D.4.3.2 – Synthesis Report

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Author (s)	Branimir Urlic (IACKR) Monika Zovko, Davor Romić, Marina Bubalo Kovačić, Marija Romić, Marko Reljić, Helena Bakić Begić, Stjepan Husnjak (University of Zagreb) Barbara Nisi, Marco Doveri, Orlando Vaselli, Matia Menichini (CNR IGG)
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1. INTRODUCTION

The project ASTERIS (Adaptation to Saltwater inTrusion in sEa level RIse Scenarios) has been approved under INTERREG V-A Italy-Croatia Cross -border Cooperation Program 2014-2020, Priority 2, Measure 2.1. The aim of the project is 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. In order to achieve this objective, three representative areas have been selected to carry out individual case studies: Emilia-Romagna Region (Municipality of Ravenna, Italy), Marche Region (Municipality of Fano, Italy) and Dubrovnik-Neretva County (, hereafter **PILOT AREAS**). The project consists of five work packages (WPs). This study provides an overview of the research carried out under WP4 "Identification of needs and barriers in the management of coastal aquifers". The objective of WP4 is to identify and map coastal aquifer management needs and barriers in the assessed risk scenarios through three activities. This report is a delivery (D 4.3.2) related to the implementation of Activity 4.3 "Case studies: synthesis and definition of future risk scenarios". The delivery (D 4.3.2) is a "synthesis of the results of activities 4.1. and 4.2 in the three pilot areas with the aim of identifying common issues for the different case studies.

This report has two major objectives:

- to provide a summary of the results from the water monitoring established in the three pilot areas
- to provide a synthesis of an analytical survey of the existing system of management and administration of coastal aquifers in the pilot areas with a focus on the analysis of administrative and regulatory management procedures, identification of potential barriers, if any, and management problems in order to design potential solutions and define best practices.

Current instrumental techniques for measuring physical and chemical indicators in the environment, especially in waters, advanced information technologies for data acquisition, and available statistical processing and modeling tools are used in this project to achieve the following objectives:

1. the establishment of an automated, continuous surface and groundwater quality monitoring system at reference sites;

2. analysis and quantification of complex natural (predominantly salinisation) and anthropogenic influences on water bodies, taking into account geomorphological, hydrological and pedological area characteristics and land use; data analysis, visualization through mapping in ISATIS and GIS, application of advanced multivariate statistical and geostatistical methods and modeling that reliably quantify the predominant influences.

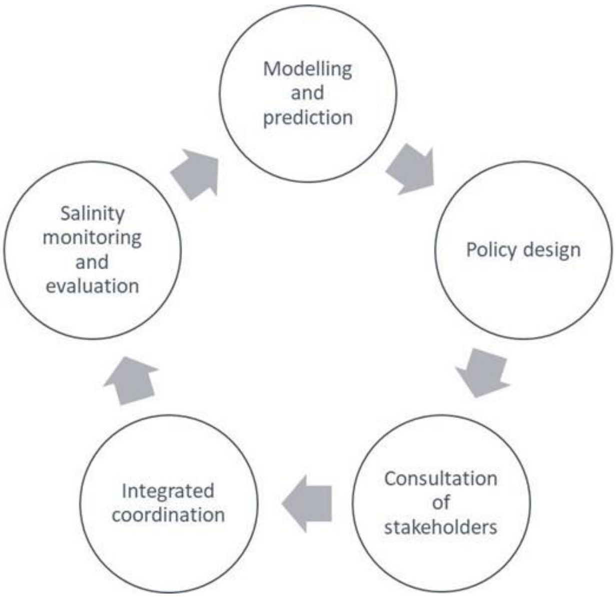


Fig. 1.1 Flowchart illustrating the summary of the issues raised by the research in work package 4 of the ASTERIS project

2. RESULTS

2.1 General results

Climate change affects many parts of Earth's ecosystem, but also the organization and quality of human life. The effects of global climate change, leading to sea level rise, more frequent droughts and other extreme climatological and meteorological phenomena, can only be predicted and prevented on the basis of the analysis of reliable long-term multiparametric measurements. This gives rise to the need to network the various sectors of society and carry out joint activities.

All investigations within the work package were carried out in three pilot areas. Apart from the different location within the Adriatic basin, the areas have different geological and hydrogeological characteristics, type of land use and socio-economic characteristics. In each pilot area, water quality monitoring was organized. In addition, existing data on groundwater and surface water status were used.

Case study		**N monitoring points**	
The Fano coastal groundwater system	the coastal plain of the Metauro river, Northern Adriatic Sea, Italy	46	41 underground water (domestic wells, industrial wells, operated by the local water management company
			5 surface waters
The Ravenna coastal system	the Ravenna coastal system in the Northern Adriatic Sea, Italy	24	18 underground water (piezometers)
			6 surface water
The Neretva Delta	the valley of the lower Neretva river, Southern Adriatic Sea, Croatia	11	8 underground water
			3 surface water

Geological data form the basis for solving many projects of national importance, such as drinking water supply, water and soil conservation, construction of transport infrastructure, urban planning, determination of mineral deposits and environmental protection. A group of scientists from different disciplines was therefore engaged in setting priorities, categorizing activities and defining actions to be implemented in the face of threats and projected impacts of climate change. To achieve these goals, it is necessary to finally provide effective technical and legislative support. This implies the need to control the further processes of salinization of water and soil in the PILOT AREAS in order to realize their full potential for sustainable management of natural resources. The project was multi- and interdisciplinary in nature, particularly in the area of sustainability, to ensure the visibility and applicability of the monitoring results. Several groups of activities were carried out to develop a model to predict the changes caused by climate change and to propose mitigation measures. The data on geochemical processes and status, as well as the recommendations on which system management decisions are based, could be available to relevant government administrative bodies and other institutions, agencies, non-governmental organizations and associations. The data can also be used to cross-check with sectoral and local planning documents and international commitments.

