SeCURE
Saltwater intrusion and climate change: monitoring, countermeasures and informed governance

Deliverable 3.1.1

Exploitation plan covering for the knowledge arose from MAC IT-HR projects

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1. Introduction

An effective exploitation of the MAC IT-HR project outcomes (monitoring networks, guidelines, web) has been carried out by the SeCure PPs. A summary of the main achievements for each of the three projects is provided in the following.

2. MoST project

Saltwater intrusion in coastal aquifers is a worldwide problem that affects water quality and agricultural production. Italy and Croatia are two of the Mediterranean countries that are mostly damaged by this phenomenon. The main objective of the MoST Project (Monitoring Sea-water intrusion in coastal aquifers and Testing pilot projects for its mitigation) was the monitoring of saltwater intrusion in specific regions of the northern and central Adriatic coasts of Italy and Croatia to assess its relevance and test appropriate countermeasures.

2.1 The Italian pilot site

The Italian pilot site is located at Ca' Bianca, near Chioggia, at the southern margin of the Venice Lagoon, approximately 7 km from the Adriatic Sea coast and 500 m from the lagoon edge. The experimental field is bounded by two main rivers (Brenta and Bacchiglione) and by the Morto channel. In the past, the area was a coastal swamp and was reclaimed for agricultural purposes between the years 1892 and 1967. As the farmland lies between 1.5 to 3.3 m below the mean sea level, the water table is kept below the soil surface by a network of ditches and a pumping station that drives the excess water into the lagoon.

The pilot site is strongly affected by saltwater contamination and the intrusion dynamics are affected by (i) the land subsidence exacerbated by peat oxidation, (ii) the presence of sandy paleochannels that cross the farmland providing a hydraulic connection between freshwater aquifers and the lagoon and thus facilitate seawater intrusion and freshwater dispersion, (iii) the contamination of the two main river bottom with an intrusion extent ranging from 1 to 5 m from the land surface and from 10 to 20 km inland.

2.1.1 The experimental infrastructure at the Italian pilot site

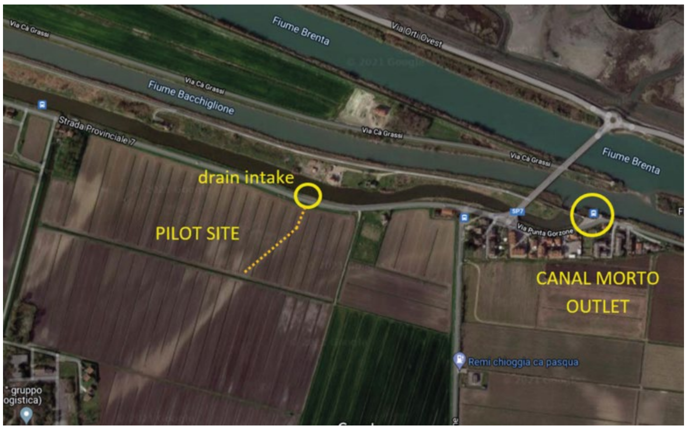


Figure 1. Map of the experimental filed with the drain intake location and the drain path.

Small-scale infrastructures were planned during the MoST project with the aim of testing the effectiveness of a freshwater sub-irrigation system at the Venice pilot site (Figure 1). The experimental infrastructure was completed in September 2020 and consists of an intake from the Morto channel to supply freshwater by gravity into a 220 m-long pipe drain installed into a sandy paleochannel at a depth of 1.5 m. The water main and pipe diameters are 220 mm and 160 mm, respectively, granting a maximum discharge of 28 l/s with a maximum head difference of 2.25 m. The Morto channel intake is realized by means of a vertical pipe with two openings at different heights, each one controlled by a valve. The whole system of pipes and valves is inside a concrete box supported by a foundation made of wooden logs. The piping phenomena is limited by two metal cutoffs (upstream and downstream) and the concrete box is protected along the liver by a grid that prevents the intrusion of floating debris. Moreover, a cut-off wall was realized at the end of the sub-irrigation pipe with the aim of keeping the freshwater inside the field. The water flux in the drainpipe is controlled by a system of valves, one upstream and one downstream, and by a flowmeter.

2.1.2 The flume experiment

A flume experiment was set up to test the effects of the freshwater recharge in both homogeneous and heterogeneous porous media (Figure 2). The lab equipment was set up as follows: a 500 cm long, 30 cm wide, and 60 cm high sandbox made of plexiglass with two tanks located upstream and downstream. The tanks were filled with freshwater and saltwater, respectively, and a constant water level is guaranteed by two spillways that discharge the excess water. Red food dye was added to saltwater to trace its movement. The porous media consists of glass beads. A channel drain was added to the system to simulate the freshwater withdrawal close to the coastline. The saltwater wedge evolution was monitored using two methods: photographs taken every five minutes, and resistivity measurements through electrical resistivity tomography every twenty minutes.

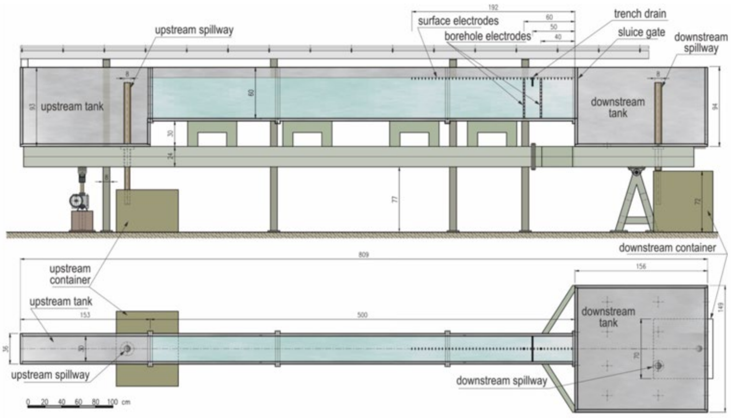


Figure 2. The lab equipment used for the flume experiment.

2.1.3 Monitoring and analyses at the Italian pilot site

2.1.3.1 The hydro-geomorphological map

A complex hydro-geologic system characterizes the pilot site because of the relationship among littoral, deltaic, lagoon, and alluvial deposits together with the natural and man-induced morphologic evolution of the Venice Lagoon. Several hydrogeological surveys were performed to characterize the area of the pilot site: boreholes, salinity logs and permeability tests. The final database is made by 20 surveys performed at the pilot site down to a depth of 50 m, 68 in the surrounding area, and 320 surveys performed during a previous project (ISES). Moreover, 6 30m-deep geological and hydrogeological cross-sections were performed to highlight the geometry of the major sedimentary bodies. The data were analyzed to obtain the hydro-geomorphological map.

2.1.3.2 Map of the vulnerability to saltwater intrusion

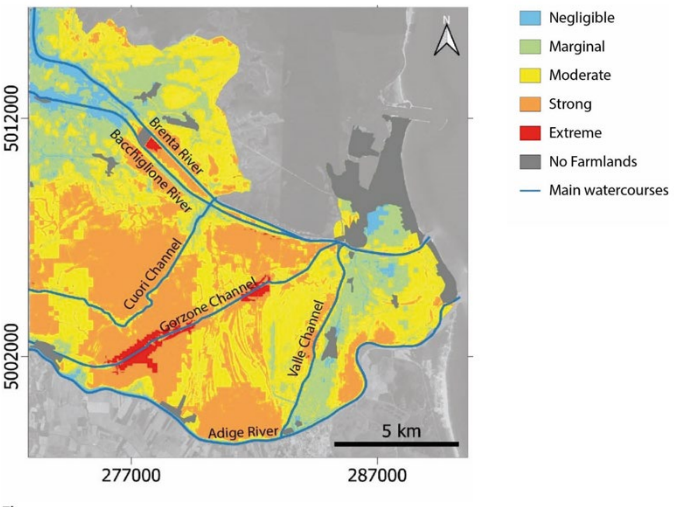


Figure 3. Map of the vulnerability to saltwater intrusion.

The vulnerability analysis developed as part of the MoST project refers to the propensity of the farmland system (from the vadose to up to 3-4 m depth) to be adversely affected by groundwater salinization from the Adriatic Sea and the Venice lagoon when different triggers modify the current hazard status (Figure

3). The hazard status is defined through the indicators fresh-saltwater interface depth (SIN), electrical resistivity of the shallow subsoil (AER), and their combination (SIN&AER), while the intrinsic sensitivity is defined using the following indicators: distance from salt- (SAD) and freshwater sources (FRD), ground elevation (GEL), permeability of the shallow aquifer (PER), potential runoff (ROF), and relative ground level change (RGLC) due to land subsidence and sea-level rise. After the selection of relevant indicators, the corresponding dataset of thematic layers was set up. Then, each layer was classified into five intervals of increasing importance with respect to its contribution to the sensitivity or hazard status. Finally, the sensitivity map was computed by weighting the sensitivity indicators by pairwise comparison, while three vulnerability maps were computed by combining the sensitivity map with the hazard status SIN, AER, and SIN&AER.

2.1.3.3 Monitoring network, sampling campaigns, and laboratory analyses

Small-scale soil and water monitoring and analyses

A monitoring network was established in the 2019, 2020, and 2021 cropping seasons to assess the groundwater dynamics inside and outside the main sandy paleochannel and quantify the freshwater recharge effects through the 200-m long-buried drain installed in September 2020. The network consists of five monitoring stations (S) equipped with one 2.5 m deep piezometer for groundwater monitoring (water table, electrical conductivity, and temperature), and soil sensors installed at 0.1, 0.3, 0.5, and 0.7 m depths for soil moisture, matric potential, soil electrical conductivity, and temperature monitoring. Three of those stations were placed inside the main paleochannel and two outside (Figure 4). In addition, six additional piezometers (P)

Figure 4. Map of the experimental site with the main sandy paleochannel, the drain path, and the location of the monitoring sites.

were installed in 2021 and 2022 at 5, 10, and 20 m from both sides of S2 to monitor the lateral spread of freshwater. With the aim of assessing the freshwater recharge effects, S1 and S2 were also equipped with electrical resistivity tomography (ERT) lines crossing the recharging infrastructure. The ERT lines were 14.4 m long with an electrode spacing of 0.3 m and a maximum investigation depth of 2.5 m. Data were collected on five dates during 2021, two before and three after the drain opening. The freshwater supplied to the farmland caused a resistivity increase at both S1 and S2, with a higher resistivity increase at S1, suggesting a certain effectiveness of the implemented recharge solution.

A sampling campaign was performed at each S location to assess soil hydraulic, physical, and chemical properties. The hydraulic characterization was performed by assessing the soil water retention curves and the saturated hydraulic conductivities on undisturbed soil samples collected in the field at different depths. Moreover, disturbed soil samples were analyzed for texture, pH, EC, organic carbon, and exchangeable cations. The analyses show that the sand fraction increases in the south direction, while the clay content is almost constant. The average pH is around 7.5 in all stations, except for S5 which is characterized by a greater acidic peat content. The amount of exchangeable cations varies along with the EC, with a lower amount found inside the paleochannel, and higher content at S5.

The sampling campaign consists also of the collection and analysis of groundwater samples (EC, pH, cations, and anions) to assess the degree of groundwater contamination and the salinization source. The results show that the experimental site is strongly affected by saltwater contamination, and two major contamination dynamics were identified: seawater intrusion and the interaction between the peaty soil and salts that were originally in place before the area reclamation.

Crop traits and yield monitoring

The pilot site was cultivated with maize during the spring-summer periods of 2019, 2020, and 2021. The crop status was assessed through biomass samplings and analyses (biomass nitrogen %, total humidity, and dry weight, grain nitrogen %, protein %, fat %, and starch %) performed at the S locations and yield monitoring. The biomass analyses show that the nitrogen fraction decreases during the growing seasons according to maize phenological stage, while the grain analyses show differences between the monitoring locations. At the end of each growing season, the maize yield was monitored with a Claas yield monitoring system mounted on a Lexion 750 TT. The obtained yield maps show that lower productions were obtained in the southwest part of the experimental site because of the high sand content and deep water table. On the contrary, higher productions were found in the central-east part of the site.

Hydrogeological monitoring (groundwater, sea level, and surficial waters)

The aquifer system was monitored through 18 piezometers of which five 2-m deep and nine 10-m deep were installed in the phreatic aquifer, three in the locally confined aquifer, and one in the confined aquifer. Electrical conductivity, temperature, and pressure were monitored through vertical profiling and measurements at a fixed depth using CTD Divers. The piezometric head was obtained through barometric compensation of pressure (Figure 5).

Sea level data were obtained from the Chioggia tide gauge station and analyzed to verify possible correlations between groundwater and sea level dynamics.

Figure 5. Monitoring activities at the pilot site.

Surficial waters salinity was monitored at 5 monitoring sites located in Brenta and Bacchiglione rivers, Morto channel, and at the inflow of the Casetta pumping station. The results show that Brenta and Bacchiglione are affected by the tide encroachment that causes seawater intrusion from the river mouth. The artificial Morto channel is protected from high tides by a system of gates named Porte Vinciane. Three main hydrological dynamics were identified. (i) Dry periods with high tide and Morto channel gates closed: the saltwater flows through the lagoon and the river mouths into the aquifers, while Morto channel remains fresh. The leaching from the latter is negligible. (ii) Dry periods with low tides and gates opened: Brenta and Bacchiglione freshwater leaks into the aquifers mitigating the salinity of the north-easternmost sector of the area. (iii) Wet periods with intense precipitation, high/low tides, and opened/closed gates: EC decreases in the uppermost layer or in the whole aquifer, but the freshening lasts for a few days. The confined aquifer is not influenced by rainfall events.

