DRIN CORDA

Enabling & Transboundary Cooperation & Integrated Water Resources Management in the extended DRIN RIVER BASIN

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Pilot Project
"Design and testing of a multipurpose transboundary groundwater monitoring network in the Extended Drin River Basin" (DRIN) 2017 - 2020
Final Report

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Pilot Project
"Design and testing of a multipurpose transboundary groundwater monitoring network in the Extended Drin River Basin" (DRIN) 2017 - 2020

Final Report

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Executive Report

Hydrogeological Conceptual Model of the Skadar/Shkoder – Buna/Bojana Transboundary Aquifer System

The Skadar/Shkoder Buna/Bojana transboundary aquifer system represents a groundwater resource is of great importance for both Montenegro and Albania. This project aims to design and test a groundwater monitoring network, which should:

- improve transboundary cooperation for the sustainable management of groundwater resources in the area, and
- comply with European Water and Groundwater Framework Directives (EU WFD and EU GFD) requirements.

The EU WFD states that the design of a monitoring network should be based on the "characterization, assessment of risk and building of a conceptual model of the groundwater system, in which the general scheme 'recharge-pathway-discharge' is known". This report aims to generate a hydrogeological conceptual model of the transboundary aquifer system, as required by the EU WFD for the preparation of the groundwater-monitoring programme. The characterization, should include the definition of groundwater bodies, which are the main groundwater management units used by the EU WFD. The conceptual model should present an integrated overview of the state of the groundwater resource, including information about hydrologic, environmental and socioeconomic aspects. Moreover, this characterization should be based on the most up-to-date available information, where data gaps should be highlighted in order to be tackled through the monitoring network design.

For the sake of consistency with the EU WFD requirements, four groundwater bodies of sedimentary nature have been identified for each hydrogeological unit:

1. ***GWB-01 Zeta plain.-*** The GWB formed by alluvial aquifer of the Zeta, Morača and Cijevna rivers. It is considered an excellent aquifer. Recharge is due to karst lateral inputs, rainfall and, locally, stream infiltration. Main discharge is towards Skadar/Shkoder Lake, occasionally stream discharge, and groundwater withdrawal for urban (mainly, Podgorica city), industrial and agricultural demand. Main pressures are groundwater abstraction and pollution from urban, industrial and agricultural sources, reasons why we consider it highly vulnerable.
   This GWB lays entirely on Montenegrin territory. Therefore, the only transboundary interactions that are expected are through the groundwater seepage to the

Skadar/Shkoder lake, and if any, recharge of the Zeta plain through the upper Cijevna catchment which lies in Albanian territory.

2. ***GWB-02 Koplik-Skhodër plains*.-** The GWB formed by the alluvial fan aquifer of the Koplik-Skhodër plains. Hydrogeological dynamics is comparable to the GWB of the Zeta Plain, and main human pressures are pollution from urban and agricultural sources. It also shows large vulnerability.
   This GWB and related surface water catchment lays entirely on Albanian territory. Therefore, no transboundary issues arise from the GWB headwaters. The only common issue is the groundwater seepage to the contribution the Skadar/Shkoder Lake, as for GWB-01.

3. ***GWB-03 Trush and Zadrima plains.-*** The GWB formed by alluvial aquifer created by the Drin and Buna/Bojana river sediments that created the Trush and Zadrima plains. This is a highly productive aquifer, which gets its recharge from stream, rainfall infiltration and lateral recharge from surrounding limestone ranges. The main pressures are groundwater abstraction for domestic and agricultural use, and pollution of agricultural sources..
   This hydrogeological system lays entirely in Albanian territory. Therefore, the only transboundary issues that could arise are those related to the quality of the Buna/Bojana River as a source of groundwater recharge, and future stream discharge capture from the Drin river discharge towards Albanian territory.

4. ***GWB-06 Buna/Bojana delta area.-*** This GWB integrates the most recent deltaic system of the river. The recharge of the deltaic aquifer is related to stream and rainfall recharge, as well as form lateral contribution from limestone formations. Groundwater flow discharge is mainly to the sea. Given a high human activity, mainly touristic, pressures are high, involving groundwater withdrawal and the associated seawater intrusion when high pumping regimes are set in wells close to the coastline.
   This is the only identified GWB that lies entirely in both countries. Low topographic gradient and the meandering morphology of the river should enable recharge to cross the river course, thus the country borders, leading to any kind of transboundary effect from one site to the other.

The four identified groundwater bodies present good status. However, information on groundwater quantity and quality was scarce. It allowed neither to draw solid conclusions nor to perform a proper trend analysis. Therefore, this initial characterization and assessment of state should be completed with additional information, especially when it comes to groundwater levels and hydro-chemical analysis. Moreover, the risk assessment identified serious risks to both groundwater quantity and quality. Despite three of the four groundwater bodies situate within a single country, indirect transboundary effects occur mainly through surface water – groundwater hydraulic connectivity.

Consequently, the design and implementation of a monitoring network, based on the EU WFD requirements, will provide a necessary database that permits developing adequate water resources management plans and facing, as well as avoiding, potential transboundary conflicts regarding groundwater availability and quality issues. The design and development of a groundwater monitoring network and program is developed in a companion report to fulfil the scope of this project[1].

[1] Mas-Pla, J (2019). Design and development of a groundwater-monitoring network and program for the transboundary aquifer between Albania and Montenegro. Project "Design and testing of a multipurpose transboundary groundwater monitoring network in the Extended Drin River Basin" (DRIN). Unpublished, 37 pp.

Groundwater Bodies	Geomorphology	Average thickness	Recharge / discharge	Potential groundwater quantity risks	Groundwater quality	Potential groundwater quality risks	Groundwater dependent Ecosystems	Environmental protection areas
GWB-01 Zeta Plain	unconsolidated clastic deposits	100 m	Main recharge mechanism: surrounding karst system of the Cijevna River catchment, which upper catchment is located in Albania Main discharge mechanism: discharge to the Skadar Lake though Morača surface discharge and direct groundwater seepage	- Water abstraction in Podgorica urban area (MTN) - Water abstraction due to agricultural activity (MTN).	Dominant facies is calcium bicarbonate In general good quality with EC values below 700 mS/cm	Point sources: -Aluminium production facility (MNT) - Food-processing and plastic industries as potential pollution focuses (MNT) - Gravel mining along Morača River (MNT) Diffuse sources: - Fertilization (MNT) - Stream recharge due to well capture zones (MNT)	Karstic springs Shkoder/Skadar Lake and lake marshes	Lake Shkoder/Skadar and River Buna (RAMSAR)
GWB-02 Koplik-Skoder Plains	unconsolidated clastic deposits	100-150 m	Main recharge mechanism: surrounding karst system Main discharge mechanism: discharge to the Skadar Lake though groundater seepage		Few data available Good quality	- Fertilization (ALB) - Waste Water disposal from Skodra city (ALB)	Karstic springs Shkoder/Skadar Lake and lake marshes	Lake Shkoder/Skadar and River Buna (RAMSAR) Lake Shkoder/Skadar National Park

Groundwater Bodies	Geomorphology	Average thickness	Recharge / discharge	Potential groundwater quantity risks	Groundwater quality	Potential groundwater quality risks	Groundwater dependent Ecosystems	Environmental protection areas
GWB-03 Trush plain	unconsolidated alluvial deposits	50 m	Main recharge mechanism: drainage from Skadar/Skoder lake and surrounding moundatin ranges Main discharge mechanism: seepage towards Buna/Bojana river	- Well field near Fshati i Ri for urban supply (ALB). - Overpumping for agricultural demand (ALB).	Few data available Good quality	Point sources: - Landfill near Shkjezë (ALB). - Saski Lake has been reported to show high heavy metal concentrations. - Gravel mining along the Drin River left-bank, near Ashtë (ALB). - Pollution from septic systems and network (where existing). Diffuse sources: -Fertilization		Managed natural reserve (IUCN)
GWB-06 Buna/Bojana Deltaic Area	deltaic deposits	30 - 50 m	Main recharge mechanism: contribution from Buna/Bojana river and local limestone mountain ranges Main discharge mechanism:groundwater seepage to the sea	- Domestic and agriculture wells near the coastline in Velipojë (ALB) and Doni Štoj (MTN) - Saline water in karstic springs (Gac spring). - River salinization.	Few data available, mainly in shallow wells	Point sources: - Leakage from salt production ponds (ALB, MTN). Diffuse sources: - Fertilization (ALB, MTN). - Stream recharge due to well capture zones affected by wastewater dumping (urban drainage). - Non-farmed stock breading (ALB).	Sasko Lake Viluni Coastal brackish lagoon Ulcinj Saline	Managed natural reserve (IUCN) (ALB) Important Bird Area and EMERALD site (MNT)

ACVM Method Vulnerability analysis

ACVM (Aquifer Comprehensive Vulnerability Mapping) method is a new tool for evaluating aquifer vulnerability. It is based on a new, expanded concept of vulnerability mapping that is derived from the concept of intrinsic aquifer vulnerability itself. This method is easy to use and is able to work also with inexpensive data. Moreover, this method is able in describing on a map all the vulnerability aspects of an aquifer.

Therefore, the application of the ACVM (Aquifer Comprehensive Vulnerability Mapping) method on the transboundary aquifer located within the Skadar/Shkoder - Buna/Bojana shared by Albania and Montenegro, constitute a new approach for design the monitoring network and for providing to stakeholder a new tool for a wise exploitation of the territory.

A first draft of the ACVM Vulnerability map was elaborated at the end of 2018 using the DIKTAS project data. But in 2019 new detailed data were available on the studied area so it was possible to elaborate a new vulnerability map at the scale 1:100000. This new map describes the ability or inability of the various part of the territory to cope to the external threat that can degrade groundwater quality. In particular the considered threats are a pollutant dispersed on the land surface and the salt water intrusion. Moreover, a first draft of the map that also consider the flooding events, was elaborated.

In the elaborated map we can see that a large part of the territory has comprehensive vulnerability ranging from severe to medium, while other minor parts have low vulnerability. This means that a large part of the territory is fully exposed to a pollutant coming from surface due to the high permeability of the outcropping rocks. On the other hand, the aquifer is fully exposed to the threat of salt water intrusion only near the coast line, while it has some means of defence on the other parts of the aquifer at the north of the Trush area. Finally, the aquifer is exposed to the flooding events in the flat areas on the south part of the studied area.

So, Vulnerability analysis, elaborated using the ACVM Method, provides management recommendations and an additional tool to help the design of the monitoring network.
In particular the areas of Trush and the Buna/Bojana delta are places where sea water is partially present in the aquifer. So, the monitoring network can give information on the modification of the limits of salt water intrusion relating it to the exploitation of the aquifer and the precipitations.

On the other hand, monitoring the areas on the north part of the transboundary aquifer and in particular the Z Plain and the Koplik-Skhodër Plains can give information about the feeding of the aquifer. This aspect is related not only to the groundwater quality, but also to the salt water intrusion, because a reduction of the feeding of the aquifer can lead a reduction of aquifer specific energy in the area near Trush favouring salt water intrusion.

The intersection of these information with the considerations done applying the Water Framework Directive constitute a new approach for design the monitoring network and could be applied on other coastal aquifers.

Monitoring Network Design

The implementation of the Water Framework Directive (WFD) requires a defined procedure that involves, among other items, defining groundwater bodies (GWBs). Based on their characteristics as well as on the pressures and impacts from human activities, this procedure allows for setting a monitoring network that permits achieving the management and environmental goals required by the Directive.

For the studied area, six GWBs have been proposed. However, the WFD goals are at risk in only four of them: two located in Albania (the Koplik-Skhodër plain and the Trush plain GWBs), a third situated in Montenegro (the Zeta plain GWB), and a fourth one the Buna/Bojana delta area situated between both countries and, therefore, the only one defined as a transboundary GWB. For all four selected GWBs, a monitoring plan is defined based on their hydrogeological characteristics and on the present exploitation and water resources demand.

Monitoring programs are set for all GWBs, yet two priority areas are defined:

1. the Zeta plain, where urban and industrial pressures are high and hamper the accomplishment of the WFD goals, specifically in the urban area of Podgorica and along the Morača River valley,
2. the Buna/Bojana delta area, where intense development may cause over-exploitation and seawater intrusion with negative effects on groundwater resources and on coastal ecosystems.

A hydrogeological conceptual model derived from the review of the existing information permits indicating where the monitoring wells should be located. Yet, it does not allow identify existing wells or boreholes to be used for data gathering. Therefore, unless such monitoring wells exist so that data can be obtained to satisfy a quantitative and qualitative characterization of the GWB, new monitoring wells should be drilled.

The specific parameters for the quantitative and qualitative characterization are set according the WFD guidance documents. The use of automatic devices, as CTD data-loggers that permit a continuous record of water pressure (as a reference for the hydraulic head data), temperature and electrical conductivity (EC) of the water, is prioritized. These instrumentations allow daily measurements that will satisfy the quantitative and surveillance (at least as regards of EC) monitoring, with the necessary detail to identify tendencies and variations in the aquifer behaviour. The acquisition of qualitative data also implies taking groundwater samples for a complete hydrochemical analysis. This analysis must include all major chemical constituents, nutrients and other parameters as listed by the WFD and the Groundwater Directive, and should be conducted at least on quarterly basis.

Data integration and interpretation should be conducted annually to identify and report the GWB status and potential trends. Given the hydrological relationship among all four GWBs, common operational procedures in both countries are encouraged, especially in the transboundary Buna/Bojana delta area.

Our proposal of sampling sites does not differentiate between surveillance and operational monitoring. Indeed, it considers the available information, and sets which areas should be monitored. This report considers that such zones must be monitored as operational sampling sites, while the rest of the database can be maintained as surveillance sampling sites. Nevertheless, local technicians and experts have the final decision about it.

Chapter 1.

Hydrogeological Conceptual Model of the Skadar/Shkoder – Buna/Bojana Trans-boundary Aquifer System (Albania and Montenegro)

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1. Introduction

Problem statement

The Skadar/Shkoder Buna/Bojana transboundary aquifer system is an unconsolidated aquifer situated between Albania and Montenegro. These groundwater resources is of great importance for both countries. It provides fresh water to highly populated areas like Podgorica or Shkoder cities. It is affected by intense human activities, like agriculture and industry. Additionally, it is located in the Mediterranean coastal region, an area highly vulnerable to climate change variability, thus increasing frequency of extreme flooding and droughts. These are some of the reasons why several initiatives already took place in the area: DIKTAS project (GEF/UNDP/UNESCO), Integrative Management Framework (IMF) for Bojana/Buna Area – MedPartnership (GEF/UNEP/MAP), Development of Hydrological and Hydraulic Study of Regulation of Skadar Lake and Bojana River Water Regime and Initial Characterization of Lakes Prespa, Ohrid and Shkodra/Skadar projects funded by the GEF (UNDP, World Bank). The project to which this report contributes is entitled "Design and testing of a multipurpose transboundary groundwater monitoring network in the Extended Drin River Basin" (DRIN). It builds on mentioned previous efforts, targeting the urge for monitoring of the shallow unconsolidated aquifer shared between both countries, as a mechanism to improve transboundary groundwater management.

The project aims to enable transboundary cooperation and integrated water resources management in the extended Drin River Basin, by designing and testing of a multi-purpose (transboundary) groundwater monitoring network (Albania & Montenegro). This project is executed under the framework of the UNESCO Programme and Budget 2018 – 2019 (39C/5) Main Line of Action 3: Improving knowledge and strengthening capacities at all levels to achieve water security, by (ER 7) ensuring Member States to strengthen their response to water security challenges towards the achievement of water related SDGs and targets, and other targets from relevant international water agendas. Therefore, to comply with the overall UNESCO strategic objectives, the process of designing and testing the transboundary groundwater monitoring network must enhance cooperation in reaching sustainable development in the transboundary region.

Additionally, both countries operate under the influence of the European Union, as both aim to comply with requirements to become part of the union. Harmonization of national policies with supranational European Union (EU) environmental directives related to water (WFD, 2000/60/CE, and GWD, 2006/118/CE) is a key priority for both administrations. Therefore, principles, requirements and methodologies described in these norms and in associated documents, such as Guiding documents, are taken as guiding principles along the project implementation.

The project results will be based on an exhaustive review existing knowledge on the status of the aquifer's groundwater resources. This includes a review of peer-reviewed publications, technical reports and data hold by the national administrations and local experts. In this sense, unknowns and information gaps should be highlighted by the project, and included in the design of the monitoring network and cooperation strategy between both countries.

The guiding principle for the project execution should be therefore to achieve appropriate level of symmetry in the involvement of both countries in the management of the Transboundary Aquifer System. The transboundary monitoring network design and testing becomes not only an objective on itself, but also a mean to improve transboundary cooperation.

The Water Framework Directive (WFD)

Regarding groundwater resources, the EU WFD and its "daughter" the Groundwater Directive (GWD) can be taken as a way to express the scientific problems and solutions in a language which could be understood and applied by the policy-makers, so adequate management actions are taken based on conventional data, monitoring programs and an international agreement to achieve a sustainable groundwater resources management.

Under the WFD, the framework for groundwater protection imposes on Member States to:

1. delineate groundwater bodies within River Basin Districts and characterise them through an analysis of pressures and impacts of human activity on the status of groundwater in order to identify groundwater bodies presenting a risk of not achieving WFD environmental objectives,
2. establish registers of protected areas within each river basin districts for those groundwater areas or habitats and species directly depending on water, including all bodies of water presently used for the abstraction of water intended for human consumption and those intended for such future use,
3. establish a groundwater monitoring network providing a comprehensive overview of the groundwater chemical and quantitative statuses,
4. Set up a river basin management plan (RBMP), and establish a programme of measures for achieving WFD environmental objectives (e.g. abstraction control, measures to prevent or control pollution). In particular, a river basin where use of water *may have transboundary effects*, the requirements for the achievement of the environmental should be coordinated for the whole of the river basin district, producing a single international RBMP. Moreover, the GWD state that Member States sharing bodies of groundwater should coordinate their activities in respect of monitoring (set in Annex V, point2, of the WFD), the setting of threshold values, and the identification of relevant hazardous substances.

Such environmental objectives for groundwater consist on (Article 4),

i. implementing the measures necessary to prevent or limit the input of pollutants into groundwater,
ii. protecting, enhancing and restoring all bodies of groundwater, ensuring a balance between abstraction and recharge of groundwater, with the aim of achieving good groundwater status, and
iii. implementing the measures necessary to reverse any significant and sustained upward trend in the concentration of any pollutant resulting from the impact of human activity.

Beyond these particular points, a larger perspective of the WFD, the one that seeks to integrate all significant management actions devoted to achieve the environmental objectives, is of great interest for this study. It also seeks to integrate different decision-making levels within each Member State, and among the different Member States (existing and/or future Member States), that share river basins.

Goals and content of this document

The goals of this document is to set up a conceptual model of the hydrodynamics of the main groundwater bodies of the aquifer system, namely the Buna/Bojana delta and the Skadar/Shkoder Lake areas. The conceptual model should include the necessary information for the design of a transboundary groundwater monitoring program.

This report follows the requirements of the EU Directives (WFD and GWD) in the way that groundwater bodies, as management units, are proposed in the integrity of the hydrogeological systems of the Skadar/Shkoder Lake and the Buna/Bojana delta aquifer systems (**Figure 1.1**). The Skadar/Shkoder Lake area includes the aquifers of the Zeta plain in Montenegro, and the Koplik-Skhodër plain in Albania. As stated in the European Water Framework Directive (EU-WFD) Guidance Document No. 15 “Guidance on Groundwater Monitoring” (European Commission, 2007), “the design of a monitoring network should be based on the characterization, assessment of risk and building of a conceptual model of the groundwater system, in which the general scheme ‘recharge-pathway-discharge’ is known”. The compliance of these requirements is the objective of this report.

Figure 1.1 Map depicting initial boundaries of Buna/Bojana Skadar/Shkodra Transboundary Aquifer System (extracted from GEF UNDP Project proposal).

Available information

The report is based on existing knowledge on the area, which is mainly in the form of peer-reviewed publications, technical reports, knowledge from local experts and information hold by both administrations. A phase for data collection was included in the project design and implemented as one of the first activities. This phase included the contracting of two local experts, a mission of the project international consultants to both countries and the involvement of both administrations. Scientific papers and non-governmental reports are referenced when cited along the document. The data collection phase carried by the country administrations has been crucial to the consecution of the project objectives, and especially to the construction of the hydrogeological conceptual model. Information submitted by the Government Authorities of Albania and Montenegro is described in Annex I and II.

2. Characterization of Groundwater Bodies

This document understands that the study area includes the hydrogeological systems of the two areas, shared by both countries:

1. the Zeta and Koplik-Skhodër plains, geologically unrelated and hydrographically linked to the base level set by the Skadar/Shkoder Lake, and
2. the fluvial-deltaic plain of the Buna/Bojana River, up to the Drin River in its north-east boundary, and its coastal geomorphological environments.

We first admit that both areas are hydrogeologically unrelated, except for the fact that the Skadar/Shkoder Lake contributes to the discharge of the Buna/Bojana River. Nevertheless, this hydrological relationship will not interfere on the groundwater bodies' definition, yet the output from the Skadar/Shkoder Lake will be indeed considered as a component of the water balance that governs the groundwater level and chemical status of the Buna/Bojana delta. Therefore, both areas will be treated independently along the document defining their hydrogeological and environmental characteristics, as well as the pressures and impacts resulting from the human activity separately.

2.1. Geology

Regional geology

The Skadar/Shkoder – Buna/Bojana hydrogeological systems are transboundary aquifer located between Montenegro and Albania. Both are formed during the Quaternary by the post-tectonic deposits located around the Skadar/Shkoder Lake and Drin river lower catchment. In the so-called Dinaric region, geology is dominated by complex tectonics and the intensively Mesozoic karstified-carbonatic sediments and the Eocene flysch. Today, the still active deformation front is located close to the coastaline buried under the thick deposits of the Buna/Bojana river (Pingel, 2017).

Radulovic et al. (2015)[2] describes three tectonic zones within the study area (**Figure 2.1**): (1) the Paraautochton (Adriatic-Ionian) zone, which extends all along the Adriatic coast and is composed mainly by limestone and low permeability flysch affected by a series of reverse faults parallel to the coast; (2) the Budva-Cukali zone extending in a belt shape parallel to

[2] Radulovic et al. (2015). Hydrogeology of the Skadar Lake basin (Southeast Dinarides) with an assessment of considerable subterranean inflow. *Environ Earth Sci*, 74: 71-83. DOI 10.1007/s12665-015-4090-7.

the coast, that acts as a hydrogeological barrier; and (3) the Visoki zone which extends all over the inland part of the study area, formed by highly karstified limestone and dolomite in two regional anticlines, creating karst depressions in between. The unconsolidated clastic sediments of Lake Skadar/Shkoder are deposited on top of this karst system.

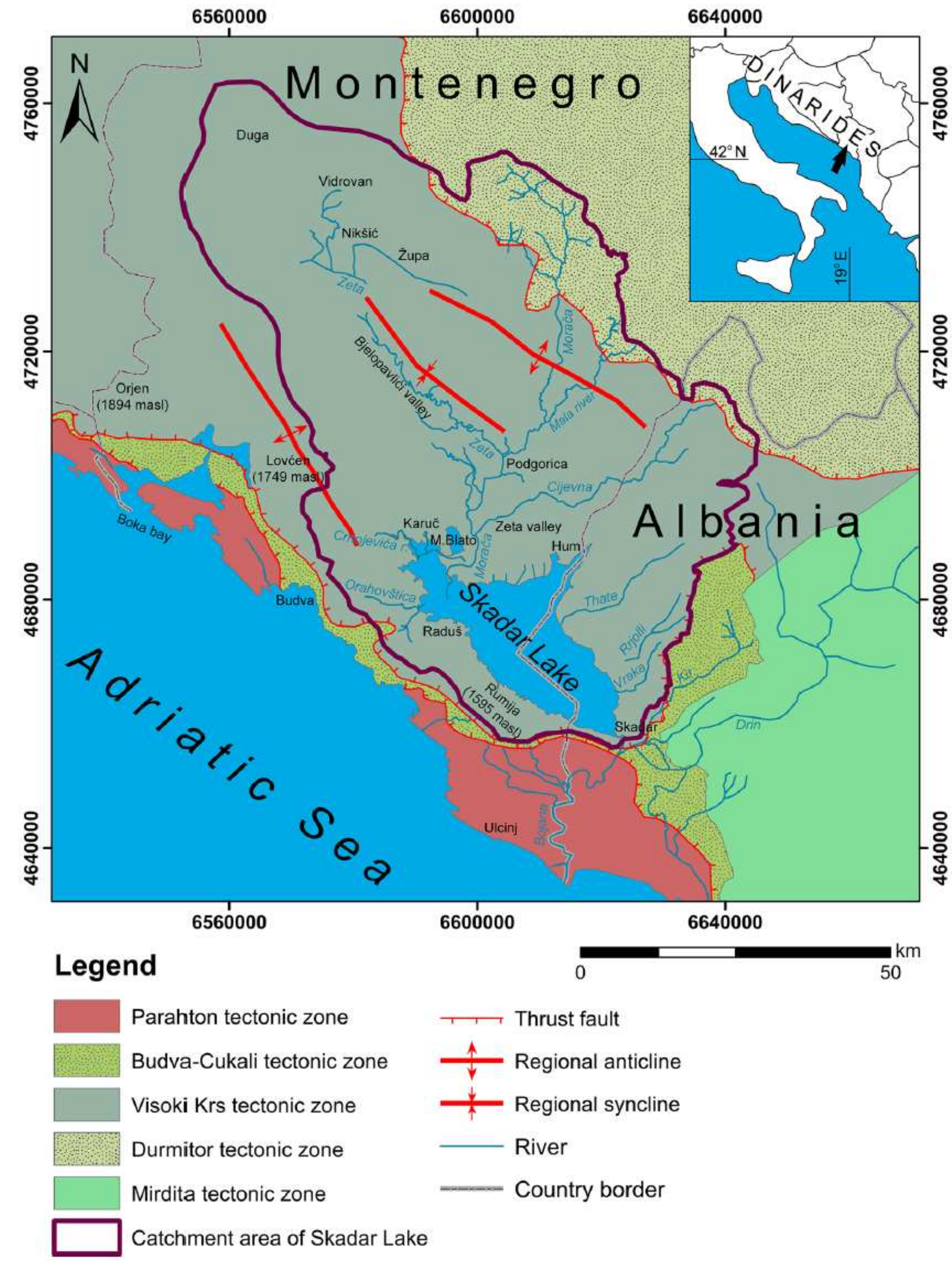

Figure 2.1.- Map with Regional Tectonic areas (Radulovic et al., 2015).

These zones are separated by reversed faults, resulting on the Visoki tectonic zone being pushed over the Budva-Cukali zone, and this over the Paraautochton zone (Radulovic et al., 2015).

The karst depression of the Skadar/Shkoder basin and the Zeta valley is one of the largest karst depressions in the area of the Dinarides. This depression is filled with unconsolidated clastic deposits up to 100 m thick. The karst aquifer has a wide distribution in the Skadar/Shkoder Lake catchment area. It is presented in the area of the karst plateau, but also at the base of the aforementioned depressions. Despite the dominant karst geomorphological features of the area, faults and fractures also determine the landscape relief, which is led by thrust and reverse faults that are responsible for the main mountain ranges in the area.

Regarding the Buna/Bojana fluvio deltaic area, it is occupied for the most part by extensive alluvial plains, with an altitude not exceeding 15 m asl. To the east and north, the plains are framed by up to ca. 1600-m-high mountain chains, forming an extremely steep relief between the coastline and the peaks ca. 8–20 km inland. Near the coast, the plains are interrupted by sets of prominent circa coast-parallel NW-SE striking anticlinal ridges (≤610 m asl maximum elevation) connecting to the topographically higher regions in the north and northwest. The region is traversed by major rivers (Drin and Buna/Bojana) and a few minor rivers (Kir, Međurečka River) that strongly control sedimentation in the plains (Biermanns et al., 2019[3]). Mean annual flow at the mouth of the River Bojana into the sea is Q = 682 m^3/s. The maximum average monthly flow is characteristic for the month of January, and it amounts Q = 1067 m^3/s (Radulovic and Sekulic, 2012[4]).

In the coastal area, the anticlines on the Albanian and Montenegro sides, as consecutive tectonic structures, consist of Upper Cretaceous rudist limestone, framed by narrow fringes of Eocene biomicritic limestone with nummulites. The synclines are made up of folded Eocene flysch. The alluvial plain, fully encircling the anticlines in Albania, only reaches the SE branches of those in Montenegro, slightly exceeding the Old Town of Ulcinj and the western shores of Šasko Lake toward the WNW (**Figure 2.2**). Geomorphological evidence suggests that differential uplift ('growth') of the anticlines is still ongoing but rather controlled by active bounding faults instead of folding. The anticlines exhibit different degrees of partly intense karstification. Also, the influence of jointing, fracturing, and faulting varies locally.

[3] Biermanns et al., (2019). Tectonic geomorphology and Quaternary landscape development in the Albania - Montenegro border region. *Geomorphology* 326: 116–131. DOI: 10.1016/j.geomorph. 2018.09.014.

[4] Radulovic and Sekulic, (2012). *Hydrology and Hydrogeology inputs for the preparation of the Buna/Bojana Transboundary Integrated Management Plan*. United Nations Environment Programme, Mediterranean Action Plan, Regional Activity Centre for the Priority Actions Programme (PAP/RAC), UNEP/MAP GEF Strategic Partnership for the Mediterranean Large Marine Ecosystem; 73 pp.

The Holocene sea level trend is characterized by a rapid rise of ca. 120 m immediately after the LGM ca. 18 ky ago in Albania. A significant slow-down to more moderate rates occurred around 6-7 ky ago. As a reaction to this, coastal plains in the study area prograded up to 40 km. Both processes (prograding coastline and rising sea level) are still ongoing today. As coastal progradation is heavily dependent on fluvial sediment load, recent coastal erosion tendencies on the delta fronts of Drin and Buna/Bojana rivers were evoked by avulsion, and later by damming of the Drin River. The Bojana Island, as a result of the accumulated sediment after the Drin River joined the Buna/Bojana River in the XIX century, reflects this nowadays active sedimentation process.

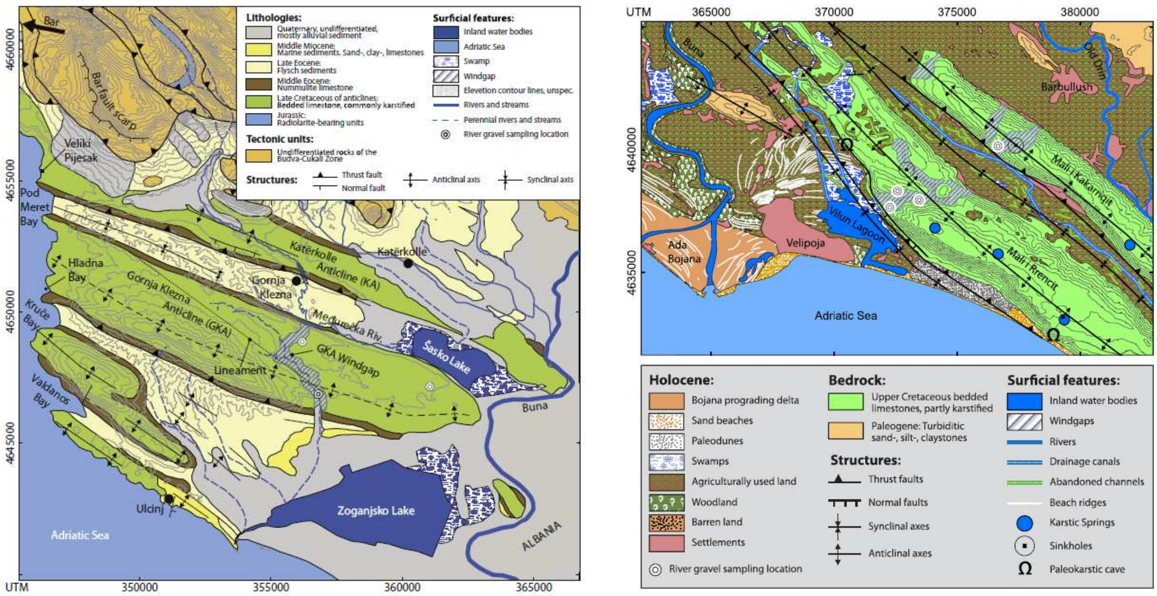

Figure 2.2.- Geological maps of the Montenegro and Albanian parts of the Buna/Bojana area, after Biermanns et al. (2019).

Geology of the Zeta and Koplik-Skhodër plains (Skadar/Shkoder Lake area)

Both, the Zeta plain and the Koplik-Skhodër plain are the result of the sedimentary infilling of the karstic Skadar/Shkoder basin. The Skadar/Shkoder Lake stands as the remnant unfilled area of the basin. Despite its low bathymetry, it defines the base level of the area that controls the most recent sedimentary events in the area.

The Zeta plain, in the Montenegrin side, is filled by a granular aquifer formed by the high-permeable gravelly sandy sediments as alluviums of the main rivers. These are related to a fluvio-glacial and alluvial sedimentary dynamics of Zeta valley (Radulovic et al., 2015) than contributed to the infilling of the karstic basin; namely, the Zeta, Morača and Cijevna rivers. This main granular aquifer, named as “Terrace 3” in the Montenegro Geological Maps

(MGM)[5,6], shows some degree of cementation in the gorges of the Cijevna River as a result of incision in the old, inactive terrace. Geomorphological features observed in satellite images (Google Earth) illustrate the braided facies of the streams related to the old alluvial fans that filled the basin, indicating a dominance of large size (boulder, gravel) particles in the sediments and an scarcity of silt and clay (i.e., low permeability) layers.

The Zeta and Morača rivers have eroded the sediments of “Terrace 3” in the western limit of the Zeta plain, and deposited two more recent terraces: “Terraces 1 and 2”, being “Terrace 1” the present flood-plain of both streams. The lithology of both terraces is similar to that of “Terrace 3”, yet it is expected to show finer sediments in their surface. Nevertheless, gravel-mining ponds along the Morača River, mainly in its left-bank floodplain, indicate the coarse and unconsolidated nature of its sediments. A degraded scarp appears between “Terraces 2 and 3”, whereas a morphological continuity appears between “Terrace 2” and the present floodplain.

Lacustrine sediments are deposited in the transition between the terraces and Skadar/Shkoder Lake. Sediments transported by the Morača River, as well as for those small streams that erode “Terrace 3” in the 2-km strip close to the lake, are mainly constituted by fine grained sediments. The lacustrine sediments have a very low permeability.

This Quaternary infilling of the Zeta plain lays on the low-permeable sediments of the flysch and the existing volcano-sedimentary formation, which represents an aquitard (Radulovic et al., 2015) and separates the fluvial sediments from the underlying karstified rocks.

Finally, karstic hydrological features, as springs, are found along the lacustrine strip near Skadar/Shkoder Lake, indicating the high potentiometric pressure of the underlying karstified limestones. Such springs, which are related to limestone dissolution processes, can hypothetically be associated to fault alignments that control the karst development, and both –karst and fractures– govern groundwater flow in depth. Nevertheless, faults might also function as barriers; this may be the case of reversed faults. In fact, some springs occurring in the nearby ranges are distributed along the structural contact between the permeable karst formations and the impermeable flysch.

As regards the Koplik-Skhodër plain, also known as the MbiShkodra aquifer, it is composed by the contribution of three alluvial fans: that of the Prroni i Thatë River at the north, that

[5] Radulović, M., Radulović, V., Popović, Z. 1982. Osnovna hidrogeološka karta list «Titograd», 1:100 000. Zavod za geološka istraživanja SR Crne Gore, Titograd.

[6] Radulović M. i ostali, (1989): OSNOVNU HIDROGEOLOŠKU KARTU LISTA "BAR SA ULCINJEM" 1:100 000, Fond J.U. Republički zavod za geološka istraživanja, Titograd

of the Zica River in the middle, and the fan of the Kir River, with an area of near 164 km^2. The later flows out of the North Albanian Alps and nowadays is a distributary of the Drin just below Shkodër, yet it contributed to form the alluvial plain north of this city. These alluvial fans are also constituted by coarse sediments (boulders, gravels), gradually changing to finer sediment to the lake, reaching a thickness of near 90 m (Figure 2.3). The lacustrine strip along the coast is narrower here than in the Zeta Plain. In their proximal reaches, streams are incised in the fan morphology, denoting the present lack of intense activity of these depositional systems. However, they still bring sediment to the lake and it may form some minor fans in its distal reaches, as near Kamice.