- The results of this WP could be also beneficial to the wider community as the real-time data can be used for planning various economic and social activities and adopting strategic documents and implementing development/sustainability policies at local, regional and national levels in the light of global climate change. Some project modules can be used, maintained and updated by the following users:
- scientific and academic community in the interdisciplinary field (STEM)
- decision-making institutions and resource management in the legal field, especially in vulnerable sectors and / or transversal sectors;
- competent state administrative bodies and other relevant institutions, agencies and non-governmental organizations and associations;
- state, regional and local government bodies;
- agricultural producers.

2.2 The Fano coastal groundwater system

The pilot area within the municipality Fano corresponds to the coastal plain of the Metauro River with a secondary network of drainage channels for a total extension of about 60 km^2. The processing of the acquired data was carried out in three steps: 1. geochemical characterization of the near-surface aquifers, 2. processing and mapping of geostatic data, and 3. flow and transport models (conceptual and numerical) of the aquifer system that can be used to simulate possible future sea level rise scenarios.

Geochemical characterization of the near-surface aquifers

The chemical quality of the groundwater system is mainly determined by the interaction of water with carbonate and silicate minerals. With the resulting and dominant $Ca\text{-}HCO_3$ groundwater composition, some secondary processes overlap. The first is the input of N-rich pollution, which affects a large part of the study area. This contamination is relatively contrasting and diluted in the zones where the plume formed by the injection of water from the Metauro River via artificial recharge wells has been detected. Other secondary processes are probably due to the interaction of groundwater and clayey evaporite minerals of the substrate,

which have favored the increase of Cl concentrations in some wells. In addition, ion exchange processes were invoked when Na-HCO_3 and Ca-Cl water were found, albeit very locally.
A preliminary assessment of the chemical composition of the water from the Fano coastal area, related to the monitoring campaigns considered representative of opposite hydrological regime conditions, wet and dry seasons (June 2019, September 2020 and November 2020), was carried out considering the following:

i) Cl-SO_4-HCO_3 and (Na+K)-Ca- triangular plots,
ii) the Langelier-Ludwig diagrams and
iii) Total Ionic Salinity (TIS)

From these diagrams it was possible to distinguish three groups of waters with different compositions, reflecting the lithological type and the main geochemical processes that characterize the shallow aquifer in the coastal area of Fano:

1. the Ca-HCO_3 composition. It comprises the great majority of the water samples analyzed, whose salinity is between 10 and 30 meq/L.
2. the Ca-Cl facies. It is represented only by the analyzed water from the one sampling site for which the highest salinity among the analyzed samples was recorded.
3. (Na+K)-HCO_3-Cl facies. It is characterized by the analyzed water from the three sampling points with an intermediate salinity.

Processing and mapping of geostatic data

This study also resulted in iso- piezometric level and iso-EC (electrical conductivity) maps for opposite hydrological regime conditions. Geostatistical data processing was performed using the ISATIS® software package, which allows the generation of experimental variograms, variogram models, and cross-validation tests. The geostatistical models was successfully validated. Piezometric maps obtained by geostatistic modelling 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, characterised 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.

Flow and transport models (conceptual and numerical)

Modelling activity has produced flow and transport models that are calibrated and considered sufficiently representative of the natural aquifer system. Considering the inherent error in the model definition and all the uncertainties associated with their construction, these models can be used to simulate numerous future scenarios by changing the associated boundary conditions. In this project, 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 this sea level rise is the latter 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 take into account to avoid the risk of seawater intrusion.

Conclusions

Starting from field activity, six hydrogeological monitoring campaigns (June 2019, September 2019, December 2019, June 2020, September 2020 and November 2020) were carried out with the aim to assess geochemical and isotopic variations due to climatic and hydrodynamic conditions, as follows:

June 2019 – water sampling piezometric and physicochemical measurements;

September 2019 – piezometric and physicochemical measurements and vertical physicochemical logs;

December 2019 – piezometric and physicochemical measurements;

June 2020 – piezometric and physicochemical measurements;

September 2020 – water sampling, piezometric and physicochemical measurements and vertical physicochemical logs;

November 2020 – water sampling, piezometric and physicochemical measurements and vertical physicochemical logs.

(see D. 4.1.2 section Materials and methods)

As a consequence, the main results obtained from activities 4.1 are, as follows:

1. hydrogeochemical characterization of Fano hydrogeological system (brief summary see D. 4.1.2 section results: water chemistry),
2. assessment of the main geochemical processes that affect the aquifer system (brief summary see D. 4.1.2 section discussion: origin the main solutes, trace elements and stable isotopes),
3. definition of a conceptual model of the coastal aquifer of Fano has been proposed according to geological, hydrogeological, physical-chemical and geochemical-isotopic data (brief summary see D. 4.1.2 section conceptual model),
4. utilization of the conceptual model of the aquifer system by a TDS transport model that was realized in order to simulate scenarios of sea level rise and/or changes in climate conditions and/or increased water demand (brief summary see D. 4.1.2 section numerical model).