2.1.4 Numerical modeling

2.1.4.1 The flume experiment

The flume experiment performed in the lab was analyzed in terms of numerical modeling using the SUTRA code. After setting up the model, numerical simulations were run to test the efficiency of a number of saltwater intrusion dynamics: artificial recharge, free intrusion, and drought periods. The recharge experiment begins with 24 h of saltwater intrusion after which the saltwater wedge is established. After that, the freshwater recharge starts. The results show that the effect of the freshwater recharge on the vertical displacement may differ due to the presence of local heterogeneities. Moreover, the freshwater injected is effective only if reaches the wedge without lateral or towards inland dispersion. Artificial freshwater recharge results are effective in stopping the progression of saltwater edge, but not suitable to push it backward.

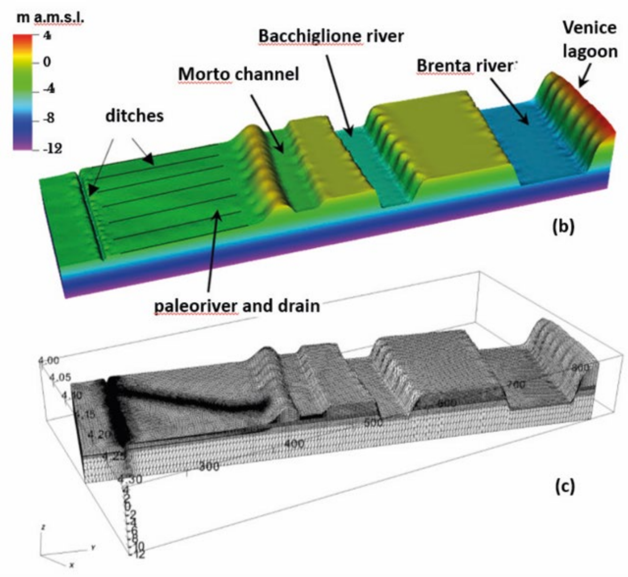


Figure 6. The three-dimensional finite-element density dependent flow and transport model at the field scale.

2.1.4.2 The experiment site at the field scale

A three-dimensional finite-element density-dependent flow and transport model was developed to simulate the field-scale dynamics of saltwater intrusion and to assess the potential effects of the recharge infrastructure (Figure 6). After setting up the model, the simulation consisted of three phases: (i) steady-state analyses for model initialization, (ii) transient analysis to investigate the effects of the main natural factors forcing the system dynamics using the output of (i) as initial conditions, (iii) transient analysis of the recharging drain effects using the outcome of (ii) as initial conditions. The results show that effective precipitation, water level, and watercourse salt concentration are the main factors driving groundwater and salt dynamics. When the freshwater recharge was simulated, its effects involved the whole sandy paleochannel, with the freshwater moving southward due to the natural hydraulic gradient. The effect of ditches was also noticeable. The results suggest the effectiveness of the installed recharge infrastructure in improving the water quality in the whole paleochannel, but without significant effects in a wider area.

In addition, a 3D finite difference salt-water intrusion model was developed with SEAWAT software with the aim of testing the influence of lagoon, Brenta, and Bacchiglione levels on the propagation of the saltwater wedge over a long-time window.

2.1.4.3 The experiment site at the local scale

This modeling activity aims to characterize water and solute dynamics in the vadose zone of the pilot site. The numerical model Hydrus-1D was used to simulate water flow in the MoST agricultural area as it can account for plant water uptake. The data collected in the field (e.g., soil water content) were used to calibrate the model and simulate the water dynamics at the monitoring locations (S).

2.2 The Croatian pilot site

The Neretva valley is an important agricultural area where citrus fruits are mostly grown followed by watermelons, plums, olives, and vegetables. In the past, the Neretva area was wetland surrounded by the hydrophilic vegetation. The most intensive transformation occurred from the 1950s to the 1980s when modern land reclamation began and was essentially completed. The reclamation method is called “jendečenje” (creation of small canals) and consists of digging canals and removing sediments from them to obtain material for filling moist soil. Moreover, in the 1960s the drainage of Lake Modrič and the construction of the coastal embankment Diga began and it still represents 1800 m long dividing line between the valley and the sea, from the mouth of the Neretva to the mouth of the Mala Neretva. Then, channel system and pumping stations for drainage of the areas surrounding Opuzen Ušće and Vidrice were constructed. In the area of Opuzen Ušće, channels converge towards the intake basin of the Modrič pumping station that pumps water into the sea at the mouth of the Mala Neretva maintaining favourable water table in the shallow unconfined aquifer. Drainage of the Vidrice area is maintained by the pumping station Prag that pumps water into the Mala Neretva, which then flows into the sea. The Mala Neretva represents a freshwater retention basin for irrigation and its regulation is carried out by two sluices: the upstream gate is located in Opuzen and is closed for most of the year to preserve the water quality of the Mala Neretva, while the downstream sluice is located at the mouth of the Mala Neretva to regulate the water level and prevent the intake of salt water upstream. After the construction of the water management infrastructure, the natural water regime changed. Due to the groundwater level lowering, the inflow of the sea water towards inland enhanced. As a consequence, additional effort has to be given to ensure the water quality conservation to preserve the agricultural production.

The sea water intrusion that causes salinization of water and soil along the Neretva valley is shown to be influenced by different external loadings and conditions specific for this area.

Besides the oceanographic, hydrological, climatological and meteorological conditions, the operational regime of water management system leads to more complex and dynamic spatio-temporal changes in the salinity of both ground and surface water.

2.2.1 In situ investigations and site characterization

One of the main goals was the litho-stratigraphic definition of the aquifer system of the Opuzen Ušće and Vidrice including a number of field activities, application of geoelectrical tomography (ERT), seismic reflection, geoelectric probes, exploratory wells, laboratory processing of extracted samples, and application of geophysical method based on the concept of electromagnetic field (AEM). By combining different methodological approaches, the goal was to increase the reliability of the results and provide prerequisites for the development of a numerical model of saltwater intrusion into the coastal aquifer and thus increase the capacity of predicting the salinization of the project area. Tomographic profiles demonstrate the field of the resistance interpreted by taking into account the properties of both aquifers and groundwater for the depth of up to 200 m where bedrock has been detected. The transition zones from one stratigraphic unit to another were determined by using seismic reflection while the borehole logs were used as a first order data to calibrate the results of geophysical methods. Unlike conventional geophysical methods, AEM was applied for the first time in the project area and

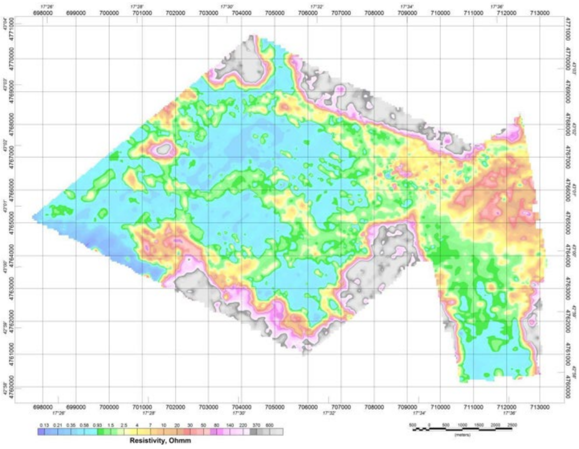


Figure 7. Resistivity field performed by AEM application interpretation depth of 20 m.

represents the only method that allows a spatially continuous description of resistance within the project area (Figure 7).

2.2.2 Monitoring activities

A real-time monitoring system of surface water and groundwater was established and 36 different variable time series were collected on a server and are now available via the MoST mobile app.

Two probes were implemented in the shallow aquifer to ensure the capacity to monitor the state of water in conditions of pronounced salinity stratification. The development, implementation, and improvement of the system enables the analysis of processes affecting water quality, its dynamic properties, and spatial variabilities (Figure 8).

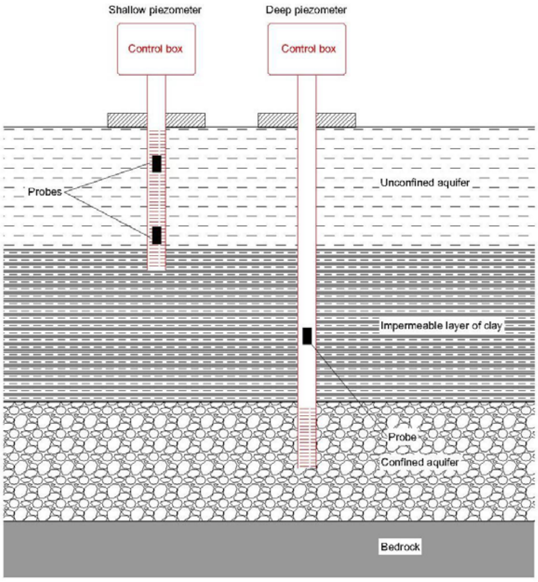


Figure 8. Schematic view of the monitoring infrastructure implementation.

2.2.3 Laboratory modeling

The salinity conditions within the project area have been modeled under laboratory conditions (Figure 9). In addition, the impact of climate changes has been examined through the projected sea level rise as well as the impact on the salinity status of the water in the area of interest.

Moreover, the effectiveness of mitigation measures to protect the coastal aquifer from saltwater intrusion (SWI) induced harmful effects has been tested in the laboratory. This includes solutions such as an injection barrier along the Diga profile and construction of a recharge channel along the left bank of the Neretva, from the location of the future barrier to the sea. Given that the conditions of active seawater intrusion were detected in the project area, the barrier at Diga has not been shown to be an effective mitigation measure. On the other hand, the recharge channel in terms of functionality and water quality improvement has been classified as a very successful protection measure.

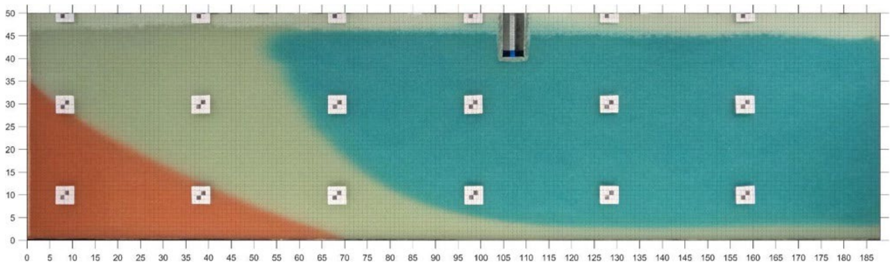


Figure 9. Laboratory experiment result of active seawater intrusion with recharge channel implemented.

2.2.4 Numerical modeling

For the purpose of assessing the water quality under the conditions of climate change and implemented mitigation measures within the GMS environment, a dual-density numerical model has been implemented to simulate the spatio-temporal properties of the water salinity along the project area. For appropriately selected boundary and initial conditions, the calibration procedure lead to the determination of the model parameters, after which the model was validated with data from the monitoring system. The forecast of an 84 cm mean sea-level increase (IPCC; RCP8.5) indicates a visible deviation from the existing salinity status and an additional threat to agricultural production (Figure 10). By implementing a recharge channel on the left bank of the Neretva River downstream from the location of the future barrier, model results indicate a significant and long-term improvement of water status in the catchment, indicating the suitability of the solution and the need for further technical solution development.

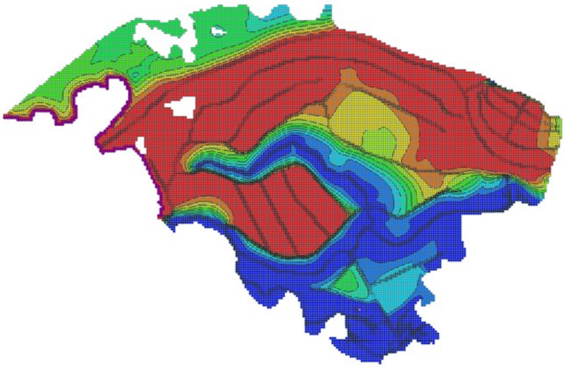


Figure 10. Salinity distribution characterizing the shallow aquifer for 84 cm increase of the mean sea level.

