and trends of salinization. This work package will be closely integrated with other methods (modelling, hydrochemistry, geo-statistics, WP4) and operational forecast (WP5).

WP4: Models and Software Tools (LP: CUT, PPs: CERTH, HAO, MEU, FST, MGRE): This WP constitutes the research core of MEDSAL, as it will combine a cascade of existing and new techniques/methodologies to develop state-of-the-art simulation tools of GWS assessment and forecast. The physical-based models for groundwater flow and contaminant transport (e.g. FEFLOW) will be based on a variable density flow approach to estimate the salinity distribution in the aquifer systems, as well as the potential GWS of pumping wells with accuracy. Furthermore, the hydrogeochemical modelling of groundwater (e.g. through PHREEQC and compartmental modelling) involving speciation, redox potential and pH as key drivers, will facilitate the physical-based modelling to distinguish the various types of GWS (e.g. types I to V) and simulate their relative processes (carried out by HAO, supported by MEU and FST). Furthermore, geostatistical simulations (carried out by CUT) will be employed for generating alternative realistic 2D or 3D numerical representations (realizations) for the spatial distribution of key hydrogeological and/or hydrogeochemical parameters[14]. These simulated parameter realizations will reproduce: (a) known measurements at their sample locations,

[11] Leibundgut, C., Maloszewski, P., & Külls, C. (2009). Tracers in Hydrology. Tracers in Hydrology, (1. Ed.), 403
[12] Carreira, P. Marques J., Nunes D. (2014) Source of groundwater salinity in coastline aquifers based on environmental isotopes (Portugal): Natural vs. human interference. Applied Geochemistry, 41, 163-175 ISSN 0883-2927,
[13] Vinson, D.S. Lundy, J.R., Dwyer, G.S., Vengosh, A. (2018) Radium isotope response to aquifer storage and recovery in a sandstone aquifer. Applied Geochemistry (https://doi.org/10.1016/j.apgeochem.2018.01.006).
[14] Liodakis, S., et al.. (2018), Conditional Latin hypercube simulation of (log)gaussian random fields, Mathematical Geosciences, 50(2), 127-146.

e.g. boreholes, (b) models of spatial correlation of those parameters encapsulating parameter variability in space, and (c) relationships of those parameters with relevant auxiliary data, such as information provided by geological maps or local geophysical surveys, accounting for spatial resolution differences and spatial heterogeneity in those relationships. In a second level, and in those cases afforded by data availability, geostatistical inverse modelling will be employed to render parameter realizations more realistic[15]. This will be achieved by considering the information brought by hydrogeochemical measurements through physical-based models, and by linking the input parameters to those measurements. The set of alternative, realistic, parameter realizations constitute a model of uncertainty regarding the real but unobserved distribution of parameters in space, and can be used for risk conscious decision-making in a comprehensive water resources management.

Moreover, shallow machine learning techniques and advanced deep learning methodologies (carried out by CERTH) will be applied for the early detection of latent patterns and the forecasting of GWS from spatio-temporal time series data. Finally, the diverse models, techniques, and methods (e.g. modelling; geostatistics; shallow and deep learning) which have been thoroughly examined, applied, and developed in WP4 and previous WPs (e.g. WP3 – isotopes), will be integrated in order to deploy a robust tool-box of novel proxy indicators for GWS, regarding its identification, monitoring, assessment, and spatio-temporal forecast.

WP5: Demonstration Activities in MEDSAL Test Sites (LP: POLIBA, PPs: All): This WP intends to demonstrate the outcomes of the previous research-oriented WPs to MEDSAL test sites; thus, it aims to evaluate, verify and optimize the initially developed tools, techniques and methods. The MEDSAL Framework will be applied in six different test sites, which cover diverse physical, environmental, and bio-geographical conditions. Test-sites include different aquifer types (porous and karstic) of variable extent (regional and local), regions of different characteristics (continental and island) and water uses (agriculture and mixed), areas of variable aridity and climatic conditions, and finally of different socio-economic context. Specifically, the test sites are located in: (i) Rhodope, Greece, (ii) Samos Island, Greece, (iii) Salento, Italy, (iv) Tarsus, Turkey, (v) Boufichia, Tunisia, and (vi) Bouteldja, Algeria. In support of an effective alerting and monitoring of GWS, WP5 foresees the installation of multi-sensor probes at selected boreholes of the test sites. The sensors will give high-frequency (HF) real-time feedback for critical parameters related to GWS, such as the electrical conductivity (EC), density, pH, Eh, dissolved oxygen (DO) and groundwater level. This will significantly enhance the monitoring and alerting process by developing potential proxies for salinization phases and trends based on the recognition of latent patterns with learning techniques (interactions among WP4-WP5).