2.3 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. 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. Absolute piezometric values are near or below sea level in most cases, indicating seawater intrusion and highlighting high seasonal variability. Consistent with the behavior of water levels, the highest values of EC were observed in the summer of 2020 (low tide). A vertical gradient of EC was observed at each sampling site, indicating continuous coexistence of saline and freshwater and the resulting mixing processes. However, in December 2019, after a significant period of precipitation, local and inland water recharge was able to replace most of the saline water in the aquifer with freshwater in some locations. This process resulted in vertical profiles with consistently low EC values. Measured electrical conductivity (extended on the first occasion the acronym is used in the text) (EC), which is directly related to ion concentration, varied from 0.57 to 66.41 mS/cm and from 0.56 to 58 mS/cm for December 2019 and July 2020 transects, respectively. The waters were classified:

(i) bicarbonate-alkaline earth (Ca^{2+}-Mg^{2+}-HCO_3^-),

(ii) bicarbonate-alkaline (Na^+-HCO_3^-),

(iii) sulphate-chloride-alkaline (Na^+-Cl^--SO_4^{2-}), and

(iv) sulphate-chloride-alkaline earth (Ca^{2+}-Mg^{2+}-Cl^--SO_4^{2-}).

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. The vast majority of waters were characterized by Na+-Cl composition and high TDS (this needs to be written extended on the first occasion the acronym is used in the text) values, indicating the phreatic nature of the system, which favors infiltration of freshwater. The latter process and its variability across seasons are readily apparent from the vertical logs and illustrate the sensitivity of the system to the hydrologic regime. As noted above, some samples from different sampling campaigns have relatively different geochemical compositions. 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 SO_4 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. However, apparent contradictions are also observed, probably related to the differences in hydraulic permeability between the different layers through which all sampled piezometers pass. In particular, the lower layer of the piezometer stratigraphy appears to have lower permeability than the upper layer. When the water column is static and the measurements are made, the vertical salinity is mainly influenced by the actual geometry of the saltwater wedge and the density ratio between freshwater in the upper part and seawater in the lower part. On the contrary, when the sampling pump is in operation (during sampling), a larger inflow of freshwater into the piezometer is promoted by the higher permeability of the upper layer, resulting in dilution within the piezometric tube. Most samples are located near the Cl-/Br seawater value and the seawater intrusion field. 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.
Within WP4, a semi-quantitative conceptual model of the coastal shallow aquifer extending in the northern part of the Ravenna municipality was proposed.
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. Due to the effects 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 particular 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.

Conclusions

Starting from field activity, five hydrogeological monitoring campaigns were carried out, as follows:
July 2019 – water sampling, piezometric and physicochemical measurements and vertical physicochemical log;
December 2019 – piezometric and physicochemical measurements and vertical physicochemical log;
July 2020 – piezometric and physicochemical measurements and vertical physicochemical log;
September 2020 – water sampling, piezometric and physicochemical measurements and vertical physicochemical log;
November 2020 – water sampling, piezometric and physicochemical measurements and vertical physicochemical log;
(see D. 4.1.2 section Materials and methods)
As a consequence, the main results obtained from activities 4.1 are, as follows:

1. hydrogeochemical characterization of Ravenna hydrogeological system (brief summary see D. 4.1.2 section results: Hydrodynamic data and Water physicochemical parameters and chemical and isotopic composition),

2. assessment of the main geochemical processes that affect the aquifer system (brief summary see D. 4.1.2 section discussion: Water source and physical-chemical processes in the shallow aquifer of Ravenna),
3. definition of a conceptual model of the coastal aquifer of Ravenna according to the geological, hydrogeological, physical-chemical and geochemical-isotopic data (brief summary see D. 4.1.2 section conceptual model)

2.4 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) emphasize, among others, water and Marine Resources Management as a vulnerable sector. It is also 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. Previous studies have shown tendencies towards salinization of surface and groundwater as well as agricultural soils in the Neretva Valley. In addition, aquatic systems within the delta, as well as the coastal sea, are subject to agricultural pressures. Changes in the environment are inevitably reflected in the efficiency of agricultural production. Saline water usage for irrigation, can decrease yields by more than 50 %, directly affecting the economic profit of farmers. Therefore, producers facing the problem of salinization of water and soil need, first of all, timely and reliable information on the possibility of irrigation during the growing season, but also other agrotechnical measures on which the yield of crops and sustainable production depend from an agronomic and economic point of view. At this point, the link with the overarching sector Risk Management becomes clear. The monitoring, forecasting and prevention of negative impacts is possible through the linking and implementation of joint activities between different sectors of society.

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. Through the activity of work package 4 the following tasks were carried out: i) collection and processing of national monitoring data (fig. 2.1); 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 - 10 sites, 2 seasons: dry and wet period of the year, conduct laboratory tests - ionic composition and isotopes $\delta^{18}O$ and δD and v) Analysis of surface and groundwater management at national level.

Fig. 2.1. Field work, field research, sampling and laboratory testing at University of Zagreb Faculty of Agriculture

Statistical analysis included electrical conductivity (EC can be used here if specified before in text) values at surface, groundwater, and soil monitoring station within the Neretva Valley. First, a basic descriptive statistical analysis was performed including the following indicators: arithmetic mean, median, standard deviation, minimum and maximum values, and coefficients of variation (V) to provide basic insight into the collected data sets. In addition, EC values at selected monitoring stations were analyzed using a non-parametric Mann-Kendall (M-K) test applied to identify significant monotonic changes in time series (Bubalo, 2016). Due to the objective of determining only the trend stability in the monitored EC_w (please make this uniform through text: EC or EC_w? The latter is possibly better) values, the non-parametric Theil-Sen method (Theil, 1950; Sen, 1968), i.e. Sen's slope estimator (z - value) was used to determine the trend slope.