2.2.5 Mitigation measures and effectiveness

A number of mitigation measures to improve water quality status and reduce the intensity of saltwater intrusion to the coastal aquifer system of the Neretva Delta have been tested. The analysis of rainy and dry periods identifies different seawater intake corridors. While the SWI is predominantly achieved through the coastal embankment Diga in the length of 2.0 km the rainy period, during the dry season the

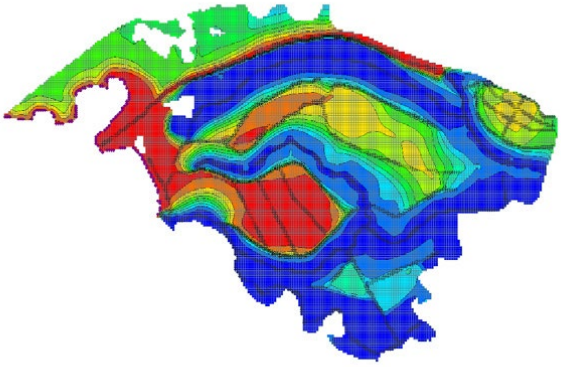


Figure 11. Salinity distribution of the shallow aquifer in case of barrier implementation into the river Neretva and recharge channel along the left Neretva bank.

dominance of sea water in the Neretva river bed is detected, turning the river into a source of salt water. After the implementation of the injection impermeable barrier along the Diga, the reduction of SWI into the coastal aquifer is improved. Given the fact that the process of SWI in the project area is active, it is necessary to intervene on the left bank of the river Neretva. This intervention drastically improves the state of water in the project area and represents a systematic and unique solution for protection against the harmful effects of the seawater (Figure 11).

2.2.6 Summary of project activities and results at the Croatian pilot site

The implementation of MoST project activities lead towards the increase of knowledge about the processes influencing ground and surface water salinity along the Neretva valley. Furthermore, MoST enabled to increase the preparedness level for the climate changes response and adaptation. The main contribution of MoST outcomes are:

- Real time monitoring of ground and surface water bodies was established and implemented. Datasets and time-series observed are available via the MoST mobile application and can be used to follow up water quality parameters and for decision making on irrigation activities.
- The litho-stratigraphic definition of the pilot site aquifer system was determined. A multi-method based geophysical, geotechnical, and laboratory approach was applied to identify different geological layers, transition zones, hydraulic conductivity, effective porosity and their spatial heterogeneities.
- Taking into consideration prognostic scenarios of climate changes, impact on water

bodies along the project area was forecasted applying numerical models. Salinity increase trend was recognized as well as the decrease of water quality parameter values, which present a relevant threat to local agricultural production.

- Primary scope of mitigation measures application is to protect the coastal aquifer system from the negative effects caused by SWI. Systematic analysis of mitigation measures effectiveness through laboratory and numerical modeling activities highlighted positive effects. The implementation of both climate change and mitigation measures offered detailed insight into the water quality recovery and its spatial peculiarities (Figure 12).

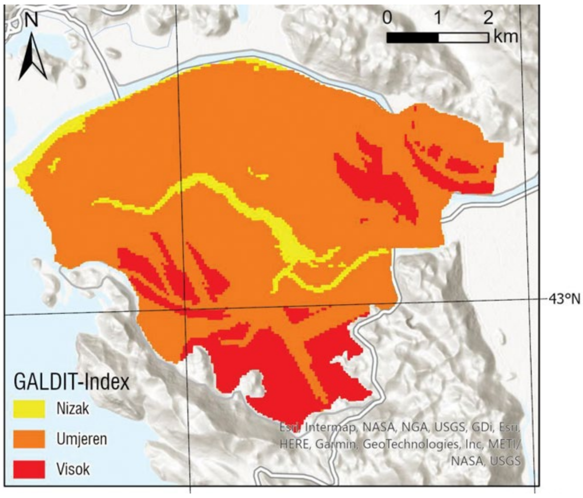


Figure 12. SWI vulnerability definition for climate change projections and implemented mitigation measures.

3. CHANGE WE CARE project

The CHANGE WE CARE project aimed to develop specific instruments and measures to address local environmental and socio-economic priorities at the five Pilot Sites Neretva River, Jadro River and Kaštela bay, and Nature Park Vransko Lake in Croatia, Banco Mula di Muggia and Po River Delta in Italy. Adaptation/management Plans are issued with the contribution of local stakeholders, following the principles of the ICZM and MSP, in order to increase the resilience to climate change impacts. In each Pilot Site, adaptive methodology studies are carried out addressing the key socioeconomic aspects of anthropic activities and defining the most important ecosystem services.

3.1 The Neretva river pilot site

The area of the Neretva Delta ecological network belongs to the Mediterranean region and is recognized as a climatic hotspot. The effects of climate change are particularly strong so that an average increase of 1.5 °C has already been reached. Neretva Delta is one of the most valuable wetlands on the eastern Adriatic coast and one of the rare remaining wetlands in the European Mediterranean. For this reason, the development of the Adaptation plan, which defines the strategy for adaptation to climate change, is extremely important for the future of the Neretva Delta.

3.1.1 Methodology

A detailed analysis of the existing literature was the first step toward the development of the Adaptation Plan. The workshop was chosen as a basic participatory technique to involve as many stakeholders as possible in its development. The design phase included the choice of an ideal participatory approach method, the definition of workshop programs, as well as the identification of potential stakeholders. The implementation phase followed the design phase, with three participatory workshops, each of which has a specific objective.

3.1.2 Activities

The key activities were the organization of three participatory workshops and the implementation of four research projects: (i) *Research on physico-chemical factors as potential drivers of climate change in the ecological network River Neretva Delta* (HR5000031), (ii) *Mapping of target fish species in the area of the ecological network Neretva Delta* (HR5000031), (iii) *Fishery management study of ecological network Neretva Delta* (HR5000031) and (iv) *Socio-economic analysis of the fisheries sector in the River Neretva delta* (Eastern Adriatic coast, Croatia).

The project (i) consists of a research on physico-chemical factors that are climate change drivers in the protected ecological network River Neretva Delta during July 2020-June 2021 as a basis for comparison with historically available data. Moreover, the impact of physico-chemical changes, mainly temperatures and salinity, on the recent status of the native ecosystems were assessed. The main goal of project (ii) was to map fourteen target key fish species and to propose new levels of endangerment, main threats and necessary measures to improve the status of target species. Project (iii) aimed to evaluate the potential development of freshwater sport fishing in the ecological network, from the aspect of economic benefits for the future fishing license holder and restrictions arising from ecological network protection principles. Finally, project (iv) focused on the position of local fishery in relation to other economic activities over the past three hundred years and provide an overview of this activity today and its perspectives in terms of expected climate change.

The workshops brought together a large number of local stakeholders from the civil, private, and public sectors and improved the preliminary document and the Action Plan for adaptation to climate change. The first one *Effects of climate change on the Neretva delta* took place at the Metković City Library on 30 March 2021 and included a discussion on the key challenges of this area, on measures and definition of climate change by stakeholders. The second workshop *Adaptation measures to different climatic scenarios for the delta Neretva* was held at the City Library in Opuzen on 30 August 202. Participants discussed potential objectives, measures, and activities in adapting to climate change. The third workshop *Action Plan for adaptation to expected climate change in the Neretva delta* was held on 20 September 2021 at the Public Open University in the city of Ploče and stakeholders actively updated the existing action plan for adapting to climate change.

3.1.3 Main results

According to the results of the first workshop, the vision of the ecological network of the Neretva Delta in adapting to climate change is *Symbiosis of river and people*. The vision of adaptation to climate change is elaborated through a hierarchy of goals and measures. In line with the vision, the following five goals were defined: (i) preserved and adaptable ecosystem, (ii) Sustainable management of aquatic ecosystems, (iii) Improving the functionality of important ecosystems, (iv) Sustainable and resistant economy, and (v) Aware and proactive population.

3.1.4 Transferability

The results of this project will serve as the basic strategic document for climate change adaptation of all local and regional self-government units in the Neretva Delta. Climate change is a threat to the future survival of this area and all results represent key contributions to improving climate change monitoring, as well as to improving adaptation to future scenarios.

3.2 Jadro river pilot site

3.2.1 Methodology

The Adaptation Plan For Jadro River aimed to transfer common knowledge on the current and expected dynamics of coastal systems in the area of Jadro river. It was developed taking into account the results of work packages 3 and 4 and the participatory process itself, including joint vision, objectives, measures/actions/interventions, possible resources/funding, and roles and responsibilities for its implementation after the completion of the Change We Care project.

3.2.2 Activities

The Plan development was carried out through participatory processes to ensure that all information is gathered, joint decision and stakeholder consensus is reached. Participatory workshops for the Jadro River and Kaštela Bay Pilot Area covered three topics: Climate change impacts, Scenarios and adaptation measures, and Planning options. In addition, the process of Plan development included participation in project training, presentations at project conferences and info days.

3.2.3 Results

The Plan describes the current state of the pilot area, the knowledge gathered during the participatory process, the vision for the pilot area and derived goals, measures, and activities. The document ends with monitoring indicators and examples of potential projects. The Plan mainly focuses on water management and urban development and thus proposes an integrated approach for the management of natural-urban river basins. In addition, the Plan analyses the state of the Jadro River Basin in the climate change scenario and proposes measures and activities aimed at maintaining and improving the life quality in the area.

In the area of the topographic basin, the settlements Solin and Klis are growing in terms of population and urbanization although the urban development is not accompanied by the construction of wastewater-rainwater drainage systems and waste disposals. For these reasons, waters are under constant threat of pollution. Including the planned zones, the ratio of natural and artificial areas in the topographic basin is 62% of natural versus 38% of artificial areas. Such a large share of artificial surfaces leads to the need of an integrated management of the river basin and urban areas through the application of a urban design sensitive to water, green city, and sustainable development.

3.2.4 Project result transferability to similar contexts

In order to transfer the knowledge from this Plan into development plans and documents, the first step is to present the Plan to the local government to the Mayor and City Council of Solin and Klis. The first meeting was planned for February 2022 in order to take and coordinate the steps needed to implement the proposed measures of this Plan. There are several calls for projects with the aim of "green transition" and the idea is to apply for projects together and thus achieve a synergy of forces and an integrated approach to management. Most of the Croatian coastal cities have an underdeveloped stormwater drainage system and hilly areas. Therefore, any experience in analyzing the needs for green infrastructure, planning and preferably implementing is highly transferable for any Croatian coastal city.

3.3 Nature Park Vransko Lake Pilot Site

3.3.1 Methodology

The adaptation plan for Nature Park Vransko Lake focuses on a broad range of adaptation to climate change problems (temperature rise, sealevel rise, precipitation level low) and to particular challenges such as salt water intrusion and nutrient discharge, and eutrophication. The first step was a better understanding of the state-of-the-art through surveying, organizing, and gathering data and information on the physical, geological, and ecological status of the Pilot Site. Effective joint actions and adaptation measures were planned and developed in cooperation with competent authorities and discussed with identified stakeholders.

3.3.2 Activities

The emphasis was on the systematic collection of information about climatic processes that trigger physical, biogeochemical, morphological, and biological changes. In addition to the reports that analyze the data collected about the impact of climate change on the lake, future monitoring of water and air quality was planned.

3.3.3 Results

The climate change Adaptation plan resulted from communicating with many diverse stakeholders and the local community by involving them through several workshops, surveys, and interviews. The emphasis in the adaptation plan was placed on methods of returning carbon back to the soil. The plan elaborates in detail the possibility of implementing a pilot measure for carbon production in the Vrana Lake Nature Park area and its surroundings. The conceptual solution of regenerative agriculture to adapt to the effects of climate change in the Jasen area proposes the revitalization of floodplain meadows and extensive livestock on the principle of rotational grazing, planting flower strips and windbreaks, establishing plantations of tame asparagus and artichokes and short-range crops for wood chips.

3.3.4 Transferability

The Project outputs consist of climate change Adaptation, Action, and Monitoring Plans for the Pilot Site. Training activities have enabled technical and administrative operators to take full advantage of the data and protocols made available by the project. Dissemination events and workshops have increased the stakeholders and community awareness on CC impacts and on the existence of adaptation measures tailored on their needs. The established network for sharing data and procedures will maintain an efficient monitoring activity, allowing the continuous assessment of the Adaptation Plans outcomes in the face of the ongoing climate change impacts.

3.4 Banco di Mula di Muggia Pilot Site

3.4.1 Methodology

The pilot site Mula di Muggia is really sensitive to sea-level rise and storm patterns. Two contrasting elements, such as an area for marine tourism development and a Natura 2000 site, coexist in the same area. Change We Care helped to understand the sediment dynamics in the pilot site test. Land subsidence and sea level rise were compared and coastal vulnerability scenarios were defined. Different flooding models for RCP scenarios were obtained by imposing the respective sea level rise values on the model. Thanks to the historical analysis and more recent data collection, areas with varied morphosedimentary characteristics and with distinct tourist-recreational, ecological, and conservation values have been identified and mapped. The map emphasizes how coastal areas have been developed without considering their inherent characteristics, in the absence of ICZM or coordinated coastline management guidelines. The activation of Participatory Processes at the local level is an excellent way to identify and co-design options and solutions to be developed in the future. The structure of the participatory process, organized in public and restricted phases accompanied by non-technical reports gave excellent results providing an orientation for future decisions.

3.4.2 Results

“Living with nature” is a solution driven by natural trends and a fundamental guideline for a correct human use, thus forcing us to a responsible and sustainable development. This allows to limit possible impacts of definitive choices, as those following hard engineering philosophy. Possible options should be configuration regimes aimed at beach nourishment or morphological reshaping. The strategies for the future of the Grado area should focus on the monitoring and evolution of the sand bank area, on the adaptation of the infrastructures and use to the natural evolution, and on the eventual implementation of light interventions that can adapt to natural evolution.