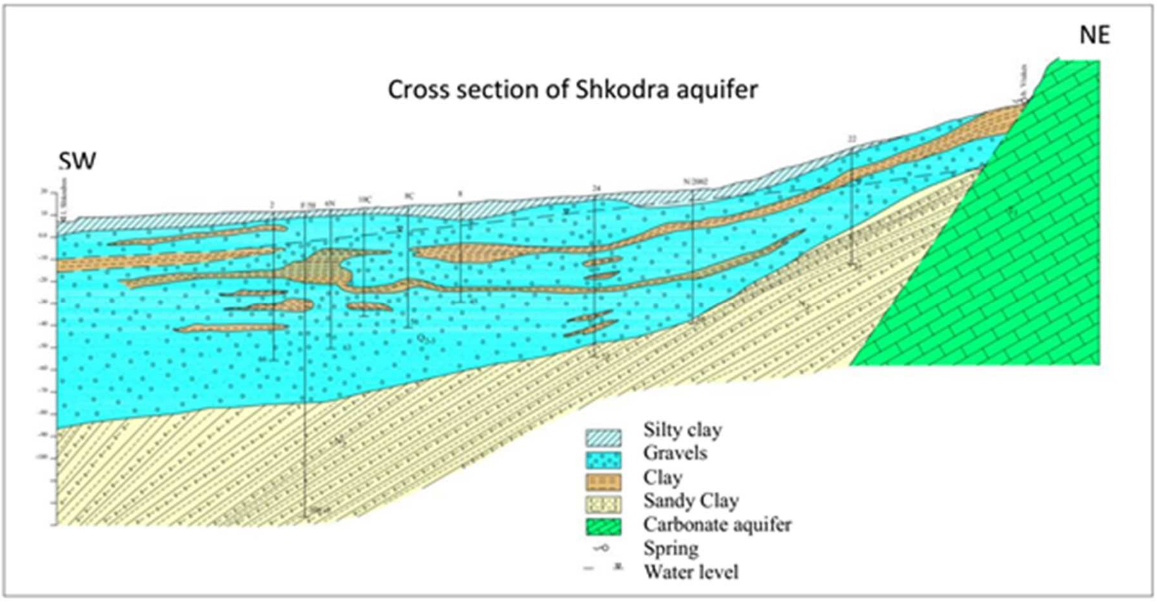

Figure 2.3.- Cross-section of the Koplik-Skhodër plain.

Despite the sedimentary and depositional similarity of the deposits of the Zeta plain (fluvial/alluvial fan) and the Koplik-Skhodër plain (alluvial fan), both geological units must be considered as hydrogeologically similar, but independent from a groundwater resource abstraction perspective. The facts that 1) their deposits join in their distal parts below the Skadar/Shkoder Lake, and 2) the lake level itself stands as a variable constant head boundary for both aquifers, are not reasons for considering both as a single hydrogeological unit. Therefore, from a geological perspective they must be considered as distinct groundwater bodies with no transboundary effects, except the related to the level and water quality of the Skadar/Shkoder Lake when it is forced into the aquifers by intense groundwater withdrawal near the lake coastline. Let's recall that Morača River contributes by 62% to Skadar/Shkoder Lake recharge.

Geology of the Buna/Bojana alluvial and deltaic plains

The geology of the Quaternary materials of the Buna/Bojana alluvial plain is the result of the sedimentary contributions of the main rivers, among them the Drin River and the outflow from Skadar/Shkoder Lake as the two major watercourses, in a moment of rising sea level. Both allowed the building of an inland alluvial plain and a deltaic system among the mountain ranges defined by the tectonic structure, namely the Mesozoic and Eocene rocks that constitute the present highlands in the area (**Figure 2.2 and 2.4**). We assume that the geological structure of the recent fluvio-deltaic unit is not affected by tectonic, so it can be understood as a prograding delta system in a steady coastline. In consequence, their inner sedimentary structures should be defined using geological approaches based on observations from wells and boreholes.

However, it must be noticed that this sedimentary structure must show a high spatial variability according to the uneven structural landscape that constituted the original basin of the entire alluvial and deltaic plains. The occurrence of mountain ranges parallel to the coastline, especially in the Albanian side, and small hills within the fluvial plain suggest that the growing delta had to accommodate to this particular relief. Indeed, the Drin River built up its own present alluvial plain towards the south-east, in the region of Nenshkodra, from Trush and Zadrima plains until Lezhe, where the alluvial ends. The formation of the present delta did not eventually occur until the Buna/Bojana River (as the watercourse discharging from Skadar/Shkoder Lake before the Drin flood in the 19th century) was able to cut and cross this mountain ridges in its gorge, or water gap, near Pentar.

Limestone mountains parallel to the coast reflect the tectonic thrust towards the SW that dominates the structure of the area. These thrusts are constituted by a folded structure in which anticlines stand as ridges and synclines as valleys, as clearly seen in the Montenegro side (municipalities of Ulcinj and Bar). These ridges are mainly constituted by karstified limestones and flysch sediments occur in the synclinal areas. Miocene marine sediments lay upon Mesozoic and Tertiary materials on an unconformity contact, yet they only outcrop in a small area near Zogan, in Montenegro.

Based on well loggings, the inland Drin alluvial plain in Albania is characterized by a basal coarse sediment deposit that fills the entire Trush basin, north of the limestone ridges. Well information reveal a prograding unit of coarse sediment, presumably unconsolidated, that mainly originates in the Drin River that also growths towards the south-east, forming the aquifer formation near Zatrima this unit gradually changes to finer sediments.

Present geomorphology reveal the evolution of the Drin / Buna-Bujana plain during the late Holocene. Its major features are:

- The main alluvial plain of the Drin River develops in the inland area, north from the limestone ridges parallel to the coast on the Albanian side. This main alluvial plain is almost inexistent in the Montenegro side. It includes the Trush and Zadrima basins.
- The main deltaic formation develops after the water gap ("cluse") near Pentar, where the prograding forms of a coastal plain, defined by dune ridges, lagoons and marsh areas is clearly observed. In the Montenegro side, Doni Stoj place is built upon a large dune ridge, parallel to the present coastline. These dunes close the Zoganjs Lake. Coastal geomorphology is more complicated in the Albanian side as the limestone hills had shaped the development of the delta front and, therefore, coastal geomorphological elements adapted to the existing landscape. Distinct ancient dune ridges can be identified in the plain between Gomsiqe and Velipojë, as well as ancient marsh areas north of Gonsique influenced by the occurrence of limestone hills. Present coastal lagoons, as the Këneta e Vilunit, shape the coastline morphology.
- Since 1859, the delta of the Buna/Bojana River growths without human occupation, creating new a lobule in the Adriatic Sea. Nowadays, however, there is an evident recession of the coastline that has reached more than 500 m since 1936[7].

2.2. *Hydrogeological conceptual model*

Main hydrogeological units

Geological description is the basis to set the main hydrogeological units, and the relationships among them. Those are exposed for the two main study areas.

Hydrogeological units of the Zeta Plain

The Zeta Plain in Montenegro is constituted by the following hydrogeological units (**Figure 2.4**),

1. The **Mesozoic karstified limestones** that constitute the surrounding ranges and act as watersheds of the main rivers and groundwater recharge zones. Highly karstified, their hydrogeological interest lays on the lateral efficient recharge towards the Quaternary infilling of the Zeta Plain. Parts of this limestone formations that constitute the watershed of the Cijevna River, and therefore a part of the basin

[7] Faloutsos et al. (2017). *Integrated Resources Management Plan (IRMP) for the Buna/Bojana area*. GWP-Med, PAP/RAC and Unesco-IHP.

headwaters, are located in Albania. Therefore, some transboundary issues may arise in this case.

This hydrogeological formation also appears in the Zeta Plain basin basement; however, Eocene flysch deposits lay among the limestones and the Quaternary alluvial deposits, acting as an aquitard and reducing possible upward recharge from the karstified basement to the upper alluvial formations.

2. The **alluvial sediments of "Terrace 3"**, formed by coarse sediments, locally cemented, yet they constitute a major hydrogeological unit all over the region. It has a thickness ranging between 50 and 100 m and hosts the main urban supply wells in Podgorica. Its lithological uniformity suggests a behaviour close to a water table aquifer. However, due to the cementation observed in the field, it is plausible that the deeper layers of these terrace act as confined or leaky aquifers. Recharge is attributed to rainfall infiltration, lateral groundwater flow from the karstified limestone ranges that limit the plain, except in its southern boundary (Skadar Lake), and to the Morača River recharge mainly induced by nearby wells wherever they are. Upward flow from the karstified basement may occur in these areas where the flysch formation is inexistent.
3. The **alluvial sediments of "Terraces 2 and 1"** are also considered aquifers, yet their smaller area compared to that of "Terrace 3" defines them as less relevant at a regional level. Nevertheless, both formations can be important in the proximities of the Morača River which is expected to highly contribute to the aquifer recharge. Their lithology is similar to that of "Terrace 3", yet it expected that the younger terraces show a less cemented matrix. We expect a hydraulic continuity among the three terraces, so they can be considered as a unique hydrogeological unit.
4. **Lacustrine sediments**, because of their location, small thickness and expected low hydraulic conductivity, <u>are not considered here as valuable hydrogeological units</u>. The occurrence of karstic springs within the lacustrine sedimentary unit confirms the above mentioned upward fluxes from the basement, but it is not a reason for considering lacustrine sediments as pertinent hydrogeological units.

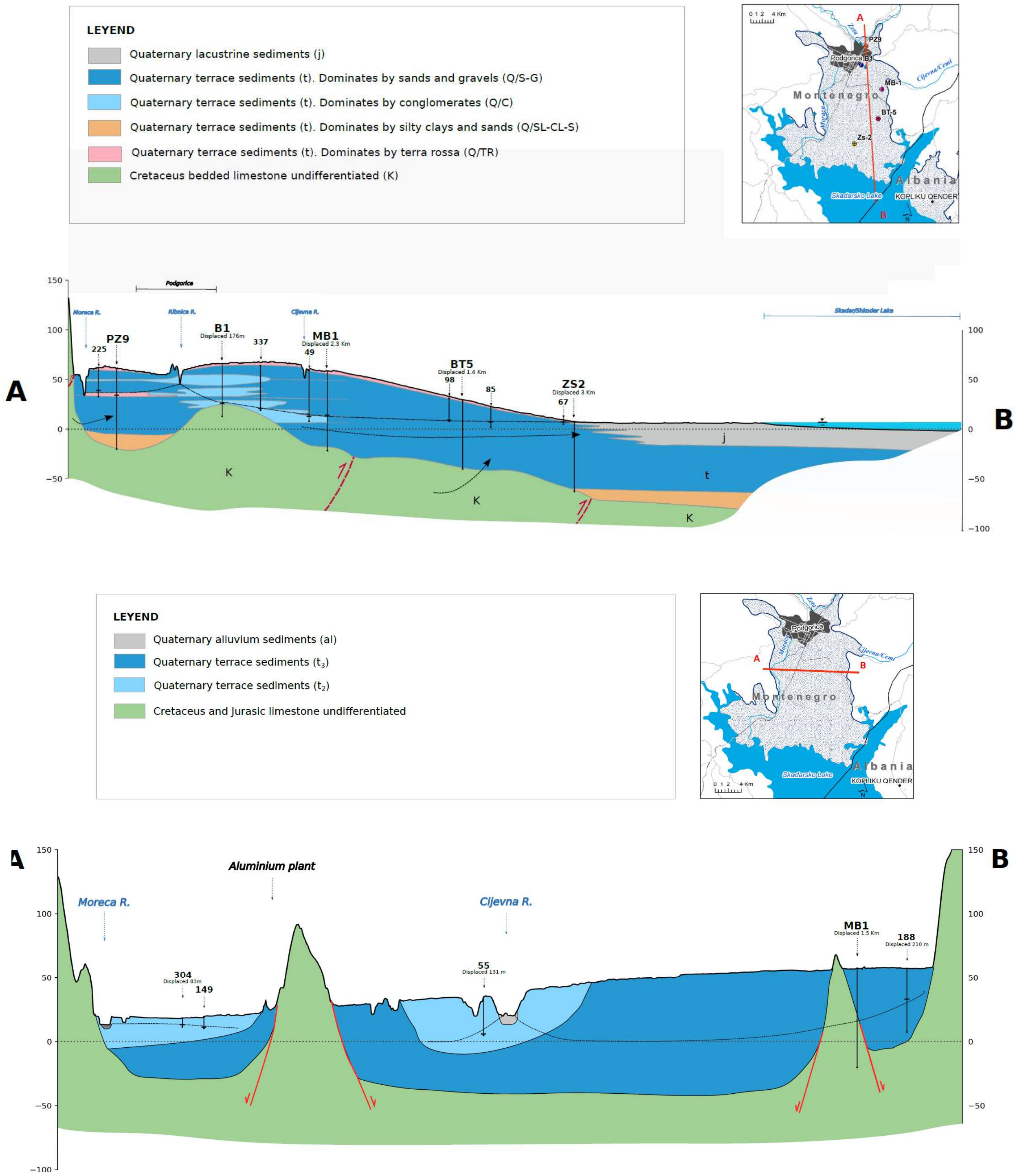

Figure 2.4.- Cross-sections, longitudinal and transversal, of the Zeta Plain alluvial and fluvio-glacial deposits, according to geological maps and to well logs for the Quaternary deposits thickness. Borehole lithological description based on borehole construction reports provided by Montenegrin authorities (Annex VII)

Hydrogeological units of the Koplik-Skhodër Plain

Showing a great similarity with the hydrogeological setup described for the Zeta Plain, the Koplik-Skhodër Plain in Albania is constituted by the following hydrogeological units,

- The **Mesozoic karstified limestones** that constitute the surrounding ranges and act as watersheds of the main rivers and groundwater recharge zones. Hence, they stay as sources of lateral efficient recharge towards the alluvial fan deposits that form the plain. Karstic springs, as those in Syri i Sheganit (Shegan's Eyes), illustrate the relevance of this type of recharge.
- The **alluvial fan deposits** represent coarse-grained sedimentary formations of high hydrogeological value, and constitute the main aquifer units of the plain. They can be defined as unconfined aquifer, even though lateral fine sediment facies usually occurring between fans and some degree of cementation may produce some degree of confinement. They lay upon limestone formations, and the geological-geophysical section clearly shows also that, generally, the depth of gravel layers deposits goes until 100-150 m (Muceku et al., 2011[8]). Recharge is similar to that of "Terrace 3" in the Zeta Plain.
- Groundwater levels have high fluctuations, they range from – 1 m to – 35 m of the soil surface. The aquifer has high filtering properties (Tyli, N. 1988; Lako, A. 1963, etc). The average transmissivity and specific discharge values are respectively T = 1000 – 9000 m^2/day and q = 20 – 100 L/s/m. The water – bearing potential of aquifer is also high with dynamic reserves of 3000 L/s.
- Again, **lacustrine deposits** are not considered as factual hydrogeological units.

It is worth recalling that the hydrogeological units of the Zeta Plain (Montenegro) and the Koplik-Skhodër Plain (Albania) are herein considered <u>as independent hydrogeological units</u>. It is also significant that Skadar/Shkoder Lake acts as a variable constant head boundary for the alluvial deposits of both plains, yet this is not highly crucial for management effects and it does not implies a transboundary issue, except for the aspects related to the lake water quality (pollution) levels.

Skadar Lake water level varies seasonally. Its average level is 6.46 m asl; the lowest level was registered in October 1985 when it was 4.76 m asl, and the average low level is around 5.22 m asl, while the average high level is 8.50 m asl and the highest level recorded was 10.44 m on January 2010 (Radojevic and Sekulic, 2012). This difference in water level varies

[8] Muceku et al. (2011). Engineering geology and geophysics studies for urban planning and development in Shkodra area, Albania. *Liqeni i Shkodres - Gjendja dhe Perspektivat - Vellimi I*, pp. 201-212. [*Note*: Because of the low quality of the pdf-copy, it is hard for the reader to locate the SEV and to understand the locations of cross-sections in Figs. 4 and 6; therefore, this information must be taken with caution].

the hydraulic gradient in the aquifer zones close to the lake, influencing groundwater flow. For instance, a rise of the lake level may enhance aquifer recharge with lake water. The maximum level of Drini River at Bahçallëku Bridge is 1 m above the maximum level of the lake. During the winter season, Drini water often flows towards Shkodra Lake.

Hydrogeological units of the Buna/Bojana River area

In this area, two major hydrogeological units appear: a) the Mesozoic limestone ridges, parallel to the coast, with a thrust fault tectonic structure and the associated folds, and b) the Quaternary deposits associated to the fluvio-deltaic plain of the Drin River and to the coastal processes. Despite the transboundary continuity of these general hydrogeological units, it is suitable to describe them according to each country features.

In Montenegro, the main hydrogeological units are:

- The **Mesozoic karstified limestones** that outcrop in most of the area and constitute the main mountain ranges. Given its multiple thrust fault structure, each limestone unit is not in contact from the next at least at low depth (< 200 m) given the occurrence of the Eocene flysch, so hydraulic connectivity between them can be inefficient.
  It is obvious that all limestone formations stand as true hydrogeological units. However, we emphasize their capacity to recharge the Buna/Bojana alluvial plain. In the northern part, for instance, the mountain range located south of Skadar/Shkoder Lake, constituted by Triassic limestones, is bounded in its southern slope by the Eocene flysch, which may limit the recharge from this range towards the alluvial plain. Conversely, the Cretacic limestone formation that form the Katërkolle and Gornja Klezna anticlines (**Figure 2.2 and 2.5**) drain their groundwater flow towards the alluvial plain. Indeed, in the syncline between them alluvial and marsh sediment appear along with the Sasko Lake (**Figure 2.6**).
- The extension of the **fluvio-deltaic deposits** of the Buna/Bojana River are mainly covered by the Zoganjs Lake area, in the Montenegrin side, as well as by other marshes/wetland areas originated by the progradation of the delta and the effect of coastal processes. An aquifer constituted by sand and silt sediments, as well as by the dune formation, is expected to develop in this area. Alluvial deposits thickness is estimated between 30 and 50 m in the right bank, while it may reach down to 60 m in the left-bank, according to Radulovic and Sekulic (2012) or to more than 90 m according to the cross-section **Figure 2.6**.

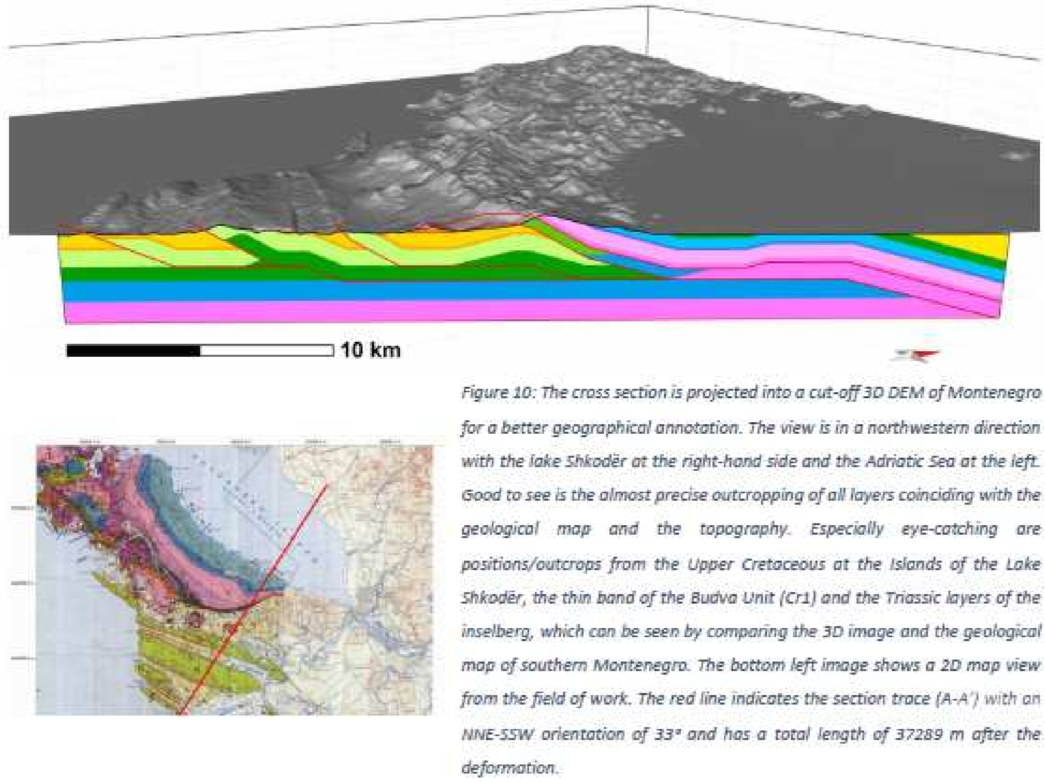

Figure 2.5.- Cross-section of the tectonic structure of the mountain ranges south of Skadar/Shkoder Lake in Montenegro until the coastline, after Pingel (2017)[9].

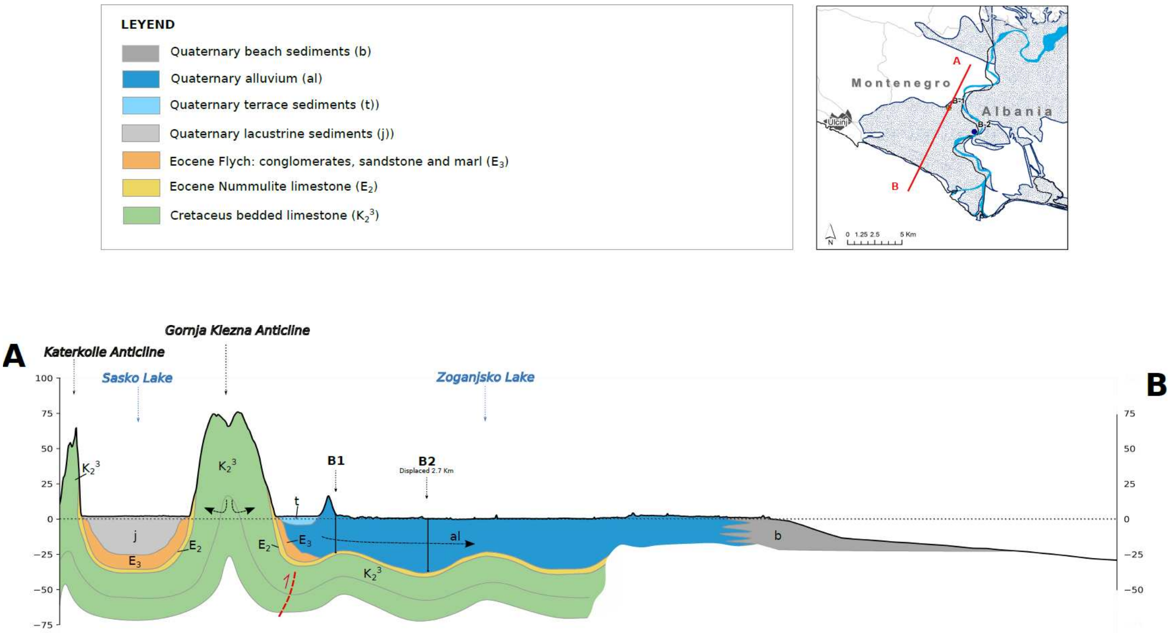

Figure 2.6.- Cross-section of the Montenegrin bank of the coastal Buna/Bojana River area, according to geological maps and to well logs for the Quaternary deposits thickness.

[9] Pingel J. (2017). *Construction of a balanced cross section in the Dinarides fold and thrust belt between the city of Ulcinj and the Lake Shkodër, Montenegro*. Fidrich Schiller Univesität Jena, 38 pp.

In Albania side, the main hydrogeological units are:

- The **Mesozoic karstified limestones** in this area are constituted by two distinct tectonic blocks that act as aquifers. First, the mountain range located south form Skadar/Shkoder Lake, that creates a high relief in Montenegro, continues and narrows towards the east outcropping in the hills north of the line between Shkodër and Vau i Dejës. This Triassic limestone formation may thus constitute an aquifer by itself. Its groundwater flow laterally recharges the entire Drin River alluvial plain downstream from the dam at Vau i Déjés.
  Secondly, the Mali i Kakarriqit and Mali i Rrencit Cretacic limestone ranges (**Figure 2.5**), are two blocks defined by thrust faults that develop an anticline structure. They are two aquifers that separate the Drin River alluvial plain from the Buna/Bojana delta formation. They also produce a lateral recharge towards the alluvial plain as indicated by the karstic springs located in its boundaries. The Eocene flysch layers, stratigraphically located in the upper part of these two limestone formations, may act as barriers that limit the hydraulic connectivity with the alluvial formation.
- The **alluvial sediments of the Drin River** had formed the Nenshkodër-Zadrima aquifer that includes the Trush basin as, perhaps, the most productive area. These deposits constitute thick layers of gravels and grits with high infiltration capacity. They accumulate considerable amounts of fresh groundwater reserves. The water – bearing gravels and grits dominate in section and occupy 60 – 80 % of it. Their thickness range from 5 – 10 to 60 m, and even larger in some specific areas. The sandy upper cover varies from 2 – 3 m to 25 – 30 m. In the zone of Mjedë, Kaç – Naraçi and Stajkë, gravels appear on the surface. The thickness of sandy and silty clay cover increases from north to south and east to west as well as towards Buna and Drin Rivers. A cross-section based on well log reports provide a detailed description of its internal structure and explain the high productivity of the Trush well field (**Figure 2.7**).
  The basement of the Trush basin is presumably constituted by the flysch layers as it outcrops in the hills rising in the middle of the basin (e.g., in Cunaj). We should then rule out any recharge from the basement.
  These alluvial sediments mainly appear in the Albanian left-bank of the Buna/Bojana River, and it extents to the right-bank in the area of Obliqë and Dodaj in Albania, and to the foothill area of Vladimir-Sukobin-Sas in Montenegro where a colluvial-alluvial deposit constitutes the surface aquifer.

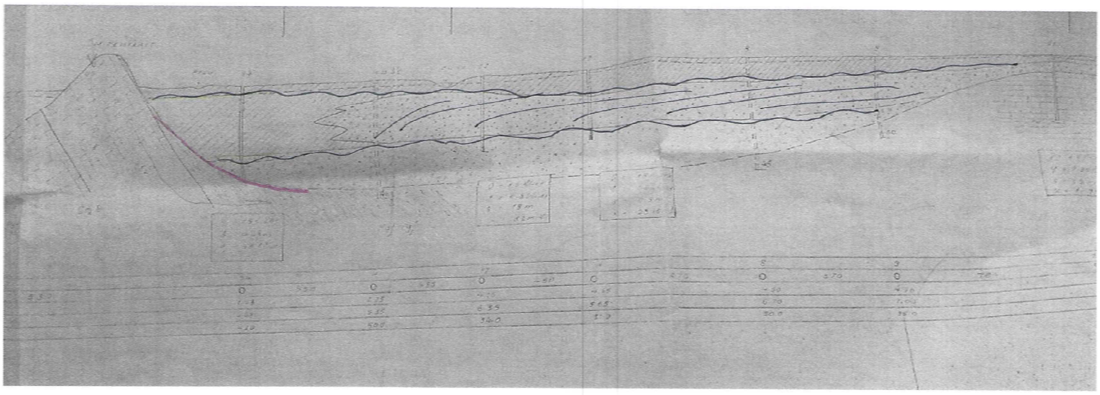

Figure 2.7.- Cross-section of the alluvial infilling of the Trush basin based on well-log information. Hand-drawn in the field-trip on 2018.

- The **fluvio-deltaic sediments of the Buna/Bojana River** constitute the aquifer that develops downstream from Pentar (**Figure 2.6**). As its counterpart in the Montenegro side, it constitutes an aquifer formed by the river sediments as well as by the dune and beach formations caused by coastal processes. The aquifer structure is thus formed by high hydraulic conductivity layers. It proximity to sea makes it vulnerable to seawater intrusion.

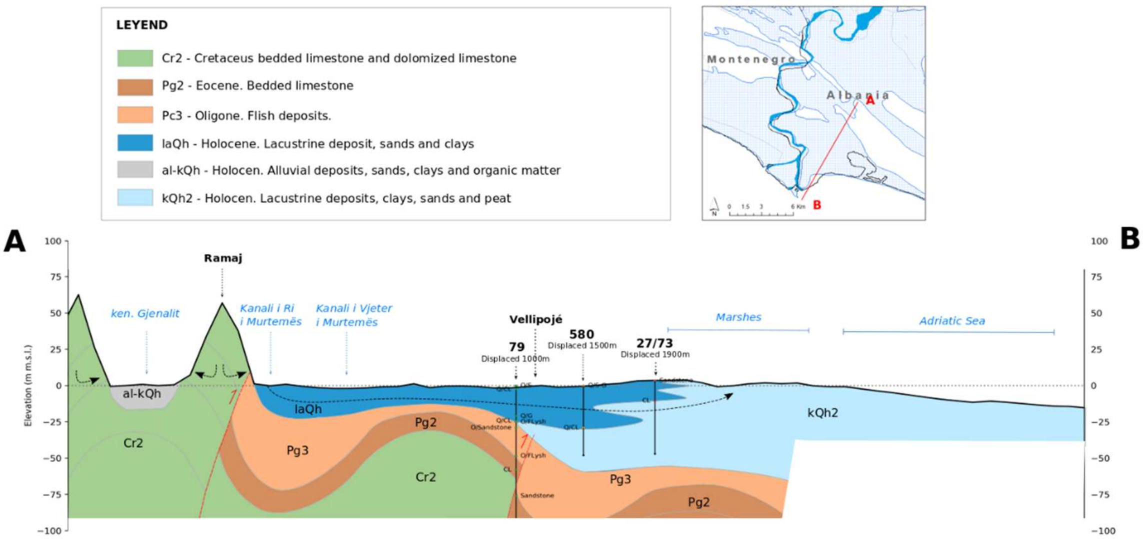

Figure 2.6.- Geological cross-section of the Albanian side of the Buna/Bojana delta.

Water balance and recharge/discharge pathways

The water balance (or water budget) and the groundwater flowpath are paramount to determine the dynamics of each hydrogeological unit and, especially, the relevance of those components that relate to water transfer between hydrogeological units.

Water balance

Montenegro

Rainfall is an important component of the recharge. Rainfall data was only provided for five stations in Montenegro (Podgorica, Karuc, Djuravci, Ostros and CKLA; **Figure 2.7**). From the five meteorological stations, those located in Podgorica and CKLA are the most representative of the study areas, from the Zeta Plain and Skadar/Shkoder Lake area respectively.

In general, precipitation occurs between October and January (**Figure 2.8).** Annual precipitation is lower in the North of the Zeta plain, at the Podgorica meteorological station, while the highest values occur at the Ostros meteorological station. This indicates that areas closer to the sea present higher precipitation. However, the location of the stations in the northern face of the range between the Skadar/Shkoder Lake and the sea, could lead to some differences in the recharge patterns. Unfortunately, no meteorological data is available closer to the Buna/Bojana delta.

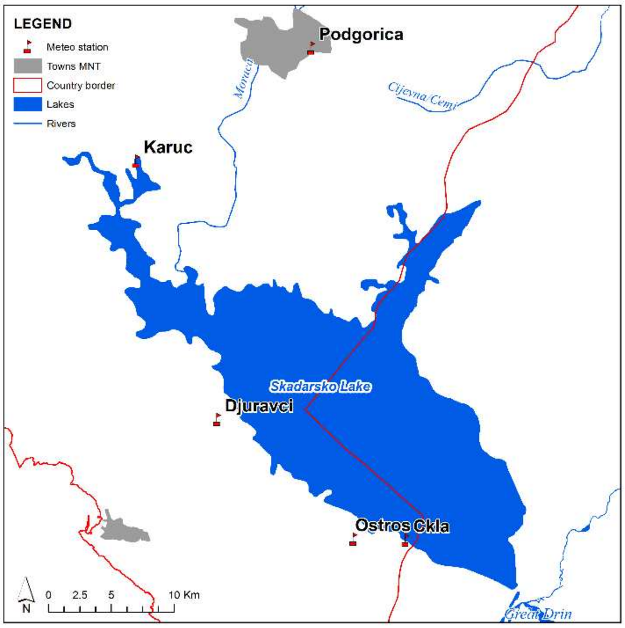

Figure 2.7.- Location meteorological station in Montenegro.

Rainfall data provided covered the period from 1960 to 2018 (**Figure 2.8a and b**). Except for the Podgorica station, all stations show a decreasing tendency. However, the data gaps present at the latest times of the time series are a source of uncertainty, and therefore no further conclusions can be drawn from the analysis.

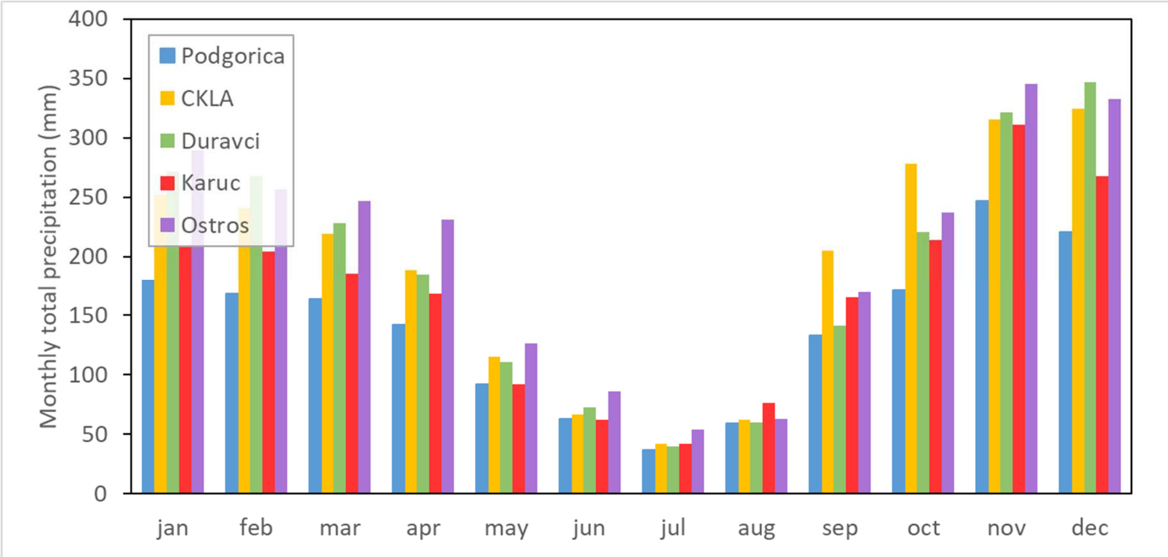

Figure 2.8a.- Average monthly precipitation for five meteorological stations in Montenegro

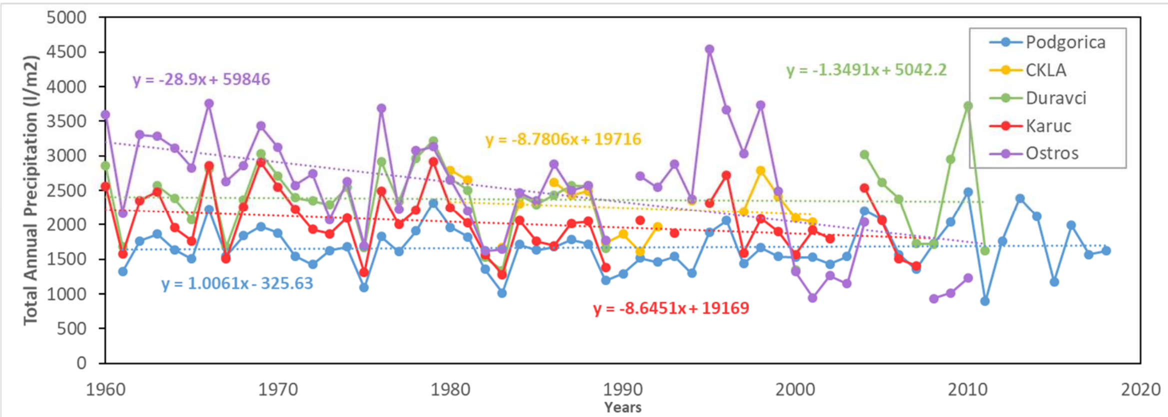

Figure 2.8b.- Precipitation for five meteorological stations in Montenegro

A general water balance that accounts for the available water resources given by the monthly difference between precipitation and potential evapotranspiration (estimated using Thornthwaite equation) calculates a total average annual water resources availability of 885 mm, thus a 49.2% of the annual precipitation reaches the groundwater or flows as surface discharge towards the drainage network or the ocean (**Figure 2.9a**).