According to the statistical indicators from Table 1, it can be seen that during the period of 2009-2018 the minimum value of EC_w of 0.19 dS m^{-1} was determined in the 3rd group of water bodies (surface water monitoring stations established (located?) on drainage canals) and the maximum value of 38.9 dS m^{-1} was determined in the 4th group of water bodies (groundwater monitoring stations from shallow piezometers), which also has the highest arithmetic mean of 9.7 dS m^{-1} EC_w.

The coefficient of variation as a complete measure of relative dispersion, which is higher than 70 %, indicates a very high variability of the observed amount (surveyed parameters?), so it can be concluded from the obtained results that the EC_w values in groundwater were extremely variable (V = 109 %).

- The results of the statistical analysis indicate that the groundwater in the Neretva Valley belongs to the class of moderately saline waters (arithmetic mean of EC_w in the range of 2-10 dS m^{-1}) to very highly saline waters (maximum value of EC_w in the range of 25-45 dS m^{-1}).
- Among the surface waters, the highest arithmetic mean value EC_w was obtained in the 2nd group of waters (surface water monitoring sites established (located?) 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 (Romić et al., 2020)
- Although the range of EC_w 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 EC_w 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 EC_w 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 EC_w 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 (EC_w 0.7 - 2 dS m^{-1}), suitable for irrigation.

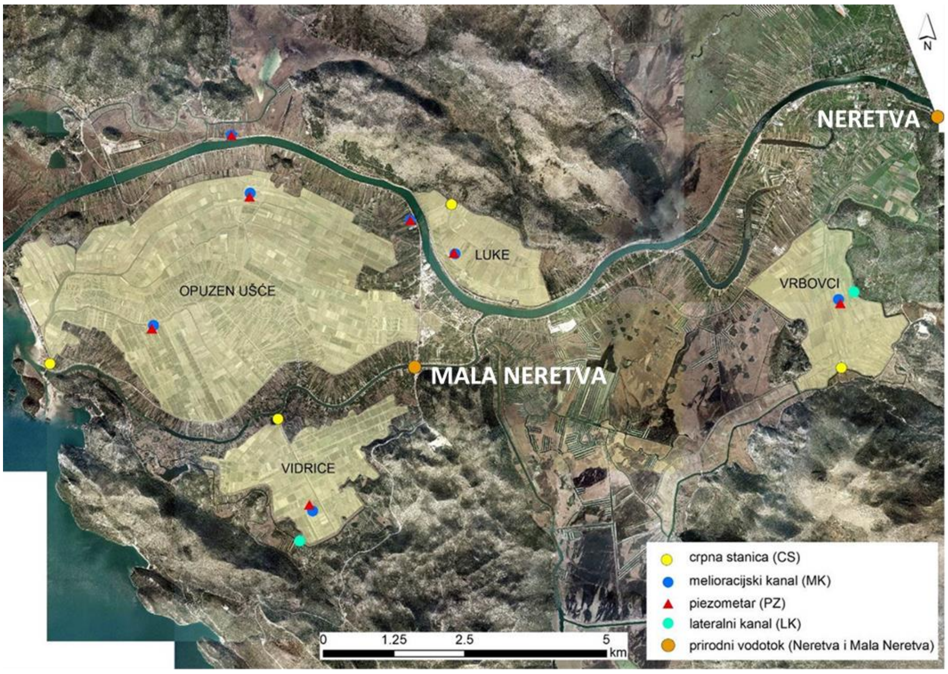
Table 2.1 Assessment of water salinity based on monthly data during 2009-2018

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

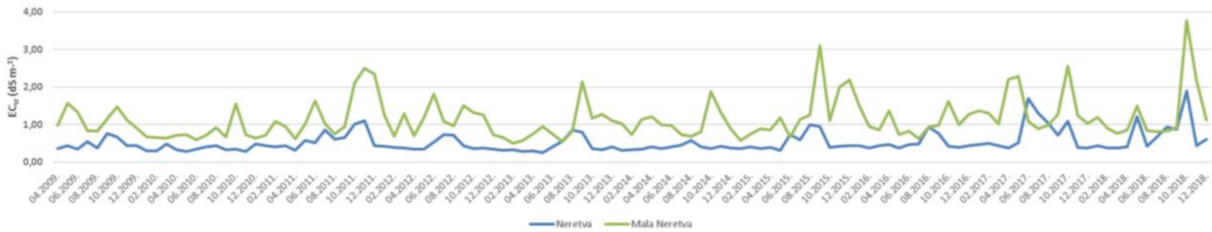
Table 2.1 Summary statistics of electrical conductivity values, EC_w (dS m^{-1}) at 16 water monitoring sites in Neretva Valley for the time series 2009-2018. by groups of surface water monitoring sites (Class 1-3) and groundwater (Class 4).