3.4.3 Transferability

The philosophy of knowing in order to plan and design must become a habit. The experience of the Banco Mula di Muggia suggests the transferability of the decision-making process, starting from the integration of missing knowledge up to the use of innovative systems for scenario simulations. In this process, close collaboration between public administrations and research centers is fundamental. The cost / benefit ratio suggests that the structure of the participatory process should be transferred to many other cases.

3.5 Po River Delta Pilot Site

The Po Delta represents the final sub-basin subtending the entire hydrographic basin of the Po River, and it develops as a flat region with an area of 472.55 km^2 (1.6 % of the total hydrographic basin). In this area, the Po River is divided into several branches: Po di Levante, Po di Maistra, Po di Pila, Po di Tolle, Po di Gnocca in the Veneto Region, and Po di Goro, which is part of the Emilia-Romagna Region. The Sacca of Goro lagoon is a shallow-water lagoon in the Po Delta, with an average depth of approximately 1.5 m, which receives freshwater inputs from the Po di Goro branch and the Po di Volano artificial canal. Most of the population works directly in the pilot site being involved in the fishery or in its satellite activities such as the transformation of fish products. Despite the economic value, the area of Sacca di Goro suffers from a low schooling rate and not adequately developed tourism.

3.5.1 Methodology

A participatory process was planned with the aim of involving as many stakeholders as possible in the development of actions for climate change adaptation. The participatory process in the Sacca di Goro consisted of 3 workshops, each one including a plenary section and 4 parallel sections based on the stakeholder target (fisherman, tourist and economic operators, educational bodies, and public bodies). The participatory process also included two phases of research and development by the technical staff of the project in order to contrast/mitigate/solve the critical issues pointed out. A communication campaign and information actions were planned before and after each participatory workshop in order to involve stakeholders and disseminate project activities and results.

3.5.2 Activities

During the first workshop, different stakeholder groups were composed in order to point out the perceived criticisms, prioritizing them and identifying the main objectives to be contrasted or solved. The tools proposed to facilitate this process included the construction of descriptive posters asking clear questions in order to collect the chair's answers. During the second workshop, project researchers and technicians drafted some ideas or best practices for each issue outed in the target group. Therefore, the presentations and the discussion towards the choice of one or two really feasible practices took place. Impressions and ideas during the debate were collected to better develop these proposals. The project proposals chosen during the second workshop were presented to the stakeholder groups during the third one. Posters and post-its were used to collect suggestions. The method to facilitate the initial discussion on commitments was inspired by the European Awareness Scenario Workshop (EASW) and the elaboration of the EASW graph as a tool for visualizing the discussions.

3.5.3 Main results

The participatory process involved 26 participants in the Workshop I, 28 participants and 10 member staff in the Workshop II, and 31 participants and 11 member staff in the Workshop III. During the first Workshop, the working groups identified critical issues in the Sacca di Goro and defined aims to solve them. During the Workshop II, project technicians showed to stakeholders the projects selected as answers to the critical issues highlighted at the Workshop I. The Workshop III contributed to the awareness of the participants and stakeholders with a presentation dedicated to climate change scenarios focusing on hydrodynamics and specific ecological targets of the Po Delta. The public bodies and competent agencies stakeholders group identified the 1) temporary sand duct, 2) diversor brush, 3) technical table projects; the Tour operators and other competent operators identified the fundraising to climate change project; the Educational institutions and environmental associations group identified the 1) “Nice to meet you, Mrs Eel” educational project and the 2) testimonials for the awareness of citizens and network with associations; the Fishermen and shellfish farmers group identified the 1) establishment of the sacca observatory starting from a coordinated and interrelated database, 2) Bassunsin’s cut and 3) the contrast of the loss of wild seed project.

3.5.4 Transferability

The results collected through the participatory process represent a key contribution from stakeholders to identify real issues related to climate change and to identify local solutions promoted by users themselves.

3.6 Conclusions

The main output is a set of Adaptation/Management Plans for the Pilot Sites, where the shared knowledge base on the present and expected dynamics of coastal systems in the cooperation area is conveyed. These Plans are made with the establishment of participatory processes, transparent, and common decision practices among a heterogeneous community of stakeholders, scientists, policymakers, technicians, and administrative operators that provide a relevant legacy for coordinated management actions in a cross-border cooperation perspective.

Transfer of adaptation measures over different coastal typologies is enabled by the broad representativeness of the Pilot Sites, tackling a variety of most relevant issues as well as the transfer of the methodological achievements that will enable the replication and improvement of this approach, fostering cooperation at different administrative levels up to a cross-border scale.

4. ASTERIS project

The project ASTERIS (Adaptation to Saltwater inTrusion in sEa level RIse Scenarios) is aimed to identify and map water risk management needs and barriers, based on a joint assessment of spatial and temporal variability of seawater intrusion, and to provide practical tools for sustainable management of coastal aquifers at the local scale.

This objective was achieved through a multidisciplinary investigation approach that addresses the complex problem of salinization of coastal aquifers and provides two main outputs: a map of vulnerability to coastal salinization at the macro-regional scale (Adriatic) based on future scenarios for sea-level rise and the hydrological cycle, and guidelines for the management of vulnerable site defined though an analysis of three representative case studies in Italy and

Croatia: Emilia-Romagna Region (Municipality of Ravenna, Italy), Marche Region (Municipality of Fano, Italy) and Dubrovnik-Neretva County.

4.1 Vulnerability assessment to coastal salinization at the macro-regional scale (Adriatic)

4.1.1. Introduction

Italian and Croatian coastal aquifers, on one hand, are subject to groundwater extraction, e.g., to meet tourism pressure and irrigation needs; on the other hand, they are affected by climate change, particularly sea level rise and drought. All these pressures exacerbate salt intrusion, which is often not taken into account in the water catchment management plan. In this context, it is important to understand the potential risk of salt ingression in coastal aquifers.

A conceptual model for the risk assessment to salt intrusion in North Adriatic basin for future scenarios of climate change has been proposed. This work is extended to almost 2000 km of coasts, involving three Countries (Italy, Croatia and the short portion of Slovenia facing Adriatic coast) and including a variety of geological, morphological and also socioeconomical conditions.

4.1.2. Basic structure of the model

The assessment of risk of salinisation has to simultaneously consider vulnerability (that embeds also the probability of occurrence) and the potential loss (defined as economic consequences due to the contamination of groundwater supply, impacts on human health due to well contamination, or multiple consequences on ecological systems). According to Simpson et al. (2014), the equation of risk assessments reads:

Risk (R) = Vulnerability (V) * Loss (L) (1)

where the vulnerability is defined as aquifer susceptibility and hazard threat, and the probability of occurrence is attributed to each hazard threats:

Vulnerability (VA) = Aquifer susceptibility (SA) * hazard threat (TH) (2)

Following the scheme proposed by Klassen, and Allen (2016), the scheme in Figure 13 is proposed for modelling risk of salt ingression in coastal aquifer.

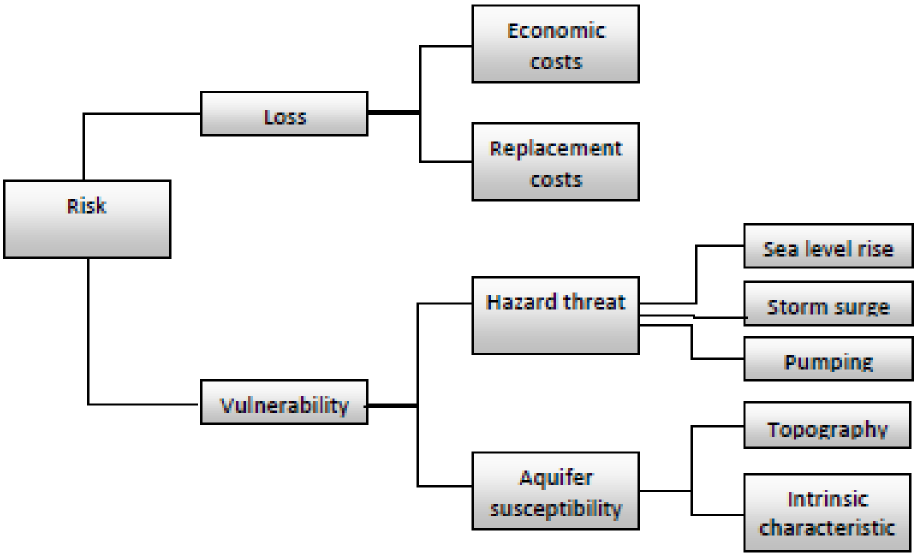


Figure 13. Scheme for modelling risk of salt ingression of coastal aquifers.

For the assessment of each component of SA, HT and L, the parameters contributing to each variable introduced in the model have been associated to a rank (from 1, very low, to 5, very high). The analysis has been performed along a 5 km buffer from the coast to the interior. We used a grid of 1 km X 1 km to analyse and combine the considered parameters.

4.1.3. Assessing vulnerability

4.1.3.1. Aquifer susceptibility

To assess the risk component deriving from aquifer susceptibility, both intrinsic characteristics and topography have been considered. The intrinsic characteristics are based on hydrogeology, and specifically on lithology and aquifer type. For topography, both elevation and distance from coast have been considered.

Different rating were associated to topographic elevation, distance from the coast, aquifer type and lithology to assess the vulnerability.

4.1.3.2. Hazard threats

For hazard threats, information on sea level rise and storm surge projection is introduced in the model. In analysing hazard threats it is also necessary to include pumping.

Sea level rise is a key parameter in analysing salt ingression in coastal aquifer, since it will move the transition zone of freshwater and saltwater inland, increasing the risk of saltwater intrusion for inland wells (Eriksson et. Al, 2018). The long-term sea-level variations at a given place and time stem from the combination of several contributions, which were modeled according to state of the art procedure (Figure 14).

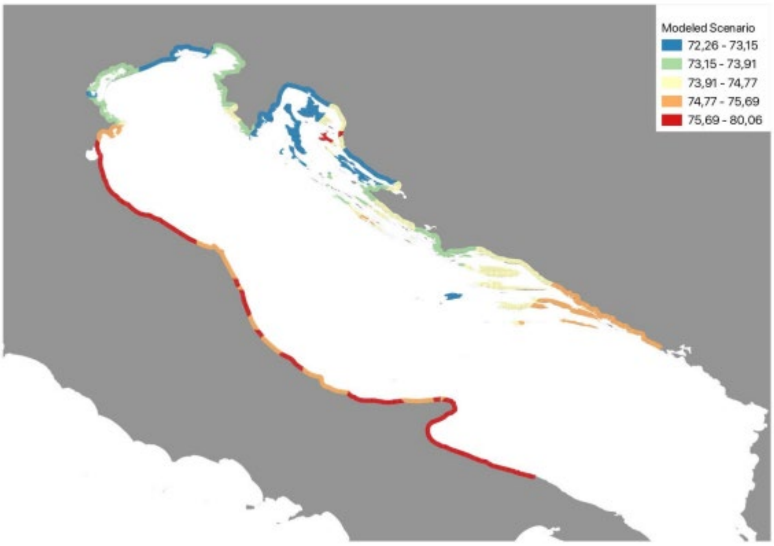


Figure 14. Model based sea-level scenario.

Storm surges are an important coastal hazard component and their contribution to salt intrusion in coastal aquifer is relevant. Nevertheless, the evolution of sea level storm surge along coastline in view of climate change, is not well known. This study modeled the return period which is commonly used for risk analysis when associated to design of structure or utilities, or, as in our case, with planning of use of resources.

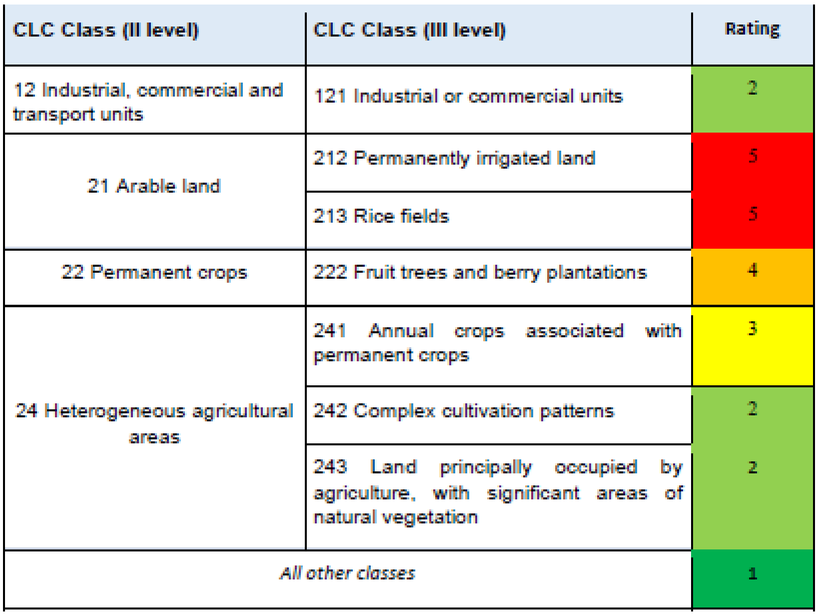
Pumping from coastal aquifers alters the natural equilibrium between seawater and freshwater. For this study, following the methodology proposed by Kennedy (2012) and refined by Klassen et al. (2016), we used well density per grid unit and volume of water extracted per day. Since the information on volume extracted are not always available, following a precautionary approach, the rating is assigned to the worst situation between well density and water extracted.