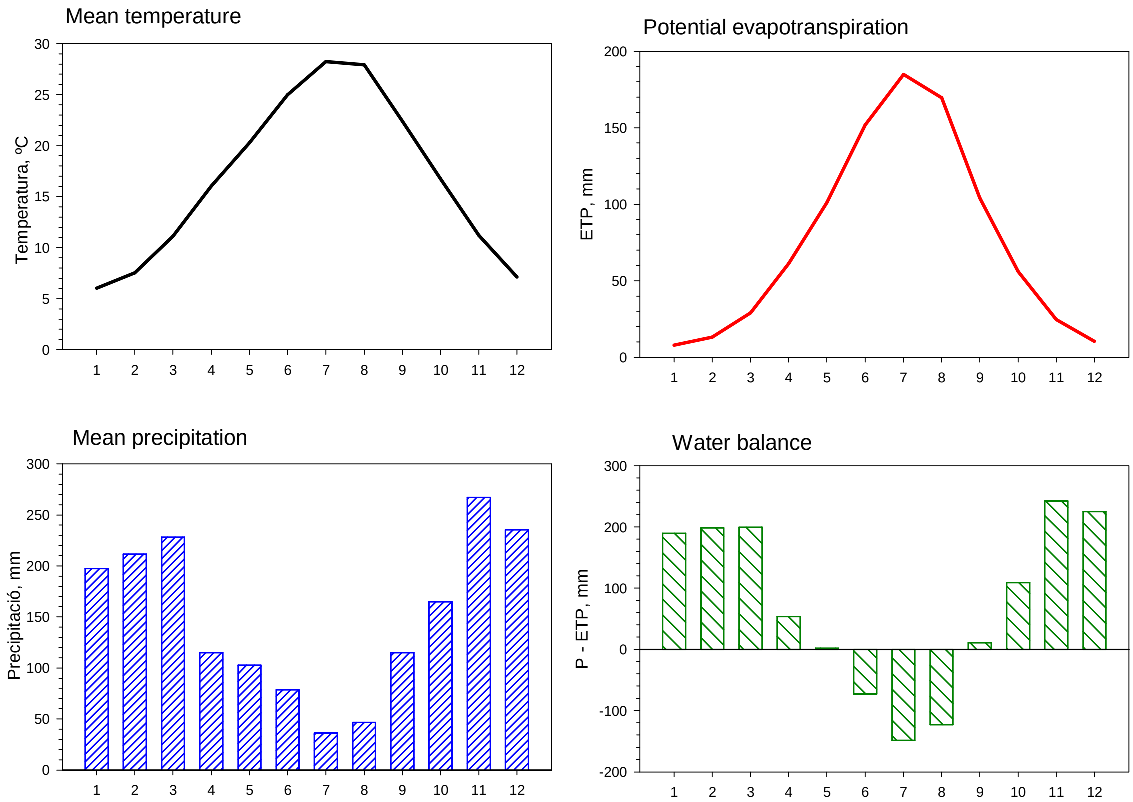

Figure 2.9a.- Water balance of unsaturated zone using average data from Montenegro.

Albania

Available mean climatic data (temperature and precipitation) for Albania refer to the areas near Shkodra and Lezhe. These data represent the northern field Mediterranean climate subzone, downstream of Drin and Buna River. Average annual temperature in this zone is 14 – 15°C. The amount of precipitation is approximately 1500 – 2500 mm. In the northern part of the area, the amount of rainfall can reach up to 4500 – 5000 mm.

Using the same methodology, the water balance for the Albanian region considered in this study, taken the average data for both station in the period (1968-1995), indicates an average water resources availability of 981 mm, which represents a 57.4% of the annual precipitation (**Figure 2.9b**)

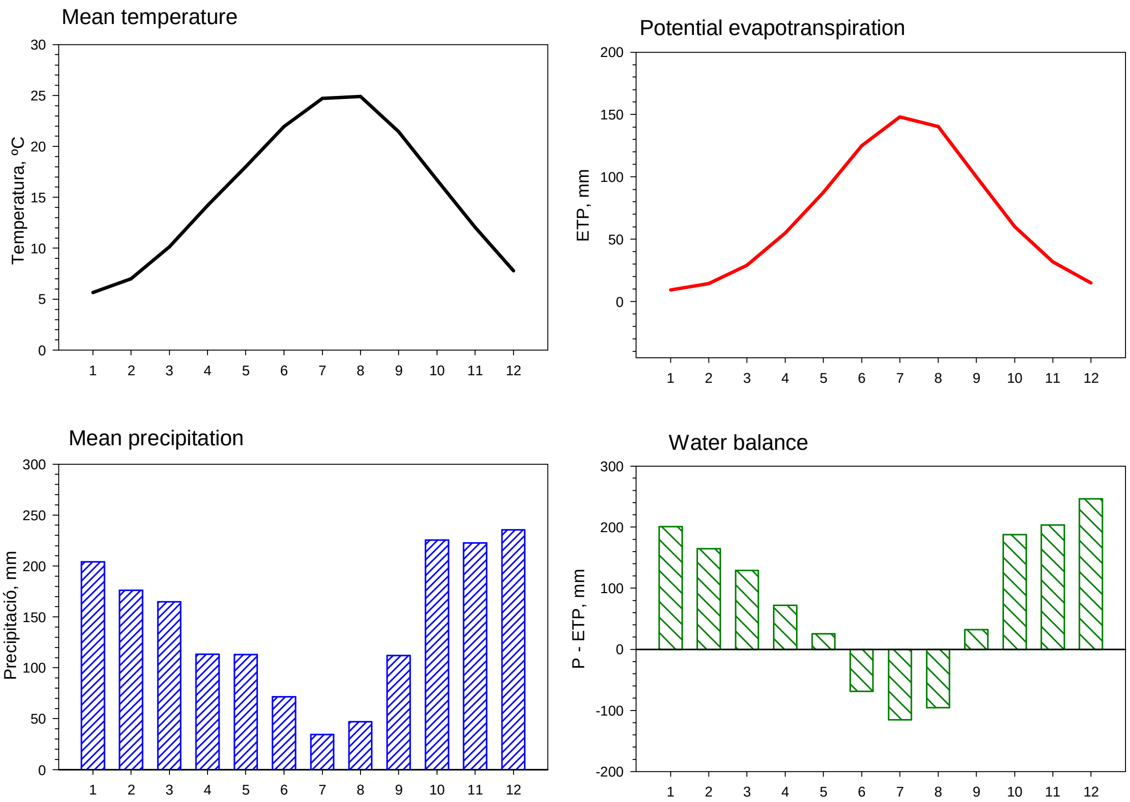

Figure 2.9b.- Water balance of unsaturated zone using average data from Albania.

Recharge/discharge pathways

Mountain hydrogeological units, mostly composed by Mesozoic karstified limestones and dolomites may present complex flowpaths depending on the internal tectonic structure of the ranges. Main thrust fault as well as other minor fractures and folds will control groundwater flowpaths beyond the intuitively ones obtained from topographic information and watershed distribution. Nevertheless, for a large-scale estimation and considering the carbonate rocks (consequently, karstified and high hydraulic conductivity formations) are the dominant lithology, topographic driven flow path can result in a good approximation to describe pathways.

In this sense, potentiometric data from the Zeta Plain – provided by the Geological Survey of Montenegro - indicate that groundwater flow from the closest mountain ranges will converge towards the Zeta Plain through the distinct watersheds (**Figure 2.10a**). Lateral groundwater recharge would presumably be specially relevant from the Cijevna and Morača river watersheds as both reach the highest altitudes in their headwaters. Similar lateral groundwater recharge can be envisaged for the alluvial fan aquifers of the Koplik-Shkodër plain. In both cases, karstic springs suggest that some upward recharge from the basement is also feasible at located spots.

Similar lateral groundwater recharge also happens in the limestone ranges of the Buna/Bojana area in their contact with the alluvial aquifer. However, the outcropping of flysch sediments along the synclines may difficult such research at specific locations. Nevertheless, mountain ranges in these area must be considered in all cases as potential recharge fronts.

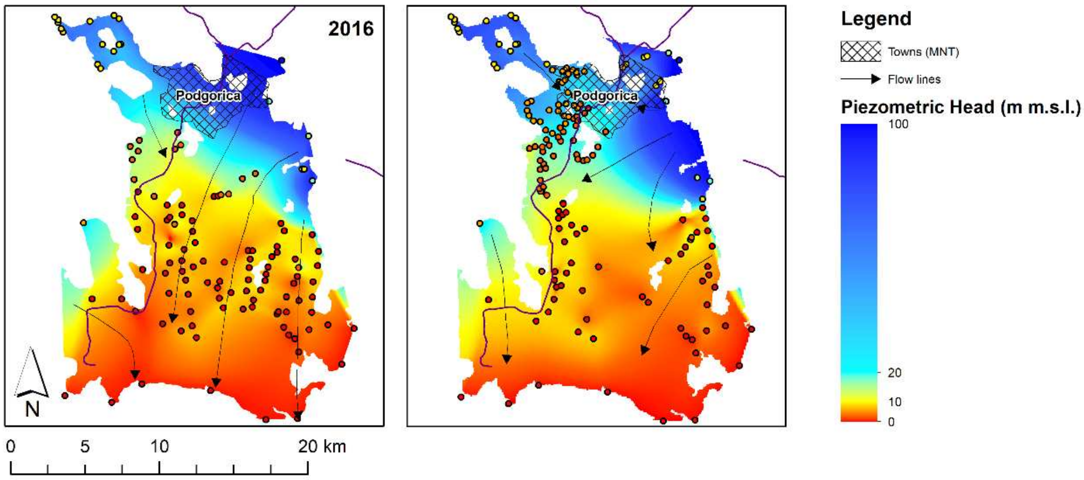

Figure 2.10a.- Piezometric surface of the Zeta Plain. The analysis is based on groundwater depth values provided by the Geological Survey of Montenegro for two consecutive years (2016 and 2017).

Skadar/Shkoder Lake plays a relevant role in the hydrography of the whole area, linking the northern part (Zeta Plain) with the Buna/Bojana fluvio-deltaic plain. Natural groundwater discharge of the alluvial sediments of the Zeta and the Koplik-Shkodër plain, as well as that of the surrounding massifs, drains towards the lake,. We admit that lacustrine sediments may reduce the discharge rate, yet a hydraulic connection between the alluvial aquifers and the lake is assumed as certain. The natural exit of the lake is through the Buna/Bojana River, whereas subsurface discharge from the lake is also expected to recharge the surrounding terrains. Radulovic et al. (2015) present a water balance for Skadar/Shkoder Lake with a total inflow of 314 m^3/s, 64% of which corresponds to the contribution of Morača River. The main outflow corresponds to the Bojana River, with 304 m^3/s. Indeed, a 54% of the Buna/Bojana River discharge originates from the lake outflow and a 46% as a contribution of the Drin River.

The natural water balance in the lake links human pressures on the areas discharging to the lake with resource availability, in quantity and quality, on the areas recharging from the Buna/Bojana River. This relationship is eased by the contribution of the Drin River once its course joined that of the Buna/Bojana after a severe flood in 1859 (Petković and Sekulić, 2018[10]). Such severe geomorphological change modified the water and sediment transport dynamics of the Buna/Bojana River. An increase in stream discharge has its effect on the river channel morphology and in the coastal evolution. From a hydrogeological perspective, the new stream reach from Vau i Dejës to Shkodër turned into a losing stream that had, and still have, influence in the aquifer mass-balance.

Another key element is the course of the Drin River itself. In particular, the reach of the Drin River between Ashtë and Kosmaç stands as a recharge boundary for the alluvial plain of the Trush basin, creating some flow lines perpendicular to its course and heading south (**Figure 2.10b**). Natural groundwater discharge to the Trush basin aquifer is assumed to happen along the Buna/Bojana River to the west (towards the water gap in Pendar), and to the old course of the Drin River to the east. Given the flat topography in the whole area that will determine very small hydraulic gradients, we expect that natural groundwater flow is small despite the large hydraulic conductivity of the alluvial sediments. In this sense, it is for these reasons that the Trush basin aquifer stands as a groundwater reservoir of high productivity.

[10] Petković S, Sekulić G (2018). Erosion and sedimentation processes in the Bojana River Delta at the Adriatic Sea. *Journal of Coastal Conservation*, DOI: 10.1007/s11852-018-0634-9.

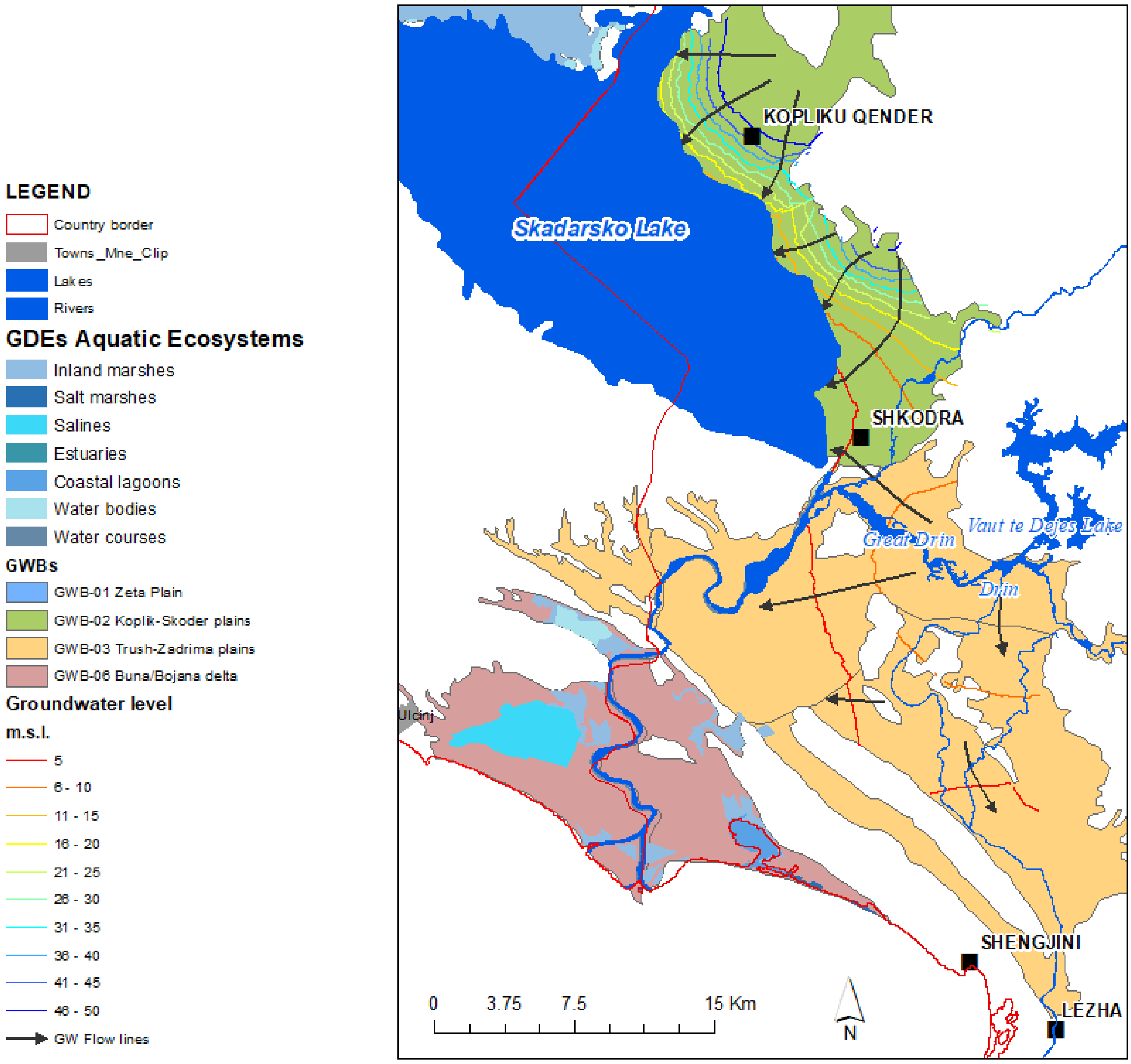

Figure 2.10b.- Schematic cross-section of different types of GDEs and the general pattern of recharge-discharge (Kløve et al., 2011)

Natural groundwater discharge to the Adriatic Sea occurs from both the karstic mountain ranges close to the coastline and through the Buna/Bojana delta. Some groundwater discharge also feds the coastal lagoons (Zoganjs and Këneta i Vilunit lakes) which open to the sea. Indeed, Zogansj Lake underwent severe dry up works at the end of the XIX century that could not achieve their purpose as the water level in the lake was lower than the average sea level. This produced a salinization of the lake. The larger discharge and the floods of the Buna/Bojana River after the Drin River joined its course produced a reverse effect on the lake. Today the channel is closed due to the interests of the salt production in the lake (Radojevic and Sekulic, 2012[11]).

[11] Radojevic D, Sekulic G (2012).

Besides the natural groundwater pathways, groundwater withdrawal effects also interfere with the flowpaths and the aquifer water budgets. Major well fields are located in Podgorica, in the Zeta Plain and in the Trush basin.

Groundwater depended ecosystems

Groundwater Dependent Ecosystems (GDEs) are defined as those ecosystems for which current composition, structure and function are reliant on a supply of groundwater(Klove et al., 2011[12]). Rivers, lakes, riparian zones, caves, wetlands, springs, estuarine and nearshore ecosystems can be considered GDEs. There are plenty of approaches for the identification of GDEs such as inferential methodologies, using hydrological, geochemical and geomorphological indicators, biotic assemblages, historical documentation, or remote sensing methodologies (Eamus et al., 2016[13]). Rather than a unique definition of GDEs, authors provide different classifications of the types of ecosystems that can be considered dependent on groundwater. Eamus et al. (2016) provides a simple classification in three major classes of GDEs. (I) GDEs that reside within groundwater (e.g. karsts; stygofauna). (II) GDEs requiring the surface expression of groundwater (e.g. springs; wetlands). The WFD devoted a Guidance document to these ecosystems nominating them Groundwater Associated Aquatic Ecosystems. (III) GDEs dependent upon sub-surface availability of groundwater within the rooting depth of vegetation (e.g. woodlands; riparian forests). Again, the WFD provides a Technical report on this matter nominating them as Groundwater Dependent Terrestrial Ecosystems.

Most important GDEs present in the region are associated to Eamus et al. (2016) second class, GDEs requiring the surface expression of groundwater. These are karstic spring, wetlands and coastal lagoons. Additionally, GDEs depending up the sub-surface water availability within the rooting depth might also be important, especially in the low lands of the Buna/Bojana area and riparian areas of main rivers.

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[12] Kløve, B., Ala-aho, P., Bertrand, G., Boukalova, Z., Ertürk, A., Goldscheider, N., et al. (2011). Groundwater dependent ecosystems. Part I: Hydroecological status and trends. Environmental Science and Policy, 14(7), 770–781. https://doi.org/10.1016/j.envsci.2011.04.002

[13] Eamus, D., Fu, B., Springer, A. E., & Stevens, L. E. (2016). Groundwater Dependent Ecosystems: Classification, Identification Techniques and Threats. In A. J. Jakeman, O. Barreteau, R. J. Hunt, J. D. Rinaudo, & A. Ross (Eds.), Integrated Groundwater Management: Concepts, Approaches and Challenges (pp. 1–762). https://doi.org/10.1007/978-3-319-23576-9

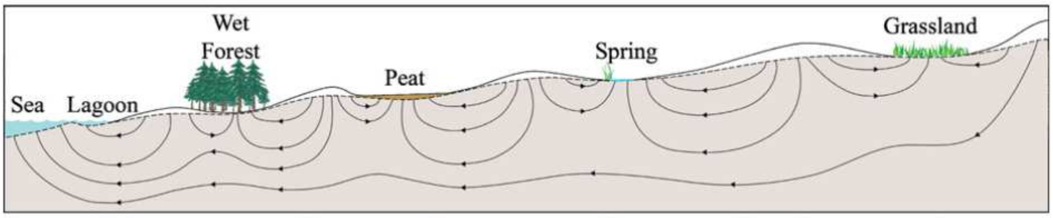

Figure 2.11.- Schematic cross-section of different types of GDEs and the general pattern of recharge-discharge (Kløve et al., 2011)

Groundwater Dependent Aquatic Ecosystems

Springs can occur in two ways, as the result of the karst formation through the limestone deposits and as the contact of a permeable layer with an overlaying impermeable layer.

- The so-called “oko”, meaning “eye” in the local tongue, are circular holes in the ground formed by the dissolution of the underlying limestone deposits. They occur at the low-laying areas around the Skadar/Shkoder Lake feeding directly into the lake. Moreover, these karstic springs are a source of water supply for the surrounding settlements. This is the case, for example, of the large spring Syri i Sheganit in Albania. These karstic features are of especially characteristic of this region, and tend to develop a humid ecosystem around the little pond formed by the spring and the drainage of water towards the lake.

- Other springs occur at the contact between a permeable and impermeable layer where groundwater is forces upwards towards the surface. These springs are especially frequent in the Buna/Bojana at the low laying areas of the anticlinal limestone deposits, where the flysch acts as a barrier. In this region, we can observe how spring appear aligned following the outcrop of the flysch formation. These springs are used in many cases for water supply of the surrounding households.

Wetlands are areas were water level is at the surface that can be inundated permanently or seasonally, and they are causally related to the water table occurrence near or upon the land surface. Even tough, some wetlands depend on both, surface drainage and groundwater flow, we highlight all potential areas where groundwater contributes to support the occurrence and good status of these ecosystems. They can occur inland, and thus we will call them inland marshes, or at the coast, in the form of salt marshes or salines. In any case, these areas are of extreme importance, as they tend to host rich ecosystems completely dependent on the groundwater seeping.

- The **Shkoder/Skadar Lake and lake marshes** is the most important humid ecosystem in the region. 60% of the water input to the lake comes from the Morača river, however a large inflow is also coming from subterranean discharge trough the karst system of the whole catchment. Radulovic et al. (2013) estimated 11.62 m^3/s of water inflow coming from the Zeta plain inter-granular aquifer discharge to the lake. The lake is involve in some of the main bird migratory corridor. 90% of the bird species present in the lake are regionally and intercontinentally mobile (Royal Haskoning, 2016[14]). In general, the lake offers many environmental services affecting directly to the local economy. For example, the lake marshes are the home of a frog *Rana ridibunda* used for consumption and exportation. The poison of local vipers is extracted for serum fabrication. Seasonally flooded fields, which dry out during the summer, are used for cattle grazing. The reeds are used in construction, interior deco- ration and handicrafts. The flooding willow forests are used for the production of fuel wood and construction. Fishery is the most important economic activity associated to the lake. About 10 species are commercially exploited. The most important are cyprinids and salmonid fish.

- The **Sasko Lake** is a depression below sea level. It is again part of the network of wet environment in the Adriatic bird migration corridor.

- The **Viluni Coastal brackish lagoon** in Albania, is communicated to the sea through a channel. The lagoon is an important nursery area for the fish species migrating between wetlands and the open ocean[15].

- The **Ulcinj Saline** at the Montenegrin site of the Buna/Bojana delta is a rich environment where different environments appear depending on the salt concentration. The salt pans have a total area of 620 ha. The salt pans are completely engineered, but currently they don´t operate. As the rest of the coastal lagoons, the Ulcinj Saline I part of the Adriatic bird migration corridor, being stop and habitant for more than 250 bird species.

Groundwater Related Terrestrial Environments

Some rich ecological environments depend on groundwater being available at a root reachable depth. The ecosystems associated to shallow groundwater levels are especially important in the low-laying areas of the Zeta plain and Buna/Bojana river. They are not inundated areas as wetlands, but still with a strong dependency on groundwater. Unlike wetlands and groundwater bodies, these ecosystems are not systematically mapped. Therefore, we will do a simple analysis to discern the areas which ecosystems might depend on shallow groundwater levels.

[14] Royal Haskoning. Lake Shkoder Transboundary Diagnostics Analysis. (2006).
[15] IRMP Buna/Bojana report

First, the area with a “shallow” groundwater level was identified by comparing the DEM and the groundwater levels. The maximum groundwater depth that an ecosystem can tolerate varies depending on the species. Canadell et al. (1996) provide maximum rooting depths mean values for different biomass around the world: 2 m for cropland, 3 meters for deciduous forest and 2.6 for temperate grassland. Therefore, areas with a groundwater level located at less than 3 meters depth were considered potential spots for terrestrial GDEs.

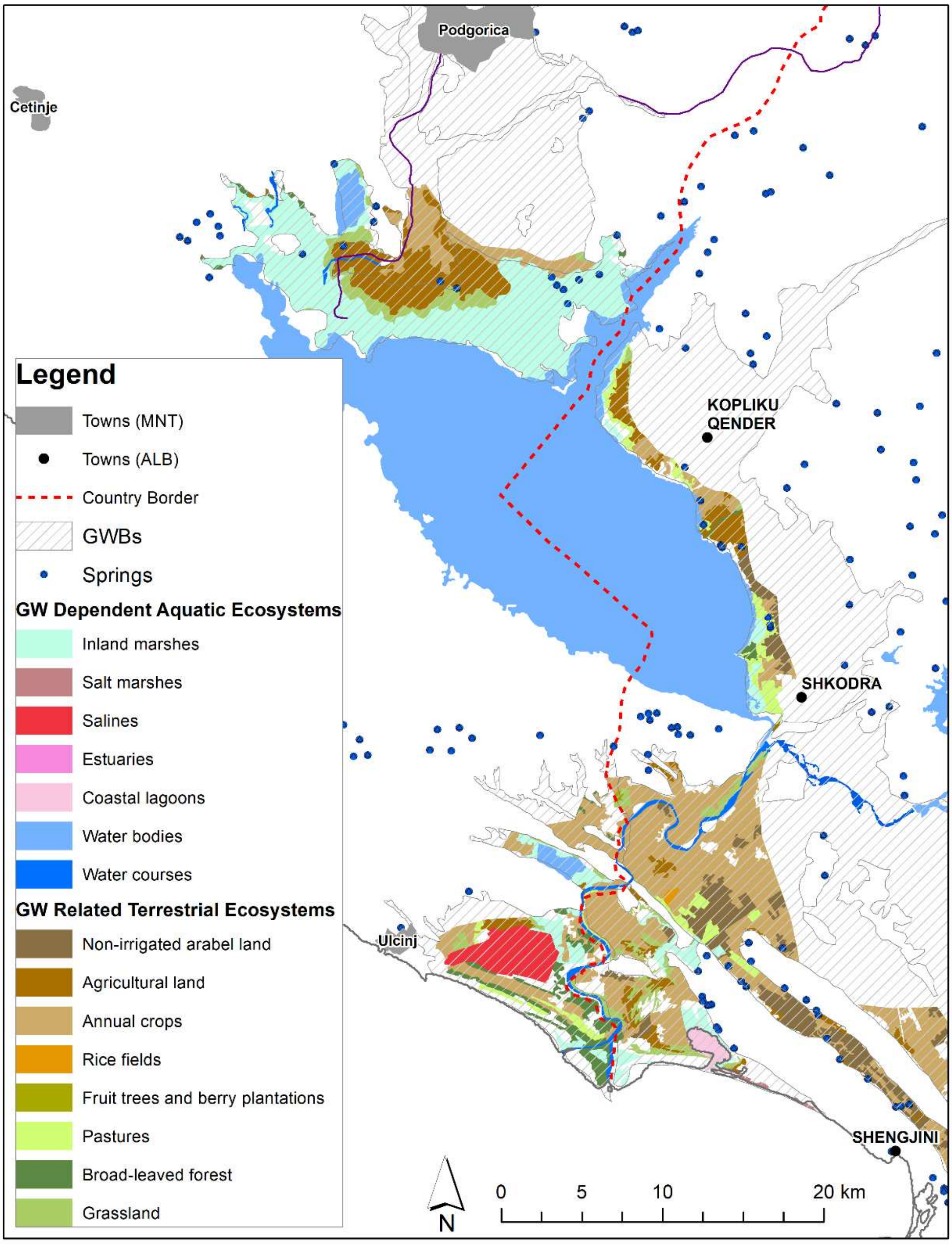

Figure 2.12. Groundwater dependent ecosystems and Groundwater Related Terrestrial Environments. Map based on land-use and hydrogeological information.

This "shallow" groundwater area was compared with the CORIN land cover. Only land covers with potential groundwater dependency were considered. This assumption leaf outside the selection areas with no vegetation like urbanized areas or areas not dependent on groundwater but other water inputs, like irrigated croplands. Finally, the land covers that could be potential GDEs and that are located in areas with "shallow" groundwater level, were reclassified based on possible dependency to groundwater and type of use

The results (**Figure 2.12**) shows that most of the possible shallow GDEs are located in areas occupied by managed ecosystems, like arable lands around Trush. Further information on the types of crops would be necessary to identify the water requirements of each plot and root depth, and therefore estimate the dependency on groundwater. Natural ecosystems such as grasslands or forests are located mainly close to the coast, the lake and the river. Finally, some wetlands and marshes are identified, especially at the coastal section of the porous aquifer. These areas are going to be heavily dependent on fresh groundwater resources.

Protected areas

The environmental importance of some of the identified GDEs is already acknowledge through the implementation of several protection figures at national and international level.

Table 2.1.- Protected areas (based on IRMP Buna/Bojana report)

Site name	National category	International category	Country
Lake Shkoder/Skadar and River Buna		Ramsar	Albania
Lake Shkoder/Skadar	National Park		Albania
Lake Shkoder/Skadar including Viluni lagoon, Velipoja forest and Dumi wetland	Managed natural reserve (IUCN)	Important Bird Area	Albania
Lake Shkoder/Skadar	National Park	Ramsar	Montenegro
Ulcinj Salina		Important Bird Area and EMERALD site	Montenegro

Most of the GDEs in the study area are included in a environmental protection area (**Figure 2.13**). One of the most important protection figures is the RAMSAR network in which the Shkoder/Skadar Lake and the associated humid environments are included.

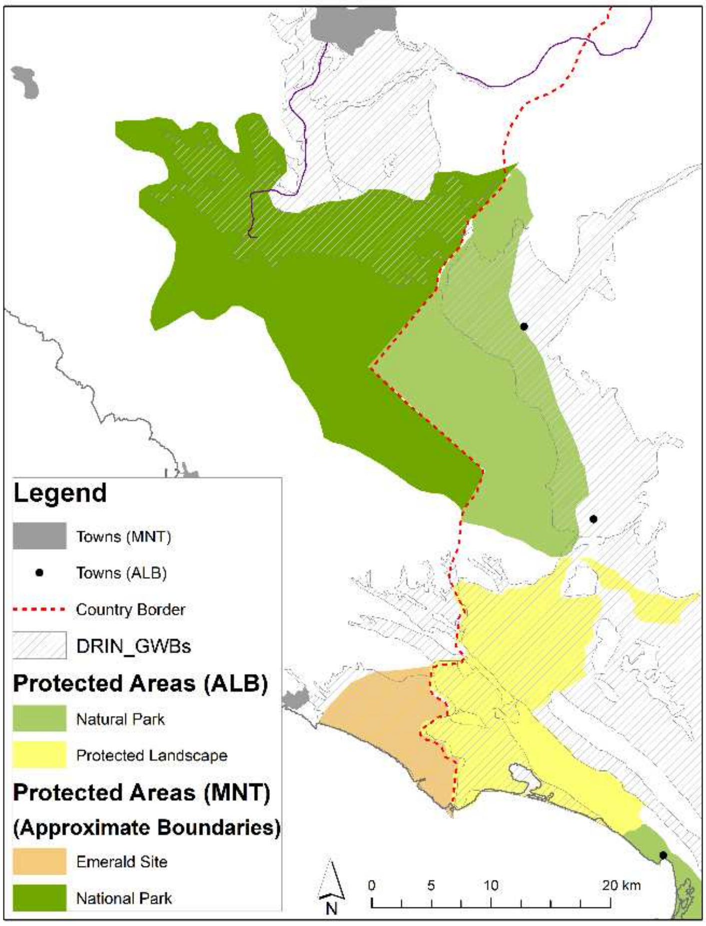

Figure 2.13. Protected areas.

The protection areas are based on the importance of the humid ecosystem, compose by the Shkoder/Skadar lake and the Buna/Bojana riverine and delta areas, in the birth migrational regional and intercontinental corridors. Additionally, the area is reach in endemic species.

Hydrochemistry and groundwater quality

Hydrochemical data is relevant to characterize the type, origin and human pressures on the quality of water resources. In this section, available data is summarized and interpreted to support the hydrogeological conceptual model and the proposed groundwater body list introduced in this report.

Zeta Plain (MNT)

As mentioned before the Zeta Plain intergranular aquifer provides multiple environmental and human services. It provides water for Montenegro capital, and it directly contributes to the ecological status of the Shkodra/Skadar Lake, the biggest fresh hydrological unit in the region. However, it also suffers impacts from various anthropogenic activities like wastewater disposal, agriculture or industry. Because of its importance for water supply and vulnerability, the quality of the aquifer has been object of various studies. We have based this analysis on the data provided by the Geological Survey of Montenegro and publically available references.

Devic and Filipovic (2005)[16] provide a comprehensive geochemical dataset of well-distributed locations around the Zeta Plain, covering most important spots for groundwater quality monitoring. The dataset provides average values of mayor ions and cations, for samples taken between February 1996 and December 2005. Based on these data, the Piper diagram (**Figure 2.14**) indicates that dominant hydrochemical facies in the Zeta plain is Calcium Bicarbonate, which is clearly driven by the groundwater interaction with dominant limestone regional lithology.

Additionally to these data, the Geological Survey of Montenegro provided information on temperature, electrical conductivity and pH for a wider inventory of wells. Most of the quality data is concentrated in 2017, therefore instead of mixing all samples we analysed exclusively this year, focusing on the spatial distribution rather than on temporal trends.

[16] Devic & Filipovic (2005) Geochemical Quality Parameters, as tracer of outside influence on water of intergranular aquifer of Zeta plain. In Water Resources and Environmental Problems in Karst.

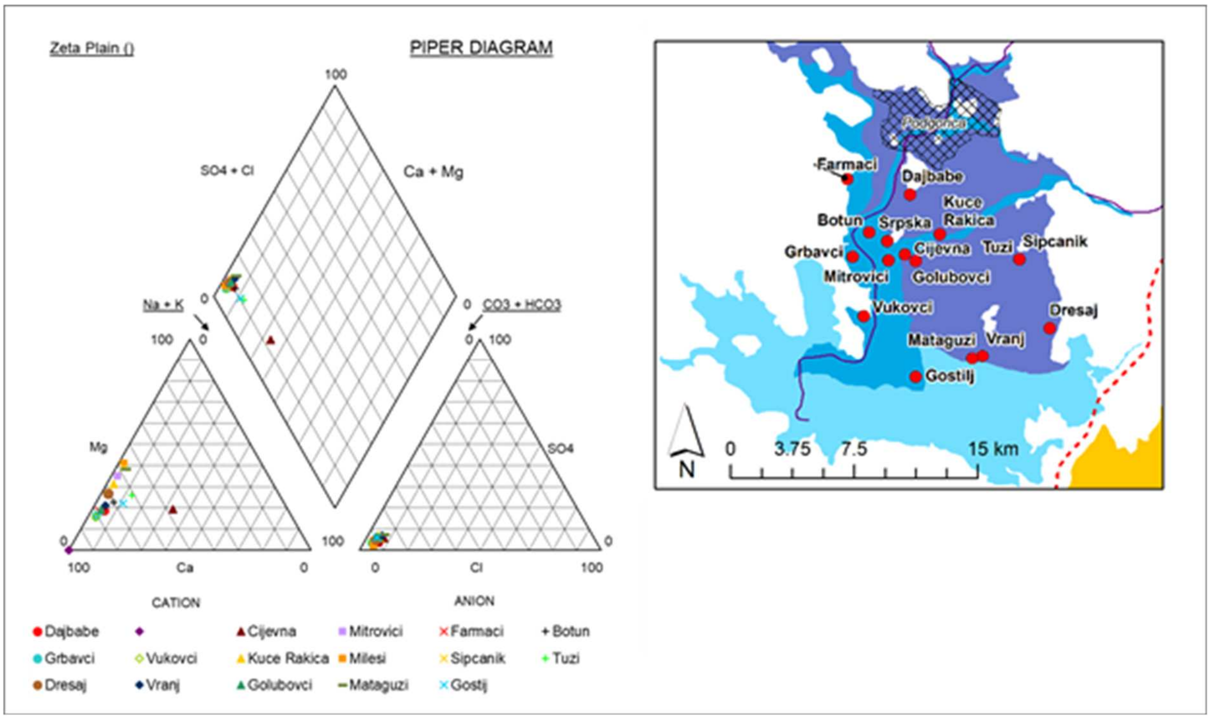

Figure 2.14.- Piper plot of hydrochemical data in the Zeta plain aquifer.

Figure 2.14 presents the 2017 spatial distribution of EC and pH. Sampling points are mainly located near 1) the Morača River, 2) in the city of Podgorica, and 3) in the eastern part of the Zeta plain, matching with the sedimentary unconsolidated deposits (i.e., the distinct terraces) of this river floodplain. In addition, in the Eastern section of the Zeta plain, groundwater recharges laterally from subterranean inflow from the karst regional aquifer and from stream infiltration as well. This also is also indicted by the concentration of springs aligned along the geological contact between the limestone formations and the fluvial deposits.

In general, electrical conductivities are low; between 300 and 700 µS/cm. Highest values appear concentrated in three areas: downstream the Aluminium plant, at the lower parts of the Morača alluvial plain, and at the west of Podgorica city (**Figure 2.15**). These values are within the order of magnitude of common EC values in karstic aquifers. Consequently, it is hard to infer human impacts without complete hydrochemical analysis of the samples.