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

CLASS 1
Rivers



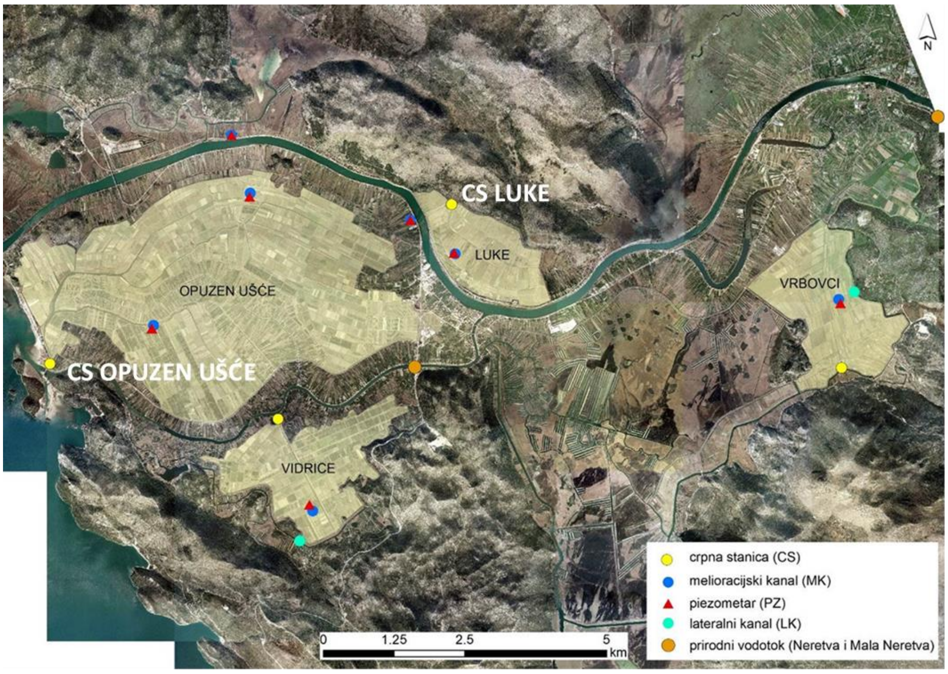
Values of electrical conductivity (dS m^{-1}) in surface water samples (CLASS 1) in the period 2009-2018. and trend analysis results by the original M-K test



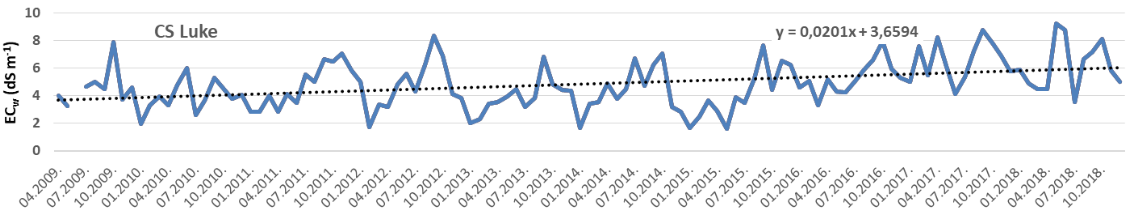
Station	***Start/ end monitoring***	***Z***	***significance***
Neretva	2010/2018	3,14	**
Mala Neretva	2010/2018	1,66	+

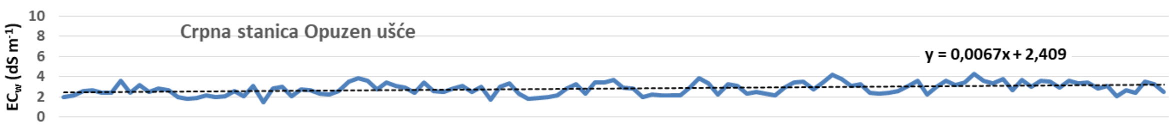
+ = a statistically significant trend at the level of significance 10 %

** = a statistically significant trend at the level of significance 1 %



Values of electrical conductivity (dS m^{-1}) in selected /representative surface water samples of pumping stations - CS (CLASS 2) in the period 2009-2018. and trend analysis results by the original M-K test