4.1.4. Economic loss

Economic loss represents the economic consequences due to contamination of water supply. These could include different aspects, as impacts on human health or consequence to ecological systems. The main economic loss for contamination to groundwater resources are related to: i) economic cost associated with damage to intensive business (mainly agriculture); ii) costs to replace/restore water resources.

The Corine Land Cover (CLC) map, which classifies soil uses, has been utilized as a basis for the analysis (Table 1). Between the CLC classes, those which implied a potential use of water in agriculture and in industry, have been associated with a rank for the hazard.

Table 1. Ranks for Loss assessment.



CLC Class (II level)	CLC Class (III level)	Rating
12 Industrial, commercial and transport units	121 Industrial or commercial units	2
21 Arable land	212 Permanently irrigated land	5
	213 Rice fields	5
22 Permanent crops	222 Fruit trees and berry plantations	4
24 Heterogeneous agricultural areas	241 Annual crops associated with permanent crops	3
	242 Complex cultivation patterns	2
	243 Land principally occupied by agriculture, with significant areas of natural vegetation	2
All other classes		1

4.1.5. Regional High-Resolution Map of Vulnerability

Based on the results of the conceptual model of the risks, the map in Figure 15 shows the Adriatic coastal aquifers vulnerability to salt ingression according to different scenarios of climate change. The map represents a tool for the administration in the decision of authorising further water extraction and in comparing different locations.

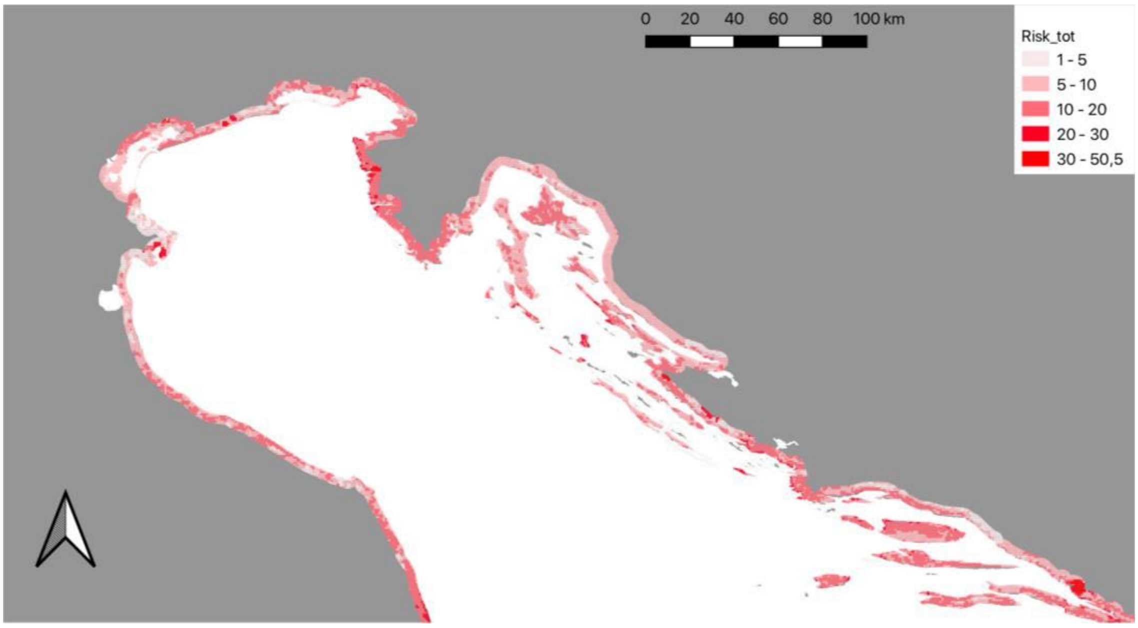


Figure 15. Map of vulnerability.

4.2. Local scale representative studies

4.2.1 Fano

The study area is in the lower part of the coastal plain of the Metauro river, close to Fano, Northern Adriatic Sea (Italy). It is included within a sedimentary valley and comprises a 10 km wide strip of land parallel to the coast with an extension of about 60 km^2 (Figure 16). The riverine hydrographic system includes the course of the Metauro River and a secondary network of drainage channels. The Metauro drainage basin has a total extension of about 1400 km^2 and is the largest one in the Marche region.

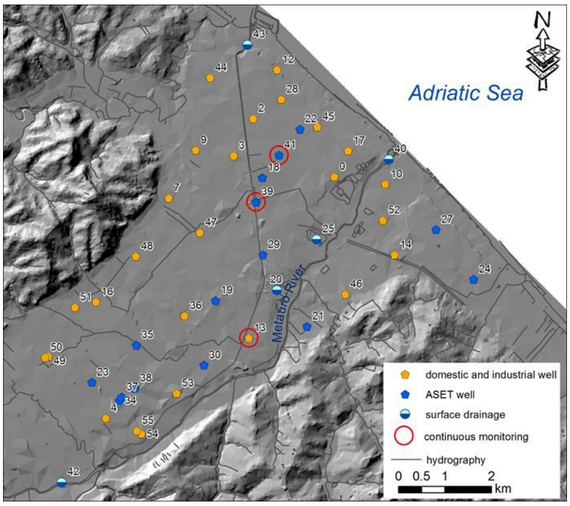


Figure 16. The study area of Fano with the location of the monitoring network.

4.2.1.1. Geochemical characterization of the near-surface aquifers

Monitoring campaigns (Figure 16) were carried out considering opposite hydrological regime conditions, wet and dry seasons (June 2019, September 2020 and November 2020). Three main groups of waters with different compositions have been identified: 1) the Ca-HCO3 composition; 2) the Ca-Cl facies; 3) (Na+K)-HCO3-Cl facies. These three groups reflect the lithological type and the main geochemical processes that characterize the shallow aquifer in the coastal area of Fano. The chemical quality of the groundwater system is mainly determined by the interaction of water with carbonate and silicate minerals. Some secondary processes overlap: i) the input of N-rich pollution, which affects a large part of the study area; ii) the interaction of groundwater and clayey evaporite minerals of the substrate, which have favored the increase of Cl concentrations in some wells; iii) ion exchange processes were invoked when Na-HCO3 and Ca-Cl water were found, albeit very locally.

4.2.1.2. Processing and mapping of geostatic data

Geostatistical data processing was performed to develop iso- piezometric level and iso-EC maps for opposite hydrological regime conditions (Figure 17). Piezometric maps show that the Metauro River drains the aquifer system in the central part of the study area during all survey periods. From the central area down to the coast, the relationship between the river and the aquifer varies depending on the hydrological regime: i) in wet seasons, characterized by higher piezometric values, the river drains the aquifer almost to the coast; ii) in dry seasons, the river is either in equilibrium with the aquifer or even feeds it. Finally, the piezometric maps also clearly show the effects of artificial recharge of the aquifer by water from Metauro River in the sector SW.

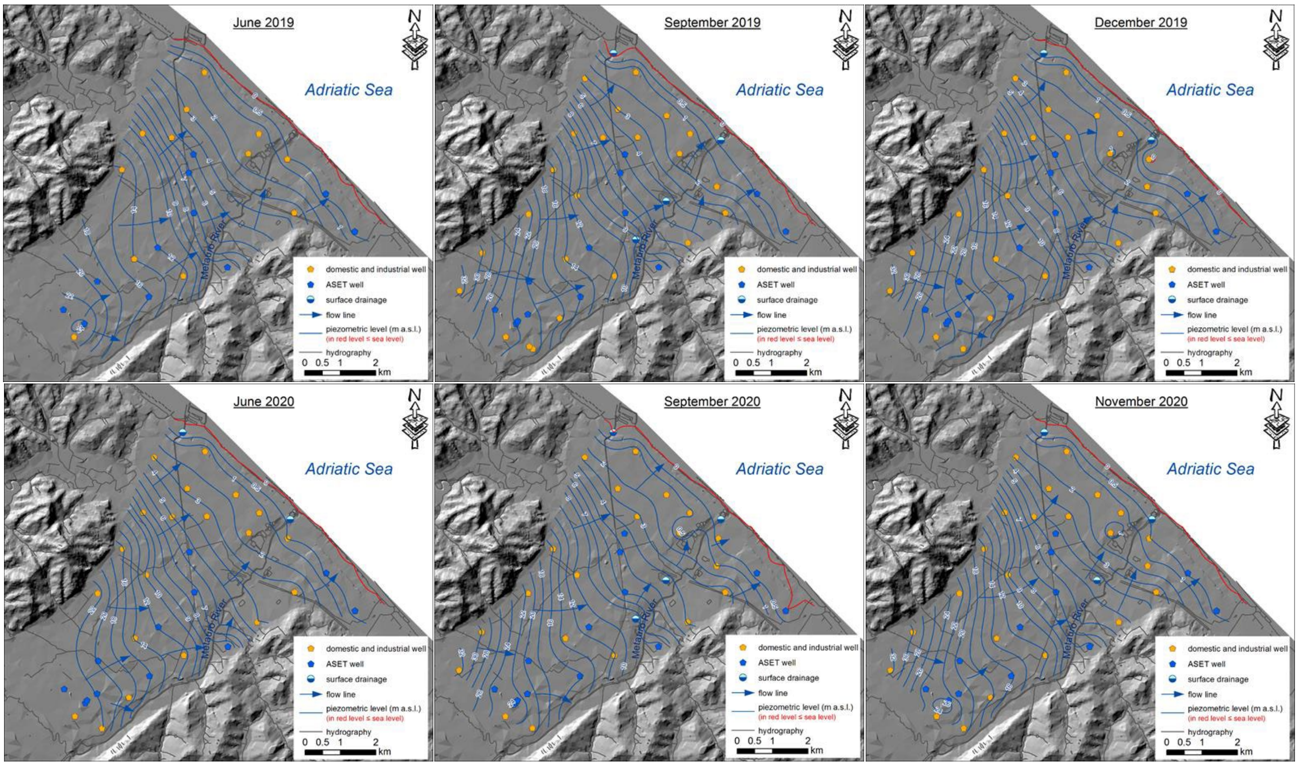


Figure 17. Piezometric level maps for June 2019, September 2019, December 2019, June 2020, September 2020 and November 2020

The iso- EC maps are shown for December 2019 (wet season) and September 2020 (dry season) in Figure 18. In December 2019, the EC values were relatively low (< 800 µS/cm over most the studied area), thus indicating the local rainfall recharge effects during the wet season. On the contrary, in September 2020 the low EC values extended to form a sort of plume, which starts from the group of wells used for the aquifer artificial recharge (#34-37-38) following a SW-NE direction down to the shoreline. Close to this plume, the EC rises up to values over 1500 µS/cm, indicating the presence of natural or anthropic processes, likely responsible of the registerd salinity increase. As a whole, the EC arrangement suggests a groundwater dilution generated by the injection of the Metauro River (#42) waters by the artificial recharge wells into the shallow aquifer.

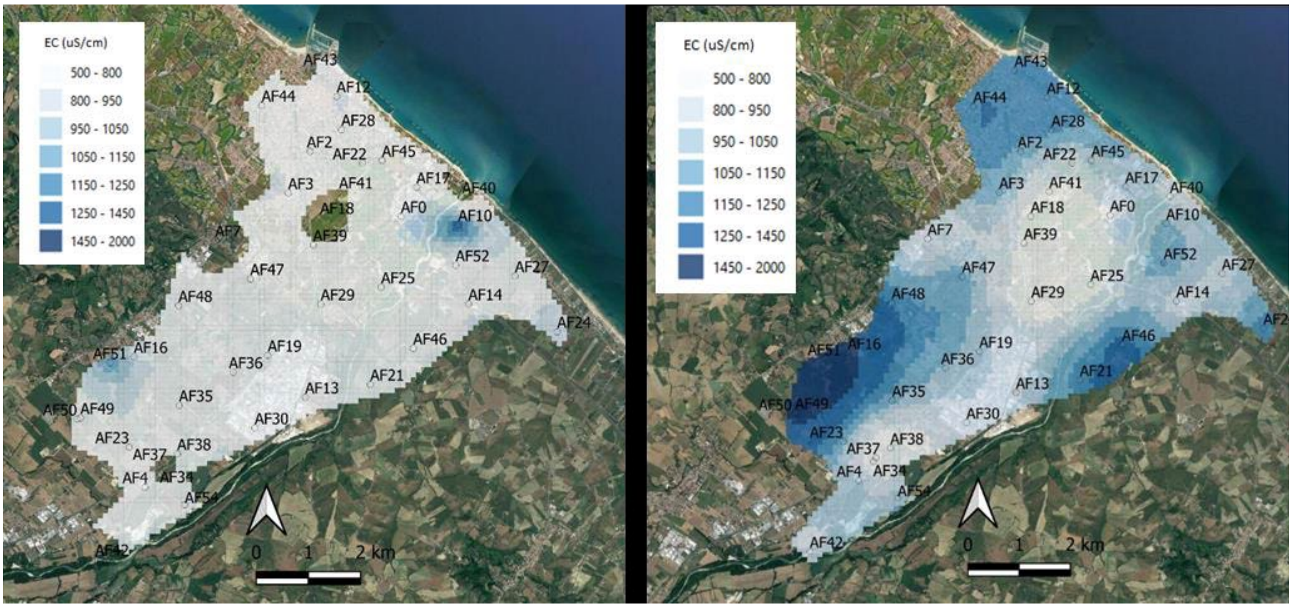


Figure 18. Iso-conductivity map generated by Ordinary Kriging for December 2019 (left panel) and September 2020 (right panel). Values in µS/cm.