In addition, processing of multi-sensors' data will give an extra tool to the envisaged tool-box for GWS forecasting; the latter is the focal point of WP5. Thus, a full demonstration of the developed tools and methods shall be used to elaborate a comprehensive simulation and forecasting of the GWS, for all test sites. In this context, test sites with good spatio-temporal data availability (e.g. times-series, records of analyses, etc.) such as Rhodope, Samos and Salento, will be used as demo sites for the verification of all tools, in order to be tested, evaluated and finally, successfully applied to case studies with fewer data (e.g. Tarsus, Boufichia, Bouteldja). Following the successful forecasting of GWS, the anticipated impacts of climate change for each test site will be assessed, based on established climate change scenarios and down-scaled projections. Specifically, the climate change impact assessment will be based on projected climate data gathered from existing, state-of-the-art Regional Climate Models (RCMs) runs under RCP4.5 scenario, which are distributed from the CORDEX Initiative. Indicatively, data from the EUR-11 CORDEX domain will be used, assisted by AFR-44 domain. For the case studies in which sufficient historical time series of precipitation and temperature are available (>20 years of daily data), bias-correction will be performed based on well-established statistical methods such as linear scaling and distribution mapping.

Finally, tailor-made risk assessment studies for salinization will be elaborated for all test sites, accompanied by comprehensive risk management plans. The risk will be mainly focused on (but not limited to) droughts and their potential adverse effects to groundwater availability and induced GWS. Droughts have been selected as a key climate change impact for Mediterranean area, as they are expected to increase in frequency duration and severity in southern

[15] Chilès, J. P. and Delfiner, P. (2012), Geostatistics: Modelling Spatial Uncertainty, 2nd Edition, John Wiley & Sons.

Europe[16] and to become more intense and longer-lasting and affect North Africa[17]. The risk assessment and management plans will start with the definition of intrinsic vulnerability of test sites, that depends not only on local (geological and hydrogeological) properties of the aquifers, but also on water levels and 3D salt content of groundwater. Because these latter are not "pristine" but defined by exploitation rates and distribution, and climate, which are both time-dependent, implicitly the vulnerability maps are "dynamic" hazard maps, variable with time.

WP6: Development and Operation of MEDSAL Participatory Framework (LP: MEU, PPs: All): This WP is dedicated to the development of the holistic MEDSAL Framework, expressed through specific tools; actions; and protocols to be followed towards the sustainable management of coastal groundwater reserves. The envisaged Framework has a clear inter-domain participatory approach, as it aspires to join the technocratic issues with decision making of stakeholders and public participation. To this aim, both pilot and demonstration actions are included. The main technological tool for the realisation of MEDSAL Framework, is the envisaged web-GIS MEDSAL Observatory (MO). Its interactive character, its wide accessibility (open access) and the extended capabilities provided for data visualization constitute it more than a simple front-end and upgrade it to a multi-purposed versatile tool for alerting, monitoring, and decision making. The MO will contain in databases and visualized maps all recorded data and developed models, simulations and forecasts; in other words, it will integrate the available information for all test sites, through a visualized approach which can be customized according to user requirements. It is envisaged to be a fully operational tool for the Project's end-users and other stakeholders, during and beyond the lifetime of the Project. The operational framework of the web-GIS Observatory can be divided into three categories: (a) database to manage in-situ and monitoring data, (b) visualization system for monitoring and derived data (GWS risk, overexploitation), (c) analyzing and warning system to identify action levels of potential threats. The participatory MEDSAL Framework also foresees the development of a mobile app for volunteers towards public participation and active societal engagement. A thorough evaluation of the existing policies, regulations and constraints shall be performed, with the active participation of stakeholders, in conjunction with the Water Framework Directive (2000/60/EC). Overall, WP6 includes the development of protocols for alerting, monitoring, decision support, and integrated management of coastal groundwater reserves.

WP7: Dissemination, Training and Networking (LP: MGRE, PPs: All): This WP include demonstration actions that aim to effectively disseminate Projects' activities, achievements, and outcomes, thus securing the highest possible propagation of MEDSAL's Framework and, enhance the transferability of the developed tools and methodologies to a wide audience (academia, stakeholders, local population and targeted groups). The above will be demonstrated through variable activities including MEDSAL official website, promotional material, open info days, raising awareness activities, and social-media. The operational and technical outcomes will be disseminated through scientific publications, participation in international conferences, symposia, and fora. A critical element of MEDSAL approach are training actions: (a) training of researchers/post graduates/post doctorates to MEDSAL's innovative tools and methods, in order to increase the mobility of young scientists; (b) training of selected key personnel of the end-users, who have expressed their interest, as well as of other stakeholders that will be interested during Project's implementation. Finally, WP7 envisages the establishment and operation of MEDSAL Network that will be dedicated to the accomplishment of Project's goals and aspires to create a synergy between academia, stakeholders and local communities, towards the implementation of MEDSAL Framework in coastal Mediterranean regions.