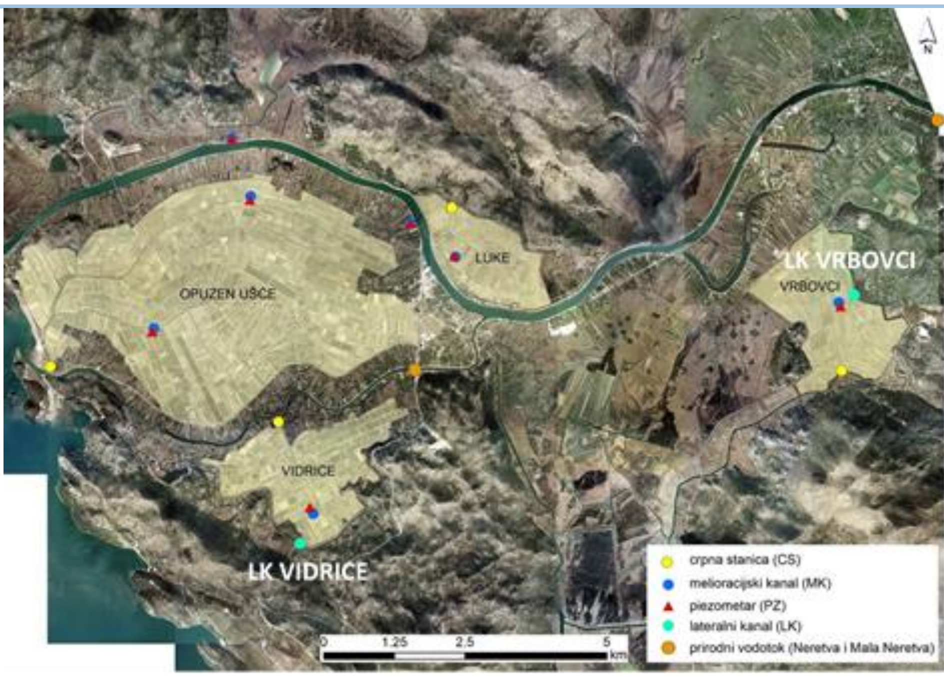


Station	***Start/ end monitoring***	***Z***	***significance***
CS Opuzen Ušće	2010/2018	3,02	**
CS Luke	2010/2018	3,98	***

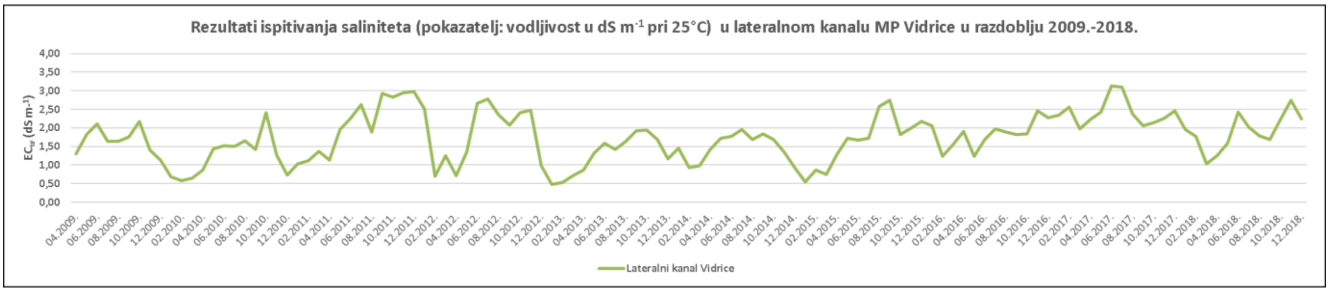
** = a statistically significant trend at the level of significance at 1 %

*** = a statistically significant trend at the level of significance at 0,1 %

CLASS 3
Drainage canals



Values of electrical conductivity (dS m⁻¹) in surface water samples - drainage/lateral canals (LK) (Class 3) in the period 2009-2018. and trend analysis results by the original M-K test

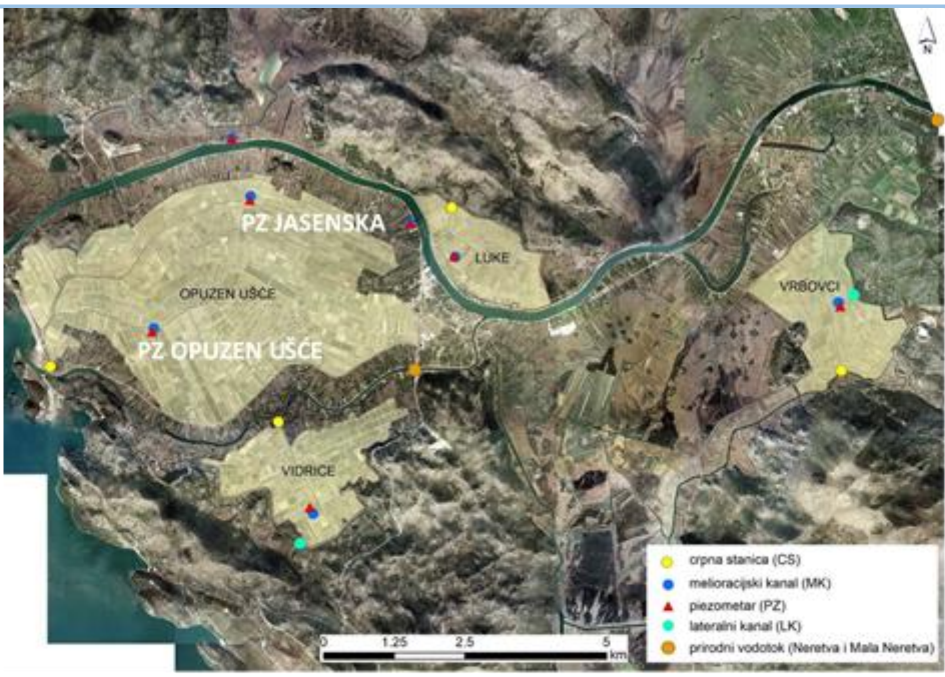


Station	***Start/ end monitoring***	***Z***	***significance***
LK Vrbovci	2010/2018	6,64	***
LK Vidrice	2010/2018	2,61	**

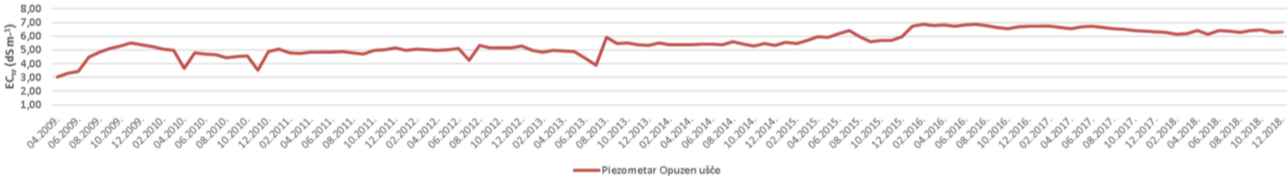
** = a statistically significant trend at the level of significance at 1 %