4.2.1.3. Flow and transport models

The conceptual model of the natural system, which was preparatory to the development of the numerical model, is based on geological, hydrogeological, physical-chemical and geochemical-isotopic data (Figure 19).

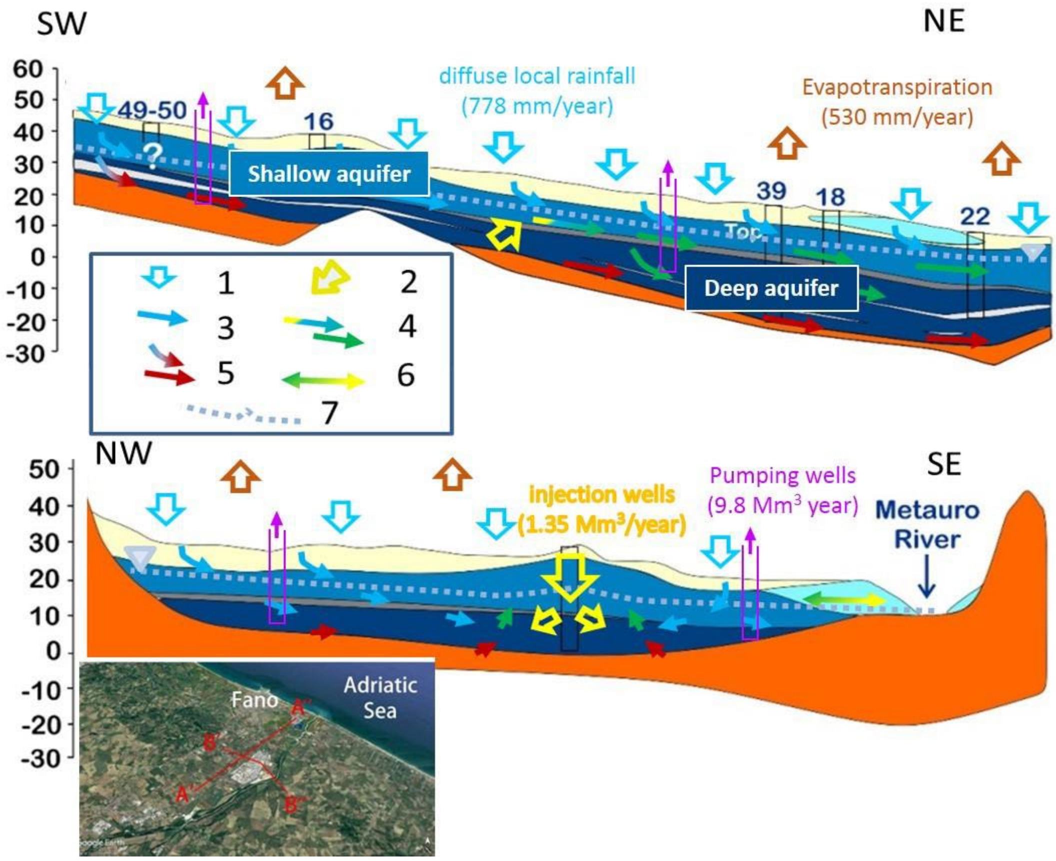


Figure 19. Schematic quantitative conceptual model of the Fano coastal aquifer system: 1: local rainfall infiltration; 2: Ca-HCO3 water of the Metauro River artificially injected in the aquifer; 3: Ca-HCO3 groundwater mainly fed by the infiltration of local and hills-surrounding rainfall ; 4: result of mixing between the component locally generated by rainfall and the component from artificial recharge; 5: chemical evolution resulting in Cl contents increasing due to groundwater interaction with the substratum; 6: exchanges between Metauro river waters and groundwater; 7: piezometric profile.

Based on the conceptual model of the aquifer system, groundwater flow models were implemented using MODFLOW-2005 and MT3DMS, SEAWAT and PEST related codes; Groundwater Vistas (v7) was used as graphical user interface. Initially, a steady-state flow model was created and calibrated. Based on this model, a transient flow model was then created for

2019 and 2020 with monthly stress periods. Finally, a TDS transport model was realized in order to simulate scenarios of sea level rise and/or changes in climate conditions and/or increased water demand.

Modelling activity produced flow and transport models representative of the natural aquifer system. A 100-year simulation with a sea-level rise of 1 m was elaborated as an example. Considering that the piezometric level is currently well above sea level, with values above 1 m even in the nearshore area, a sea level rise of 1 m does not appear to have a direct effect on the aquifer, although a slight overall increase in TDS content is expected. However, the area that appears to be strongly affected by the sea level rise is the final part of the Metauro River, where it feeds the aquifer with seawater and significantly increases the TDS content of both the surface and deep aquifers.

As a general and significant result of the ASTERIS project, this study has shown that there is no significant seawater intrusion in the shallow aquifer system of Fano. Nevertheless, scenarios of sea level rise and/or possible increasing water use should consider avoiding the risk of seawater intrusion.

The main results obtained are: i) the hydrogeochemical characterization hydrogeological system; ii) the assessment of the main geochemical processes that affect the aquifer system; iii) a conceptual model of the coastal aquifer of Fano; iv) the input for a TDS transport model realized in order to simulate scenarios of sea level rise and/or changes in climate conditions and/or increased water demand.

4.2.2 Ravenna

The coastal system of Ravenna in Northern Adriatic Sea (Italy) covers a 7 km wide strip of land parallel to the coast and extends over about 56 km^2 (Figure 20). In order to evaluate possible hydrological and geochemical differences due to the influence of different climatic conditions, three surveys (July 2019, September 2020 and November 2020) were carried out, including water sampling (for water chemistry and water isotope analyzes), physicochemical parameters and water level measurements, and vertical physicochemical logs (Figure 20).

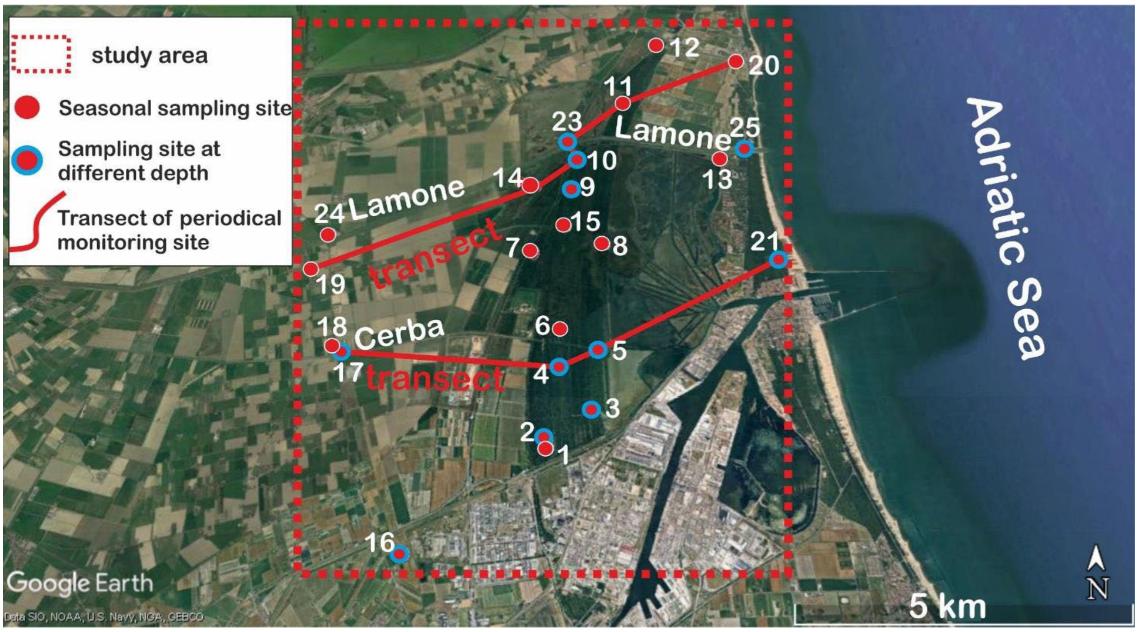


Figure 20. Location of the study area. The sampling sites and monitoring transects are also reported.

Absolute piezometric values are near or below sea level in most cases, indicating seawater intrusion and highlighting high seasonal variability with EC varying from 0.5 to 66. The waters were classified as following: (i) bicarbonate-alkaline earth (Ca2+-Mg2+-HCO3-), (ii) bicarbonate-alkaline (Na+-HCO3-), (iii) sulphate-chloride-alkaline (Na+-Cl--SO42-), and (iv) sulphate-chloride-alkaline earth (Ca2+-Mg2+-Cl--SO42-).

Among the major anions, chloride (Cl-) was the most abundant species in each sample and reached the highest concentration up to 25 g/L and among the major cations, sodium (Na+) was the most abundant species in all water samples and reached the highest concentrations up to 13.6 g/L. Most waters were characterized by Na+-Cl composition and high TDS values, indicating the phreatic nature of the system, which favors infiltration of freshwater. Many samples showed As concentrations above the legal limit (10 μg/L). A possible source could be related to the oxidation of pyrite, a mineral formed by SO4 reduction during the decomposition processes of organic material in the alluvial sediments. The relatively high B concentrations, with many samples exceeding the legal limit, are closely related to seawater intrusion.

A marked increase in solutes, closely associated with marine intrusion, was observed towards the sea, albeit with some exceptions. In agreement with the vertical record, these data confirm the active process of subsurface intrusion of seawater from the coast.

Most samples are located near the Cl-/Br seawater value and the seawater intrusion field (Figure 21). The significant increase in isotope values indicates increasing interaction and mixing between freshwater and seawater. The river Lamone seems to act as a possible carrier of saline water into the aquifer.

A semi-quantitative conceptual model of the coastal shallow aquifer extending in the northern part of the Ravenna municipality was proposed (Figure 22).

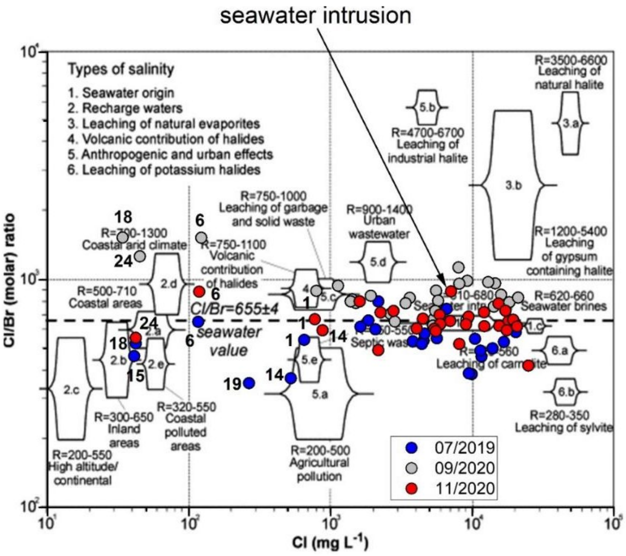


Figure 21. Diagram Cl−/Br− molar ratio vs. Cl− (mg/L) for all the samples. Modified from Alcalá and Custodio (2008).

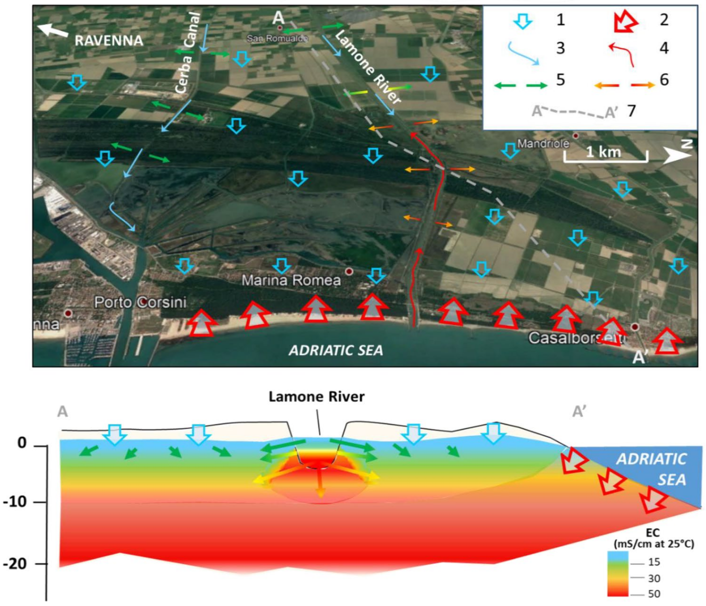


Figure 22. Schematic model of the shallow coastal aquifer of Ravenna: 1) local rainfall infiltration; 2) seawater intrusion from the shoreline; 3) freshwater flow in superficial water courses; 4) seawater intrusion along river beds; 5) transfer of freshwater from superficial water courses to groundwater; 6) transfer of saline and brackish water from the superficial water courses to groundwater; 7) trace of the section A-A'. EC= Electrical conductivity

As a general result of this study, high vulnerability of the shallow aquifer to seawater intrusion and considerable sensitivity of the system to meteorological conditions were noted. Given the general trend of climate change and associated sea level rise, these features are particularly hazardous to this groundwater system. Accordingly, the threats to the shallow aquifer under study may be exacerbated by seawater inflow via surface waters. Because of sea level rise and climatic conditions increasingly characterized by extreme regimes and longer dry periods, surface watercourses may facilitate the transfer of seawater up to several kilometers inland, into their riverbeds and then into the groundwater system. It is expected that the management of the area will take these aspects into account in order to plan appropriate measures to mitigate the effects of sea level rise and climate change and to ensure the survival of particular ecosystems such as those of the Ravenna coastal system.