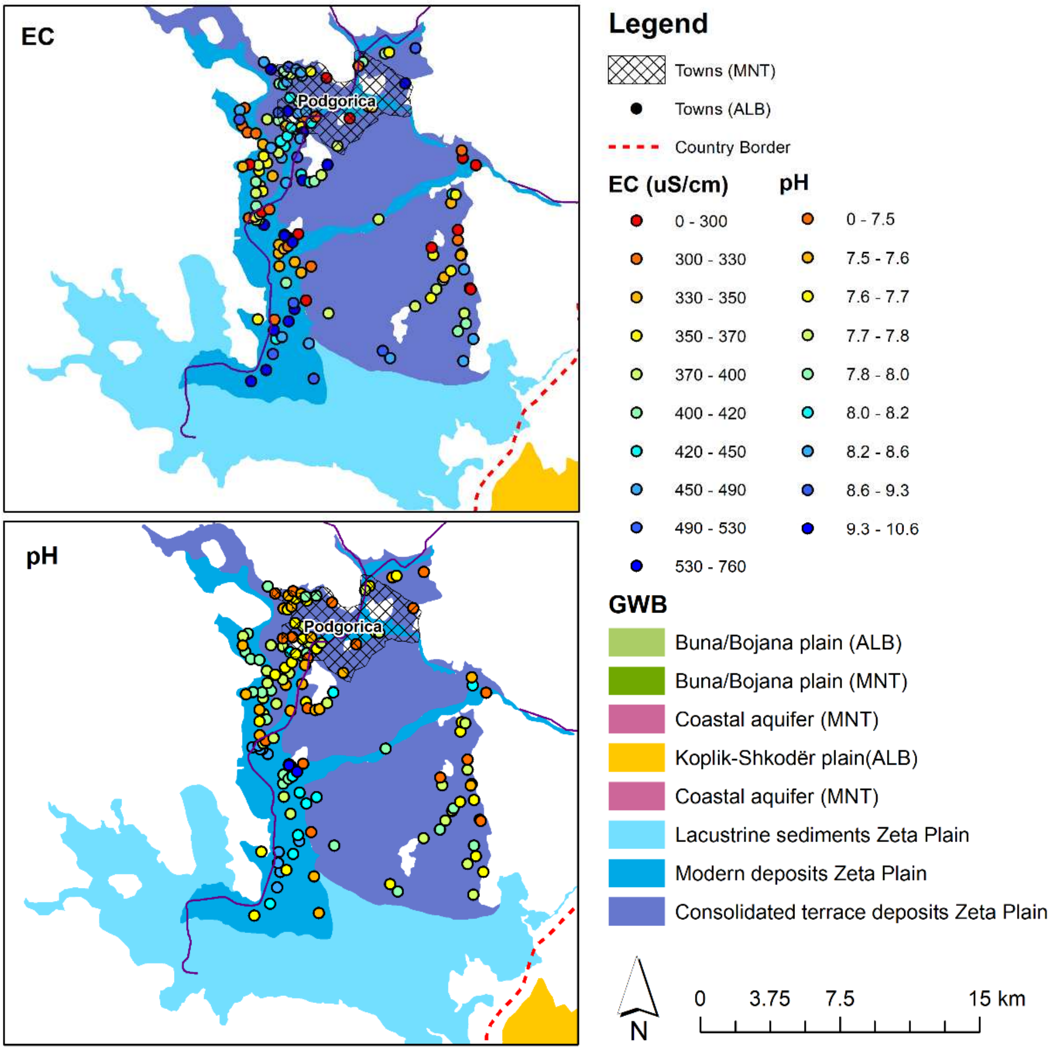

Figure 2.15. Water electrical conductivity and pH for monitored wells during 2017 in Zeta plain. Data provided by Montenegro Geological Survey under the project framework.

pH values are concentrated around 7.2 and 8.2; with a significant number of samples between 8.2 and 8.7. Surprisingly, three samples present very high pH values around 10.5 (**Figure 2.16**). The negative slope between EC and pH, within the range 7.2 and 8.2, can be convincingly attributed to the dominance of calcite dissolution in the groundwater chemical composition, in which pH, as a result of CO_2 dissolution in groundwater controls the amount of dissolved $CaCO_3$. However, the concurrence of high pH and high EC suggest that other chemical inputs, whether natural or artificial, have altered the sample hydrochemical content. It can also be asserted that basic pH values larger than 10 indicate the likelihood of some kind of singular hydrochemical composition that cannot be only attributed to water-rock interaction. The fact that the three samples with pH > 10 and large EC were taken from wells right downstream from the Aluminium plant, at Srpska suggest that pollution effect of leaking inputs from the Aluminium plant waste ponds. Indeed, Devic and Filipovic (2005) relate the origin of this increase in pH to phosphates leaking from the factory.

CE and pH values already provide some insight on potential groundwater origin and pressures. It thus becomes clear that a complete hydrochemical analysis, which includes major constituents and nutrients, will be highly useful to distinguish natural geochemical processes from human pressures on groundwater quality.

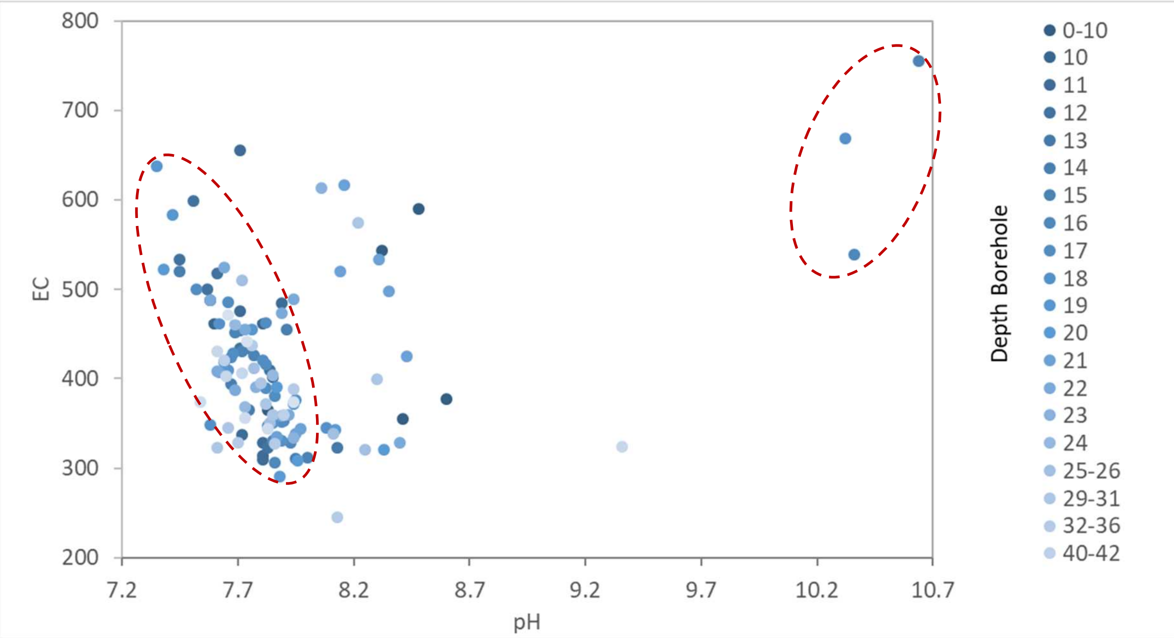

Figure 2.16. Groundwater Electrical conductivity and pH for monitored wells during 2017 in the Zeta Plain Data provided by Montenegro Geological Survey under the project framework.

Koplik - Shkoder (ALB)

Published references provide information about groundwater quality for the Koplik-Shkoder Plain. For instance, the paper by Ozler & Xhahysa (2013)[17] includes geochemical data from the Koplik-Skhodër Plain alluvial aquifer. In particular, it presents maps of nitrate, nitrite, ammonium and organic matter, based on surveys from 2011 and 2012. In the northern part of the plain, around Koplic values of nitrate are below 5 mg/l, while organic matter is higher, around 2 mg/l. On the contrary, nitrate concentrations increase around Skodra city, up to 20 mg/l, accompanied by high concentrations of nitrite and ammonium, and low concentrations of organic matter. Nitrate levels are below the 50 mg/l threshold. Hot spots around Skodra city might indicate the presence of wastewater. Ammonium

[17] Ozler, H. M. & Xhahysa, 2013. Surface and groundwater contamination in Shkoder - Trush aquifer (Albania). in *Seventeenth International Water Technology Conference, IWTC 17* (2013).

occurs downstream of high nitrate locations, indicating some type of biological degradation of nitrate in the presence of organic matter (AKM 2014 report)[18].

Data by (AKM 2014 report)[18] shows the evolution of nitrate in several wells. Most of the samples are below the nitrate threshold of 50 mg/L. Indeed most of the wells show uniform nitrate concentrations below 15 mg/L; and among them, a few show nitrate values even below 5 mg/L. However, the well located near Koplik shows an increasing tendency from tens of mg/L since 2010. Even though concentrations are below the directive threshold, such increase is significant and relevant to achieve the WFD goals and force to define actions to reverse it.

Trush and Zadrima alluvial plains (MNT – ALB)

The Trush and Zadrima alluvial plains extend south from the Drini River and the outlet of the Shkoder/Skadar Lake to Baks i Ri. Several references, as those by Ozler & Xhahysa (2013), Bahr & Gomez (2018), and Barbieri et al. (2015), provide an insight for this aquifer's hydrochemistry (**Table 2.2** and **Figure 2.19**).

Nitrate concentrations are high around the Trush. Likewise, the Koplic-Shkoder Plain, ammonium concentrations increase down-gradient in the high nitrate concentration areas, indicating nitrate reduction by organic matter. Nitrate pollution could be produced by both wastewater disposal and fertilizers leakage.

[18] AKM (Agjensia Kombetare e Mjedisit). Report chapter 2, "CILESIA E UJERAVE". 2014. http://akm.gov.al/wp2014_ok//wp-content/uploads/2014/12/Cilesia-e-Ujerave.pdf

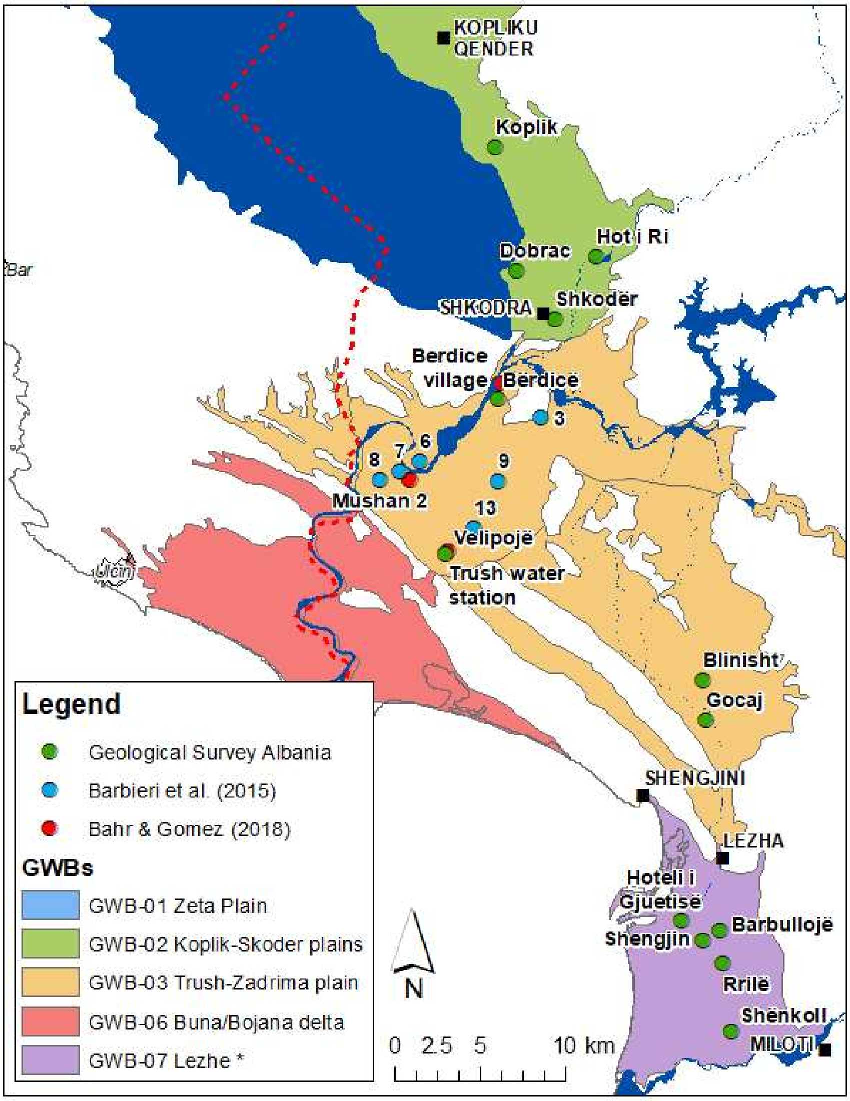

Figure 2.19. Location sampling points (* Groundwater Body not included in study area)

Additionally, Bahr & Gomez (2018) provides information on pH, electrical conductivity, temperature, and chloride concentration (**Table 2.2**). Electrical conductivity is a bit high around Berdice village, matching with the high nitrate concentrations reported by Ozler & Xhahysa (2013). In general, chloride concentrations are low, at the usual level of any alluvial plain aquifer. Indeed, chloride and EC as well as low near Trush. The characteristics of this particular sampling point are related to the fact that wells at this pumping station draw water from the deeper artesian aquifer, which might imply a high protection against anthropogenic pollution not found in wells located in the shallow layers of the aquifer. Information about the exact location of the wells and their depths will permit confirming this hypothesis based on few physico-chemical parameters.

Most of the Buna-Bojana flood plain is located in Albania, It is therefore reasonable that no information of groundwater quality for the Montenegrin segment have been found as this hydrogeological unit has little presence in Montenegro

Table 2.2. Geochemical parameter from four groundwater sampling locations.

	Source	pH	EC uS/cm	T ºC	Cl mg/l	SO4 mg/l
Berdice Village (Irrigation well)	Bahr & Gomez (2018)	6.86	870	17.3	12	
Mushan	Bahr & Gomez (2018)	7.55	570	17.3	14	
Trush water station	Bahr & Gomez (2018)	7.74	407	16.2	8	
Velipoja (Gomsique)	Bahr & Gomez (2018)	7.11	1012	16.2	32	
7	Barbieri et al. (2015)				2.3	1.2
3	Barbieri et al. (2015)				81.5	63.9
6	Barbieri et al. (2015)				32.5	10.7
8	Barbieri et al. (2015)				14.8	14.2
9	Barbieri et al. (2015)				21.0	14.2
13	Barbieri et al. (2015)				25.5	8.9

Buna-Bojana delta (MNT – ALB)

Despite its ecological and economical importance, the deltaic aquifer of the Buna/Bojana delta has been little researched with respect to the groundwater quality. No official information was provided neither by Montenegro nor by Albania about this area. Moreover, only scattered information was found in reports and in literature. For instance, the work by Puri (2010) in the AQMOD, which implied an extensive bibliographic research in the Montenegrin national archives, highlights this fact, yet it provides some field data (**Figure 2.23**).

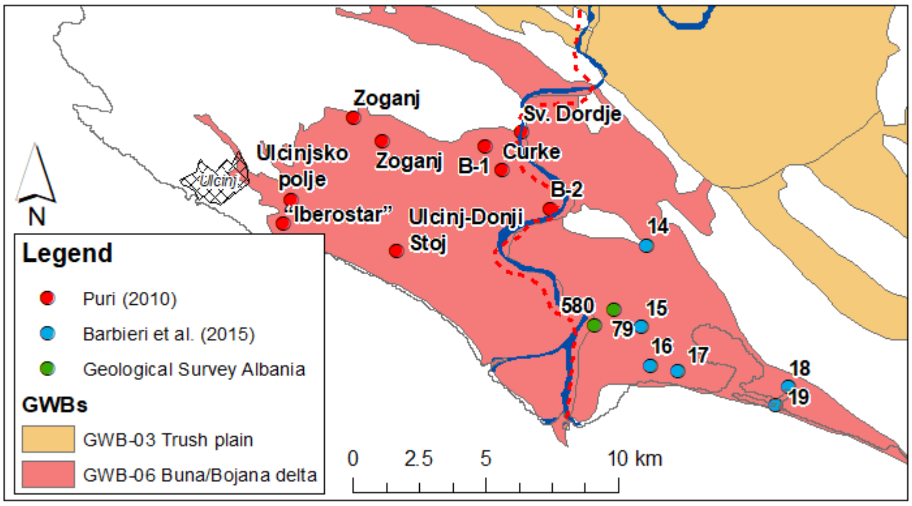

Figure 2.23. Location sampling points

Puri (2010) AQMOD report is the only source of quantitative information found on groundwater for the Montenegrin segment of the Buna/Bojana delta aquifer. Unfortunately, no information on mayor ions and cations was gathered, therefore no facies analysis can be done. Still, information on temperature, electrical conductivity, pH and Dissolved Oxygen (DO) is available (**Table 2.3**). Except for the drilled wells B1 and B2, all samples are taken from shallow wells, between 5 to 10 m depth. This can explain for example the high concentration of DO and low EC values. Only two samples present EC values higher than 700 µS/cm: (1) the well located close to the Iberostar hotel located by 500 m from the sea, and (2) the B2 borehole, which is the deepest and probably is intersecting the saline intrusion at a very low percentage. Indeed, a EC of 4600 µS/cm can roughly represent a 5% of mixing with seawater, which should be cautiously taken as indicative of severe seawater intrusion.

Table 2.3. Geochemical parameter based on Puri (2010) AQMOD report for Montenegro Buna/Bojana delta segment.

	Sampling date	Total depth	GWL	Temp	EC	pH	DO
		m	m	ºC	µS/cm		mg/l
Ulcinj – Hotel "Iberostar"	02/04/2009	de 6 a 7	2.3	15.5	1158	7.32	1.33
Ulcinj-Donji Stoj	02/04/2009	6	2.2	19.1	387	7.9	6.81
Ulcinjsko poldje	02/04/2009	de 7 a 10		17.5	236	7.84	5.43
Zoganj	02/04/2009	de 5 a 6	1.55	15.6	649	7.5	1.88
Gac –water supply resource	02/04/2009			18	338	7.61	10.1
Zoganj	02/04/2009	6.5	0.7	15.8	260	7.79	7.23
Curke	02/04/2009	6.22	4.57	16	384	7.93	8.38
Sv. Dordje	02/04/2009	4.53	2.7	15.9	488	7.45	4.18
STOJ - Guska (B1)	18/09/2009	27		18.5	1.76	8.3	9.05
B2	18/09/2009	37		16.8	4600	7.9	

Based on this data, none of the shallow boreholes seems to be affected for water intrusion, or any other pollutant that could cause and increase in the electric conductivity, or a deviation of the pH. Notice that the B1 sample presents an extremely low EC, high Temperature and high DO concentration, which could indicate that even if the water is taken from the borehole, water could come from rain or similar.

For the Albanian segment of the coastal aquifer information provided by Barbieri et al. (2015; **Table 2.4**). Barbieri et al. (2015) classifies the water as calcium-bicarbonate. All samples had a NO_3 content below the WFD standards (50 mg/l), except sample 15, close to Velipojë, which presented a nitrate concentration of 131 mg/L. The authors related this high nitrate concentration to poor management of sewage. They also highlight that pesticides might represent major pollution risk toward public health.

Table 2.4. Geochemical parameter based on Barbieri et al. (2015) for Albania Buna/Bojana delta segment.

	Sampling date	Total depth (m)	NO3 (mg/l)	CL (mg/l)	SO3 (mg/l)
14	October 2012	0	9.16	60.8	85.4
15	October 2012	5	**131**	54.6	58.5
16	October 2012	5	14.3	18.7	18.8
18	October 2012	6	0.37	44.7	48.8
19	October 2012	0	1.14	10.8	9.16
15	June 2013	5	n.a.	24.7	17.8
17	June 2013	6	n.a.	34.6	30.2
18	June 2013	6	n.a.	44	35.5

Finally, the hydrochemical data of the Drin River also in agreement with the karstic nature of its basin, can be used as a reference of the surface recharge to the aquifer.

Pressures and impacts on groundwater resources

The WFD sets that pressures and impacts must be defined according to precise targets or objectives, their size and the susceptibility to being impacted, being the most general ones achieving a good groundwater status in a given timeframe, and reversing those pressures that impede achieving it (EU, 2003[19])

As regards groundwater resources, the main targets are summarized as,

1. To implement measures to prevent or limit the input of pollutants into groundwater and to prevent the deterioration of the status of the groundwater body (groundwater status consists of two parts; quantitative status and chemical/qualitative status);
2. To protect, enhance and restore all bodies of groundwater, and ensure a balance between abstraction and recharge of groundwater, with the aim of achieving good groundwater;
3. To reverse any significant and sustained upward trend in the concentration of any pollutant resulting from the impact of human activity.
4. To ensure the protection of groundwater dependent ecosystems by easing the pressures upon them.

The foreseen **pressures on groundwater resources** in the distinct study areas, based in the Guidance Doc. No 3, are summarized in **Table 2.5** Point and diffuse source pollution and

[19] EU Commission (2003). Common Implementation Strategy for the Water Framework Directive (2000/60/EC). Guidance Document No 3 - Analysis of Pressures and Impacts. Produced by Working Group 2.1 – IMPRESS, 157 pp.

change in water levels due to abstraction have been considered as the major pressures. No large land use changes are envisaged for these areas, except a potential urban growth in the major towns (e.g., Podgorica) or in coastal areas due to an increase of touristic places and resorts. Moreover, the natural change of the Drin course and the building of dams are not considered as a pressure for the Buna/Bojana area as we assume that the affected region has already adapted to the new hydrological scenario since changes occurred centuries or decades ago. Present gravel-mining activities may have effects on groundwater in the immediacy of the mining pits, as well as, at local scale, to modify some erosional-depositional dynamics of the river.

Moreover, the analysis of pressures and impacts is restricted to the quaternary formations that hold the most human affected hydrogeological units. Aquifers located in the karstified limestone formations are not expected to show large pressures as land use and urbanization density is rather small, or even inexistent, due to geographical and orographic reasons.

Impacts derived from the identified pressures are as follows,

- *Quantitative impacts*.- Groundwater withdrawal for urban supply at large rates can produce large and deep depressions cones and reduce the storage and availability of water resources. Jointly with sparse groundwater exploitation in the countryside, depleted levels may alter the water balance an induce stream recharge (decreasing river flows) and decrease recharge to lakes or wetlands.
- *Qualitative impacts*.- Crop fertilization introduce nutrients (N, P) in groundwater that may affect related ecosystems (streams, wetlands, …) and human health when chemical thresholds are exceeded. Industries, urban activities and landfills may be responsible for gross pollution of groundwater as well as of surface water (e.g., Morača River) that may later on recharge the aquifer. Moreover, sanitation structure is problematic in some areas as well as solid waste treatment policies. Both may end up being groundwater pollution sources. Nevertheless, neither Skadar/Shkoder Lake nor groundwater in the Shkodër-Trush aquifer presents pollution levels related to nitrogen compounds (nitrate, nitrite, ammonia) at dangerous levels for human consumption or environmental damage. However, surface water from the Drin River shows nitrogen compound concentrations suitable for domestic and agricultural uses, but high for environmental concern (Özler and Xhahysa, 2013[20]).

[20] Özler HM, Xhahysa A (2013). Surface and groundwater contamination in Shkoder-Trush aquifer (Albania). *17th International Water Technology Conference*, IWTC 17 2013, Istanbul, Turkey, 10 pp.

Conversely, Barbieri et al. (2015[21]) reported that no evidence of saline intrusion phenomena was obtained in the Buna/Bojana river area, including the Thrush basin and the delta formation, even in the area closest to the coast. Areas with a greater anthropogenic presence show NO_3 levels above the EU thresholds, probably due to the lack of wastewater management systems. A major concern is represented by the widespread presence of organochlorine pesticides, especially with reference to the hexachlorocyclohexane isomers that have concentrations widely above the thresholds suggested by the EU.

- *Ecological impacts*.- Eutrophication due to nutrient high levels, and progressive desiccation due to altered water regimes in the nearby groundwater systems because of groundwater withdrawal.

[21] Barbieri et al (2015). First groundwater chemical status assessment of the Buna River-Protected Landscape (Albania). *Environ Earth Sci*., 74:6325–6338. DOI 10.1007/s12665-015-4657-3.

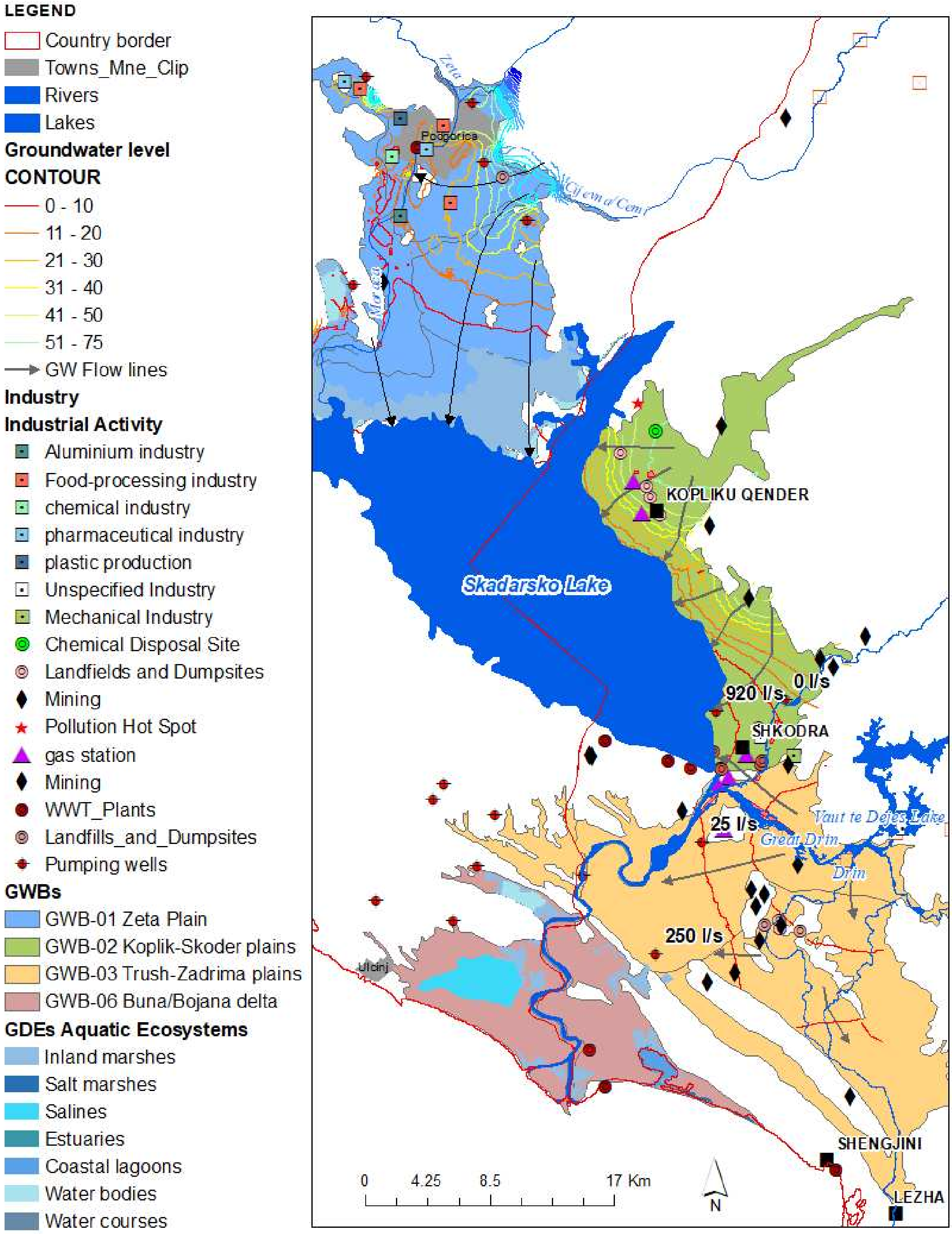

Figure 2.24. Pressures and Impacts map

Table 2.5.- Foreseen pressures on groundwater resources (ALB: Albania, MTN: Montenegro).

Area	Point source pollution	Diffuse pollution	Change in water levels due to abstraction
Skadar Lake area:			
Zeta Plain (MTN)	✓ Aluminium production facility. ✓ Food-processing and plastic industries as potential pollution focuses. ✓ Gravel mining along Morača River.	✓ Fertilization (nutrients and pesticides) in cereal and forage crops using slurries and manures (not in vineyards). ✓ Stream recharge due to well capture zones, depending on the Morača River quality potentially affected by wastewater dumping (urban drainage) and leaking septic systems.	✓ Water abstraction in Podgorica urban area (MTN). ✓ Water abstraction due to agricultural activity (MTN).
Koplik-Shkodër Plain (ALB)		✓ Fertilization in cereal and forage crops using slurries and manures	
Buna/Bojana River area:			
Trush – Zadrima Basin (ALB, MTN)	✓ Landfill near Shkjezë (ALB). ✓ Saski Lake has been reported to show high heavy metal concentrations. ✓ Gravel mining along the Drin River left-bank, near Ashtë (ALB). ✓ Pollution from septic systems and network (where existing).	✓ Fertilization in cereal and forage crops using slurries and manures (ALB, MTN).	✓ Well field near Fshati i Ri for urban supply (ALB). ✓ Overpumping for agricultural demand (ALB).
Buna/Bojana delta area (ALB, MTN)	✓ Leakage from salt production ponds (ALB, MTN).	✓ Fertilization (nutrients, especially P, and pesticides) in cereal and forage crops using slurries and manures (ALB, MTN). ✓ Stream recharge due to well capture zones affected by wastewater dumping (urban drainage). ✓ Non-farmed stock breading (ALB).	✓ Domestic and agriculture wells near the coastline in Velipojë (ALB) and Doni Štoj (MTN): effects on wetlands and lagoons due to head level decline, and drivers of seawater intrusion. ✓ Saline water in karstic springs (Gac spring). ✓ River salinization.

2.3. Groundwater bodies

With the scope to adapt the management of the studied aquifers to the requirements of the WFD, a first exploratory, working demarcation of the "groundwater bodies" is mandatory. While the aquifer definition for the WFD is the usual one for hydrogeology textbooks (*Aquifer: means a subsurface layer or layers of rock or other geological strata of sufficient porosity and permeability to allow either a significant flow of groundwater or the abstraction of significant quantities of groundwater;* Article 2, 11), the concept of "groundwater bodies" is singular to the WFD. Indeed, a *body of groundwater means a distinct volume of groundwater within an aquifer or aquifers* (Article 2, 12). Groundwater bodies (GWB) are, at the end, principal reporting units; i.e. management units (size, pressures, status issues). Therefore, the aquifer is the "structure" where groundwater is stored, and can be defined on the basis of how much water can flow into them and the ability to extract significant quantities from them. Conversely, groundwater bodies constitute the "basic units" where it is possible to assess the water status. The "groundwater body" should be a coherent sub-unit in the river basin (district) to which the environmental objectives of the directive must apply. Hence, the main purpose of identifying these bodies is to enable the (quantitative and chemical) status to be accurately described and compared to environmental objectives (EU, 2003)[22].

The characterization of GWBs is a detailed task that must be carried out by the Member States. Nevertheless, committed to our goal of "developing a proper monitoring program that allows both countries, Albania and Montenegro, to manage their groundwater resources in the context of a transboundary aquifer system, <u>we propose in this section potential groundwater bodies based on the preceding hydrogeological summaries</u>. Such recommendation must be understood as "working tool" that will need further work and review by local experts and stakeholders to end up being definite GWBs to be used in the river district management plans.

GWBs in the Zeta and Koplik-Skhodër plains (Skadar Lake area)

The northern part hydrogeological system in the Skadar/Shkoder Lake area is composed, as stated by Radulović (2018[23]), by areas of dominant recharge and dominant discharge

[22] EU Commision (2003). R*iver Basin District Management Systems. Approach to Delineation of Groundwater Bodies.* Paper by the Working Group on Groundwater Guidance document no. GW2, 18 pp.

[23] Radulović, M. M. (2018). Hydrogeology of the Skadar Lake Basin. *The Handbook of Environmental Chemistry*. doi:10.1007/698_2017_231.

areas (**Figure 2.25**) of the huge karst aquifer that constitutes the head waters of the river basins (those of the Zeta, Morača, and Cijevna rivers as the largest ones).

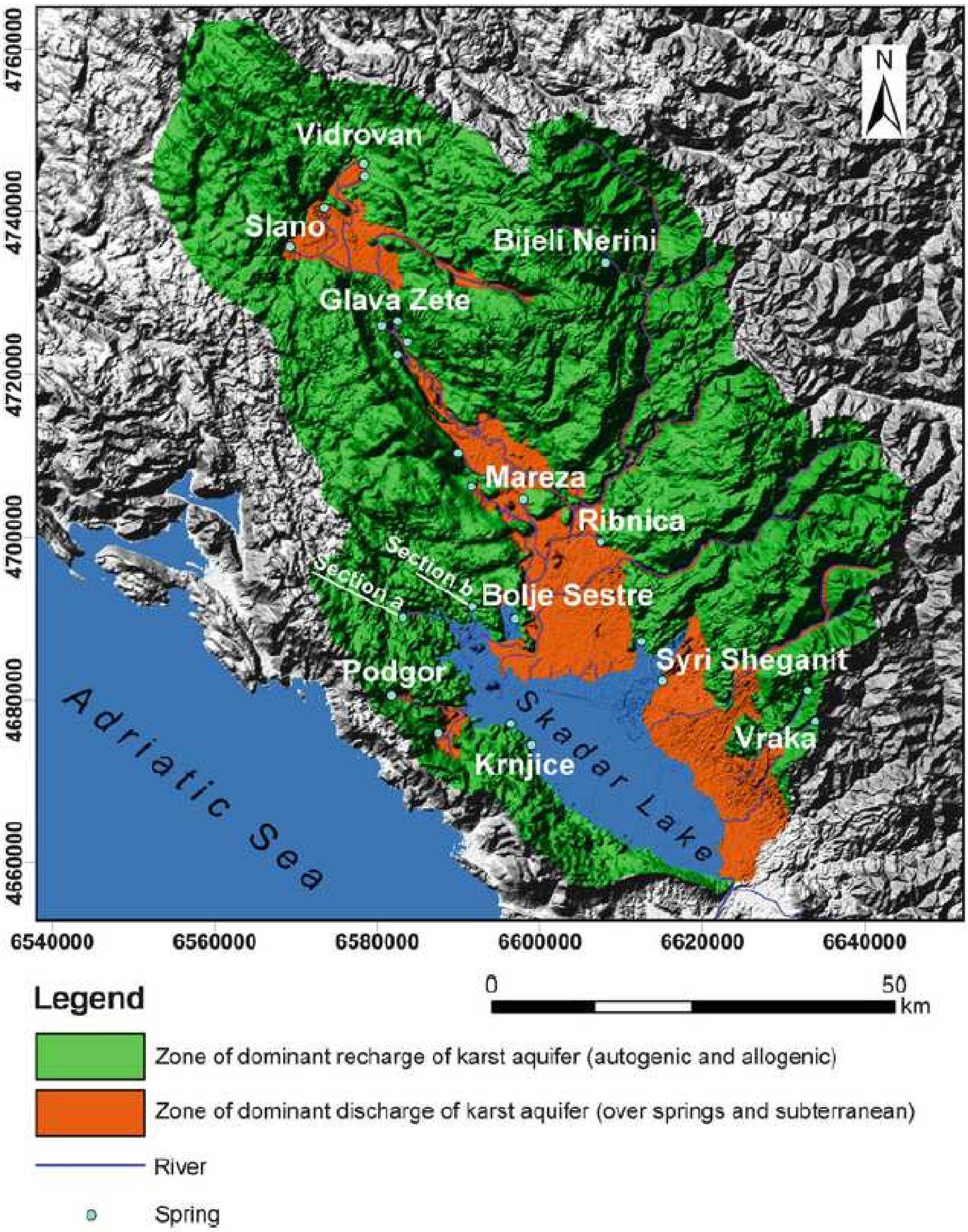

Figure 2.25.- Map of recharge and discharge areas of the karst aquifer in the Skadar/Shkoder Lake catchment area, after Radulović (2018).

The large dimension of the karstic recharge area –which will constitute one, or possibly several, GWB in the frame of a detailed river district management plan– overpasses the scope of this study that focuses on the plain areas that actually coincide with the discharge areas of the karstic system. Therefore, we will not consider the headwaters of the karstic system as a GWB in the context of this work. Nevertheless, we are convinced that its monitoring (in quantity and quality) is highly interesting because of it acts as the recharge source, whether surface or subterranean, of the Quaternary hydrogeological units.