*** = a statistically significant trend at the level of significance at 0,1 %

CLASS 4
piezometers



Values of electrical conductivity (dS m^{-1}) in underground (piezometer -PZ) water samples (class 4) in the period 2009-2018. and trend analysis results by the original M-K test



Station	***Start/ end monitoring***	***Z***	***significance***
Piezometer Jasenska Opuzen mouth	2010/2018	4,99	***
Piezometer Opuzen ušće	2010/2018	9,92	***

*** = a statistically significant trend at the level of significance at 0,1 %

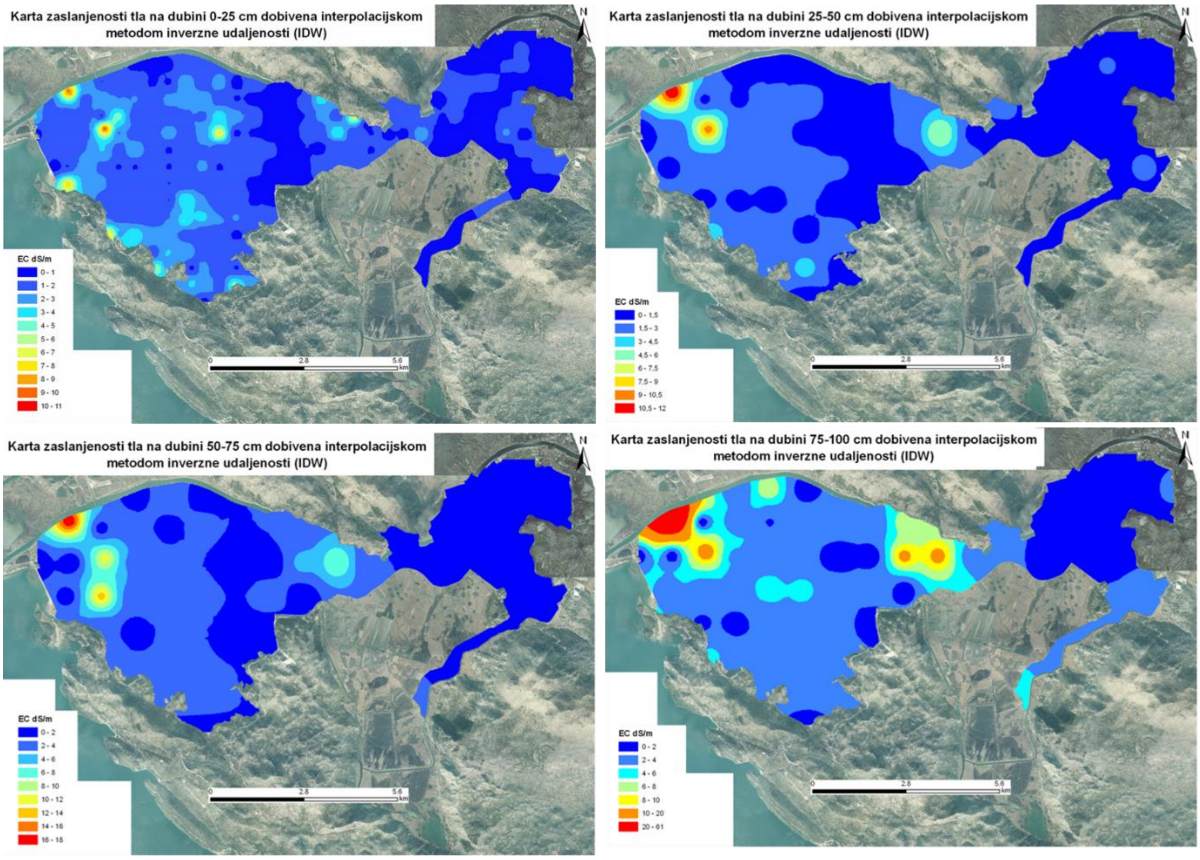
SOIL SALINITY

The EC_e (needs to be written extended the first time. Because of the distinction of EC of water and soil it is better to use EC_w and EC_e through text) map shows that most saline soils (EC_e > 2 dS m^{-1}) 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 EC_e 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. A.

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.