The main results obtained are: i) hydrogeochemical characterization of Ravenna hydrogeological system; ii) assessment of the main geochemical processes that affect the aquifer system; iii) definition of a conceptual model of the coastal aquifer of Ravenna according to the geological, hydrogeological, physical-chemical and geochemical-isotopic data.

4.2.3 Neretva

The Seventh National Report and the Third Biennial Report of the Republic of Croatia under the United Nations Framework Convention at Climate Change (UNFCCC) (Ministry of Environment and Energy, 2018) emphasized that climate change will have significant direct and indirect impacts on agriculture related to sea level rise and salinization of karst aquifers.

From this point of view, the alluvial valley of the lower Neretva - whose very complex hydrogeology implies complex water movement processes - is one of the most vulnerable areas.

The Lower Neretva area is intensively used for agriculture and, at the same time, is ecologically very sensitive. A major threat to the agro-ecosystem imbalance is water and soil salinization.

In Neretva Valley ASTERIS promoted the following tasks: i) collection and processing of national monitoring data; ii) work on available historical data on the level of salinization of surface and ground water in the Neretva Valley; iii) preparation of land use map, pedological map, soil salinization map; iv) establishment of short-term monitoring and v) Analysis of surface and groundwater management at national level.

Statistical analysis included electrical conductivity values at surface, groundwater, and soil monitoring station within the Neretva Valley (Table 2). The results of the statistical analysis indicate that the groundwater in the Neretva Valley belongs to the class of moderately saline waters to very highly saline waters. Among the surface waters, the highest arithmetic mean value ECw was obtained in the 2nd group of waters (surface water monitoring sites established at pumping station), which also places them in the class of moderately saline waters. The complex hydrology of polder-type low-lying areas is affected mainly by a dense network of canals and pumping stations, where the dynamic mixing of water from different sources occurs. Although the range of ECw values in the 2nd group of waters ranged from 0.71 dS m-1 to 9.23 dS m-1, the small coefficient of variation (37 %) indicates lower variability in the degree of salinity, i.e. smaller deviations of the measured ECw values from the arithmetic mean, which is also associated with the operation of the pumping stations or their collection canals.

It is important to note that the highest value of ECw in surface waters in the Neretva Valley was recorded in the 3rd group of drainage canals (20.9 dS m-1). In contrast to the other groups of surface water monitoring sites, the value of ECw in river streams varies relatively the most, which is expressed by a coefficient of variation of 71 %. However, according to the established value of the arithmetic mean of 1.06 dS m-1, river streams can be classified in the class of low salinity waters (ECw 0.7 – 2 dS m-1), suitable for irrigation.

Table 2. Assessment of water salinity based on monthly data during 2009-2018.

Water body	water quality monitoring stations	Nuber of stations	sampling frequency
CLASS 1	River: Neretva, Mala Neretva, canal Vrbovci, canal Vidrice	4	monthly
CLASS 2	Pumping stations: Luke; Vrbovci; Vidrice; Opuzen ušće	4	monthly
CLASS 3	Drainage canals: Luke, Vidrice, Vrbovci, Opuzen ušće-Jasenska, Opuzen ušće, Komin-left bank, Komin-right bank	7	monthly
CLASS 4	Piezometers: Luke; Vidrice; Opuzen river mouth-Jasenska, Opuzen ušće; Vrbovci, Banja, Komin	7	monthly

Table 2.1 Summary statistics of electrical conductivity values, EC_w (dS m^{-1}) at 16 water monitoring sites in Neretva Valley for the time series 2009-2018. by groups of surface water monitoring sites (Class 1-3) and groundwater (Class 4).

Parameters EC_w (dS m^{-1})	**Class 1**	**Class 2**	**Class 3**	**Class 4**
n - count	468	468	585	585
Mean	1,06	4,02	3,63	9,7
Median	0,76	3,72	3,0	5,50
Standard deviation	0,75	1,47	2,5	10,6
Minimum	0,26	0,71	0,19	0,29
Maximum	4,83	9,23	20,9	38,9
Coeficient of varaition	71	37	69	109

4.2.2.1. Soil salinity

The ECe maps in Figure 23 show that most saline soils (ECe > 2 dS/m) were restricted to the low-laying west and south-western sections of the study area, where the salinity levels generally tended to decrease from south to north. The high values of ECe visible in the north-western portion of the study area far from the coastline might result from soluble salt movements to the surface due to capillary rise and salt precipitation during dry periods. Detected processes of primary salinization caused by the capillary rising of highly salinized groundwater may initiate salt accumulation in (sub)soil horizon. Among the 245 collected in the surface soil layer, i.e. at a depth between 0–25 cm, 58 samples had a value of electrical conductivity of the soil saturation extract ≥ 2 dS/m, implying that 24% of the samples was saline. Technological measures are recommended for the management of agricultural land under saline conditions. When it comes to irrigation and saline water is used, it is necessary to apply a modified method of managing the irrigation system: special attention should be paid to irrigation amounts and intervals, flushing times and amounts, irrigation methods, and management of irrigation water sources of different quality.

Crop selection, as another important management measure, must take into account the different tolerance of plants to high salt concentrations, either in irrigation water or in the soil; the sensitivity of plants at different stages of growth and development also varies.

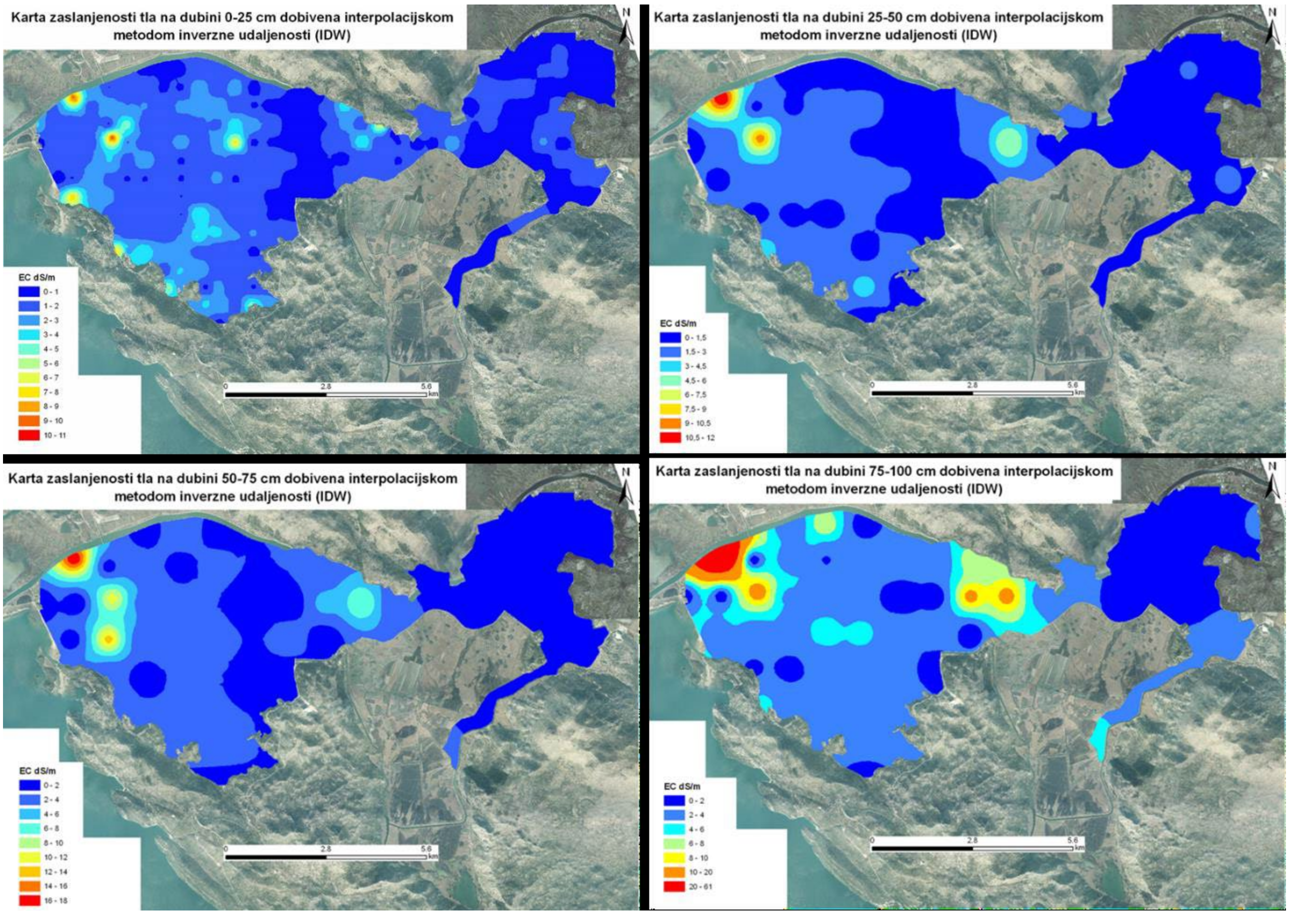


Figure 23. Soil salinity maps by depth (0-25 cm; 25-50 cm; 50-75 cm; 75-100 cm) in the Neretva Valley.

Soil salinity monitoring at Neretva Valley is conducted at 7 stations (P) distributed by reclamation unit. By determining the degree of soil salinity in March/April, the ability of the soil to maintain the equilibrium state of salt in the profile is evaluated. The second sampling was carried out 6 months apart, i.e. in the September/October period. Of all the soil monitoring stations, the highest average ECe value of 3.75 dS/m was measured in the Vidrice amelioration area during both the summer and winter monitoring periods. Soil salinity was highest in the

Vidrice amelioration area during the winter sampling period.

Of the total stations studied, the mean value of ECw in the range of 2 - 10 dS/m, which belongs to the class of moderately saline waters (primary drainage water and groundwater), was determined in three groups of stations: Pumping stations, drainage canals and piezometers, while the mean value of ECw of natural streams was in the range of 0.7 - 2 dS/m, which belongs to the class of low salinity waters. High coefficients of variability, observed high maximum values and statistically significant positive trends of ECw values indicate a possible further increase of ECw in surface and groundwater in the Neretva Valley. In this sense, given the salinity of the water, the drainage canal and groundwater monitoring stations are the most critical. Of the 7 soil monitoring stations that have been established, the soil is saline at 5 stations, and the greatest risk of salinization and associated consequences for agricultural production is in the Vidrice reclamation area. In 2009-2018, the soil was weakly to moderately salinated at all monitoring stations, with maximum ECe values of more than 2 dS/m measured. The Neretva River is characterized by typical interseasonal runoff fluctuations. Analysis of the collected surface and groundwater samples from the Neretva Delta can show a large spatial and seasonal variability with respect to the geochemical character of the water. The main anion triangle diagram shows that the water samples belong to the Cl range in September 2020. The chloride character of the samples is particularly pronounced in deep piezometers due to the direct connection of the aquifer with the sea. HCO3- is always present in relatively low concentrations, with the exception of samples from the Vrbovci piezometer and the Vrbovci lateral channel collected in September 2020 and February 2021, respectively, and River Neretva Metković and River Mala Neretva. Results showed a clear dominance of Na+K among cations for the majority of samples collected in September 2020, except for two shallow piezometers

Luke and Vrbovci. In the February 2021 sampling campaign, Ca2+ dominated both surface water samples and groundwater samples at the Luke and Vrbovci piezometers.

4.2.2.2. Exploitation of coastal aquifers

Dubrovnik-Neretva County has significant water potential, which is used for water supply and can be divided into spring water and groundwater sources depending on the type of occurrence. In the pilot area, there are a total of 5 springs used for water supply, 3 of which are located within Dubrovnik-Neretva County. Within the county are the springs Prud, Klokun and Modro Oko, while the spring Butina is located in the karst field southeast of the town Vrgorac in the Split-Dalmatia County and the spring Doljani about 2 km east of the town Metković in Bosnia and Herzegovina.