1.4 Ambition

Risk and change management requires a) early and correct identification of hazards and risks as well as b) pro-active implementation of adequate and efficient measures to prevent and mitigate risks and increase resilience. Currently, failure to notice early signs of salinization, failure to distinguish salinization from climatic or hydro-chemical variability and lack of correct identification of sources of salinization are major gaps to risk and change management with respect to

[16] European Environmental Agency (2017) Climate change adaptation and disaster risk reduction in Europe - Enhancing coherence of the knowledge base, policies and practices, EEA Report No 15/2017, ISSN 1977-8449

[17] Elrafy, M. 2009. Impact of Climate Change: Vulnerability and Adaptation of Coastal Areas. Report of the Arab forum for Environment and Development. Mostafa K.Tolba and Najib W.Saab Eds.

salinization and water quality degradation in coastal aquifers of the Mediterranean. The project features a unique combination and integration of a) hydro-geochemical and isotope methods b) numerical ground water modelling, and c) information technology including deep learning to significantly improve risk and change management:

- A **new set of geochemical and isotope methods** and introduction of **deep learning algorithms** to analyse complex hydro-chemical data and time series will be used to accelerate and improve early detection and advance source and process identification (reconnaissance and faster detection of risks).
- Numerical modelling of coastal aquifers will be improved and streamlined towards developing **adequate measures for risk and change management**. Improvements in numerical modelling will be realized by facilitating the setup of numerical models with common parameter databases (AI). In addition, risks analysis will be improved by identifying common drought and demand scenarios for the Mediterranean by collaborative research and by evaluating management measures in silico.
- Finally, geochemical & isotope methods, numerical modelling and deep learning will be combined by first integrating geochemical and water level data from all around the Mediterranean in **one common salinization database** and then searching for common patterns in well monitored case study areas and observatories.

2. Expected impacts

The results of the project could improve the timely and accurate identification of GWS as well as its spatiotemporal evolution, both needed to efficiently tackle with water availability in the Mediterranean coastal regions. MEDSAL successfully corresponds to the expected impacts of Topic 1.1.1 (Thematic Area 1) and clearly contributes towards a **more efficient water management**, linked to studies of GWS forecasting; thus, improving water availability and reduce salinity levels. In this sense, MEDSAL successfully meets the impact of the call and clearly promote "***the reduction in the risk of saline intrusion and improved management of salt accumulation in overexploited underground water bodies***", as: MEDSAL will develop an integrated Framework for the monitoring, protection and management of coastal groundwater reserves subject to seawater intrusion and other salinization sources. This new approach targets to detect and identify GWS in a fast and effective way, but it also aspires to provide a solid and novel methodology for identifying type or combination of types of GWS (single or multi-sourced) in coastal aquifers for facilitating reliable GWS forecasting, risk assessment and management plans (*Target Indicator-TI: 6 plans)*.

MEDSAL is also expected to pave the way for ***new modelling routines*** of improved efficacy for GWS forecasting: (i) by compiling physical-based models for flow and transport with hydrogeochemical processes, and (ii) by incorporating advanced geostatistics and machine learning techniques in groundwater modelling. Furthermore, it will contribute towards ***the mitigation of contamination processes*** (e.g. salinization) - potentially induced by anthropogenic activities (e.g. overexploitation of coastal aquifers, salt accumulation due to agricultural activities) - by better ***assessing water management policies*** through the MEDSAL Framework, aiming to provide better management tools and harmonized regulatory and management policies to stakeholders *(TI – approx. 8-10 impacted stakeholders)*. MEDSAL will also have an impact to the overall ability of **monitoring tools for GWS**, through the development of novel proxy indicators mainly intended to improve the operational efficacy and **smart digital technologies**, especially in Mediterranean areas of limited resources *(TI – 3 areas)*; enhancement of monitoring is also demonstrated through the installation of pilot multi-sensors *(TI – approx.12-15 sensors)* and data-gathering from public participation *(TI – approx. 2000 individuals)*, thus impacting **technological** and **social innovation** and reinforcing the alerting and decision making process. The responsive web-GIS Observatory, being the core of MEDSAL Framework, is expected to have significant impact to (a) stakeholders and local populations of the pilot sites *(TI – approx. 200.000 population impacted)*, and (b) policy makers, strategic planners and international organizations of the Mediterranean *(TI – approx.3)*, through the provision of accurate data for alerting, monitoring and forecasting (with the ability to adjust future scenarios) of GWS. Finally, MEDSAL will impact **know-how exchange** and **capacity building** among the PPs (especially young scientists) and interested end-users by training them on state-of-the-art tools and methods *(TI – approx. 70 individuals)*, whilst the developed **Network** among them will fine-tune **coordination** and safeguard the initial vision of MEDSAL Project beyond its lifetime.

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