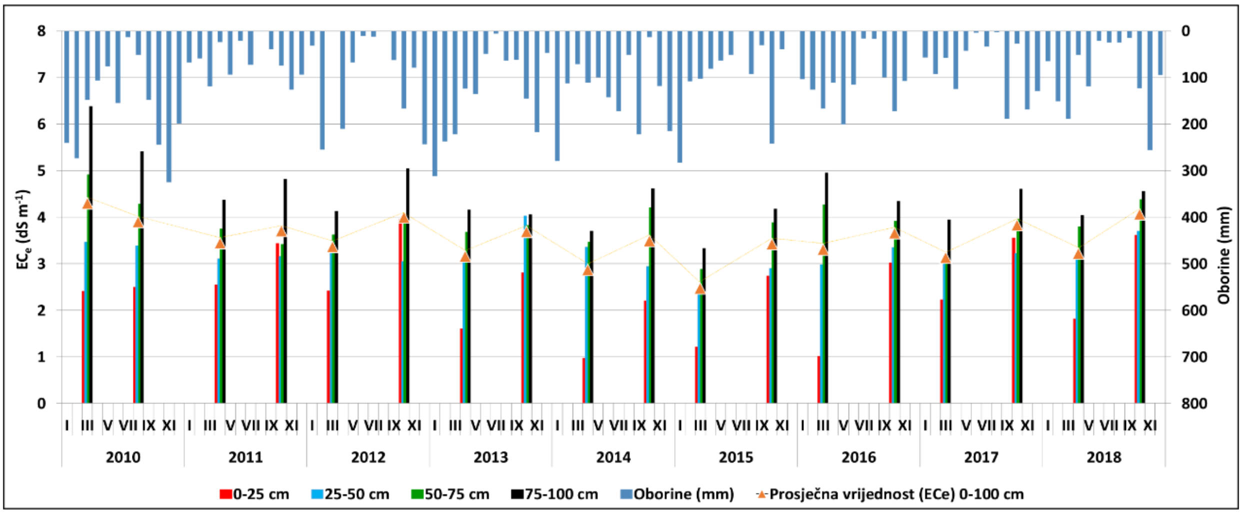
Technological measures are recommended for the management of agricultural land under saline conditions. When it comes to irrigation and saline water is used, it is necessary to apply a modified method of managing the irrigation system: special attention should be paid to irrigation amounts and intervals, 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.

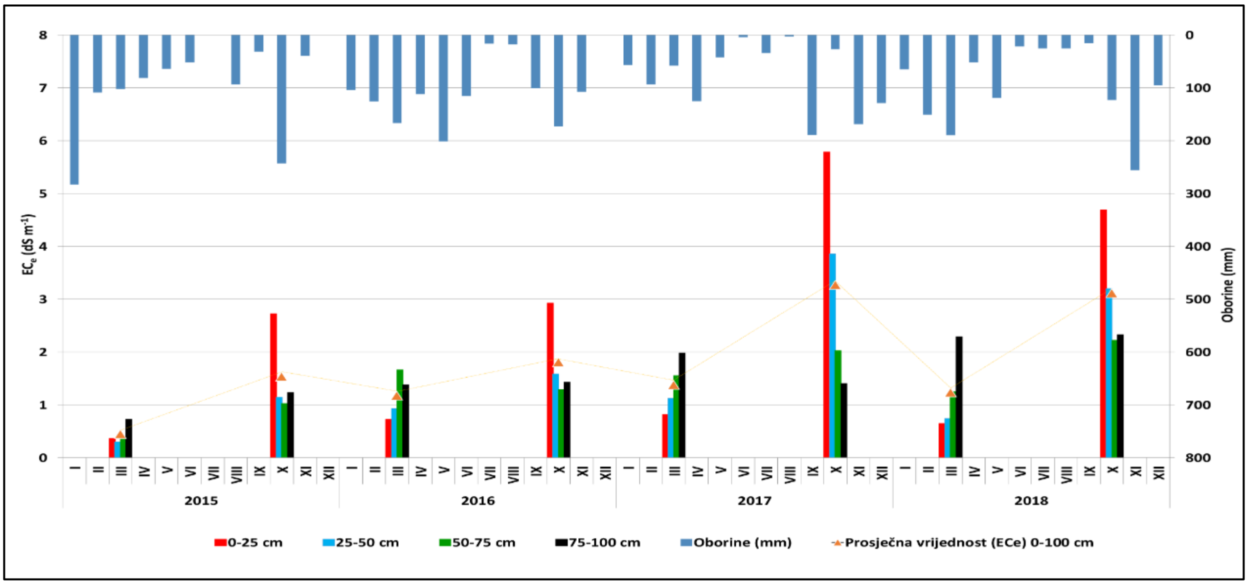


Soil salinity maps by depth (0-25 cm; 25-50 cm; 50-75 cm; 75-100 cm) in the Neretva Valley (Romić i sur., 2010.)

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. It is possible to determine if precipitation during the fall-winter period was sufficient for significant leaching of salt from the soil profile. In addition, this sampling period coincides with the start of sowing/planting of the main crops in the field and knowledge of soil salinity during germination and early plant growth is extremely important as crops are most sensitive to elevated salt concentrations at this time. The second sampling was carried out 6 months apart, i.e. in the September/October period. This is a period preceded by high air temperatures, significant water losses from the soil through evaporation, low rainfall and the application of irrigation. All of this poses a major threat to the accumulation of salt in the soil, so the highest level of soil salinity is expected during this period. Of all the soil monitoring stations, the highest average EC_e value of 3.75 dS m^{-1} 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.



Changes in EC_e(dS m^{-1}) in soil profile at MP Vidrice 2010. – 2018.



Changes in EC_e (dS m^{-1}) in soil profile at MP Komin 2015. – 2018.

Of the total stations studied, the mean value of EC_w in the range of 2 - 10 dS m^{-1}, which belongs to the class of moderately saline waters (primary drainage water and groundwater), was determined in three groups of stations: Pumping stations, draianage canals and piezometers, while the mean value of EC_w of natural streams was in the range of 0.7 - 2 dS m^{-1}, which belongs to the class of low salinity waters. High coefficients of variability, observed high maximum values and statistically significant positive trends of EC_w values indicate a possible further increase of EC_w 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 EC_e values of more than 2 dS m^{-1} 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. HCO_3- 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, Ca^{2+} dominated both surface water samples and groundwater samples at the Luke and Vrbovci piezometers.

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.