Seasonal variability is typical for coastal aquifers. Due to a significant increase in the number of users during the tourist season, water abstraction has also increased, on average by at least double compared to the winter period. This situation is similar to the other sources mentioned. These seasonal variations are even more pronounced for the sources within the PILOT AREA, since the water demand for agricultural production increases practically during the same period.

From all this, it is clear that activities to build a reliable and controllable water system should be intensified. This means that as much storage space as possible should be created, taking into account groundwater as an important resource that should primarily serve water supply in terms of integrated water resource management and irrigation reserves.

4.3. Development of adaptation plans

The need for Adaptation Plane is one of the Key-Points of ASTERIS: the transposition at the local scale of the “general” Guidelines has generated three plans that show clearly how they can be applied in different contexts – namely Neretva Delta (HR), Ravenna (IT) and Fano (IT) on both the two sides of Adriatic Sea.

The structure of the three plans presented concerns the following aspects:

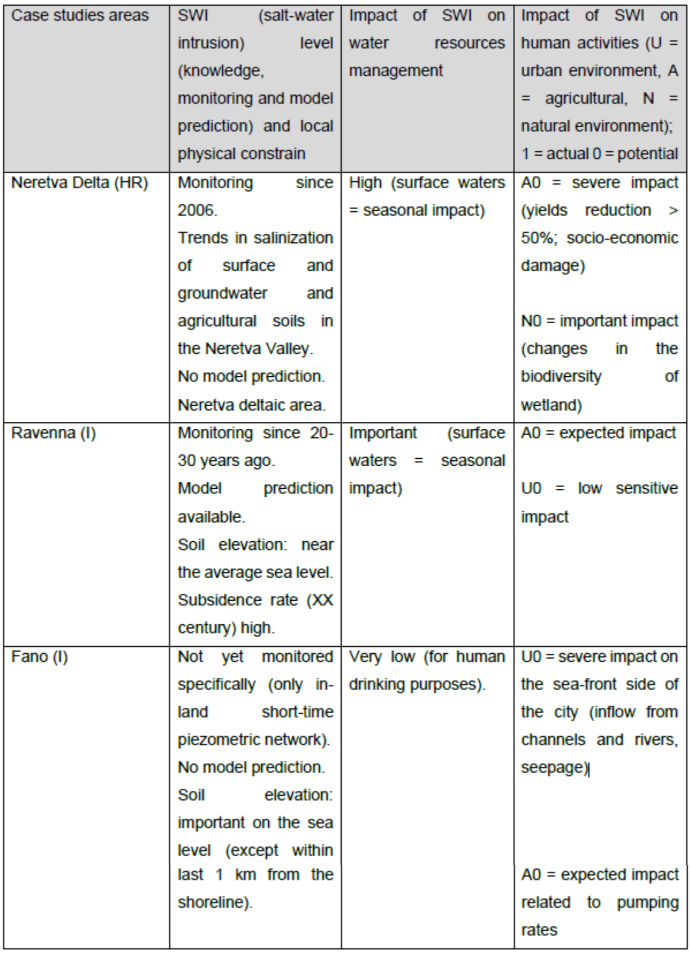
a. involved stakeholders and management of coastal aquifers,
b. the need of an adaptation plane: salt intrusion in the area, future scenarios of sea level rise,
c. possible solutions for adaptation in the study area: control activities, water resources management, urban, agricultural, natural environment,
d. implementation of the adaptation plan.

A quantitative – predictive modelling system has been developed, in order to test preliminary and verify the solutions proposed (Ravenna – IT), in particular by artificially recharge coastal retro dunes or the drainage ditches in the agricultural area located in the first inland.

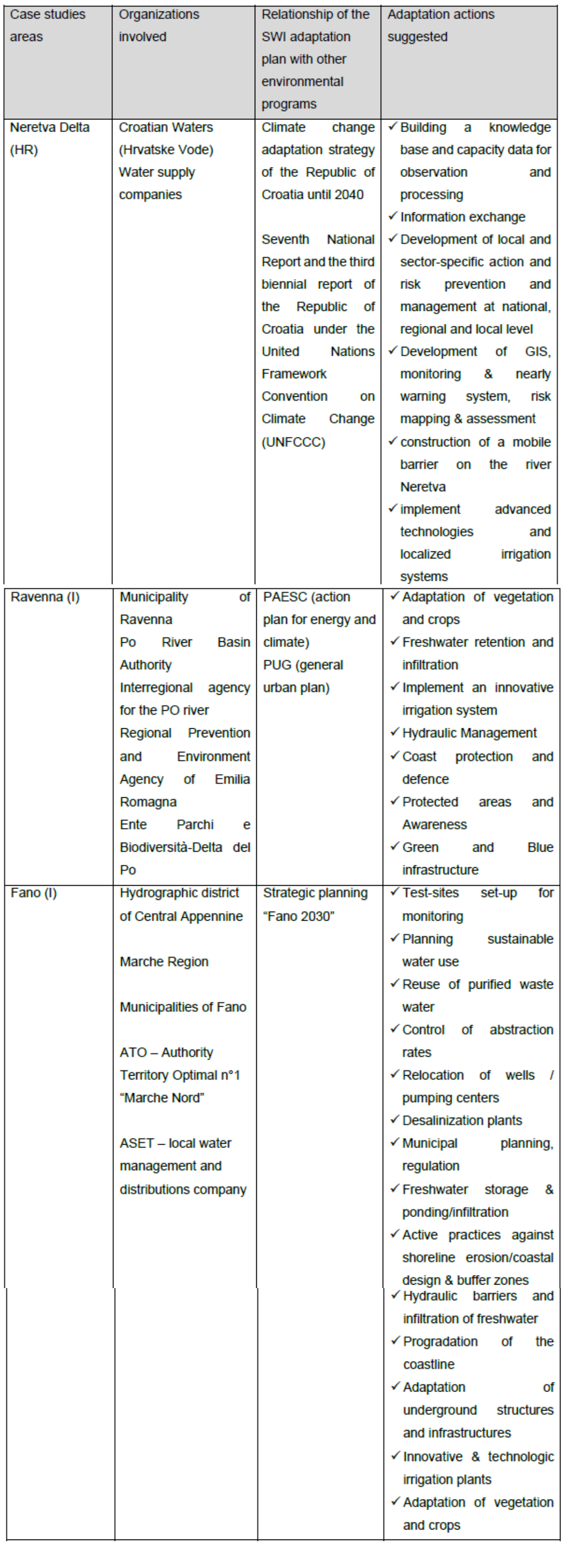
In others cases monitoring network dedicated to upgrade in the understanding of the phenomena has been designed in selected test-sites (Fano – IT); vulnerability analysis of infrastructure system (pipelines, sewerage and similar) should be implemented into the seafront sectors of the city, even allowing more freshwater infiltration.

A diffused issue to solve is linked to the progression of seawater inside the river banks, such as in the case of mobile barriers assumed on the river Neretva (HR); also the attention to the development of irrigation network results high, supported by advanced technologies; into the agricultural areas, a strategic measure is identified into planting/ sowing crops and varieties more resistant to elevated soil salt concentration. Groundwater management systems is needed, through simulation models.

The synthesis of the most characterizing factors is shown as follows:



Case studies areas	SWI (salt-water intrusion) level (knowledge, monitoring and model prediction) and local physical constrain	Impact of SWI on water resources management	Impact of SWI on human activities (U = urban environment, A = agricultural, N = natural environment); 1 = actual 0 = potential
Neretva Delta (HR)	Monitoring since 2006. Trends in salinization of surface and groundwater and agricultural soils in the Neretva Valley. No model prediction. Neretva deltaic area.	High (surface waters = seasonal impact)	A0 = severe impact (yields reduction > 50%; socio-economic damage) N0 = important impact (changes in the biodiversity of wetland)
Ravenna (I)	Monitoring since 20-30 years ago. Model prediction available. Soil elevation: near the average sea level. Subsidence rate (XX century) high.	Important (surface waters = seasonal impact)	A0 = expected impact U0 = low sensitive impact
Fano (I)	Not yet monitored specifically (only in-land short-time piezometric network). No model prediction. Soil elevation: important on the sea level (except within last 1 km from the shoreline).	Very low (for human drinking purposes).	U0 = severe impact on the sea-front side of the city (inflow from channels and rivers, seepage) A0 = expected impact related to pumping rates



Case studies areas	Organizations involved	Relationship of the SWI adaptation plan with other environmental programs	Adaptation actions suggested
Neretva Delta (HR)	Croatian Waters (Hrvatske Vode) Water supply companies	Climate change adaptation strategy of the Republic of Croatia until 2040 Seventh National Report and the third biennial report of the Republic of Croatia under the United Nations Framework Convention on Climate Change (UNFCCC)	✓ Building a knowledge base and capacity data for observation and processing ✓ Information exchange ✓ Development of local and sector-specific action and risk prevention and management at national, regional and local level ✓ Development of GIS, monitoring & nearly warning system, risk mapping & assessment ✓ construction of a mobile barrier on the river Neretva ✓ implement advanced technologies and localized irrigation systems
Ravenna (I)	Municipality of Ravenna Po River Basin Authority Interregional agency for the PO river Regional Prevention and Environment Agency of Emilia Romagna Ente Parchi e Biodiversità-Delta del Po	PAESC (action plan for energy and climate) PUG (general urban plan)	✓ Adaptation of vegetation and crops ✓ Freshwater retention and infiltration ✓ Implement an innovative irrigation system ✓ Hydraulic Management ✓ Coast protection and defence ✓ Protected areas and Awareness ✓ Green and Blue infrastructure
Fano (I)	Hydrographic district of Central Appennine Marche Region Municipalities of Fano ATO – Authority Territory Optimal n°1 “Marche Nord” ASET – local water management and distributions company	Strategic planning “Fano 2030”	✓ Test-sites set-up for monitoring ✓ Planning sustainable water use ✓ Reuse of purified waste water ✓ Control of abstraction rates ✓ Relocation of wells / pumping centers ✓ Desalinization plants ✓ Municipal planning, regulation ✓ Freshwater storage & ponding/infiltration ✓ Active practices against shoreline erosion/coastal design & buffer zones ✓ Hydraulic barriers and infiltration of freshwater ✓ Progradation of the coastline ✓ Adaptation of underground structures and infrastructures ✓ Innovative & technologic irrigation plants ✓ Adaptation of vegetation and crops

5. Conclusions: exploitation actions

The results of the MAC IT-HR project outcomes will be exploited by SeCure as described in the following table:

Projects	**Outcomes exploited by SeCure project**	**Exploitation actions**	**Dates**	**Involved PPs**
MoST	The monitoring network installed at the MoST Italian pilot site	The monitoring network will be maintained and used to collect information about saltwater intrusion and its effects on groundwater, soil water, and farmland productivity.	May 2022 to June 2023	LP, PP1
MoST	The monitoring network installed at the MoST Croatian pilot site	The monitoring network will be maintained and used to collect information about saltwater intrusion and its effects on groundwater, soil water, and farmland productivity	May 2022 to June 2023	PP3, PP4
MoST	The experimental infrastructure installed at the MoST Italian pilot site	The experimental infrastructure will be improved with a flowmeter and an electrical conductivity (EC) sensor connected to dataloggers.This improvement will be fundamental to test and control the effectiveness of the installed countermeasure over the 2022 agricultural season	June 2022 to June 2023	LP, PP1
MoST	Smartphone APP	The two smatphone APPs developed during MoST will	January to June 2023	LP, PP3

		be updated and finalize. These tools will be fundamental for saltwater intrusion monitoring in the future and will be an easy tool for local authorities (i.e., land reclamation authorities) and farmland owners.		
MoST, Change We Care, Asteris	Knowledge about saltwater intrusion and vulnerability to coastal salinization at the local and macro-regional Adriatic scale	The synergy between the projects will be fully exploited in the technical report about the investigation of climate change effects on the Italian and Croatian sites. The potential for the implementation of the results in other Adriatic vulnerable areas will also addressed considering future scenarios for sea-level rise.	Deember 2022 - June 2023	LP, PP1, PP3
MoST, Change We Care, Asteris	Knowledge arose from project results about saltwater intrusion and the potential mitigation strategies	The MAC IT-HR project results will be used by SeCure to prepare dissemination material (website, videos, press release) to make aware the general public about saltwater intrusion and possible coutermesures.	June 2022 - June 2023	PP2, PP4, PP5, PP6
MoST, Change We Care, Asteris	Knowledge arose from project results about saltwater intrusion and the potential mitigation strategies	The MAC IT-HR project results will be used by SeCure PPs to prepare technical and promotional material about saltwater intrusion and possible coutermesures that will presented to public	November 2022 - June 2023	LP, PP1, PP2, PP3, PP4, PP5, PP6

		authorities and students (from the primary school to university).		
MoST, Change We Care, Asteris	Knowledge arose from project results about saltwater intrusion and the potential mitigation strategies	The knowledge that arose from the MAC IT-HR projects will be fundamental to organize and set-up the material for an international thematic seminar on the topics.	December 2022 – April 2023	LP, PP1, PP3
MoST, Change We Care, Asteris	Knowledge and knowledge gaps arose from project results about saltwater intrusion and the potential mitigation strategies	The MAC IT-HR project results will be used to develop project ideas for the programme period 2021-2027	December 2022 – June 2023	LP, PP1, PP3