According to the hydrogeological information summarized in the previous section, the following GWBs for the Skadar/Shkoder Lake area are suggested (**Figure 2.26**):

1. ***GWB-01 Zeta plain.-*** The GWB formed by alluvial aquifer of the Zeta, Morača and Cijevna rivers that includes all three terraces and the lacustrine sediments in its distal parts, near Skadar/Shkoder Lake. It is a sedimentary unit, with dominant coarse particles and intergranular porosity. Despite that some layers can show some degree of cementation it is considered an excellent aquifer. Flow recharge is due to karst lateral inputs, rainfall and, locally, stream infiltration. Main discharge is towards Skadar/Shkoder Lake, occasionally stream discharge, and groundwater withdrawal for urban (mainly, Podgorica city), industrial and agricultural demand. Main pressures are groundwater abstraction and pollution from urban, industrial and agricultural sources. It shows large vulnerability (see Chapter 2). Specific vulnerable points are karstic springs in its limits and on the lacustrine area.

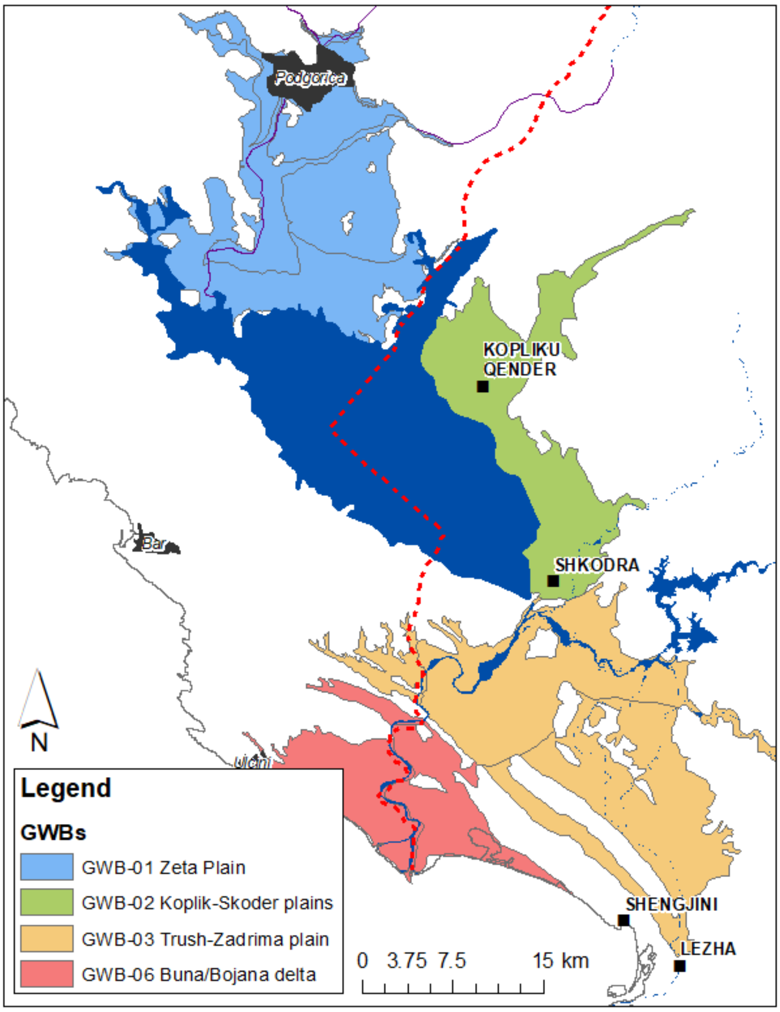

Figure 2.26. Groundwater bodies that are the object of this study; i.e., those in alluvial and fluvio-deltaic plains of the area.

2. ***GWB-02 Koplik-Skhodër plains*.-** The GWB formed by **the alluvial fan aquifer of the Koplik-Skhodër plains from the mountain front from Skadar/Shkoder L**ake, and its lacustrine sediment strip. Hydrogeological dynamics is comparable to the GWB of the Zeta Plain, and main human pressures are pollution from urban and agricultural sources. It also shows large vulnerability (see Section 2). Similarly, specific vulnerable points are karstic springs in its limits and on the lacustrine area. Porous aquifer is used for water supply of Shkodra city with a capacity of 800 – 900 L/s. This pumping station consists of 10 boreholes in Dobraç area.

Despite their similar hydrogeological features and sharing Skadar/Shkoder Lake as the common discharge unit, both GWBs are considered independent of each other. We also claim that both GWBs cannot be fully understood and managed without considering Skadar/Shkoder Lake as a surface water body by itself. Its categorisation as such is beyond the scope of this study.

GWBs in the Buna/Bojana area

In the Buna/Bojana area, and despite the relevance of the karst system that dominate the overall geological structure, we centre our discussion on the GWBs within the study area, and shall not made any reference to the contribution of the karstic inland plateaus on the GWB water balance. The two main reasons for this simplification are:

- The Drin and Buna/Bojana rivers, altogether with Skadar/Shkoder Lake, are assumed to control most of the recharge as contiguous surface water bodies, in addition to local rainfall infiltration.
- The wide occurrence of the flysch sediments, considered of low permeability, on the bottom of the Trush plain and between the folded structures. Flysch deposits are supposed to behave as aquicludes and, therefore, act as no-flow limits wherever they appear. Nevertheless, the occurrence of karstic springs in the limestone ranges parallel to the Adriatic coast must be considered as potential recharge sources.

According to the hydrogeological information summarized in the previous section, the following GWBs for the Buna/Bojana area are suggested (**Figure 2.26**):

3. ***GWB-03 Trush and Zadrima plains.-*** The GWB formed by alluvial aquifer created by the Drin and Buna/Bojana river sediments. It mainly develops in the left-bank of both rivers, but it should also include the right-bank of the Drin River around Vukatanë, and the right-bank of the Buna-Bojana River near along the strip Muriqan-Oblikë still in Albanian territory. As mentioned, this alluvial, productive aquifer gets its recharge from stream and rainfall infiltration.

In the eastern and northern side of this aquifer, the aquifer is unconfined, while in the south and west, as a result of the increased thickness of the cover and as a result of the higher elevation of the recharge zone (Drin River), it behaves as a confined, artesian aquifer, such as in Trush të Poshtëm, Pistull, Paçram, Gocaj, etc. However groundwater levels, in most of the territory are below the surface of the ground but not in great depth. The levels range from 1.0 to 3 m – 3.5 m and rarely go up to 5.0 m below the ground surface. The fluctuations of the levels are directly related to the hydrological regime of Buna and Drini Rivers, which also confirms their good hydraulic relations with groundwater.

As its bottom of the alluvial infilling is assumed to lay on flysch sediments, the relationship with the underlying karstic aquifer must be limited to fracture zones or local karstic phenomena as buried sinkholes or similar. It also gets lateral recharge from the karstic limestone ranges that lay in its southern boundary. The main pressures are groundwater abstraction for domestic and agricultural use) and pollution of agricultural sources. It shows large vulnerability (see Section 2) and it is subject to periodical floods (Schneider-Jacoby et al., 2006[24]).

The aquifer in the Zadrima basin, in the SE part of the Drin and Glader rivers alluvial plain, is not very productive. Alluvial deposits extent along an area of 45 km^2, and their thickness is limited to 25-30 m, with thin gravel layers that store and convey most of the groundwater resources in this area.

4. ***GWB-04 Albanian Karstic coastal ranges.-*** The GWB formed by the Cretaceous limestone ranges: Mali i Kakarriqit and Mali i Rrencit, parallel to the coastline and oriented NW-SE from their north-westernmost outcrops, near the Buna/Bojana River, to the cities of Balldreni and Lezhë. We consider these limestone ranges as a separate GWB, and they control the lateral recharge to GWB-03 and GWB-06. Their structure is given by diverse thrust faults and folds and these ranges can be considered hydrogeologically isolated because of structural limits and the occurrence of flysch deposits as their stratigraphic cover. Recharge is mainly due to local rainfall in its summits, and discharge occurs laterally towards the Quaternary sedimentary formations or direct to the Adriatic Sea (e.g., Shëngjin area). They lack intense human land use; therefore, the main (relative) pressure is groundwater abstraction from their karstic springs.
5. ***GWB-05 Montenegrin Karstic coastal ranges.-*** The GWB formed by the Cretaceous limestone ranges of Katërkolle and Gornja Klezna from their west limit in the Adriatic coast to the Buna/Bojana River at the east. It also includes the colluvium formations that develop from both ranges towards the Buna/Bojana River on the foothills near the villages of Vladimir-Sukobin-Sas and Donja Klezna, including Sasko Lake. The GWB excludes the areas where the Eocene flysch outcrops. As their twin limestone ranges in GWB-04, they control the lateral recharge to GWB-06. Their

[24] M. Schneider-Jacoby, U. Schwarz, P. Sackl, D. Dhora, D. Saveljic and B. Stumberger (2006): *Rapid assessment of the Ecological Value of the BojanaBuna Delta (Albania / Montenegro).* Euronatur, Radolfzell.

structure is given by diverse thrust faults and folds and they can be considered hydrogeologically separated because of structural limits and the occurrence of flysh deposits. Recharge is mainly due to local rainfall and discharge occurs laterally towards the Quaternary sedimentary formations or direct to the Adriatic Sea. Main human land use happens in the foothill area and the main pressures will be pollution from urban and agricultural sources.

6. ***GWB-06 Buna/Bojana delta area.-*** This GWB integrates the most recent deltaic system of the river, being defined by the triangle between the water gap in Pentar, Port Milena in Montenegro and Velipojë and the Këneta e Vilunit lagoon in Albania. It is a single hydrogeological units constituted by the complex development of the delta and the associated dune and beach ridges, as well as the lagoons of Këneta e Vilunit, and Zoganjs Lake, both related to the delta historical development and human transformation. Some inland wetlands also exist, north of Gomsiqe, yet they are nowadays disconnected from coastal processes (if they have ever been) and related to the draining of the Trush plain southernmost most area and to local springs. In turn, these wetlands artificially drain to the Këneta e Vilunit lagoon and, through a second channel, to the sea. Recharge of the delta aquifer levels are related to stream and rainfall recharge, as well as form lateral contribution from GWBs 05 and 06. Groundwater flow discharge is mainly to the sea. Given a high human activity, mainly touristic, pressures are high, involving groundwater withdrawal and the associated seawater intrusion when high pumping regimes are set in wells close to the coastline. Pollution form urban activity is also expected, and from agriculture as well. Salt pans, as those in inner bank of the left-bank meander and those of Zoganjs Lake, may also contribute to groundwater salinization.

Transboundary features

In the core of this project, join management of common water resources, based on the WFD regulation, by Albania and Montenegro must be described based on the issues that may result in some conflict. Up to this moment, we have proposed some GWBs as management units that permit achieving WFD goals, and we should now seek for common aspects based on the hydrological features of the GWBs. In this sense, the DIKTAS project also focused on transboundary aquifers (TBAs), examining current and potential issues of concern. The analysis of TBAs provided an opportunity to test the applicability of outcomes of the regional analysis at the local scale, dealing with concrete issues of transboundary concern. Indeed, two TBA are listed by the Transboundary Waters Assessment Programme (TWAP[25]) project, conducted by IGRAC[26]: the Cijevna River Basin (label EB93) and the Skadar/Shkodër Lake, Dinaric East Coast Aquifer (which is indeed the study area of this

[25] https://www.un-igrac.org/special-project/twap-groundwater
[26] https://www.un-igrac.org/

report!), shared between both countries (**Figure 2.27**). Delineation of each TBA surface area was also a very first step in the hydrogeological analysis conducted by DIKTAS. These areas usually comprise allogenic and autogenic zones of karst aquifer recharge (Stevanovic et al, 2012[27]).

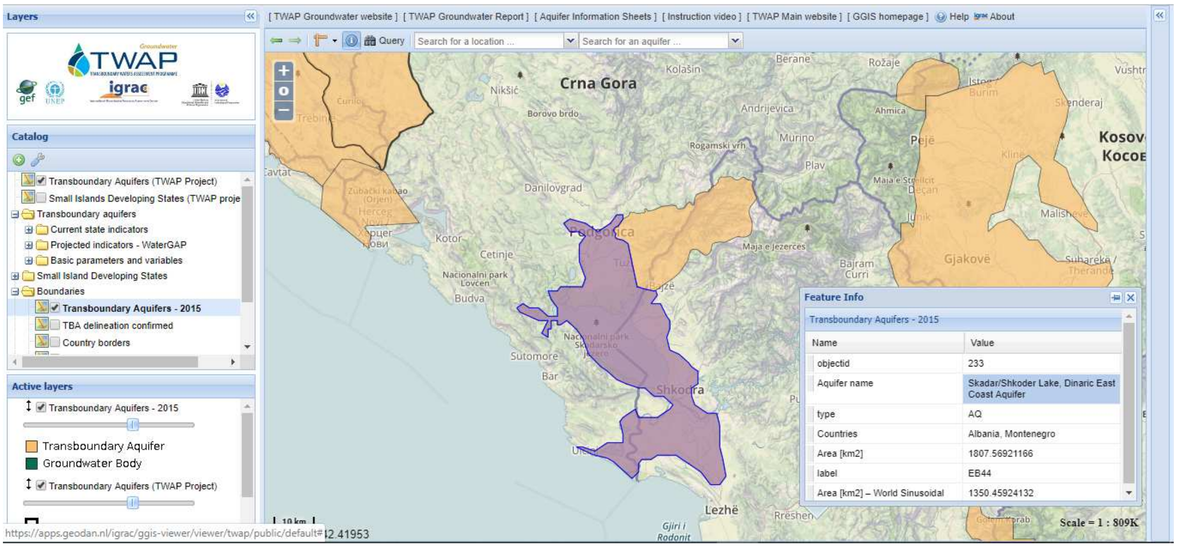

Figure 2.27.- Screen-shot of the TWAP webpage with the two TBA in the study area.

In this section, we address the issue of transboundary features for each one of the proposed GWBs.

GWB-01 Zeta plain.- This GWB lays entirely on Montenegrin territory, yet the Cijevna River that contributes to its recharge stands as a transboundary basin and aquifer. Given orographic and geomorphological features, and given the fact that the political boundary follows the mountain ridge, most of the groundwater recharge that contributes to the Zeta Plain GWB originates in Montenegro; unless some unforeseen, very deep groundwater flow systems originated inland in Albanian territory also flow towards the Zeta plain and Skadar/Shkoder Lake basin.

Therefore, the main transboundary issue relates to the stream discharge control that may occur in Albanian territory and will reduce the amount of water reaching the Montenegrin part of the lower drainage basin. This will not only reduce surface discharge and its contribution to the receiving Morača River, but also the infiltration from the Cijevna River that contributes to the groundwater recharge of "Terrace 3" in the Zeta plain.

Another common issue is Skadar/Shkoder Lake acting as a common boundary. We do not envisage quantitative problems (climate changes issues are not herein considered), yet

[27] Stevanovic Z, et al. (2012). Characterization of transboundary aquifers in Dinaric karst - a base study for sustainable water management at regional and local scale. *IAH 2012 Congres - Niagara Falls*, 10 pp.

qualitative problems can cause trouble as wells near the lake coastline may induce recharge from Skadar/Shkoder Lake. Surface water inputs, mainly from the Morača River (the one with largest human pressures) as well as those from other minor tributaries, may worsen the lake water quality, which would finally affect that of the wells that get its recharge.

GWB-02 Koplik-Skhodër plains.- This GWB, and the major river basin that relates to this GWB: that of the Prrone i Thate River, lays entirely on Albanian territory. Therefore, no transboundary issues arise from the GWB headwaters. The only common issue is that of the hydrogeological role of Skadar/Shkoder Lake, which has already been described for GWB-01.

GWB-03 Trush and Zadrima plains.- This hydrogeological system lays entirely in Albanian territory. Likely transboundary issues involve: 1) the quality of the Buna/Bojana River as a recharge source that originates in Skadar/Shkoder Lake and also gets the human pressures from the city of Shkodër; yet dilution by Drin river's discharge can reduce potential impacts, 2) future stream discharge capture towards Albanian territory, direct or induced by groundwater withdrawal near the river course, may reduce the overall discharge and affect GWB-06 water budget and water quality.

Even though the two expected issues are feasible, they can unlikely be considered critical or relevant as origin of transboundary conflicts.

GWB-04 Albanian Karstic coastal ranges.- This GWB lays entirely on Albanian territory. Despite the geological continuity of the limestone formation towards GWB-05 in Montenegro, major flow directions will take place with Albanian land, so we do not account for any transboundary issue to be considered.

GWB-05 Montenegrin Karstic coastal ranges.- This GWB lays entirely on Montenegrin territory. Same considerations as those for GWB-04. Nevertheless, as it also includes the colluvium formations that develop on the foothills between the mountain ranges and the Buna/Bojana River, we must cite the chance (presently, not expected) that groundwater flow from this surficial aquifer affect the river quality.

GWB-06 Buna/Bojana delta area.- This GWB is entirely shared by both countries because of its hydrogeological continuity between them. The fact that the political border follows a major recharge boundary, as the river itself, may look as if the river behaves a no-flow boundary; i.e., no groundwater flow occurs from on bank to the other.. Indeed, the low topographic gradient and the meandering morphology of the river clearly enables recharge to cross the river course. Therefore, we suggest GWB-06 to be considered as a single hydrogeological system by both countries' water resources agencies.

Finally, the list of transboundary issues related to groundwater resources management according to the EU WFD point out the leading role of the Skadar/Shkoder Lake and the Buna/Bojana River on preserving GWBs quality and quantity. Indeed, the chemical-physicochemical quality of the river ranges from good to moderate, but deteriorates from its sources to the river mouth (Faloutsos et al., 2017). We then appeal that national agencies must also work on the surface water (streams and lakes) body's definition and characterization, as GWBs management cannot be conducted without references to these two major hydrological elements.

Chapter 2.

Aquifer Comprehensive Vulnerability Mapping

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1. Introduction

ACVM (Aquifer Comprehensive Vulnerability Mapping) method is a new tool for evaluating aquifer vulnerability. It is based on a new, expanded concept of vulnerability mapping that is derived from the concept of intrinsic aquifer vulnerability itself.

Vulnerability is an intrinsic characteristic of an aquifer because it is linked to the intrinsic characteristics of the aquifer that provide a defence against an external threat, such as a pollutant, a contaminant or an external event that can impact groundwater quality. The main advantage of ACVM is that, with this method, it is possible to describe simultaneously many aspects of aquifer vulnerability using only one parameter called Comprehensive Vulnerability.

Therefore, the application of the ACVM (Aquifer Comprehensive Vulnerability Mapping) method on the transboundary aquifer located within the Skadar/Shkoder - Buna/Bojana shared by Albania and Montenegro, constitute a new approach for design the monitoring network and for providing to stakeholder a new tool for a wise exploitation of the territory.

2. Application of aquifer vulnerability to the transboundary aquifer located within the Skadar/Shkoder - Buna/Bojana area shared by Albania and Montenegro.

A first draft of the ACVM Vulnerability map was elaborated at the end of 2018 using the DIKTAS project data. In fact, at that time, the studied area was completely covered only by DIKTAS data that have an excellent quality at the scale of 1:500000, moreover no stratigraphic data and no geochemical data were available.

During the 2019 high resolution data were provided by Albania and Montenegro so the vulnerability map was redrawn at the scale 1:100000. In fact, the new map is based on geological and hydrogeological maps at the scale 1:100000, 1:50000 and 1:25000, and on detailed well database, geochemical data, stratigraphy description. Moreover, a new detailed database of potential pollution sources and target of possible pollution was elaborated using the information provided.

All the acquired data and knowledge of the area were incorporated into the ACVM map using QGIS and the elaborated layers and results have been loaded into the UNESCO-IHP Water Information Network System (WINS) so they are accessible on http://ihp-wins.unesco.org and can be easily queried and updated.

2.1. Description of the Vulnerability map

The resulting ACVM vulnerability map was drawn at the scale of 1:100000 it has a vertical layout (0.92 m wide x 1.65 m high) and it is composed by the following three elements (**Figure 2.1**):

⇒ On the top of the layout, the **comprehensive vulnerability map** is provided. It is an integrated vulnerability map showing the locations of potential pollution sources and the target of possible groundwater pollution on the comprehensive vulnerability map.

⇒ On the lower left side, the **vertical vulnerability map** is plotted using the numeric scale ranging from 0 to 4.

⇒ On the lower right side, the **horizontal vulnerability map** is plotted using the same numeric scale.

The three elements are plotted in the same layout because the comprehensive vulnerability map is based on the information contained in the vertical and horizontal vulnerability maps of the aquifer. Consequently, it is important to consider these two maps when viewing the comprehensive vulnerability map, in order to understand which component of vulnerability is prevalent.

In the following pages the three elements are described and commented.

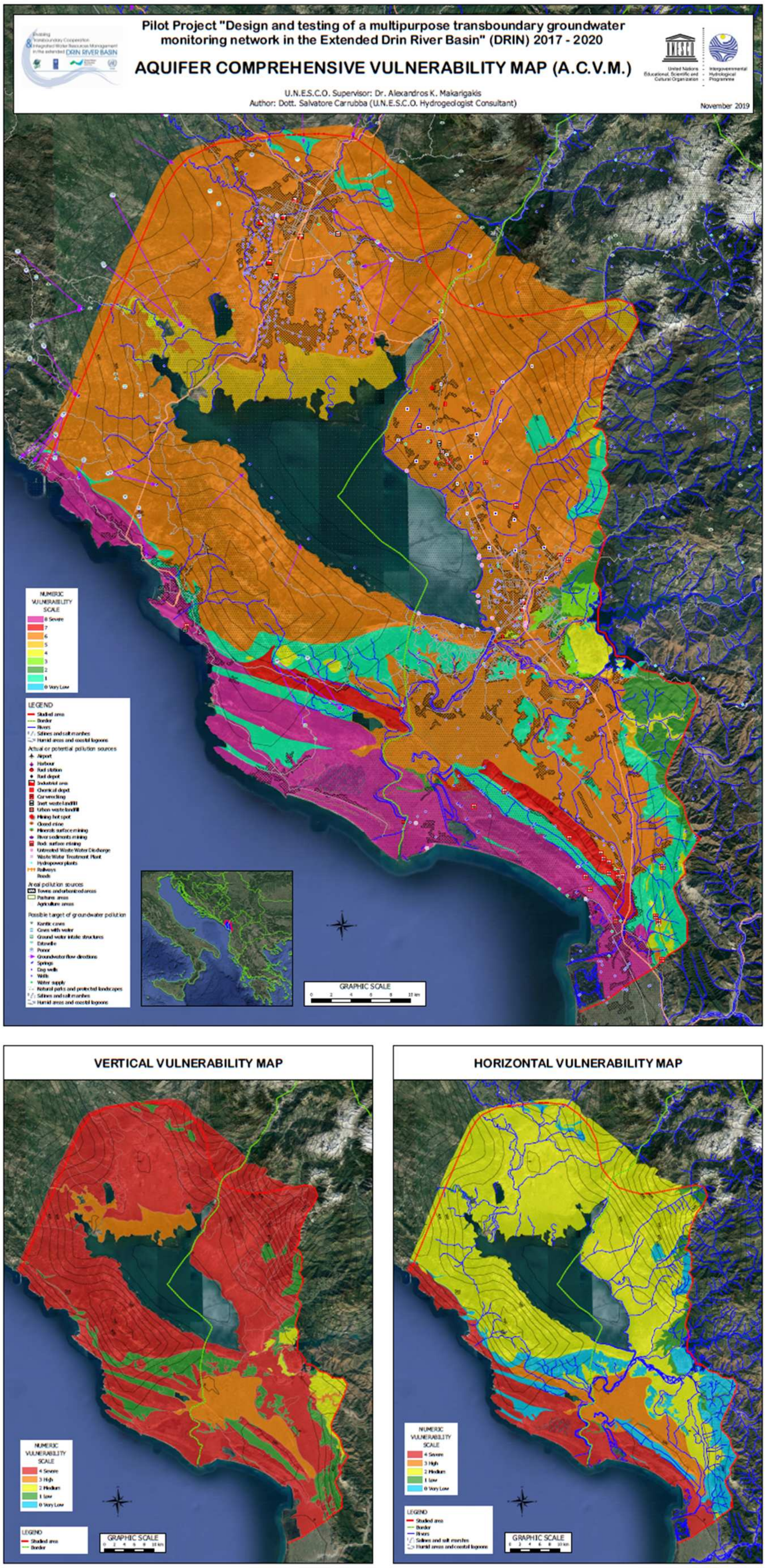

Figure 2.1.- Miniature of the ACVM vulnerability map

The vertical vulnerability map

The vertical vulnerability map was elaborated applying the Homogeneous area zoning method (HCS) in fact data distribution doesn't aloud to apply a Parametric System Method in the whole studied area.

The vertical vulnerability map is based on:

- Well data: stratigraphy and dept to water
- Permeability of the outcropping rocks
- DTM and topographic information
- Presence of impermeable soil (this data is not homogeneously available)

As we can see, the resulting vertical vulnerability map (**Figure 2.2**) has a large area where vertical vulnerability is **severe**. In these areas a pollutant can easily infiltrate the ground surface due to the high permeability of the rocks and of the soils.

In the areas where vertical vulnerability is **high**, aquifer has some means of defence against a pollutant coming from the land surface due to the presence of semi-permeable superficial layers.

While, on the area where vertical vulnerability is **medium**, rocks with no aquifers or sporadic aquifer are present.

Finally, in the area where vertical vulnerability is **low** mainly impermeable Flysch deposits are outcropping, as we can see in the **figure 2.3**, these deposits constitute impermeable deposits able to protect aquifer against a pollutant coming from the land surface and constitute a hydrogeological barrier against salt water intrusion.

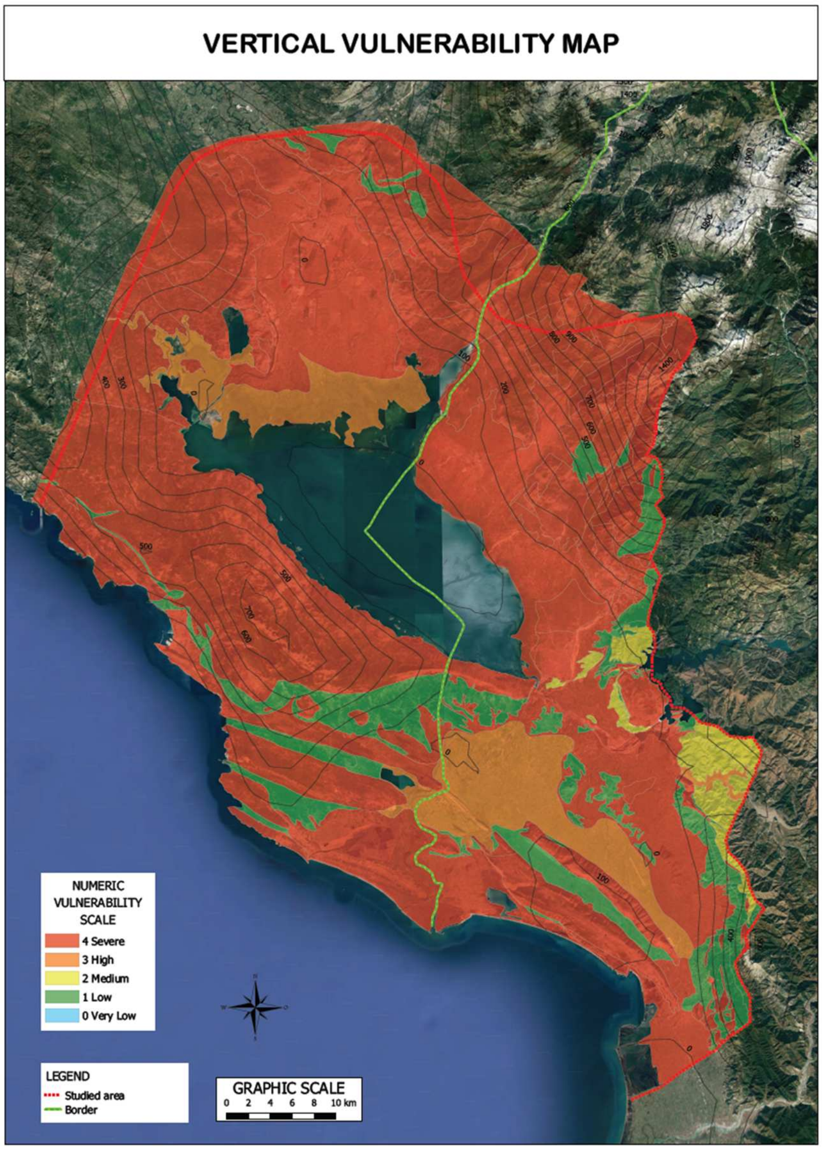

Figure 2.2.- Miniature of the vertical vulnerability map

Moreover, these deposits represent the limits of the transboundary aquifer. The vertical vulnerability of these deposits is low and not very low, because a pollutant can flow on them reaching the adjacent more vulnerable areas.

Figure 2.3.- Impermeable Flysch deposits outcrop

The horizontal vulnerability map

The horizontal vulnerability map was heavily revised thanks to the new data provided in 2019. In order to apply ACVM method on the transboundary aquifer located within the Skadar/Shkoder - Buna/Bojana area, we have to consider that the intergranular aquifer is in hydraulic connection with the rivers, with the lake and with the regional karst system on the North and East part. While it is in hydraulic connection with the sea in the South West part (**Figure 2.4**).

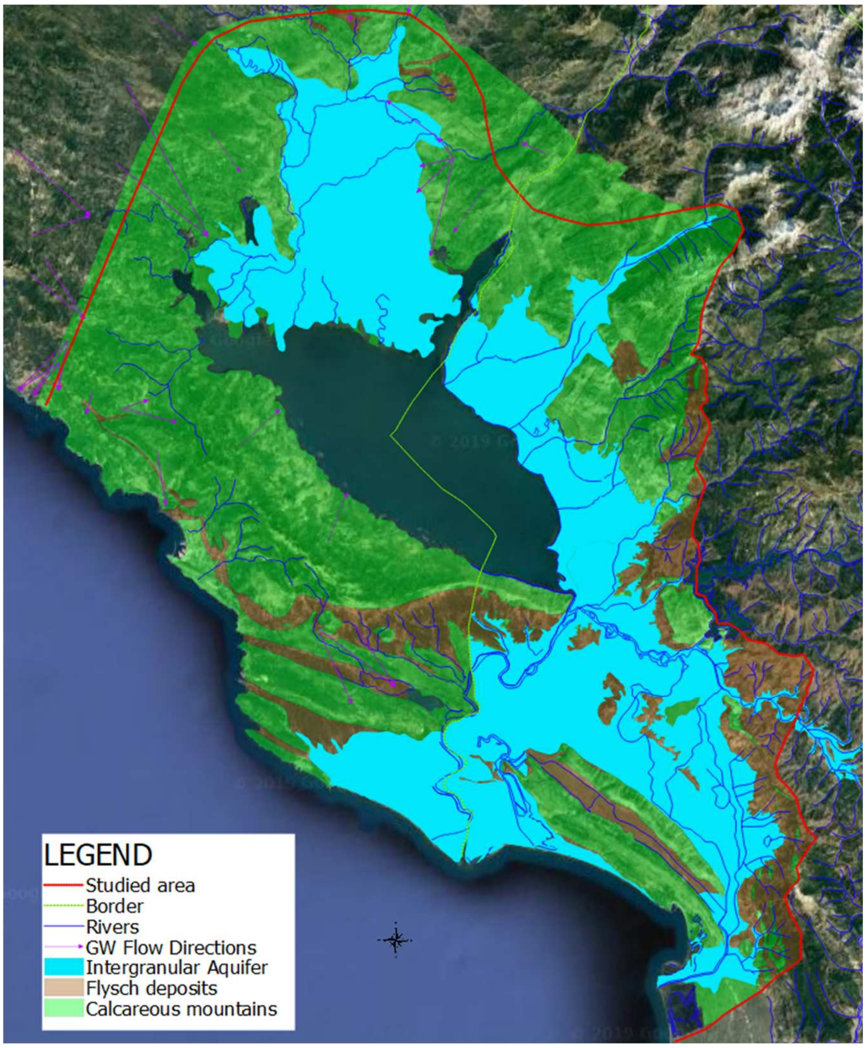

Figure 2.4.- Schematic hydrogeological asset of the studied area

In fact, the intergranular aquifer is in hydraulic connection with the regional karst system and with the Skadar/Shkoder lake. Moreover, the Skadar/Shkoder lake is in hydraulic connection with the Regional karst system and with the karst system in the mountains between the Skadar/Shkoder lake and the sea. While between this karst system on the West of the Skadar/Shkoder lake and the sea there is a layer of Flysch and impermeable deposits that constitute a hydraulic barrier against salt water intrusion Minor isolated aquifers are in hydraulic connection with the see but not with the main transboundary aquifer.

This hydraulic barrier is less efficient on the South part of the intergranular aquifer.
So, the South part of the intergranular aquifer is in hydraulic connection with the sea directly through the alluvial sediments or indirectly through the coastal karst system. Therefore, in these areas salt water can intrude into the intergranular aquifer and into the coastal karst system and following this pattern, salt water could reach the central part of the aquifer. Moreover salt water can flow into the coastal karst system as proved by salty springs on the East part of the coastal karst structures.
While on the South East part of the intergranular aquifer the Flysch deposits constitute the limit of the aquifer.
The thickness of the intergranular aquifer is very elevated so, in the most part of the intergranular aquifer, the bottom of the aquifer is under sea level also in areas that are far from the coast line. Only near the town of Bushat and Dajc and in the East part of the aquifer the bottom of the aquifer is above the sea level. While on the North of SHKODRA city the bottom of the intergranular aquifer is again under sea level.
Taking in account all these data in order to apply the ACVM method we need to draw the limits described in **figure 2.5** and use the same numeric vulnerability scale used for mapping vertical vulnerability.

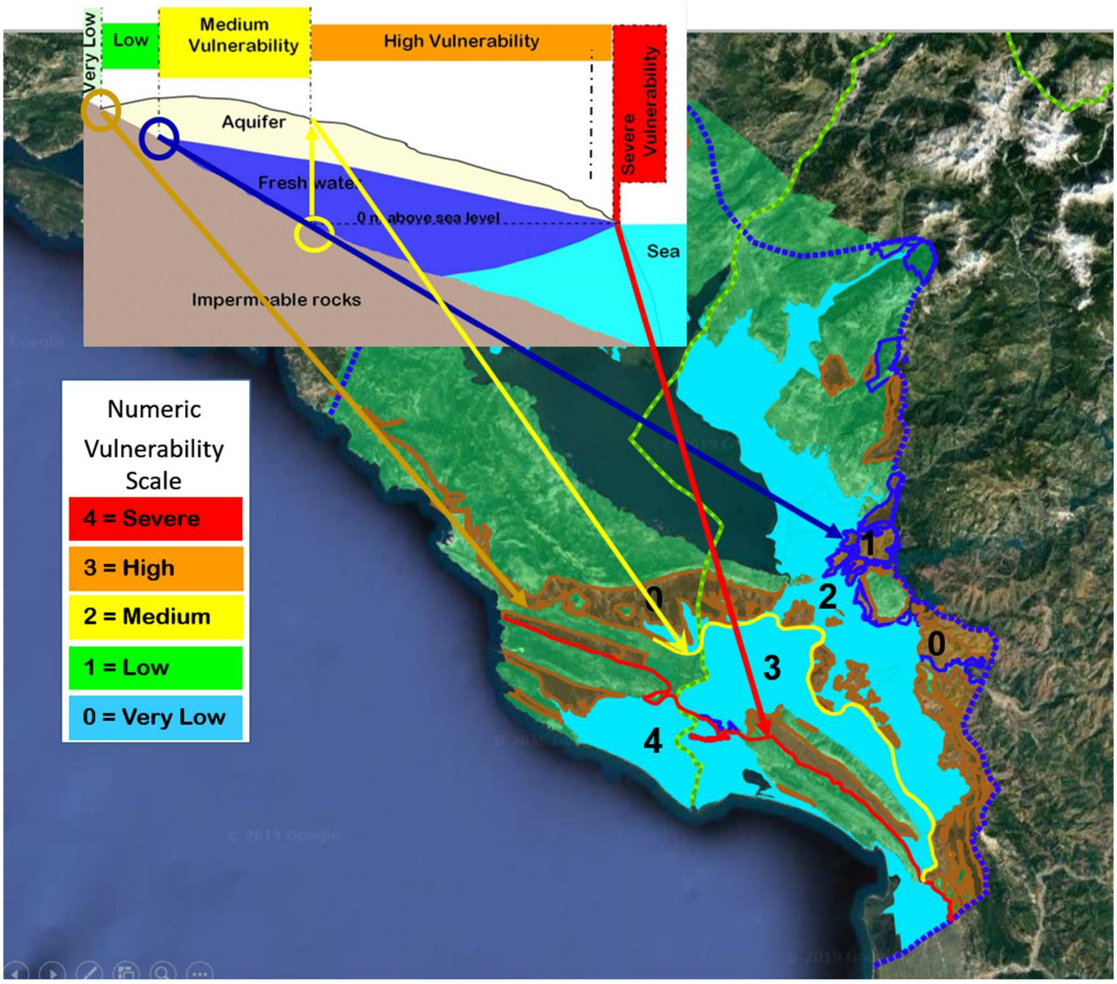

Figure 2.5.- Schematic process for mapping Horizontal Vulnerability (ACVM method).

