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D2.6– GIS map and database of hydrogeology of the selected areas

Version 1 15/05/2023

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Authors	Marino Domenico Barberio, Vincenzo Guerriero, Vasileios Karakostas, Christos Kourouklas, Eleftheria Papadimitriou, Luca Pizzino, Alessandra Sciortino, Stylianos Stoulos, Michael Strupler, Marco Tallini
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Abstract

The present deliverable regards the description of the database and maps stored into the GIS project concerning on the hydrogeology of the three areas selected within the artEmis project (Abruzzi region, Italy; Ionian islands and the Gulf of Corinth, Greece; Bedretto lab and Swiss Alps).

The potential groundwater sites for radon monitoring will be chosen within the three areas.

The Abruzzi region (Italy) has been managed by UNIVAQ and INGV, the Ionian islands and the Gulf of Corinth (Greece) by AUTH, and Bedretto lab and Swiss Alps by ETH.

The interplay of the hydrogeological data with the other geoscience ones (geology, seismotectonics and seismicity) will permit to better locate in the three areas the potential radon monitoring sites.

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1 Introduction

The present deliverable regards the description of the database and maps stored into the GIS project concerning on the hydrogeology of the three areas selected within the artEmis project (Abruzzi region, Italy; Ionian islands and the Gulf of Corinth, Greece; Bedretto lab and Swiss Alps) (fig. 1.1).

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The interplay of the hydrogeological data with the other geoscience ones (geology, seismotectonics and seismicity) will permit to better locate in the three areas the potential radon monitoring sites.

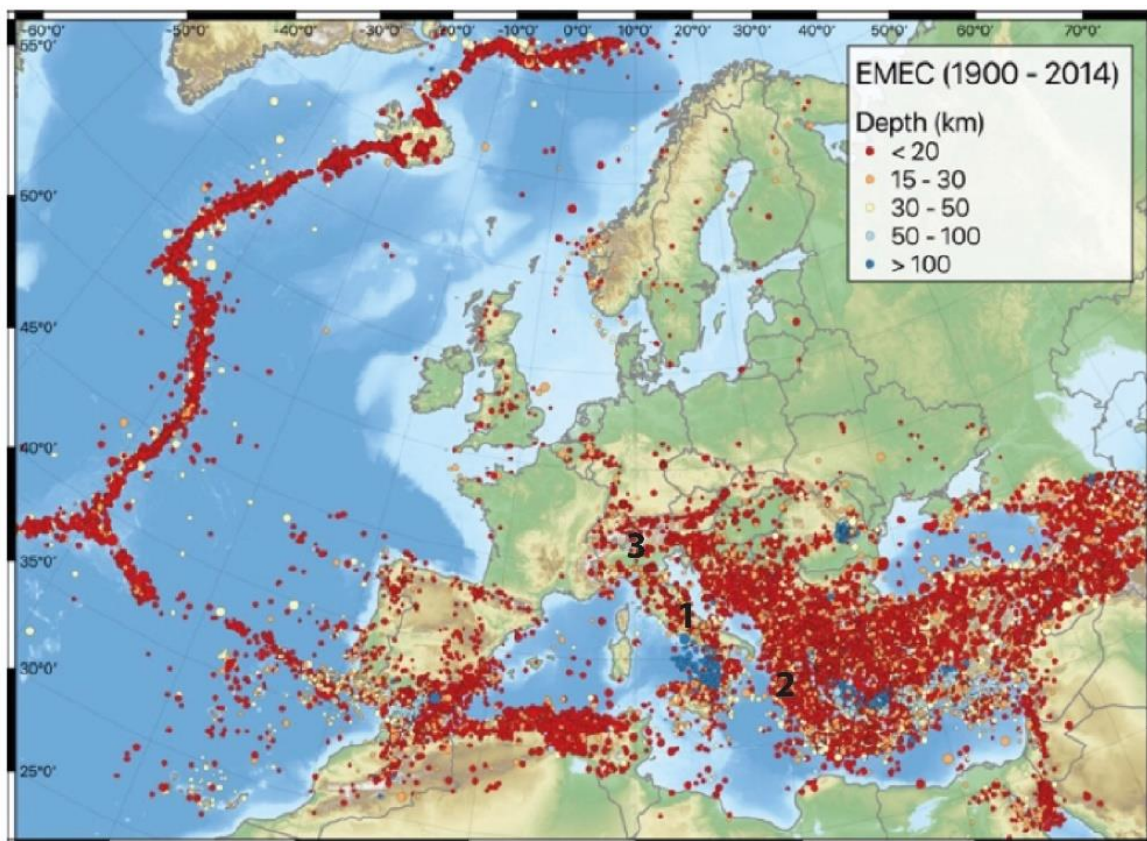


Figure 1.1: The complete European-Mediterranean earthquake catalogue (EMEC) for the period 1900 – 2012 by Danciu et al. (2021) with the location of the three selected areas (1: Abruzzi region, Italy; 2: Ionian Islands and Gulph of Corinth, Greece; 3: Bedretto lab and Swiss Alps)

1.1 References

Danciu, L., Nandan, S., Reyes, C., Basili, R., Weatherill, G., Beauval, C., Rovida, A., Vilanova, S., Sesetyan, K., Bard, P-Y., Cotton F., Wiemer, S., Giardini, D., 2021. The 2020 update of the European Seismic Hazard Model: Model Overview. EFEHR Technical Report 001, v1.0.0. <https://doi.org/10.12686/a15>

2 GIS map and database of hydrogeology (Abruzzi region, Italy)

For selecting the potential groundwater sites for radon monitoring a GIS map and database was organised. The free and open-source Geographic Information System QGIS (<https://qgis.org/en/site/>) was used.