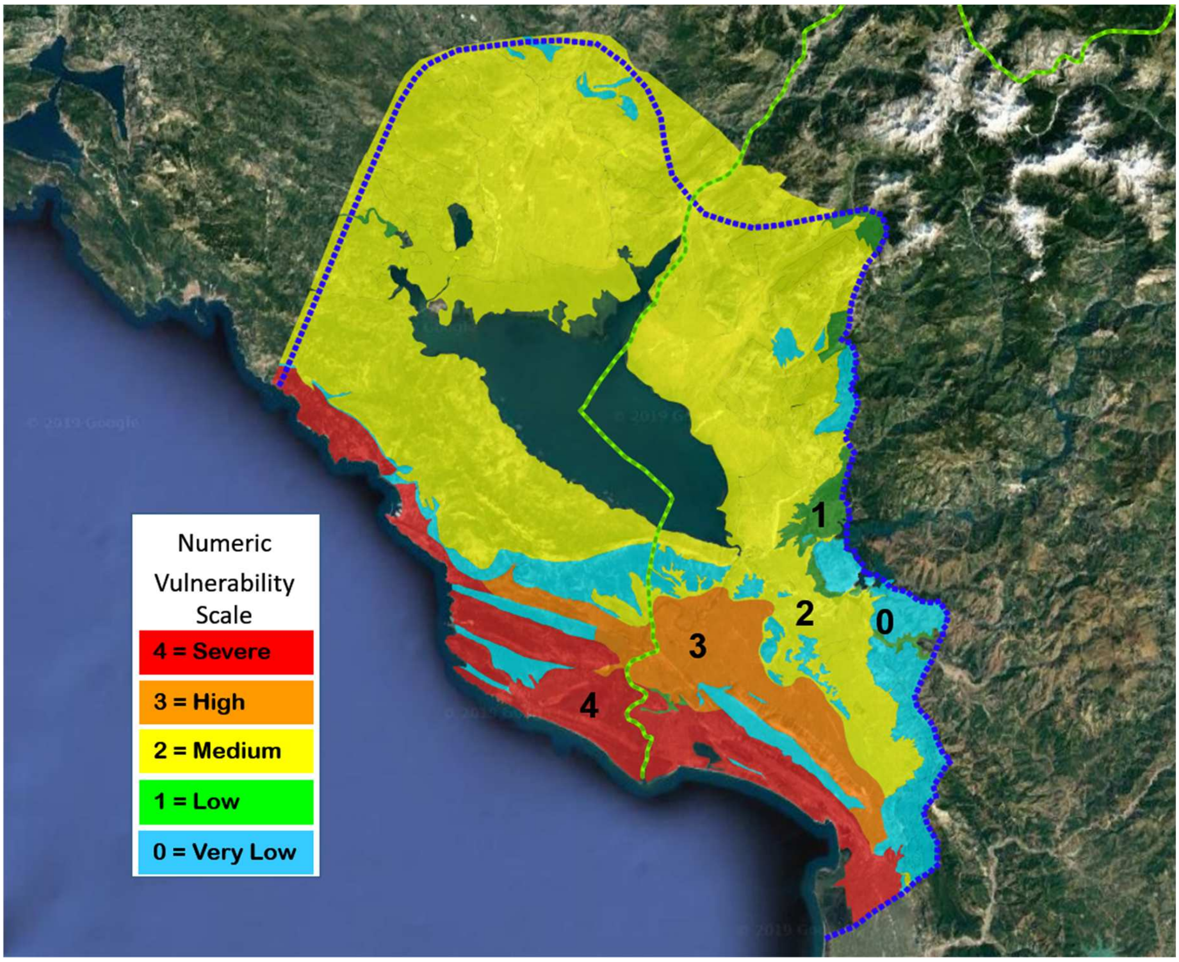

Figure 2.6.- Miniature of the Horizontal Vulnerability map (ACVM method).

The resulting horizontal vulnerability map is plotted on the lower right corner of the layout of the comprehensive vulnerability map and in **figure 2.6**.

Observing the map, we can see that, in coastal areas, horizontal vulnerability is **sever** this means that aquifer is fully exposed to sea water intrusion and that it has not any means of defence for pushing out salt water. In fact, in these areas, groundwater level is about the same of see level and water in some spring and well is salty. Moreover, in these areas, saline and coastal lagoons can also favour the presence of salt water on surface. Consequently, careful attention is needed for the proper exploitation of these areas. In fact, even a small modification of groundwater levels here can produce negative impacts across a wider area of the aquifer.

In the areas where salt water vulnerability is **high**, aquifer has some means of defence against salt water intrusion. In fact, in these areas of the aquifer, groundwater level is above sea level and the bottom of the aquifer is below sea level. So, in these areas, it is probable that salt water is naturally present under fresh water and the shape of the interface between salt and fresh water can be modified by human activities.

As a result, groundwater exploitation in this area should be controlled by regulations so that the total amount of extracted groundwater does not exceed the total amount of groundwater feeding during the same hydrological year. In this way, groundwater levels will remain constant from one year to another.
In these areas actually salt water has not reached exploited wells indicating a wise exploitation of the territory in fact this means that the extraction of groundwater in all the intergranular aquifer is balanced by the natural annual recharge. Also for this reason, this area is one of the most important to be monitored.

In the areas where salt water vulnerability is **medium** the bottom of the aquifer is above sea level or it is protected by an area where the bottom of the aquifer is above sea level. So under natural conditions, it is improbable that salt water could contaminate fresh water but groundwater exploitation needs to be conducted with the same prudence here as in the areas where the horizontal vulnerability class is high, since overexploitation can reduce the aquifer recharge and lead to salt water intrusion in adjacent areas where the horizontal vulnerability class is high.

In the areas where horizontal vulnerability is **low** it is improbable that natural conditions could lead to communication between salt water and fresh water or aquifers lack a hydraulic connection to the sea.

The comprehensive vulnerability map

The comprehensive vulnerability map is plotted on the top of the layout and it is obtained by merging the vertical and the horizontal vulnerability maps. In fact, this map is obtained overlaying the Vertical and Horizontal vulnerability maps and in intersecting all the polygons of each vulnerability map. In the resulting map each polygon has a new numeric vulnerability class that is obtained adding the numeric vulnerability class assigned to each intersected polygon of each map. The resulting numeric value gives the comprehensive vulnerability of that intersected polygon.

The comprehensive vulnerability maps are based on the information contained in the merged vulnerability maps. Consequently, it is important to consider all these maps when comprehensive vulnerability is translated into management recommendations in order to understand which component of vulnerability is prevalent in certain areas.

The Comprehensive Vulnerability Map is an integrated vulnerability map since it indicates the locations of the potential pollution sources and targets of possible groundwater pollution. The potential pollution sources and the targets of possible groundwater pollution are superimposed over the comprehensive vulnerability map.

The pollution sources include activities that can discharge a pollutant – like the operation of a factory – or places where pollutants are treated, used or stored. The targets of possible groundwater pollution are the pathways along which a pollutant can travel to reach groundwater, such as rivers, lakes, caves. Other targets include areas where there is no pollution, such as natural reserves.

The locations and types of pollution sources and the targets were mapped by studying topographical maps and free satellite images and the database provided. The following pollution sources are plotted on the vulnerability map and in the thematic maps:

- **Airport, harbour and urbanized areas,** since these can emit pollutants from activities such as fuel distribution or depot, car wrecking, garages, mechanical workshops, wastewater pipes, disposal wells, cesspools, septic tanks and hospitals;
- **Industrial areas, chemical depots,** since activities located here can disperse organic, inorganic or biological wastes or liquid effluent that may not be biodegradable**;**
- **urban and inert waste landfill, wastewater treatment plants** since pollutants can be dispersed from these locations if sufficient precautions are not taken;
- **quarries, mines and abandoned mines,** since these can be the site of pollution from spilled oil or petrol from excavation machinery operating in the unsaturated zone moreover processing waste are often dumped in these sites;
- **untreated wastewater discharge are sites where** pollutants are dispersed and precautions or actions have to be taken;
- **Irrigation areas, agricultural areas and pastures area** since these can become diffuse pollution sources if there are frequent treatments with pesticides or fertilizers. Moreover, in private livestock and pastures areas sewage can disperse on the ground;
- **railway** and **roads,** since vehicle accidents can provide pathways for the dispersion of transported chemicals or oil and petrol/gasoline.
- **Hidropower plants** can also be considered as a potential pollution source because they work with superficial water taken from the rivers or the lakes, discharging it downstream. Usually this can not produce pollution but we must consider that these machines contain oils inside or in the auxiliary plants. Moreover, these plants take water from a part of the river and discharge it into another part that usually is far from the intake point. So, this can have an impact especially if the intake point is placed in a site where the river feed the aquifer.

Figure 2.7.- Potential pollution sources plotted on the Comprehensive Vulnerability Map

The targets of possible groundwater pollution plotted on the maps are:

- **Channels** and **rivers**, since the flowing water can easily carry pollutants from one part of the hydrographic basin to another. This is more dangerous where the drainage networks cross irrigation areas, industrial areas, agriculture areas, urbanized areas or other potential pollution sources. Moreover, a network of secondary channels, that was not possible to draw at the scale of the map, are dug in the flat areas.

- **Water reservoirs and lakes,** since a pollutant that reaches a reservoir or a lake can be spread over a large area through irrigation aqueducts or channels.

- **Karstic caves, caves with water, groundwater intake structures, Estavelle and Ponor** are karstic structures that have to be safeguarded because constitute a direct pathway through which pollutants can easily reach the feeding areas of the aquifer.

- **Springs** are one of the most important target of groundwater pollution because the majority of them are exploited for drinking purpose and because they are often located in the feeding areas of the intergranular aquifer.

- **Wells**, since a pollutant can enter them easily and reach groundwater. Moreover, these same wells can also increase salt water intrusion if they are overexploited.

- **Natural parks, protected landscapes, unexploited land and humid areas** are places to be safeguarded since they are uncontaminated and thus represent areas of high natural value. On the other hand, saline, salt marshes and coastal lagoons can favour salt water intrusion due to their connection with the sea.

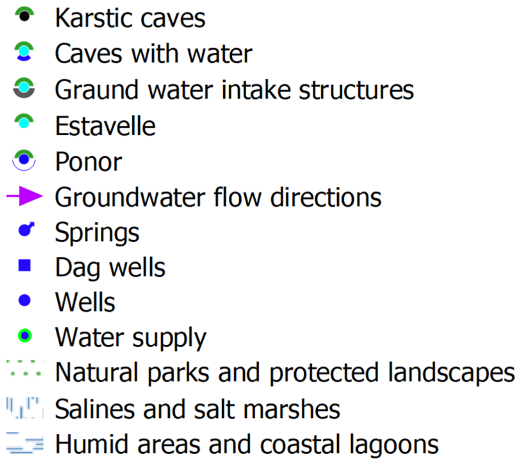

Figure 2.8.- Targets of possible groundwater pollution plotted on the Comprehensive Vulnerability Map

The map shows the locations of both potential pollution sources and targets of possible groundwater pollution. The presentation of all this information on the comprehensive vulnerability map allows stakeholders to easily identify the areas where human activities should be regulated to avoid pollution overexploitation or salt water intrusion. Moreover this map is a useful tool to support the monitoring network design in fact it shows the area that need to be monitored to avoid pollution or overexploitation.

2.2. *Management recommendations*

Comprehensive vulnerability mapping is a new tool that uses a single parameter to simultaneously describe more aspects of coastal aquifer vulnerability. Consequently, it can be a valuable resource for land use management, since it is possible to translate this parameter into management recommendations.

The comprehensive vulnerability map is based on the information contained in the vertical and horizontal vulnerability maps of the aquifer. Consequently, it is important to consider these two maps when viewing the comprehensive vulnerability map, in order to understand which component of vulnerability is prevalent.

Looking at the comprehensive vulnerability map or in the miniature of **figure 2.9**, it is easy to identify two portions of the territory near the coast that have a **comprehensive vulnerability class equal to 8, indicating 'severe' vulnerability.** In these areas, groundwater is fully exposed to pollutants from land-based activities and also to salt water intrusion. Consequently, careful attention is needed for the proper exploitation of these areas. In the first place, a pollutant coming from the land surface can easily reach groundwater resources in these areas. In the second place, even a small modification of groundwater levels here can produce negative impacts in a wider area of the aquifer.

This is due to the fact that in these areas, the specific energy of the aquifer is very low, and even minor groundwater extraction can lead to mixing between fresh and salt water, thereby increasing salt water intrusion. Moreover, Coastal lagoon and Saline are present.

A large part of the territory has a **comprehensive vulnerability class equal to 6** but this information has not the same meaning for the whole area. In fact, if we look at the two merged maps, we will see that the Southern part has high vulnerability class both for vertical and horizontal vulnerability. While on the resting part the vertical vulnerability is Severe and Horizontal vulnerability is medium.
So the management recommendations will be different for the two areas:

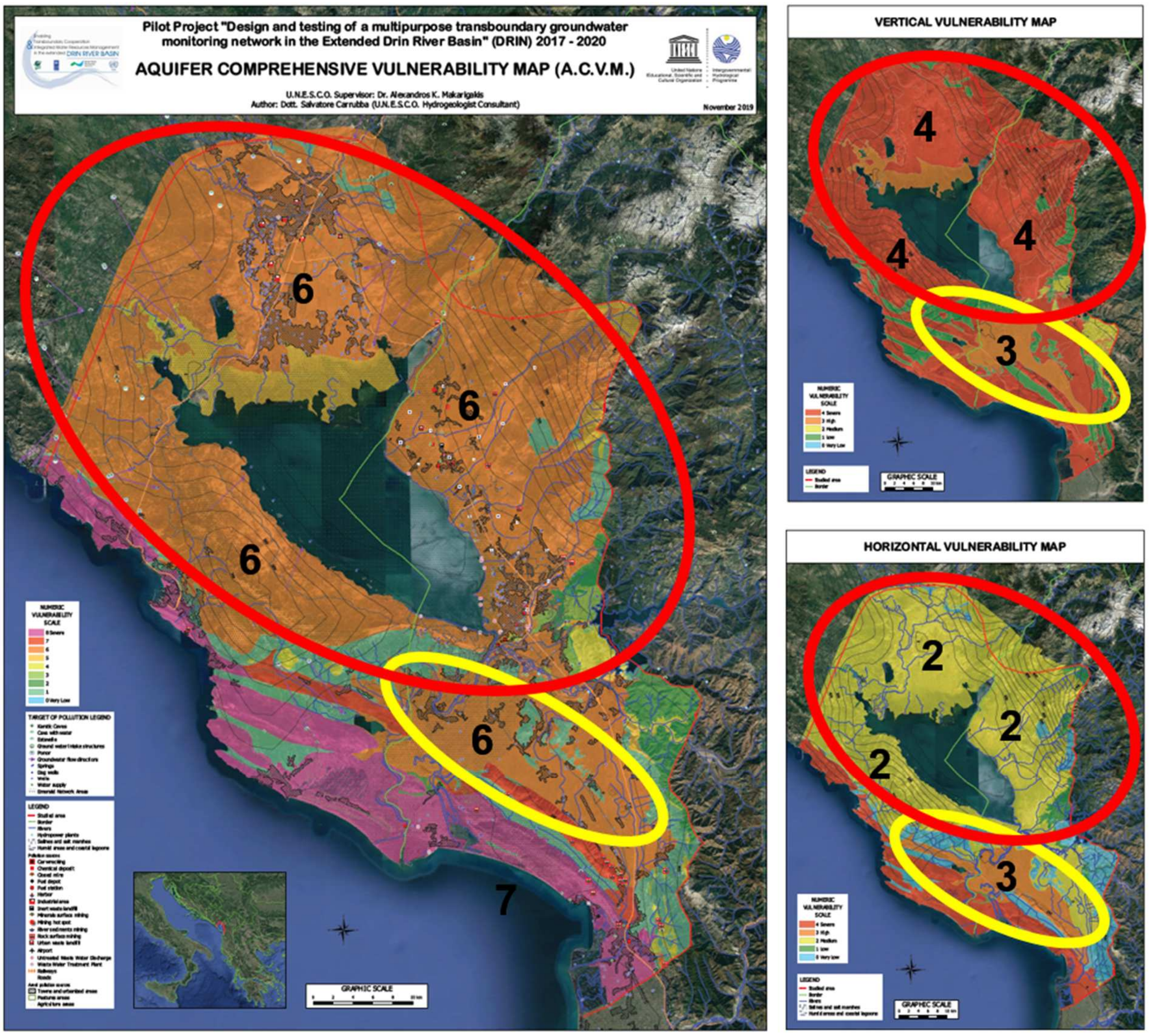

Figure 2.9.- Miniature of the comprehensive vulnerability map

In fact, referring to the numeric vulnerability scale, the area where 6 is the result of 3+3 (areas marked with the yellow circles in figure 2.9), groundwater has some means of defence against a pollutant coming from the land surface (thanks to a superficial silty layer) and also against salt water intrusion (thanks to the elevate aquifer specific energy). As a result, groundwater exploitation in this area should be controlled by regulations so that the total amount of extracted groundwater does not exceed the total amount of groundwater infiltrated during the same hydrological year. In this way, groundwater levels will remain constant from one year to another.

While in the area where 6 is the result of 4+2 (areas marked with the red circles in figure 2.9), groundwater is fully exposed to a pollutant coming from the land surface but it has some means of defence against salt water intrusion. In fact, it is improbable that under natural conditions salt water could contaminate fresh groundwater but the groundwater exploitation needs to be conducted with the same prudence here as in the areas where the horizontal vulnerability class is equal to 3, since overexploitation can reduce the aquifer's specific energy and lead to salt water intrusion in adjacent areas where the horizontal vulnerability class is equal to 3.

Other parts of the territory have '**low' comprehensive vulnerability classes (1 or 2)**. In these areas, there are no large exploitable aquifers or they are not connected with the sea, so it is improbable that salt water can occur here. In general, in these areas it is also improbable that pollutants from human activities could infiltrate to groundwater in the aquifer, but it is recommended to evaluate the specific local impact of these activities also considering that a pollutant can flow on ground surface reaching the adjacent areas where vertical vulnerability is more elevate.

Manage recommendations can also be provided as table 2.1 so stakeholder can easily translate the vulnerability classes of the maps into management recommendations. Also, by clicking on the GIS map they can get the vulnerability classes of that area.

Table 2.1 Summary of recommendations

Comprehensive vulnerability	Vertical vulnerability	Horizontal vulnerability	Comments	Recommendations
8	4	4	Groundwater is fully exposed to a pollutant coming from the land surface and to salt water intrusion.	Careful attention to groundwater levels is needed here since even a minor modification of groundwater levels can lead to negative impacts across a wider area of the aquifer. All activities that have the potential to produce vertical pollution need to be equipped with appropriate pollution prevention systems.
6	3	3	Groundwater has some means of defence against a pollutant coming from the land surface and against salt water intrusion.	Groundwater should only be exploited if controlled by regulations. All activities that have the potential to produce vertical pollution need to be equipped with appropriate pollution prevention systems.
6	4	2	It is improbable under natural conditions that salt water could contaminate fresh groundwater, but the aquifer is fully exposed to a pollutant coming from the land surface.	Groundwater exploitation needs to be conducted with the same prudence as in the area where horizontal vulnerability is 3. All activities that have the potential to produce vertical pollution need to be equipped with appropriate pollution prevention systems.
5	3	2	Groundwater has some means of defence against a pollutant coming from the land surface and It is improbable under natural conditions that salt water could contaminate fresh groundwater	Groundwater exploitation needs to be conducted with the same prudence as in the area where horizontal vulnerability is 3. All activities that have the potential to produce vertical pollution need to be equipped with appropriate pollution prevention systems.
5	4	1	Salt water cannot reach these areas under natural conditions, but a pollutant coming from the land surface could pollute the river water or groundwater feeding into the main aquifer.	Groundwater exploitation needs to be conducted with the same prudence as in the area where horizontal vulnerability is equal to 3 in order to safeguard the feeding sources of the main aquifer. All activities that have the potential to produce vertical pollution need to be equipped with appropriate pollution prevention systems.
1	1	0	It is improbable that salt water could reach the aquifer. In general, in these areas it is improbable that pollutants from human activities could directly infiltrate the aquifer but it could flow on surface reaching groundwater resources located downhill.	These local aquifers can be exploited without favouring salt water intrusion, but exploitation of these aquifers must be controlled by regulations in order to prevent local aquifer overextraction.

2.3. Flooding vulnerability map

A new potential impact on groundwater quality that should have been considered when developing the ACVM vulnerability map of the DRIN area are the flooding events. In fact, flooding constitute a real threat on groundwater quality because, in case of flooding events, superficial water can move pollutants from one part to another part of the area in a really short time.

The only available data on this vulnerability aspect is the map elaborated by prof. Dr. Agim Selenica and Dr. Nikolla Nika so only a draft of this vulnerability map was elaborated in order to show how this aspect of aquifer vulnerability can be incorporated in ACVM map. The resulting map is reported in **figure 2.10**. In this map flooding vulnerability class equal to 4 means that these areas are subjected to flooding events while in the other areas flooding vulnerability is very low. This map was merged with vertical and horizontal vulnerability and the resulting comprehensive vulnerability map (plotted in **figure 2.11**) also take in account this aspect of vulnerability. If in the future more detailed data on flooding will be available also the resolution of the flooding vulnerability map could be improved.

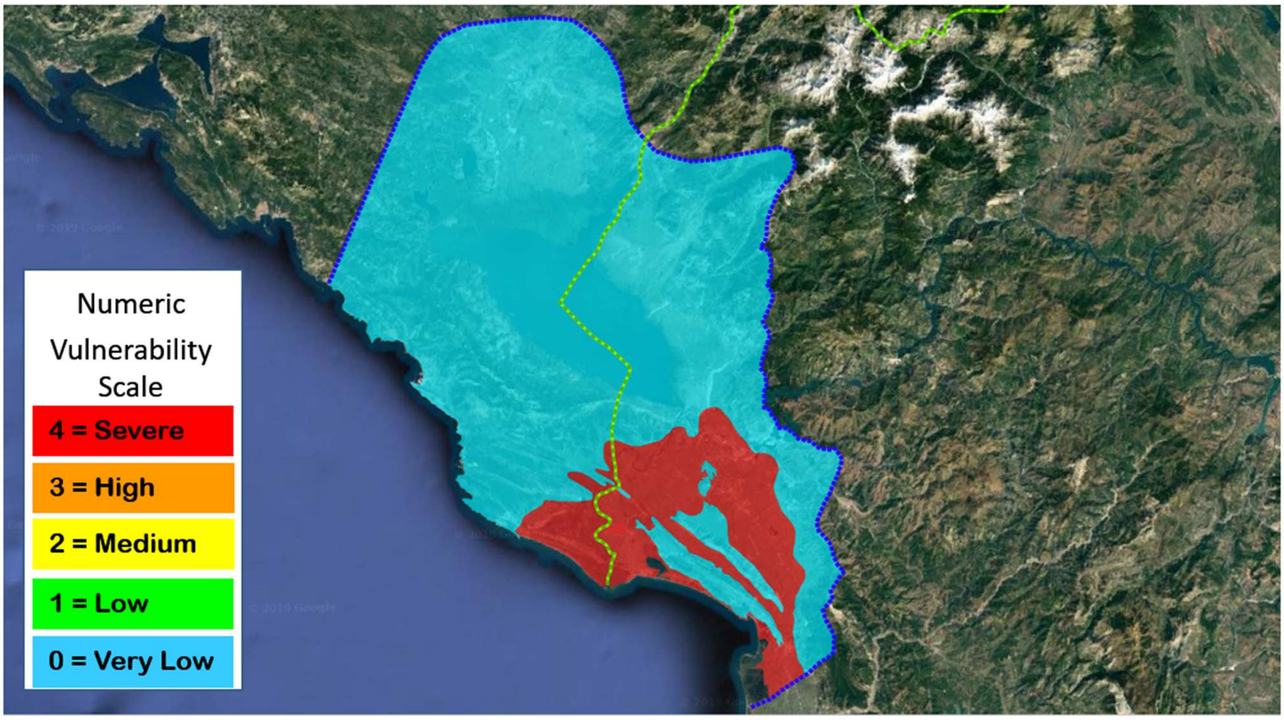

Figure 2.10.- Draft of Flooding Vulnerability Map

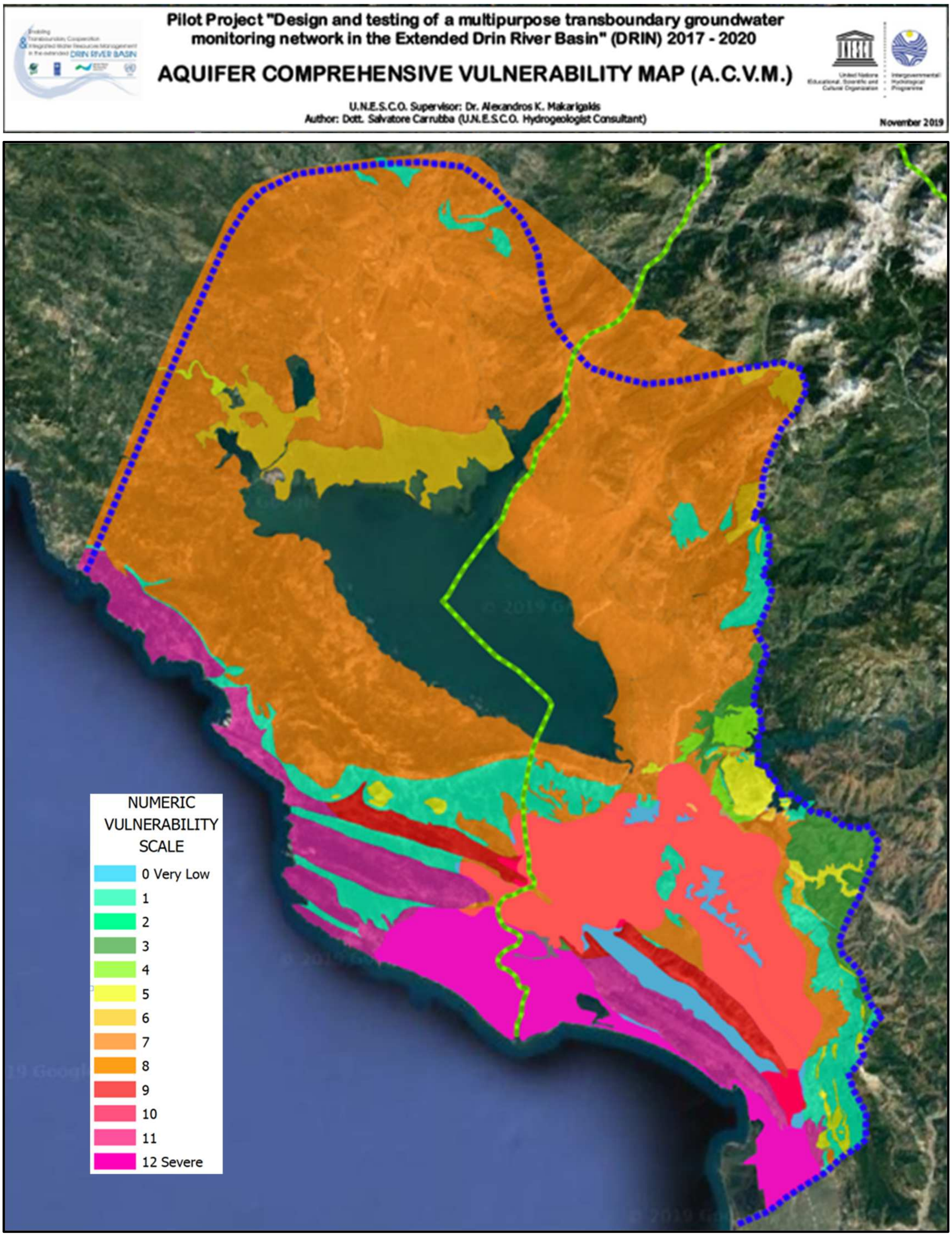

Figure 2.11.- Draft of the comprehensive vulnerability incorporating the

Vertical, Horizontal and the Flooding Vulnerability Map

Chapter 3.

Design and development of a groundwater monitoring network and programme for the transboundary aquifer between Albania and Montenegro

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1. Introduction

Problem statement

Within the framework of the UNESCO Programme and Budget 2018 — 2019 (39 C/5), Main Line of Action 3: Improving knowledge and strengthening capacities at all levels to achieve water security, ER 7: Member States have strengthened their response to water security challenges towards the achievement of water related Sustainable Development Goals (SDGs) and targets, and other targets from relevant international water agendas, and in line with the activities of the Section on Groundwater Systems and Settlements (GSS) addressing Theme 2 of the eighth phase of the International Hydrological Programme (IHP-VIII: Water Security) "*Groundwater in a changing environment*", Focal Area 2.4 — Promoting groundwater quality protection and Focal Area 2.5 — Promoting management of transboundary aquifer, this report contributes to project "***Design and testing of a multipurpose transboundary groundwater monitoring network in the Extended Drin River Basin***" (DRIN), undertaking technical activities related to groundwater monitoring of the transboundary aquifers located within the Skadar/Shkoder - Buna/Bojana area between Albania and Montenegro. Such monitoring network must enhance sustainable development in this transboundary region, reconciling socio-economic growth with protection of environmental values, harmonizing national policies, and introducing the EU Framework and Groundwater Directives principles (WFD, 2000/60/CE, and GWD, 2006/118/CE, respectively; among other related legislation).

These goals must be achieved based on a critical general overview of the present knowledge on the status of the aquifer's groundwater resources, and on the design of the mentioned networks (two) around the Skadar/Shkoder Lake area, and the Buna/Bojana delta area. This includes a selection of equipment necessary to cover the entire area of the aquifer, for monitoring of the state of groundwater in line with the requirements of the EU Directives.

In this particular project, transboundary issues becomes actually relevant. A transboundary aquifer is a continuation of adjacent domestic aquifers demarcated by national borders, nevertheless constituting a single aquifer or system of aquifers. Their management implies moving from individualized to a join governance of the aquifer resources. Major challenges refer to avoid a degree of asymmetry in the level of commitment to the governance of groundwater in each domestic part (Puri and Villholth, 2018[28]). Asymmetry can arise from socio-economic and institutional factors, as well as climatic, hydrogeological and environmental features. Therefore, unknowns and information gaps should be solved bases on fieldwork, monitoring programs and join objectives, to attain an appropriate level of symmetry that ensures a sustainable governance of the transboundary water resources. Aquifer resources management under the rules of the EU Directives allows a common frame that insures a conjoint and coordinated monitoring and management effort, and a mutual trust as well, that avoid disputes and assures the achievement of the proposed objectives.

Regarding groundwater resources, the EU WFD and its "daughter" the GWD can be taken as a way to express the scientific problems and solutions in a language which could be understood and applied by the policy-makers, so adequate management actions are taken based on conventional data, monitoring programs and an international agreement to achieve a sustainable groundwater resources management.

Under the WFD, the framework for groundwater protection imposes on the Member States several requirements, specifically:

1. <u>delineate groundwater bodies</u> within River Basin Districts and characterise them through an analysis of pressures and impacts of human activity on the status of

[28] Puri S, Villholth KG (2018). Governance and management of transboundary aquifers. In: Villholth KG, López-Gunn E, Conti KI, Garrido A, van der Gun J (eds.). *Advances in Groundwater Governance*, CRC Press/Balkema, pp. 367-388.

groundwater in order to identify groundwater bodies presenting a risk of not achieving WFD environmental objectives,

2. establish a groundwater monitoring network providing a comprehensive overview of the groundwater chemical and quantitative statuses,

Both issues are key to set up a River Basin Management Plan (RBMP), and establish a programme of measures for achieving WFD environmental objectives (e.g. abstraction control, measures to prevent or control pollution). In particular, a river basin where the use of water *may have transboundary effects*, the requirements for the achievement of the environmental should be coordinated for the whole of the river basin district, producing a single international RBMP. Moreover, the GWD state that Member States sharing bodies of groundwater should coordinate their activities in respect of monitoring (set in Annex V, point 2, of the WFD), the setting of threshold values, and the identification of relevant hazardous substances.

Goals and content of this document

The goals of this document is to define a **rational monitoring network** for selected areas in Albania and Montenegro. Such networks will permit both countries attaining the WFD goals by obtaining the necessary data to support management plans. These plans must be actually focused to solve the main pressures and impacts that presently affect these hydrogeological areas and obstruct the achievement of the WFD environmental objectives.

This document complements of a more extensive and comprehensive companion document that, based on the requirements of the EU Directives (WFD and GWD), determines the hydrogeological conceptual model (del Val Alonso, 2019)[29]. This conceptual model permits defining distinct groundwater bodies, as management units, considering the integrity of the hydrogeological systems of the Skadar/Shkoder Lake and the Buna/Bojana delta aquifer systems (**Figure 1.1**).

Groundwater bodies are thus defined based on a careful and critical revision of the essential information provided by each country (Albania and Montenegro) that has been synthesized in previous reports submitted to UNESCO within the context of this project[30],

[29] Del Val Alonso, L (2019). *Hydrogeological Conceptual model of the Skadar/Shkoder – Buna/Bojana Transboundary Aquifer System situated between Albania and Montenegro*. Project "Design and testing of a multipurpose transboundary groundwater monitoring network in the Extended Drin River Basin" (DRIN). Unpublished, 121 pp.

[30] These reports are:

- Carrubba, S. (2018). *Vulnerability Analysis of the transboundary aquifers situated within the Skadar/Shkodër-Buna/Bojana area*. Unpublished, UNESCO Contract Nº: 4500376867.

and on field and internet-based observation (mainly, Google Earth) of the areas. This revision has considered the regional geological and hydrogeological features of the area, their hydrochemistry and groundwater quality status as well as the existing (or forecasted) pressures and impacts according to an original vulnerability analysis. It ends up by defining the main groundwater bodies and, based on this information, determine suitable monitoring network that fits the environmental needs of these hydrogeological systems.

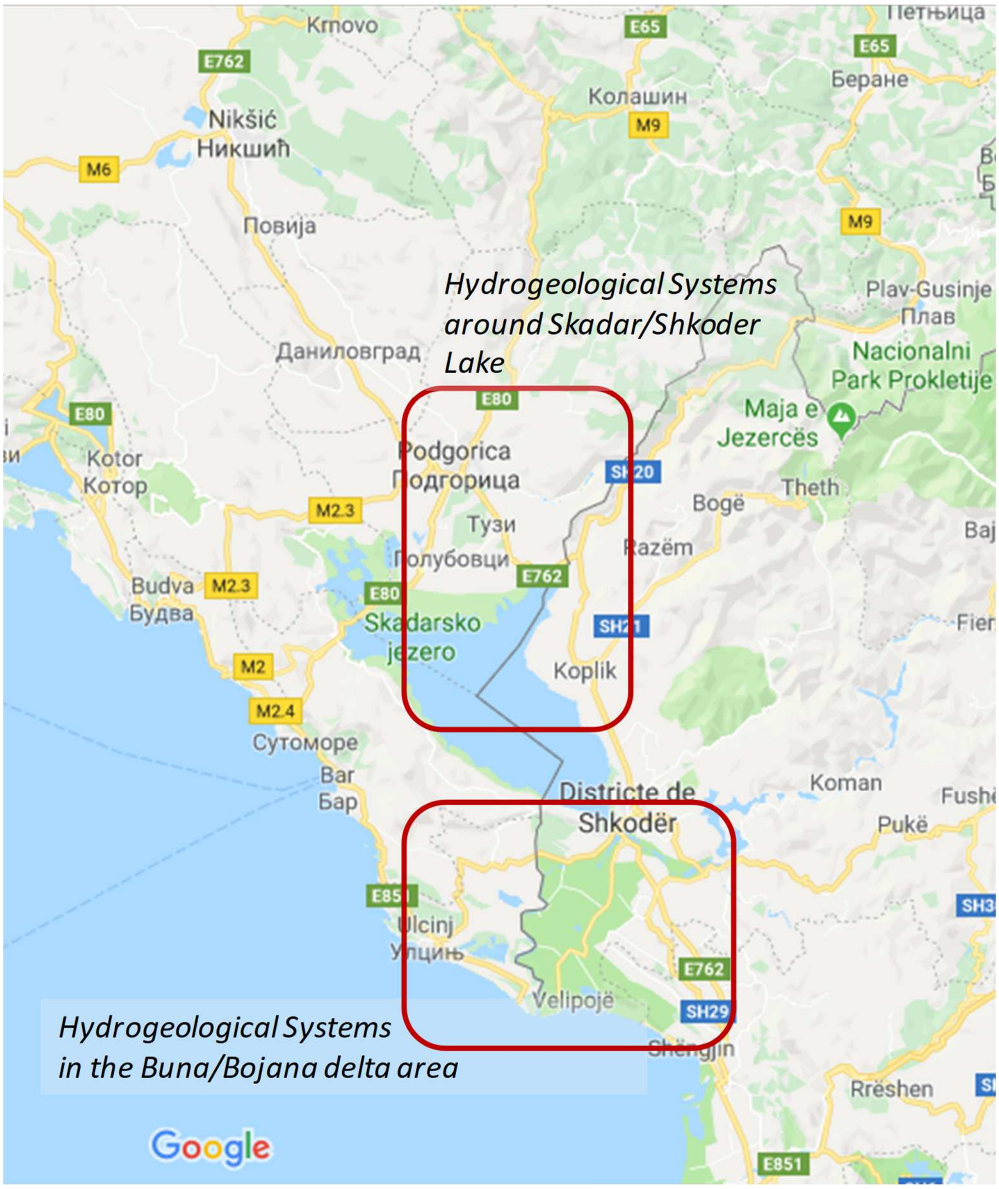

Figure 1.1. General map of the studied area, locating the hydrogeological systems around the Skadar/Shkodër Lake and those in the Buna/Bojana delta area. Source: Google Maps.

- del Val Alonso, L (2018). *Groundwater Dependent Ecosystems and Coastal Processes within the Skadar/Skhoder – Buna/Bojana area shared by Albania and Montenegro*. Unpublished, UNESCO Contract Nº: 4500376891-A1.
- del Val Alonso, L (2018). H*ydrogeological Conceptual Model of the Skadar/Shkoder - Buna/Bojana transboundary aquifer*. Unpublished, UNESCO Contract Nº: 4500376891-A1.
- del Val Alonso, L (2018). *Multi-purpose groundwater monitoring in coastal areas*. Unpublished, UNESCO Contract Nº: 4500376891-A1.

Proposed Groundwater Bodies

With the scope to adapt the monitoring and management of the studied aquifers to the requirements of the WFD, a first exploratory, working demarcation of the "groundwater bodies" is mandatory. While the aquifer definition for the WFD is the usual one for hydrogeology textbooks (*Aquifer means a subsurface layer or layers of rock or other geological strata of sufficient porosity and permeability to allow either a significant flow of groundwater or the abstraction of significant quantities of groundwater;* Article 2, 11), the concept of "groundwater bodies" is singular to the WFD. Indeed, a *body of groundwater means a distinct volume of groundwater within an aquifer or aquifers* (Article 2, 12).

Therefore, groundwater bodies (GWB) are, at the end, principal reporting units; i.e. management units (size, pressures, status issues). Therefore, the aquifer is the "structure" where groundwater is stored, and can be defined on the basis of how much water can flow into them and the ability to extract significant quantities from them. Conversely, groundwater bodies constitute the "basic units" where it is possible to assess the water status. The "groundwater body" should be a coherent sub-unit in the river basin (district) to which the environmental objectives of the directive must apply. Hence, the main purpose of identifying these bodies is to enable the (quantitative and chemical) status to be accurately described, monitored, and compared to environmental objectives (EU, 2003)[31].

The characterization of GWBs is a detailed task that must be carried out by the Member States. Nevertheless, committed to our goal of "developing a proper monitoring program that allows both countries, Albania and Montenegro, to manage their groundwater resources in the context of a transboundary aquifer system, **we propose the following potential groundwater bodies based on the companion comprehensive hydrogeological conceptual model** (del Val Alonso, 2019). Such GWBs must be understood as "working tools" that serve to the goals of this preliminary analysis of the hydrogeological systems in the study area. Later on, they will need further work and revision by local experts and stakeholders to end up being definite GWBs to be used in the river district management plans.

GWBs in the Zeta and Koplik-Skhodër plains (Skadar/Shkoder Lake area)

According to the hydrogeological information summarized in the previous section, the following GWBs for the Skadar/Shkoder Lake area are suggested (**Figure 1.2**):

[31] EU Commision (2003). R*iver Basin District Management Systems. Approach to Delineation of Groundwater Bodies.* Paper by the Working Group on Groundwater Guidance document no. GW2, 18 pp.

1. ***GWB-01 Zeta plain.-*** The GWB formed by alluvial aquifer of the Zeta, Morača and Cijevna rivers that includes all three terraces and the lacustrine sediments in its distal parts, near Skadar/Shkoder Lake. It is a sedimentary unit, with dominant coarse particles and intergranular porosity. Despite that some layers can show some degree of cementation it is considered an excellent aquifer. Flow recharge is due to karst lateral inputs, rainfall and, locally, stream infiltration. Main discharge is towards Skadar/Shkoder Lake, occasionally stream discharge, and groundwater withdrawal for urban (mainly, Podgorica city), industrial and agricultural demand. Main pressures are groundwater abstraction and pollution from urban, industrial and agricultural sources. It shows large vulnerability.Specific vulnerable points are karstic springs in its limits and on the lacustrine area.

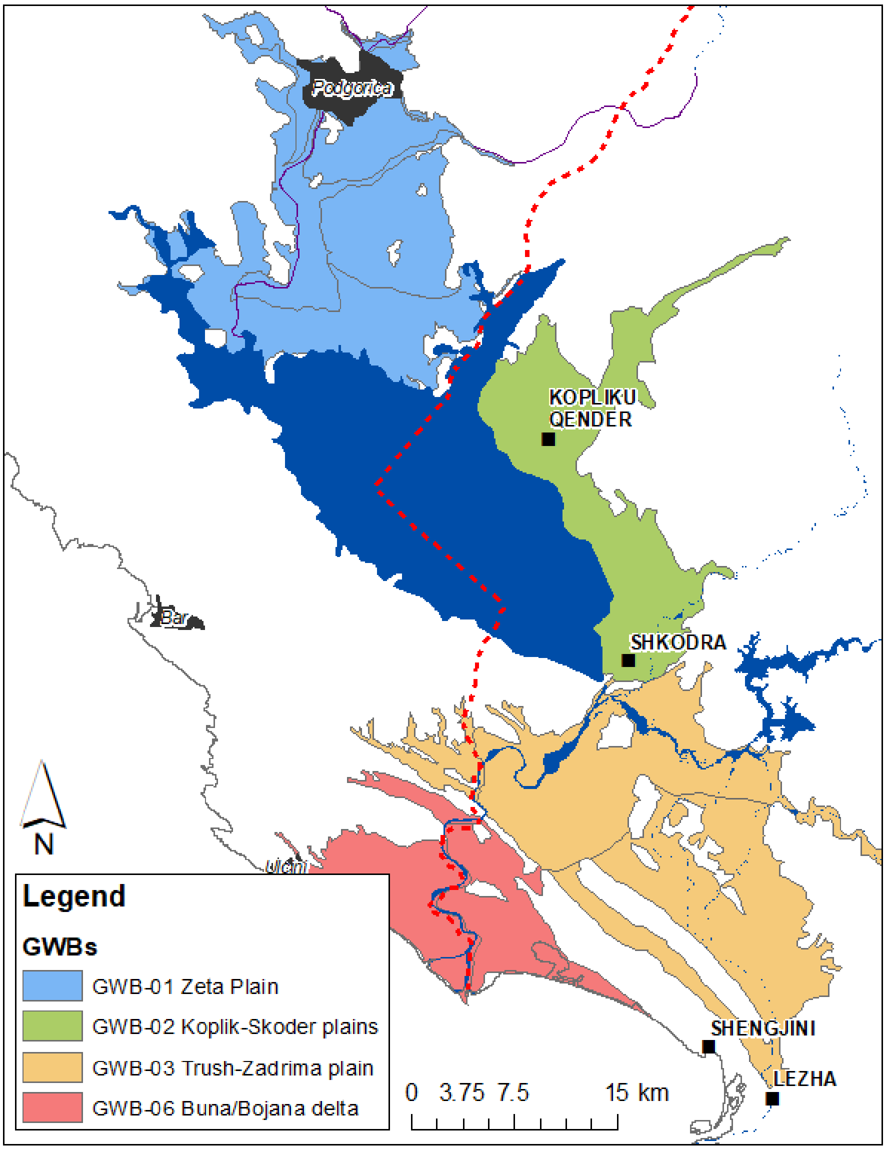

Figure 1.2. Groundwater bodies that are the object of this study; i.e., those in alluvial and fluvio-deltaic plains of the area.

2. ***GWB-02 Koplik-Skhodër plains*.-** The GWB formed by **the alluvial fan aquifer of the Koplik-Skhodër plains from the mountain front from Skadar/Shkoder L**ake, and its lacustrine sediment strip. Hydrogeological dynamics is comparable to the GWB of the Zeta Plain, and main human pressures are pollution from urban and agricultural sources. It also shows large vulnerability (see Section 3). Similarly, specific vulnerable points are karstic springs in its limits and on the lacustrine area. Porous aquifer of Mbishkodra is used for water supply of Shkodra city with a capacity of 800 – 900 L/s. This pumping station consists of 10 boreholes in Dobraç area.

Despite their similar hydrogeological features and sharing Skadar/Shkoder Lake as the common discharge unit, both GWBs are considered independent of each other. We also claim that both GWBs cannot be fully understood and managed without considering Skadar/Shkoder Lake as a surface water body by itself. Its categorisation as such is beyond the scope of this study.

GWBs in the Buna/Bojana area

In the Buna/Bojana area, we assume that 1) the Drin and Buna/Bojana rivers, altogether with Skadar/Shkoder Lake, control most of the recharge as contiguous surface water bodies, in addition to local rainfall infiltration, and 2) the wide occurrence of the flysch sediments on the bottom of the Trush plain and between the folded structures, considered of low permeability, behave as aquicludes and, therefore, act as no-flow limits wherever they appear.
According to the hydrogeological information summarized in the previous section, the following GWBs for the Buna/Bojana area are suggested (**Figure 1.2**):

1. ***GWB-03 Trush and Zadrima plains.-*** The GWB formed by alluvial aquifer created by the Drin and Buna/Bojana river sediments. It mainly develops in the left-bank of both rivers, but it should also include the right-bank of the Drin River around Vukatanë, and the right-bank of the Buna-Bojana River near along the strip Muriqan-Oblikë still in Albanian territory. As mentioned, this alluvial, productive aquifer gets its recharge from stream and rainfall infiltration. As its bottom is assumed to lay on flysch sediments, the relationship with the underlying karstic aquifer must be limited to fracture zones or local karstic phenomena as buried sinkholes or similar. It also gets lateral recharge from the karstic limestone ranges that lay in its southern boundary. The main pressures are groundwater abstraction for domestic and agricultural use) and pollution of agricultural sources. It shows

large vulnerability (see Section 3) and it is subject to periodical floods (Schneider-Jacoby et al., 2006[32]).

The aquifer in the Zadrima basin, in the SE part of the Drin and Glader rivers alluvial plain, is not very productive.

2. ***GWB-04 Albanian Karstic coastal ranges.-*** The GWB formed by the Cretaceous limestone ranges: Mali i Kakarriqit and Mali i Rrencit, parallel to the coastline and oriented NW-SE from their north-westernmost outcrops, near the Buna/Bojana River, to the cities of Balldreni and Lezhë. We consider these limestone ranges as a separate GWB, and they control the lateral recharge to GWB-03 and GWB-06. Their structure is given by diverse thrust faults and folds and these ranges can be considered hydrogeologically isolated because of structural limits and the occurrence of flysch deposits as their stratigraphic cover. Recharge is mainly due to local rainfall in its summits, and discharge occurs laterally towards the Quaternary sedimentary formations or direct to the Adriatic Sea (e.g., Shëngjin area). They lack intense human land use; therefore, the main (relative) pressure is groundwater abstraction from their karstic springs.
3. ***GWB-05 Montenegrin Karstic coastal ranges.-*** The GWB formed by the Cretaceous limestone ranges of Katërkolle and Gornja Klezna from their west limit in the Adriatic coast to the Buna/Bojana River at the east. It also includes the colluvium formations that develop from both ranges towards the Buna/Bojana River on the foothills near the villages of Vladimir-Sukobin-Sas and Donja Klezna, including Sasko Lake. The GWB excludes the areas where the Eocene flysch outcrops. As their twin limestone ranges in GWB-04, they control the lateral recharge to GWB-06. Their structure is given by diverse thrust faults and folds and they can be considered hydrogeologically separated because of structural limits and the occurrence of flysh deposits. Recharge is mainly due to local rainfall and discharge occurs laterally towards the Quaternary sedimentary formations or direct to the Adriatic Sea. Main human land use happens in the foothill area and the main pressures will be pollution from urban and agricultural sources.
4. ***GWB-06 Buna/Bojana delta area.-*** This GWB integrates the most recent deltaic system of the river, being defined by the triangle between the water gap in Pentar, Port Milena in Montenegro and Velipojë and the Këneta e Vilunit lagoon in Albania. It is a single hydrogeological units constituted by the complex development of the delta and the associated dune and beach ridges, as well as the lagoons of Këneta e

[32] M. Schneider-Jacoby, U. Schwarz, P. Sackl, D. Dhora, D. Saveljic and B. Stumberger (2006): *Rapid assessment of the Ecological Value of the BojanaBuna Delta (Albania / Montenegro)*. Euronatur, Radolfzell.

Vilunit, and Zoganjs Lake, both related to the delta historical development and human transformation. Some inland wetlands also exist, north of Gomsiqe, yet they are nowadays disconnected from coastal processes (if they have ever been), and related to the draining of the Trush plain southernmost most area and to local springs. In turn, these wetlands artificially drain to the Këneta e Vilunit lagoon and, through a second channel, to the sea. Recharge of the delta aquifer levels are related to stream and rainfall recharge, as well as form lateral contribution from GWBs 05 and 06. Groundwater flow discharge is mainly to the sea. Given a high human activity, mainly touristic, pressures are high, involving groundwater withdrawal and the associated seawater intrusion when high pumping regimes are set in wells close to the coastline. Pollution form urban activity is also expected, and from agriculture as well. Salt pans, as those in inner bank of the left-bank meander and those of Zoganjs Lake, may also contribute to groundwater salinization.

2. Monitoring network design

2.1. Groundwater monitoring under the EU WFD

The European Water Framework Directive (EU-WFD), which is our guiding norm in this document, stablish the implementation of a groundwater monitoring network as a key requirement. A groundwater monitoring programme is the combination of monitoring stations, monitoring devises, technical expertise, protocols, data management, visualization tools, stakeholders, ruling bodies and action mechanisms, which allows relevant groundwater data to be collected, stored, interpreted and integrated into useful information for groundwater managers to take informed decisions. From this definition, one can deduce the close connection of the monitoring programme with the overall management strategy (Figure 2.1). Therefore, the monitoring programme will be set up based on an initial water management strategy, which will define certain information needs based on an initial assessment of the groundwater resource. Once the data is collected and processed, the resulting information should be used to update the initial assessment and validate or modify the management strategy, and thus the monitoring programme itself.

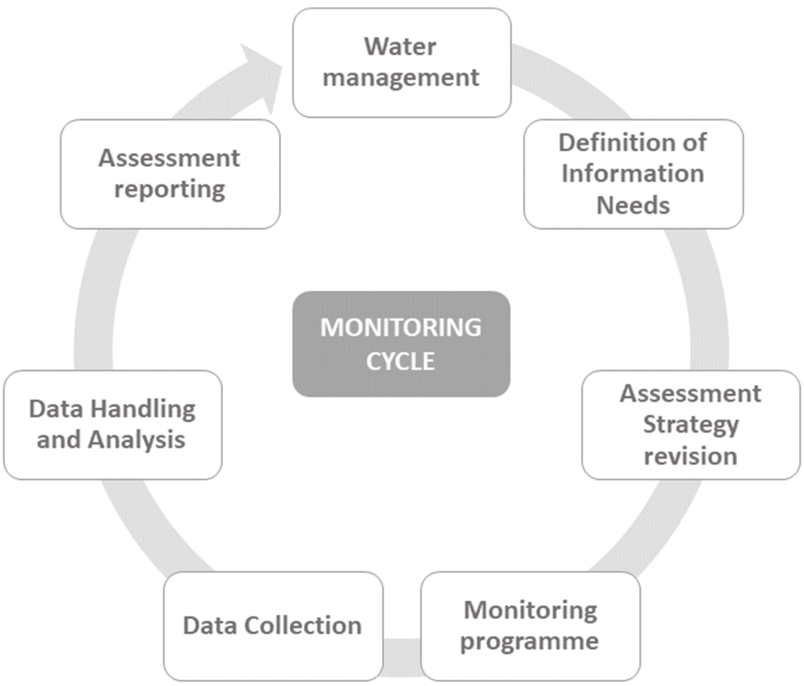

Figure 2.1.- Monitoring Cycle (based on UN/ECE Task Force on Monitoring & Assessment 2000)

Additionally, the Guidance Document No. 15 “Guidance on Groundwater Monitoring” (European Commission, 2007) states that the design of a monitoring network should be based on the characterization, assessment of risk and building of a conceptual model of the groundwater system, in which the general scheme 'recharge-pathway-discharge' is known. Both countries should agree on this general conceptual model. Additionally, it should consider the three-dimensional nature of the groundwater system and both, spatial and temporal variability, especially when determining the location of monitoring sites.

Keeping in mind the previous requirements the monitoring network design should respond to the following general objectives[33]:

- Ensure good chemical and quantitative status of groundwater bodies,
- provide information for improving characterization of groundwater bodies,
- validate the risk assessment,
- estimate the direction and rate of flow in groundwater bodies that cross Member States' boundaries,
- design and evaluate of programmes of measures,
- characterize the natural quality of groundwater including natural trends (baseline), and identify anthropogenically induced trends in pollutant concentrations and their reversal.

For transboundary groundwater bodies continuous monitoring is of even greater importance. Annex II point 2.3 of the EU WFD, states the necessity to monitor transboundary groundwater bodies, regardless of whether they have been identify as being at risk or not. Information such as the location, annual average abstraction and water chemical composition of major abstraction wells and discharge points within the groundwater body must be recorded. Information shall also be provided about recharge areas, like land use, possible sources of pollutant or any human induced alteration to the normal recharge characteristics. This implies the periodic recording the groundwater abstraction rates, as well as potentiometric heads and chemical composition. Moreover, bilateral agreements should be reached to exchange such data.

The concept of quantitative and qualitative status is used extensively to set the specific objectives of the monitoring network. Annex V point 2, of the same norm, determines the required parameters for the classification of groundwater bodies quantitative and qualitative statuses. It also states specific requirements for groundwater bodies within which groundwater flows across Member States boundary, understanding these are of special sensitivity.

A *good quantitative status* implies "The level of groundwater in the groundwater body is such that the available groundwater resource is not exceeded by the long-term annual

[33] Guidance Document No. 15 "Guidance on Groundwater Monitoring" (European Commission, 2007)

average rate of abstraction". Groundwater levels are the basic information required to identify the quantitative status. However, quantitative status also implies the prevention of seawater intrusion or any other intrusion due to anthropogenic alterations of the groundwater flow. In this sense, hydraulic head levels and electrical conductivity becomes essential parameters to be monitored.

A *good qualitative status* occurs when the chemical composition of the groundwater body is such that the concentrations of pollutants (1) do not exhibit the effects of saline intrusion, (2) do not exceed the quality standards, and (3) are not such as would result in failure neither to achieve the environmental objectives, nor any significant diminution of the ecological or chemical quality, nor in any significant damage to terrestrial ecosystems which depend directly on the groundwater body. The WFD stablishes conductivity and pollutants concentrations as the basic variables to monitor. Having in mind that this annex does not oblige to get a full hydrochemical analysis, we consider (as said before) that full analysis (involving hydrochemical as well as isotopic data) must be conducted for a comprehensive understanding of the groundwater body response to the natural and human factors that affect its dynamics.

2.2. Current state of groundwater monitoring

Based on the EU WFD requirements, an initial characterization of the status of each groundwater body has been done in the companion report (del Val Alonso, 2019). Such initial assessment of each groundwater body was done based on official information and the available knowledge published from peer-reviewed publications and scientific reports. One of the basic requirements is the identification and analysis of possible upward trends in the concentration of pollutants. This aspect should also be addressed through the implementation of an operational monitoring network.

Both countries, Albania and Montenegro, are executing efforts to improve their groundwater monitoring systems, in order to overcome the mentioned lack of information. These tasks were mentioned to the project team during the missions carried out along the project execution. In Montenegro a project entitled "*Stanje, zastita i valorizacija podzemnih voda Zetske ravnice*" was mentioned to us as being focused on developing a groundwater monitoring network around the Zeta Plain. Data corresponding to Albania has been synthesized in the hydrogeological conceptual model described in the companion report, and is herein used to propose the monitoring network and program.

In conclusion, based on the available information and the environmental objectives stated by the EU WFD, groundwater continuous monitoring of quantitative and qualitative status is necessary and required to comply with the norms. WFD and GWD list the required parameters for evaluating the chemical status, yet a full hydrochemical analysis is recommended (and somehow mandatory) for hydrogeological completeness of the initial assessment.

Monitoring zones and monitoring network types in line with the EU WFD

Having in mind the requirements and general objectives of the EU WFD, as well as the conceptual model and vulnerability and risk assessments, it is necessary to prioritize specific monitoring objectives for each groundwater body. First, priority zones are proposed for groundwater monitoring based on the hydrogeological features of each GWB, as well as the human pressures on its quantity and quality. Secondly, the specific monitoring objectives identified per groundwater body are included in the four types of monitoring networks propose by the Guidance Document No. 15 "Guidance on Groundwater Monitoring" (European Commission, 2007).

Monitoring zones

Priority groundwater monitoring zones are hereafter proposed for each groundwater body. This zonation aims to translate the results from the conceptual model, risk assessment and vulnerability assessment into concrete actions, by zooming from a larger scale (groundwater body) to a smaller scale (monitoring zones; **Figure 2.2**), as a previous step to the selection of specific boreholes or location for new boreholes.

GWB-01 Zeta plain

- **Morača River alluvial plain**.- The Morača river concentrates the drainage of the Zeta plain towards the Skadar/Shkoder /Shkodra lake. Moreover, Podgorica and several heavy industries like the Aluminium plant are located up-flow from the river, which implies that any leakage that might occur will affect the river water quality. In this sense, understanding the relation between the aquifer and the river is essential to determine the impact of these risks along the river alluvial plain and finally to the lake. Therefore, part of the Zeta Plain groundwater monitoring should concentrate in continuous recording of head level evolution along the river to infer surface water - groundwater relationship. Due to the upstream occurrence of heavy industry, additional monitoring combining hydrochemical sampling of surface and groundwater, especially at hot spots as the Aluminium Plant, is advisable.

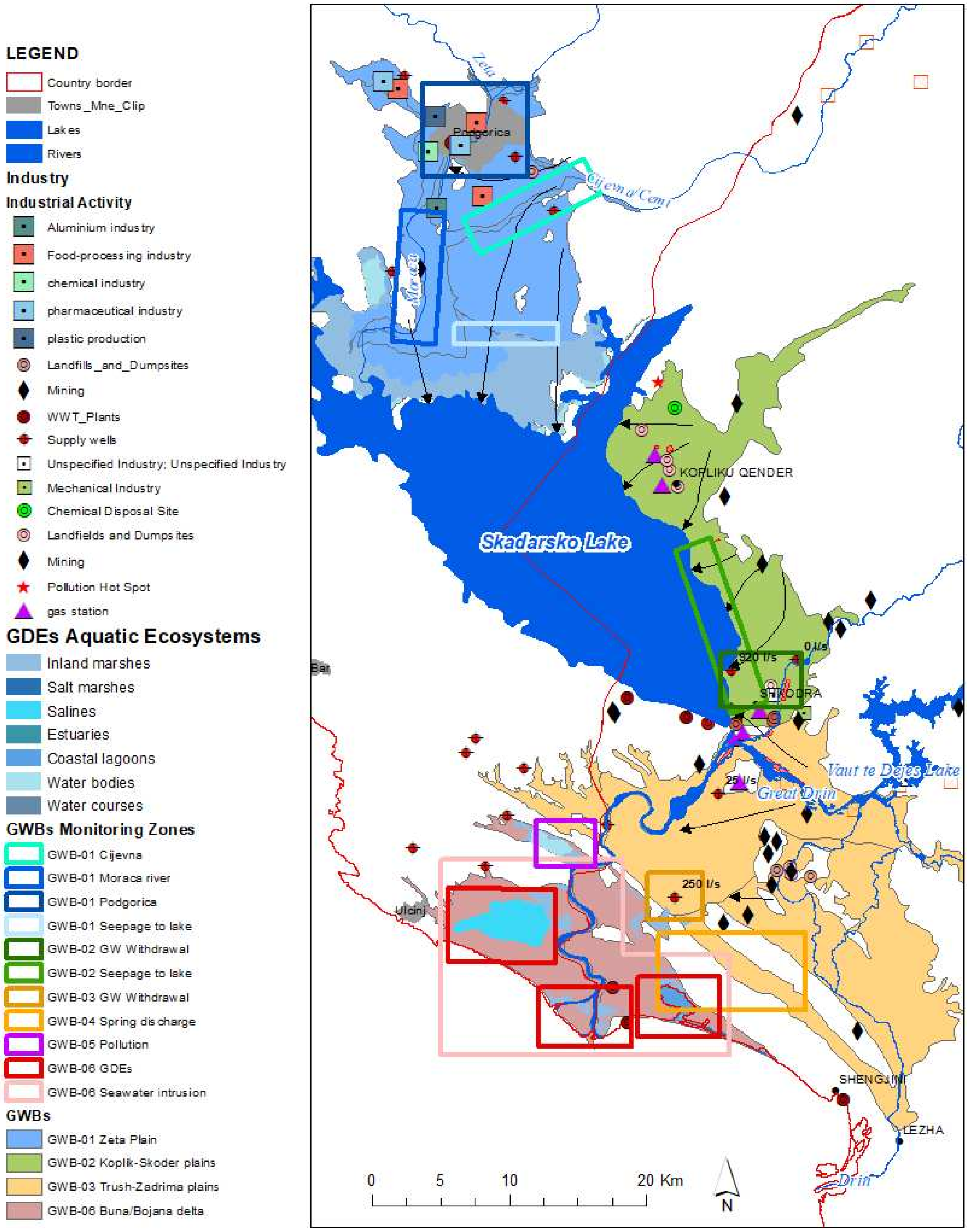

Figure 2.2.- Location of priority groundwater monitoring areas for each groundwater body.

- **Podgorica urbanized area**.- Podgorica concentrates a large population and several groundwater pumping stations, and probably many more house-hold supply wells. In this case, groundwater continuous monitoring of groundwater level is proposed to set control of depression cones created by domestic supply wells. Waster water discharges could be also a source of pollution, therefore groundwater quality information is advisable, although these could be provided by the company/institution in charge of operating the supply pumping stations.

- **Cijevna River**.- Groundwater levels in the Zeta plain show most of the groundwater recharge to the Zeta plain occurs laterally through the Easter contact between the granular aquifer and the regional karst formation. The Cijevna River is a good reference to understand the behaviour of the recharge of the Zeta plain, therefore is advisable to monitor head levels and hydrochemistry to infer stream recharge to the aquifer, and the behaviour of the whole aquifer system as well.
- **Groundwater seepage to Skadar/Shkoder Lake**.- Groundwater seepage to the Skadar/Shkoder Lake could be a strong contributor of diffuse pollution from agriculture activities. Considering that, the lake is the most important hydraulic transboundary feature connecting the Zeta plain to the rest of the transboundary groundwater bodies; it is advisable to set at least one monitoring point at the southern part of the aquifer to control groundwater contributions to the lake qualitative and quantitative status.

GWB-02 Koplik-Skhodër plains

- **Groundwater withdrawals**.- It is advisable to monitor head and chemical evolution around areas were groundwater pumping is concentrated. Based on the available information there are two interesting areas. One of the biggest groundwater pumping station is the Dobraç station, able to pump 900 l/s for the Shkodra city supply. Other sites as Hoti Ri near the Kiri River and the area of Shtoji should also be considered.
- **Groundwater seepage to Skadar/Shkoder Lake**.- Likewise in the Zeta Plain groundwater seepage to the Skadar/Shkoder /Shkodra lake could be an important source of pollutants. Therefore, it is advisable to monitor groundwater levels and quality. An important are in this regard are the areas down flow Shkodra city. Based on the risk analysis and geochemical data, this area is subjected to high risk of sewage pollution that can contribute negatively to the lake water quality and that of the aquifer.

GWB-03 Trush and Zadrima plains

- **Groundwater withdrawals**.- Main groundwater withdrawal areas in the Trush plain. The Trush Pumping Station for Velipojë, with 5 pumping wells able to pump up to 500 L/s, is a candidate for monitoring site. Wells in the Zadrima plain, near

Blinisht have also to be mentioned; however, those are located far away from the transboundary zone.

- **Groundwater/surface water relation.-** It is advisable to monitor the relation to the groundwater body of the Drin and Buna/Bojana rivers. Therefore, it is proposed two monitoring zones at the norther border of the GWB close to the Drin River, near the village of Ashtë, and at the western part of the GWB close to the Buna/Bojana.

GWB-04 Albanian Karstic coastal ranges and GWB-05 Montenegrin Karstic coastal ranges

- **Spring discharge**.- Both groundwater bodies are considered in this analysis as for being one of the recharge are as of the coastal aquifer. Both groundwater bodies lack intense human pressures. Therefore, it is advised to monitor the springs discharge and its water quality.
- **Sasko Lake**.- GWB-05, in Montenegro, includes colluvium formations that link this small lake with the aquifer. Due to occurrence of human pressures WFD goal could be at risk, reason why it is advised to monitor contribution from this area to the aquifer.

GWB-06 Buna/Bojana delta area

- **Seawater intrusion**.- This is one of the most complex groundwater bodies. Its proximity to the sea implies a high vulnerability to seawater intrusion. This fact combined with the touristic increasing activity in the area, could imply an increase in seawater intrusion as already monitored in the Velipojë area (del Val Alonso and Mas-Pla, 2019). Still, the river acts as a positive boundary. The interaction of fluvial and coastal hydrological processes is a complex puzzle. A dense network of piezometers, and the control of active wells, is needed to depict groundwater flow in this low gradient area and to detect any transboundary effects or seawater intrusion. ACVM analysis suggest that seawater intrusion may also affect limestone/karstic aquifers. Therefore, monitoring this potential impact is also advisable.
- **Groundwater Dependent Ecosystems**.- This groundwater body sustain several groundwater associated aquatic ecosystem, as relevant wetland areas. Therefore, the contribution of fresh groundwater is essential to ensure their sustainability.

Priority Monitoring zones and pilot test locations

Despite the interest of all listed monitoring zones, **a few zones are proposed as for a higher priority based on the project objectives and limited resources**. The selection of high priority areas does not exempt of the overall monitoring required to identify general trends.

GWB-01 Zeta plain

- Groundwater resources along the Morača River, especially those hot-spot sites that represent a high risk of disaster, and
- the intensive groundwater domestic supply well area in Podgorica.

GWB-03 Trush and Zadrima plains

- Trush groundwater withdrawal field as the main pressure to groundwater resources quantity, and
- Nitrate pollution due to agricultural activity and poor sewage systems; however, available data for this area shows that the threshold limit of 50 mg NO_3/L has neither been reached or any upward trends have been detected.

GWB-06 Buna/Bojana delta area

- Monitor seawater intrusion along the coastal area, specifically around main wells for urban or domestic supply, if any. Consider also potential seawater intrusion affection to the limestone aquifers.

Since this project requires **two pilot locations** were to test the monitoring equipment and protocols, we suggest either one in GWB-01, and that of GWB-06. Both represent the highest risk for human water supply in the transboundary aquifer. That means giving priority to human interest above environmental interests in this first selection.

EU WFD monitoring network types

The EU-WFD propose four types of monitoring programmes in relation to their objectives. The definition of different monitoring network types helps to coordinate an optimize groundwater monitoring execution, by grouping zones with similar monitoring purposes.

- **Quantitative Monitoring Programme** focus on monitoring the quantitative groundwater status, thus to provide information to calculate the water balance, monitor groundwater levels and groundwater discharge into other surface water bodies for all groundwater bodies. This monitoring programme should be implemented in all groundwater monitoring zones and should provide information representative from the groundwater body as a whole.

- **Surveillance Monitoring Programme**, which main purpose is the acquisition of long-term trends on groundwater chemical status for all groundwater bodies. Its main objective is to validate the risk assessment, classify groundwater bodies (risk or not) and assess long-term trends. This monitoring programme should also be implemented in all groundwater monitoring zones and should provide chemical information representative from the groundwater body as a whole.

- **Operational Monitoring Programme**, which should gather information on groundwater bodies under risk. Its purpose should be to monitor pollutant trends and assess effectiveness of the measures programme. In this case, the risk analysis identified some hot-spots which are included in the operational type of groundwater monitoring network.
- **Drinking Water Protected Areas Monitoring Programme** aim to verify the good quantitative and qualitative status of Drinking Water Protected Areas. We actually identified three areas where supply wells pump at high rates: Podgorica, Trush and Shkodra.

Table 4.1 summarize the types of monitoring networks and proposed monitoring zones (* either one or both).

	EU WFD				Project
Type of monitoring network	**Quantitative**	**Surveillance**	**Operational**	**Drinking Water Protected Areas**	**Pilot test**
GWB-01 Cijevna	X	X			
GWB-01 Morača River	X	X	X		X (*)
GWB-01 Podgorica	X	X		X	X (*)
GWB-01 Seepage to lake	X	X			
GWB-02 GW Withdrawal	X	X		X	
GWB-02 Seepage to lake	X	X			
GWB-03 GW Withdrawal	X	X		X	
GWB-04 Spring discharge	X	X			
GWB-05 Pollution			X		
GWB-06 GDEs	X	X			
GWB-06 Seawater intrusion	X	X	X		X

Selection of boreholes, time frame and variables

Selection of monitoring sites

Based on the EU WFD the "groundwater monitoring network shall include sufficient representative monitoring points to estimate groundwater level in each groundwater body". "For groundwater bodies within which groundwater flow across a Member State boundary, the design should ensure sufficient points to estimate direction and rate of groundwater flow". WFD CIS Guidance Document No. 15 Monitoring Guidance for Groundwater provides a set of criteria for the selection of adequate monitoring locations and facilities.

In an ideal situation, specific boreholes dedicated for groundwater monitoring would be drilled and equipped. There are different types of boreholes depending on their purpose and the budget:

- Single piezometer are commonly installed for general monitoring with a short screen interval close to the bottom of the piezometer. These are piezometers allow for groundwater level measurement and sampling.
- Cluster of single piezometers is used in cases where several depths are required, especially for sampling. However, the cost rises, as each monitoring depth would need a separate drilling.
- Nest of piezometers in single borehole, are an alternative to clusters of single piezometers, which decrees drilling cost while being able to monitor up to 5 depths.
- Multi-port sampling system are an option, which increases the number of sampling depths. However, these are difficult to equip and operate. They are used for chemical sampling where vertical distribution of for example a pollutant is determinant.

In most cases, resources for groundwater monitoring are limited and existing facilities are used for monitoring, and even common with other uses,

- Public supply boreholes are usually used for monitoring as they are controlled by administration, protected and workers that control the installations. However, groundwater levels are disturbed by the pumping activity, and if used for sampling this will be representative of the full vertical length of the boreholes, which is not convenient.
- Irrigation boreholes are useful specially out of the growing season when they are not used.
- Dug wells can be used for groundwater monitoring level. However, they are highly problematic for groundwater quality sampling as they are usually open to the atmosphere and might be polluted.
- Large springs can be used for groundwater chemical sampling.
- Small springs are more problematic as they might be dry in some seasons.

Additionally, to these considerations the EU WFD requires a minimum amount of information about each sampling location in order be useable for monitoring. **Table 4.2** summarizes the information required for each sampling location.

The objectives of each type of groundwater monitoring network also restricts the locations and existing boreholes that can be used for each of them. For quantitative monitoring[34]:

[34] WFD CIS Guidance Document No. 15 Monitoring Guidance for Groundwater

- "Monitoring points should not be pumped or should only be pumped for very short periods at well-defined times, such that measured water levels reflect natural conditions"
- "The locations should be outside the immediate hydraulic influence of the pressure such that day-to-day variations in pumping will not be evident in the data"
- "Large springs may be suitable where total flows are in excess of 1 litre/sec."

Table 4.2. Monitoring point information – essential and desirable factors (Source: WFD CIS Guidance Document No. 15 Monitoring Guidance for Groundwater)

Factor	Chemical monitoring points	Quantitative monitoring points	Reporting Requirement (to be finalised)
Aquifer(s) monitored	E	E	✓
Location (grid reference), name of monitoring point and unique identifier	E	E	✓
Groundwater body that monitoring point is within	E	E	✓
Purpose(s) of monitoring site	E	E	✓
Type of monitoring point – farm borehole, industrial borehole, spring, etc	E	E	✓
Depth and diameter(s) of boreholes/wells	E	D	
Description of headworks – grouting integrity, slope of ground around borehole	E	E	
Depth of screened/open sections of boreholes/wells	D	D	
Vulnerability or indication of subsoil thickness and type at monitoring point	E	D	
Visual appraisal of recharge area (including land use and pressures, potential sources of point pressures)	E	D	
Construction details	E	E	
Amount abstracted or total discharge (at springs)	E	E	
Pumping regime (qualitative description – e.g., intermittent, continuous, overnight, etc.)	D	E	
Drawdown (pumped water level)	D	E	
Zone of contribution/recharge area	D	D	
Pump depth	D	D	
Static or rest water level	D	E	
Datum elevation and description of datum	D	E	
Artesian/ overflowing	E	E	
Borehole log (geological)	D	D	
Aquifer properties (transmissivity, hydraulic conductivity etc)	D	D	

Surveillance monitoring locations should be close to locations where changes are expected to occur, thus, where impact might occur and along flow paths. In groundwater bodies, which could be at risk, the surveillance monitoring provides the basics for operation monitoring.

Based on this selection several aspects can be concluded:

- There are no existing wells that can be used in the priority area for monitoring groundwater seepage to the lake.
- In Podgorica, where most of the groundwater supply pumping stations are concentrated, there is only one well with matches with the basic requirements.
- Most of the current monitoring concentrates around the upflow zone of Cijevana priority monitoring area, and around the upstream part of the Morača priority monitoring area.

This indicates that several monitoring boreholes should be drilled to complete spatial coverage for the quantitative monitoring network, especially in the northern and southern areas of the groundwater body.

In relation to the two pilot stations that should be installed for the project, there is one well in Podgorica that at least matches with the initial requirements. For the Morača priority area, there are several wells down-gradient of the Aluminium plant that could be suitable for groundwater monitoring, and that could be included in the surveillance and operational monitoring networks. Further discussion with national authorises and local state-holders should be done in order to choose the final location of the pilot station, without discarding the possibility of a new drilling if existing facilities are not useable.

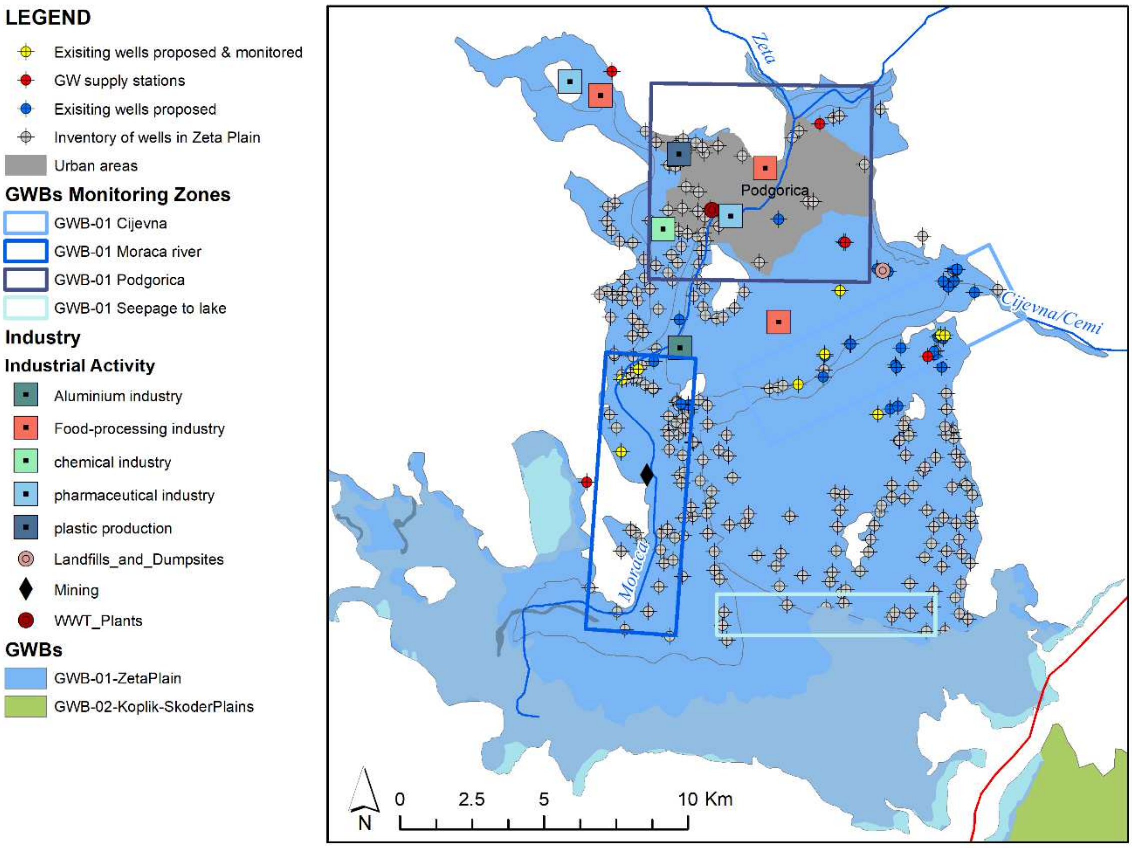

Figure 2.4. Selection of existing boreholes for continues monitoring in the Zeta plain, Montenegro.

Regarding Albania potential monitoring locations, information have been obtained from several wells that provide hydraulic head and hydrochemical data. Such information has been included in the companion report and it provide an insight of one of the main potential groundwater pollutants.

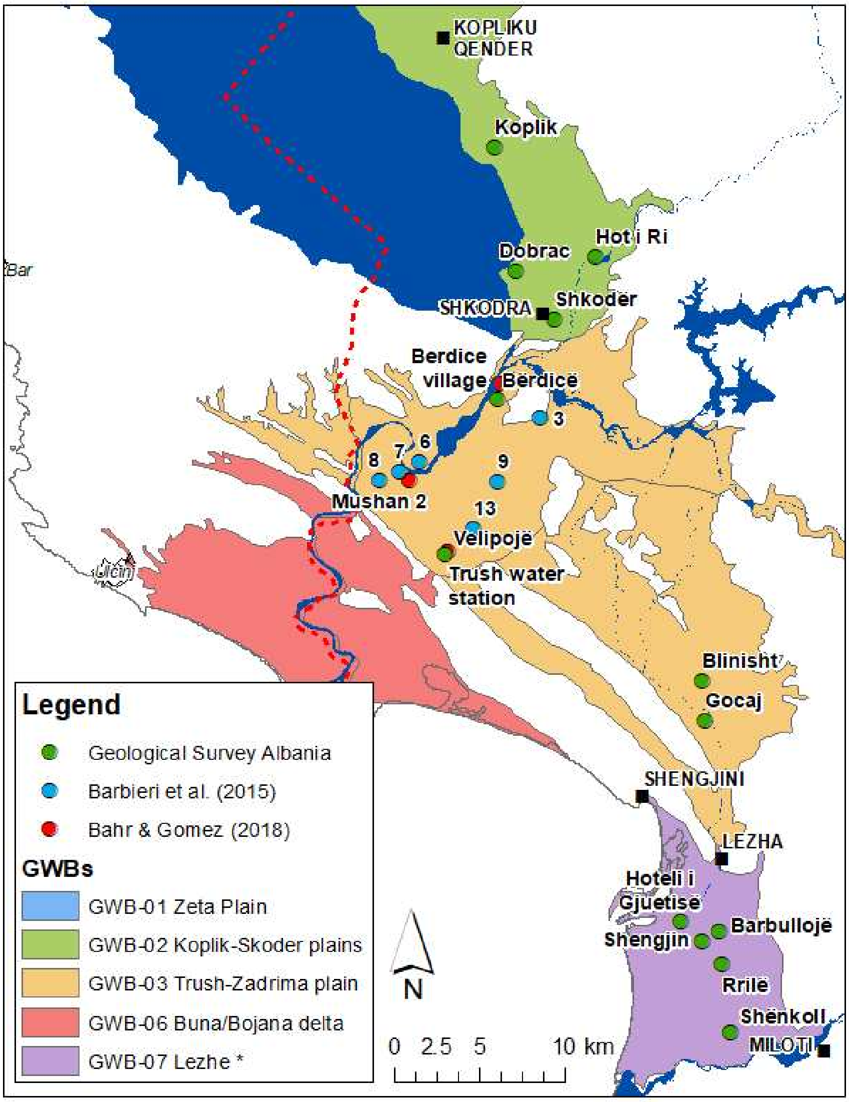

Figure 2.5. Selection of existing boreholes for continues monitoring in Albania. The groundwater body GWB-07, that represents the Lezhë aquifer, is not included in this study.

Selection of time frame

Annex V of the EU WFD (2.2.3 and 2.4.1) states that the frequency of observations should be sufficient to detect impacts. The WFD CIS Guidance Document No. 15 "Monitoring Guidance for Groundwater" provides some criteria for the selection of monitoring frequency when not enough data is available for a time series analysis. The minimum frequencies propose by the guidelines depend of course of the type of monitoring network, thus the objectives are,

- For the *quantitative monitoring* monthly monitoring is enough when low variability in groundwater levels is observed. However, if changes in groundwater levels are more dynamic and groundwater flows need to be known, daily monitoring is recommended.

- For the *surveillance monitoring* network (groundwater quality) a minimum sampling frequency of twice a year is advised at the beginning, to detect trends. However, these frequencies might vary depending on the transit times. **Table 4.3** shows proposed frequencies by the EU WFD Guidelines document.

Table 4.3. Minimum sampling frequencies proposed by the WFD CIS Guidance Document No. 15 Monitoring Guidance for Groundwater for the Surveillance monitoring network.

		Aquifer Flow Type				
		Confined	Unconfined			
			Intergranular flow significant		Fracture flow only	Karst flow
			Significant deep flows common	Shallow flow		
Initial frequency – core & additional parameters		Twice per year	Quarterly	Quarterly	Quarterly	Quarterly
Long term frequency – core parameters	Generally high-mod transmissivity	Every 2 years	Annual	Twice per year	Twice per year	Twice per year
	Generally low transmissivity	Every 6 years	Annual	Annual	Annual	Twice per year
Additional parameters (on-going validation)		Every 6 years	Every 6 years	Every 6 years	Every 6 years	-

- For the *Operational monitoring* network sampling frequencies reduce. Sampling frequency might depend on the pollutant dynamics, if they are seasonal or they depend on agriculture practices for examples. Table 4.4. shows the recommended sampling frequencies depending on the groundwater vulnerability and aquifer type.

Based on the EU WFD, recommended **monitoring frequencies** are proposed for each priority zone. Prioritized zones in GWB-01 and GWB-06 should be monitored at least four times a year and coincide with the periods of minimum and maximum exploitation rates) for full data acquisition: head level and complete hydrochemical analysis. For all the other priority zones, the mentioned frequencies proposed by the WFD guiding document could be used.

Table 4.4. Minimum sampling frequencies proposed by the WFD CIS Guidance Document No. 15 Monitoring Guidance for Groundwater for the Operational monitoring network.

		Aquifer Flow Type				
		Confined	Unconfined			
			Intergranular flow significant		Fracture flow only	Karst flow
			Significant deep flows common	Shallow flow		
Higher vulnerability groundwater	Continuous pressures	Annual	Twice per year	Twice per year	Quarterly	Quarterly
	Seasonal / intermittent pressures	Annual	Annual	As appropriate	As appropriate	As appropriate
Lower vulnerability groundwater	Continuous pressures	Annual	Annual	Twice per year	Twice per year	Quarterly
	Seasonal / intermittent pressures	Annual	Annual	As appropriate	As appropriate	As appropriate
Trend assessments		Annual	Twice per year	Twice per year	Twice per year	-

Selection of variables

- For the quantitative monitoring network, groundwater levels and spring discharges are the core parameters to be monitored. Additionally, the groundwater withdrawal rates and the stage of surface water bodies needs to be available for completeness.
- For the surveillance network (quality) Dissolved Oxygen, pH, Conductivity, Nitrate and Ammonium are the core parameters that need to be monitored. Additionally, Eh (redox potential) and turbidity can also be monitored, as well as major anions and cations. The last are extremely important, especially during the first years of operation in order to confirm the conceptual model and interpret the core geochemical parameters. Moreover, the norm indicates that major constituent analysis is highly recommended in transboundary water bodies, which are relevant for the protection of all of the uses supported by the groundwater flow.
- The Operational monitoring network is specific of the pollutants affecting the aquifer. In general terms, we can say that in areas that could be affected by heavy industry metals should be sampled, while in areas where sewage might represent a risk, fecal bacterial can be also object of sampling.
- In Drinking protected areas is important to have a full range of parameters, those specified by the international and local regulations, as water is use for human consumption.

Equipment and methods

The availability of groundwater monitoring techniques is as wide as it is the field of hydrology itself. Eagerness for enhanced and additional data has driven the improvement of classical techniques and development of new ones pushing further the limits of the hydrogeological processes we are able to observe and measure. Groundwater monitoring networks are becoming a major concern for national governments, yet they are difficult to set up and even more to maintain. However, they are essential to comply with the environmental legislation. Current state-of-the-art in monitoring technologies, together with the interest from national governments and supranational bodies, set the stage for new and more advanced groundwater monitoring networks. The challenge lies in finding a balance between the available multiple possibilities for data acquisition and the investment required in order to get the most cost-effective solution for case. Therefore, we propose the most – to our knowledge – cost-effective solution to reach the monitoring objectives set for each type of monitoring network and pilot tests.

Quantitative monitoring

Groundwater heads are the basic variable for quantitative monitoring. The most efficient method is to use automatic pressure loggers like the divers or CTDs, where conductivity is a core variable too. In these cases, the automatic pressure logger needs to be accompanied by a barometric sensor, unless atmospheric pressure is automatically compensated, to calibrate pressure data and get final hydraulic head levels. In any case, periodic manual measurements need to be conducted to check automatically recorded heads. In case automatic sensors are not available, manual measurement must be done. Such measurements are delicate in coastal piezometers affected by intrusion, as vertical changes of conductivity or density may need an extra calibration of the head data to obtain truly flow directions and hydraulic gradients. Moreover, in areas with low hydraulic gradient, this task should also be performed with special care, as hydraulic gradients are paramount to determine groundwater flow direction.

Installation of CTD devices that continuously record hydraulic pressure, temperature and EC are highly recommended in these specific zones with a data acquisition frequency every 12 or 24 hour. Smaller time steps are not usually necessary unless required by exceptional reasons; for instance, a nearby pumping station that might alter the system at smaller time intervals or to monitor the stream-aquifer relationship during floods that imply a fast modification of the water table.

Surveillance and Operational monitoring (geochemical sampling)

Geochemical water sampling protocols and material depend enormously on the piezometer characteristics (diameter, depth, etc …), as well as on the compounds to sample. Additionally, each lab has its own standards for the amount to sample necessary for each analytical procedure. In fact, one of the first thing to do when preparing a groundwater sampling campaign is to contact labs to check their availability and internal protocols so proved international procedures are being conducted.

On the field, general parameters like the groundwater head, the state of the boreholes and that of the surrounding areas are necessary to be recorded in order to put the chemical data in their appropriate hydrogeological context. Unstable parameters such as pH, temperature, conductivity, dissolved oxygen and where necessary, redox potential and turbidity must be measured in the field as quickly as possible.

The WFD CIS Guidance Document No. 15 Monitoring Guidance for Groundwater does not provide specific protocols or indications for groundwater sampling. However, the "Technical report on groundwater monitoring as discussed at the workshop of 25th June 2004" indicates that protocols should follow the ISO norms 5667-11 (1993), for groundwater sampling methods focused to survey the quality of groundwater supplies, to detect and assess groundwater pollution and to assist in groundwater resource management. The ISO 5667-18 (2001) gives the principles of groundwater sampling methods at contaminated sites, thus for Operational monitoring. Since these norms are not publicly available, an alternative reference are the groundwater sampling protocols by USGS[35]. Nevertheless, it is expected that existing national procedures already met international standards. Efforts should be addressed to harmonize such procedures among the distinct national sampling teams and technicians, and to ensure that similar procedures are followed by each country sharing a transboundary aquifer.

Automatic data transmission

Currently some of the most sophisticated solution for continuous monitoring are the installation of telemetric stations, with an autonomous data logger, able to record and transmit the data in real time from the field. These data loggers are compatible with different sensors of pressure, conductivity, or even pH and DO. However, for the last two parameters, periodic calibration (monthly) is necessary. In any case, automatic transmission allows for monitoring of detached areas difficult to reach by car, and to have real time data, which could be useful in areas with high risk.

[35] Koterba, M. T., Wilde, F. D. & Lapham, W. M. Ground-water data-collection protocols and procedures for the National Water-Quality Assessment Program: Collection and documentation of water-quality samples. USGS Open-File Rep. 95-399 123 (1995).

Summary monitoring criteria

Table 4.5.- Summary of monitoring criteria for spatial distribution of monitoring locations, time frame, variables and instrumentation to be used in each monitoring network.

Monitoring network	GWB	Spatial distribution	Time frame	Core variables	Advised variables	Instrumentation
QUANTITATIVE	GWB-01 Cijevna	Existing drilled boreholes already monitored	Monthly, if manual daily, if automatic	Groundwater level		Minidiver + baro + Head-meter
	GWB-01 Morača River	Along the river alluvial plain to control relation groundwater with surface water		Groundwater level		CTD + Baro + Head-meter
	GWB-01 Podgorica	Newly drilled boreholes evenly distributed around the urban area		Groundwater level		Minidiver + baro + Head-meter
	GWB-01 Seepage to lake	New boreholes would need to be drilled		Groundwater level		CTD + Baro + Head-meter
	GWB-02 GW Withdrawal	Any of existing boreholes upflow from pumping stations		Groundwater level		Minidiver + baro + Head-meter
	GWB-02 Seepage to lake	Any existing drilled borehole downflow from Shkodra city		Groundwater level		CTD + Baro + Head-meter
	GWB-03 GW Withdrawal	Any of existing boreholes upflow from pumping stations		Groundwater level		Minidiver + baro + Head-meter
	GWB-04 Spring discharge	High flow springs		Spring discharge		Manual
	GWB-05 Pollution	Existing or new boreholes downflow from the lake		Groundwater level		CTD + Baro + Head-meter
	GWB-06 GDEs	Exiting or newly drilled boreholes evenly distributed around the most important aquatic coastal ecosystems		Groundwater level		CTD + Baro + Head-meter
	GWB-06 Seawater intrusion	Newly drilled multiscreen borehole open at different depths		Groundwater level and electrical conductivity		CTD + Baro + Head-meter + CTD for conductivity vertical profiles
SURVEILLANCE	GWB-01 Cijevna	Same as for the quantity network	Quarterly	Electrical conductivity, Dissolved oxygen and pH (on the field). Nitrate, Ammonium	Mayor ions and cations. Redox potential (Eh) (on the field).	Head-meter Field portable pump pH-meter EC-meter DO-meter Eh-meter flow cell filters acid cooler sterilized tubes and bottles
	GWB-01 Morača River					
	GWB-01 Podgorica					
	GWB-01 Seepage to lake					
	GWB-02 GW Withdrawal					
	GWB-02 Seepage to lake					
	GWB-03 GW Withdrawal					
	GWB-04 Spring discharge					

Monitoring network	GWB	Spatial distribution	Time frame	Core variables	Advised variables	Instrumentation
	GWB-05 Pollution					
	GWB-06 GDEs					
	GWB-06 Seawater intrusion					
OPERATIONAL	GWB-01 Morača River	Existing drilled boreholes downstream of the Aluminium plant	twice a year		metals	same as for surveillance
	GWB-05 Pollution	Existing or new boreholes downflow from the lake	twice a year		faecal	
DRIKING WATER PROTECTED AREAS	GWB-01 Podgorica	Newly drilled boreholes upflow from Podgorica to control groundwater quality	twice a year		metals, faecal	same as for surveillance
	GWB-02 GW Withdrawal	Existing or new boreholes upflow from pumping stations	twice a year		metals, faecal	
	GWB-03 GW Withdrawal	Existing or new boreholes upflow from pumping stations	twice a year		metals, faecal	
PILOT TEST	GWB-01 Morača River	Existing drilled boreholes downstream of the Aluminium plant (Multi-port sampling if possible)		Same as quantitative and surveillance	Same as surveillance and operational	same as for surveillance
	GWB-01 Podgorica	Newly drilled boreholes upflow from Podgorica to control groundwater quality		Same as quantitative and surveillance	Same as surveillance and drinking protected areas	
	GWB-06 Seawater intrusion	Newly drilled Multi-port sampling borehole		Same as quantitative and surveillance	Same as surveillance	

Chapter 4.

Conclusions

Conclusions about the Hydrogeological Conceptual Model

With the aim to provide necessary information for the design of a transboundary groundwater monitoring network, the current report provides:

1. Conceptual model of the Skadar/Skoder Buna/Bojana Transboundary Aquifer System
2. Risk assessment
3. Identification of groundwater bodies

The main limitation towards the consecution of the report objectives was the limited information available. This was of special importance when determining groundwater quality status. Therefore, overcoming this lack of data, specially of time dependent variables, should be one of the objectives of the transboundary monitoring network.

The risk assessment identified serious risks to both groundwater quantity and quality. Risk are mainly related to heavy industry, like the Podgorica aluminium plant, agricultural activities, and over-abstraction. Effects of these risks seem to arise from existing information, however, more information, specially of groundwater hydro-chemical data should be gathered to confirm of neglect any negative trend related to the identified risks.

For of the six groundwater bodies indented are actually part of the intergranular formation:

1. *GWB-01 Zeta plain.*
2. *GWB-02 Koplik-Skhodër plains*
3. *GWB-03 Trush and Zadrima plains*
4. *GWB-06 Buna/Bojana delta área*

From these four, three situate within a single country. However, indirect transboundary effects occur, mainly through surface water hydraulic connectivity. Therefore, Skadar/Skoder Lake and the Buna/Bojana River are major vectors that could transfer negative trends from one groundwater body to another. This implies that no surface or groundwater management can be done independently, but both need to be integrated.

Given the lack of information, the high risk and the transboundary nature of the four groundwater bodies, we consider them to be at risk, and therefore to be considered in the design of a groundwater transboundary monitoring network.

Conclusions about the Aquifer Comprehensive Vulnerability Map (ACVM)

The vulnerability map elaborated applying the ACVM method is a great tool for territory planning and for a wise exploitation of the transboundary aquifer. In fact, this map simultaneously shows the distribution of the sensitivity of the aquifer both against a pollutant dispersed on the land surface and sea water intrusion. Moreover, a draft of a ACVM vulnerability map incorporating the flooding vulnerability was elaborated.

The locations of both potential pollution sources and targets of possible groundwater pollution is plotted on the Comprehensive vulnerability map. The presentation of all this information through the comprehensive vulnerability map allows stakeholders to easily identify the areas where human activities should be regulated to avoid pollution, overexploitation or salt water intrusion.

Moreover, the Comprehensive vulnerability map is a useful tool to support the monitoring network design and could be replicated also in other coastal aquifers, in fact it shows the areas that need to be monitored to avoid pollution or overexploitation. In particular the areas of Trush and the Buna/Bojana delta are places where sea water is partially present in the aquifer. So, the monitoring network can give information on the modification of the limits of salt water intrusion relating it to the exploitation of the aquifer and the precipitations.

On the other hand, monitoring the areas on the north part of the transboundary aquifer and in particular the Z Plain and the Koplik-Skhodër Plains can give information about the feeding of the aquifer. This aspect is related not only to the groundwater quality, but also to the salt water intrusion, because a reduction of the feeding of the aquifer can lead a reduction of aquifer specific energy in the area near Trush favouring salt water intrusion.

Conclusions about the Monitoring Network Design

With the aim to design a monitoring network of groundwater resources based on the WFD criteria in the Buna/Bojana transboundary area in Albania and Montenegro, this report proposes

1. the main groundwater bodies (GWBs) that set the frame for monitoring goals.,
2. a monitoring program, that identifies the main areas of interest, among them those that must be prioritized, based on the pressures and impacts of these areas that are at risk to achieve the WFD goals.

Six GWBs had been proposed and justified, four of them are of special interest in this project. These four GWBs are (**Figure 1.2**):

- GWB-01 Zeta plain,
- GWB-02 Koplik-Skhodër plains
- GWB-03 Trush and Zadrima plains, and
- GWB-06 Buna/Bojana delta areas

where most of its resources are related to fulfil human uses or the preserve environmental values. Nevertheless, a comprehensive analysis of all six GWBs is developed and their monitoring requirements described in the report.

These monitoring requirements refer to quantitative and qualitative data gathering, so the complete criteria set defined by the WFD is considered. Based on our knowledge of the area, the main locations of interest within each GWB are identified and justified. Among them, we prioritize three monitoring zones:

i. In GWB-01, specific placed along the Morača River valley, specially those hot-spots related to industrial activities, and the intense groundwater urban supply area in Podgorica.
ii. In GWB-03, special emphasis must be given to the Trush groundwater withdrawal field, as well as to monitor nitrate pollution in the agricultural zones.
iii. IN GWB-06, monitoring hydraulic levels and EC to control seawater intrusion stands as the main issue of concern.

Since two monitoring sites should be selected according to the project outline, those in GWB-01 (Zeta plain) and GWB-06 (Buna/Bojana delta area) are nominated.

Monitoring performance, that is: variables and frequency, are defined according to the WFD guidance documents. For quantitative data (hydraulic head), monthly measurements should be conducted if data is measured manually; while daily data is advisable if automatic pressure loggers are used. Automatic equipment, as CTDs, is highly recommended. For quantitative data that determine the operational and surveillance monitoring programs, quarterly (i.e., every 3 months) frequency is necessary. **Table 2.1** determines the monitoring requirements for each monitoring zones, while **Table 2.5** summarizes all the criteria for each zones.

Finally, this report constitutes a comprehensive, practical proposal that must be analysed and discussed in detail by local experts, stakeholders and government administrations. These actors must verify our suggestions based on their expertise, and propose changes where necessary. A constructive discussion must then arise contrasting the actual monitoring requirements and local capabilities and the achievement of the WFD goals for each groundwater body. This project sets the framework to achieve a satisfactory and productive agreement that permits developing an integral and competent monitoring program that improves groundwater resources management in the studied area.

Annex I. Information provided by Montenegro

<table>
<tr><td colspan="4">Priority Note for data request to national authorities: *ESENTIAL= Conceptual model and vulnerability analysis cannot be carried out without this information; ADVISABLE= the Conceptual model and vulnerability analysis will be more reliable with this data; and OPTIONAL = this data will improve the analysis.</td></tr>
<tr><th></th><th>Data Needed for the elaboration of geological conceptual model and ACVM vulnerability maps</th><th>Priority*</th><th>MONTENEGRO
(Provided data)</th></tr>
<tr><td rowspan="4">Topography</td><td>Detailed and georeferenced <u>topographic maps</u> as raster files or vector files (1:100.000, 1:50.000 or 1:25.000).</td><td rowspan="2">ESSENTIAL</td><td rowspan="2">Detailed topographical map 1:25000 in UTM
Detailed 10x10 m DEM in UTM</td></tr>
<tr><td><u>Detailed Digital Elevation Model</u> (cell around 10 m if available).</td></tr>
<tr><td><u>Surface waters</u> (updated maps with the natural rivers flow with the indication of the area where the river feed the aquifer and where the aquifer feed the river).</td><td>ADVISABLE</td><td rowspan="2"></td></tr>
<tr><td><u>Surface water catchment</u> (updated maps with the artificial catching and discharges area done for hydropower stations or agricultural purpose or water supply).</td><td>OPTIONAL</td></tr>
<tr><td>Geology</td><td><u>Geology/Lithology Map</u> (1:100.000 or better at 1:50000 or 1:25000).</td><td>ESSENTIAL</td><td>Geological maps 1:100000
1. Mirković M. i ostali, (1985): OSNOVNA GEOLOŠKA KARTA Bar 1:100 000, J.U. Republički zavod za geološka istraživanja, Titograd
2. Živaljević, M., Đokić, V., Pajović, M. 1967. Štampana OGK lista „Titograd“, 1:100 000, Savezni Geološki zavod, Beograd.
3. Radulović, M., Radulović, V., Popović, Z. 1982. Osnovna hidrogeološka karta list «Titograd», 1:100 000. Zavod za geološka istraživanja SR Crne Gore, Titograd.
4. Radulović M. i ostali, (1989): OSNOVNU HIDROGEOLOŠKU KARTU LISTA "BAR SA ULCINJEM" 1:100 000, Fond</td></tr>
</table>

Priority Note for data request to national authorities: *ESENTIAL= Conceptual model and vulnerability analysis cannot be carried out without this information; ADVISABLE= the Conceptual model and vulnerability analysis will be more reliable with this data; and OPTIONAL = this data will improve the analysis.			
	Data Needed for the elaboration of geological conceptual model and ACVM vulnerability maps	**Priority***	**MONTENEGRO (Provided data)**
			J.U. Republički zavod za geološka istraživanja, Titograd 5. Geological map Ulcin area 1:100000(1999)
	Tectonics (Faults, anticlinal and synclinal axis)	*ESSENTIAL*	**Geological maps 1:100000**
	Stratigraphy descriptions (borehole description and well drilling reports for construction vertical cross-sections).	*ESSENTIAL*	**Drilling reports:** 1. **V.Dubljevic (2006):** Report on the conducted exploration drilling well MB1 at the location of Mileš. Geological survey of Montenegro. 2. **V.Dubljevic (2005):** Report on the conducted exploration drilling well B1 at the location of ES Pavle Rovinjski, Podgorica. Geological survey of Montenegro. 3. **D. Radojevic (2007):** Report on the conducted exploration drilling well PZ1 at the location of Zagoric, Podgorica. Geological survey of Montenegro. 4. **N.Dević (2018):** Report of Project "State, Protection and Valorization of the Groundwater of the Zeta Plain". Geological survey of Montenegro. 5. **Radulović, V., Radulović, R., Radulović, M. (1997**). Hydrogeological Elaboration on conducted research of compacted Zeta plain in the area of Tuško polje. Geological survey of Montenegro, Podgorica. 6. **V.Radulović, etc (1985).** Seismic micro-rayonization of municipilaty Titograd. Geological survey of Montenegro, Podgorica.

	Priority Note for data request to national authorities: *ESENTIAL= Conceptual model and vulnerability analysis cannot be carried out without this information; ADVISABLE= the Conceptual model and vulnerability analysis will be more reliable with this data; and OPTIONAL = this data will improve the analysis.		
	Data Needed for the elaboration of geological conceptual model and ACVM vulnerability maps	**Priority***	**MONTENEGRO (Provided data)**
	Geophysical data (geo-resistivity).	*OPTIONAL*	
Hydrogeology	Hydrogeological units, Aquifer type, geometry (Groundwater bodies)	*ESSENTIAL*	
	Basic geochemistry (for water types definition, sea water intrusion delineation and conceptual model verification (ej. Recharge zones).)	*ADVISABLE*	**Wells data base → pH and EC and Temperature** **Devic and Filipovic, 2005** **→Geochemical parameters from Zeta Plain**
	Permeability (for fluxes and vulnerability calculation).	*ADVISABLE*	**Drilling reports.**
	Wells inventory including location, use, total depth and depth of screened interval.	*ESSENTIAL*	***Zeta Plain inventory***
	Groundwater levels time series (for groundwater flow direction, spatial variability and fluxes and time series analysis in order to select optimum sampling frequency).	*ESSENTIAL*	***Zeta Plain inventory, but few wells contain data for more than a year***
	Local uses of groundwater.	*ADVISABLE*	***National Consultants report***
Climatic	Rainfall distribution Atmospheric temperature Radiation (To calculate effective recharge and spatial distribution).	*ADVISABLE*	***Database with information about 4 meteorological stations. Time series data for Podgorica meteorological station.***
Pollution sources	Inventory of diffuse sources (with indication of the kind of sources and the presence of risk preventer).	*ADVISABLE*	***National Consultants report***

	Priority Note for data request to national authorities: *ESENTIAL= Conceptual model and vulnerability analysis cannot be carried out without this information; ADVISABLE= the Conceptual model and vulnerability analysis will be more reliable with this data; and OPTIONAL = this data will improve the analysis.		
	Data Needed for the elaboration of geological conceptual model and ACVM vulnerability maps	**Priority***	**MONTENEGRO (Provided data)**
	Inventory of point sources (with indication of the kind of sources and the presence of risk preventer).		
	Map of flood prone areas and map of the areas that in the past were flooded.	*OPTIONAL*	
Target of pollution	Shape files and database containing polygons, lines or points that mark aquifer areas have to be safeguarded like recharge areas of the aquifer, extractions sites of Drinking water, water reservoirs, natural protected areas, karst features: sinkholes, caves etc.	*ADVISABLE*	***National Consultants report***

Annex II. Information provided by Albania

Priority Note for data request to national authorities: *ESENTIAL= Conceptual model and vulnerability analysis cannot be carried out without this information; ADVISABLE= the Conceptual model and vulnerability analysis will be more reliable with this data; and OPTIONAL = this data will improve the analysis.			
	Data Needed for the elaboration of geological conceptual model and ACVM vulnerability maps	**Priority***	**ALBANIA**
Topography	Detailed and georeferenced topographic maps as raster files or vector files (1:100.000, 1:50.000 or 1:25.000). Detailed Digital Elevation Model (cell size less than 10 m if available).	***RECEIVED***	• ***Topographic maps 1:25000*** • ***Hydrography included in topographic maps***
	Surface waters (updated maps with the natural rivers flow with the indication of the area where the river feed the aquifer and where the aquifer feed the river).	***RECEIVED***	
	Surface water catchment (updated maps with the artificial catching and discharges area done for hydropower stations or agricultural purpose or water supply).	***OPTIONAL***	
Geology	Geology/Lithology (1:100.000 or better at 1:50000 or 1:25000 for the construction of detailed/operational vertical cross-sections).	***RECEIVED***	• ***DIKTAS Scale 1:500000*** • ***AGS Albania Hydrogeological map Scale 1:200.000*** • ***1:25000 Geological maps including all features***
	Tectonics (Faults, anticlinal and synclinal axis) including *"DIP direction" and "DIP angle" of discontinuity according to the Clar´s Notation* for the construction of vertical cross-sections).	***RECEIVED***	• ***1:25000 Geological maps including all features***
	Stratigraphy (borehole description and well drilling reports for construction vertical cross-sections).	***RECEIVED***	• ***In the 1:25000 Geological maps there are some lithostatigraphic descriptions*** • ***Detailed description of 11 boreholes for Shkoder plain, 38 boreholes for Lezha district, 29 for the Nenshkodra district, 59 for Shkodra district and 3 wells around Velipoja area.***

	Priority Note for data request to national authorities: *ESENTIAL= Conceptual model and vulnerability analysis cannot be carried out without this information; ADVISABLE= the Conceptual model and vulnerability analysis will be more reliable with this data; and OPTIONAL = this data will improve the analysis.		
	Data Needed for the elaboration of geological conceptual model and ACVM vulnerability maps	**Priority***	**ALBANIA**
	Geophysical data (geo-resistivity).	***OPTIONAL***	
Hydrogeology	Hydrogeological units, Aquifer type, geometry	***RECEIVED***	• ***1:25000 hydrogeological maps including all features***
	Basic geochemistry (for water types definition, seawater intrusion delineation and conceptual model verification (ex, recharge zones).)	***RECEIVED***	*Publications:* • *Barbieri et al. 2015* • *KTH report 2018* • *AKM (Agjensia Kombetare e Mjedisit). Report chapter 2, "CILESIA E UJERAVE". 2014.*
	Permeability (for fluxes and vulnerability calculation).	***RECEIVED***	• *Eftimi, 2010* • *Information for several boreholes*
	Wells database including location, use, total depth and depth of screened interval.	***RECEIVED***	• *National consultant report* • *GWL for 14 boreholes in Skoder plain*
	Groundwater levels time series (for groundwater flow direction, spatial variability and fluxes and time series analysis in order to select optimum sampling frequency).	***RECEIVED***	
	Local uses of groundwater.	***RECEIVED***	• *National consultant report*
Climatic	Rainfall distribution Atmospheric temperature Radiation (To calculate effective recharge and spatial distribution).	***RECEIVED***	
Pollution sources	Inventory of diffuse sources (with indication of the kind of sources and the presence of risk preventer). Inventory of point sources (with indication of the kind of sources and the presence of risk preventer).	***RECEIVED***	• *Land uses based on Corine land cover and explanation in report.* • *National consultant report →Inventory of hot spots of contamination and over abstraction: landfills, dumpsites, waste water treatment plants, gravel extraction locations and hydropower generation plants*

Priority Note for data request to national authorities: *ESENTIAL= Conceptual model and vulnerability analysis cannot be carried out without this information; ADVISABLE= the Conceptual model and vulnerability analysis will be more reliable with this data; and OPTIONAL = this data will improve the analysis.			
	Data Needed for the elaboration of geological conceptual model and ACVM vulnerability maps	**Priority***	**ALBANIA**
	Map of flood prone areas and map of the areas that in the past were flooded.	***RECEIVED***	• *Geological Survey Albania*
Target of pollution	Shape files and database containing polygons, lines or points that mark aquifer areas have to be safeguarded like recharge areas of the aquifer, extractions sites of Drinking water, water reservoirs, natural protected areas, karst features: sinkholes, caves etc.	***RECEIVED***	• *National consultant report. Inventory and location of protected areas and groundwater supply pumping stations*