The QGIS project is available at the Department of Civil, Architectural and Environmental Engineering of L'Aquila University (UNIVAQ).

In the QGIS project of Abruzzi region several geoscience informative database and maps concerning geology, seismotectonics, seismicity and hydrogeology, were stored and divided into three main folders:

Deliverable 2.2 – Geology and seismotectonics;

Deliverable 2.4 – Seismicity;

Deliverable 2.6 – Hydrogeology.


In this deliverable (D2.6) the maps and database of hydrogeology stored in the QGIS project are, while, in the deliverables D2.2 and D2.4 the geoscience data stored in the QGIS project concerning the geology and seismotectonics and the seismicity are outlined respectively.

The hydrogeological data and maps stored in the QGIS project are organized as shown in figure 2.1.

Deliverable 2.6 - Hydrogeology

 *Sinkhole points*



 Hydrogeological maps

 *Hydrogeological scheme of central Italy (from Boni-Bono-Capelli-1986a)*

 *Hydrogeological scheme of central Italy (from Boni-Bono-Capelli-1986b)*

 *Gran Sasso Hydrogeological map (from Petitta, Ranalli, Tallini, 2002)*

 *Hydrogeological map of central-southern Italy (Pietro Celico, 1983)*

Figure 2.1: Hydrogeological data and maps organised in the GIS project

Moreover, the location of the potential groundwater sites for radon monitoring was stored too. They are mainly wells and springs managed by the Water Management Companies of Abruzzi region (tab. 2.1) and specific sites managed by INGV (figs. 2.2, 2.3).

Further, the GIS project is enriched by various cartographic basemap such as Google Maps, regional DEM (Digital Elevation Model) with a resolution of 10 m, cadastral maps, and regional and municipal boundaries.

The D2.6 deliverable contains the WMS “Sinkholes points” (fig. 2.4), a service that allows to view the location of sinkholes surveyed by the Geological Survey of Italy – ISPRA (URL: <http://sgi2.isprambiente.it/arcgis/services/servizi/sinkhole/MapServer/WmsServer>).

WMC	ADP	Site type	Spring amount	Well amount
ACA	Pescara district	spring	98	-
ACA	Pescara district	well	-	43
GSA	L'Aquila district	spring	100	-
GSA	L'Aquila district	well	-	38
RUZZO	Teramo district	spring	123	-
CAM	Avezzano area (L'Aquila District)	spring	80	-
CAM	Avezzano area (L'Aquila district)	well	.	101
SACA	Sulmona area (L'Aquila district)	spring	74	-
SACA	Sulmona area (L'Aquila district)	well	-	29
SASI	Chieti district	spring	171	-
SASI	Chieti district	well	-	21

Table 2.1: The potential sites (wells and springs) managed by the Water Management Companies (WMC) of Abruzzi region and their relative areas of competence (Administrative District Province and main towns: ADP)

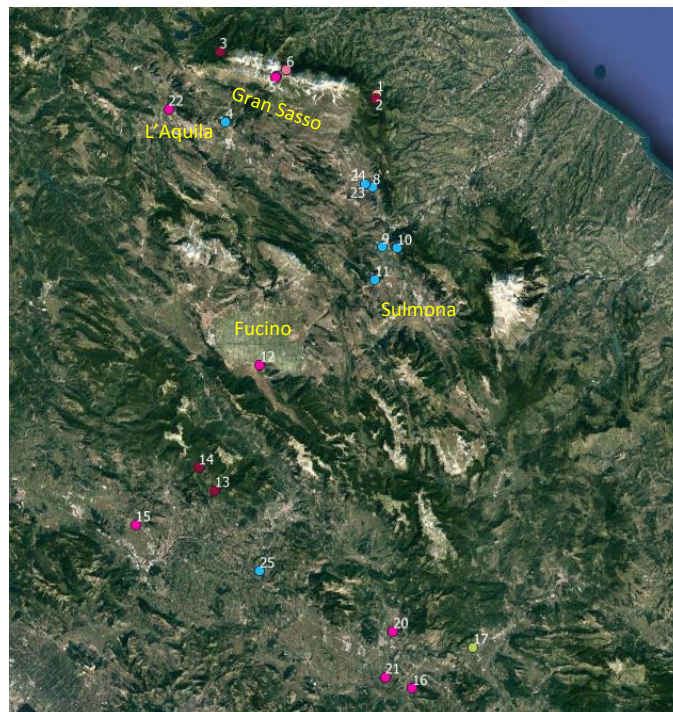


Figure 2.2: Location of several sites managed by INGV that can be selected as potential sites for radon monitoring

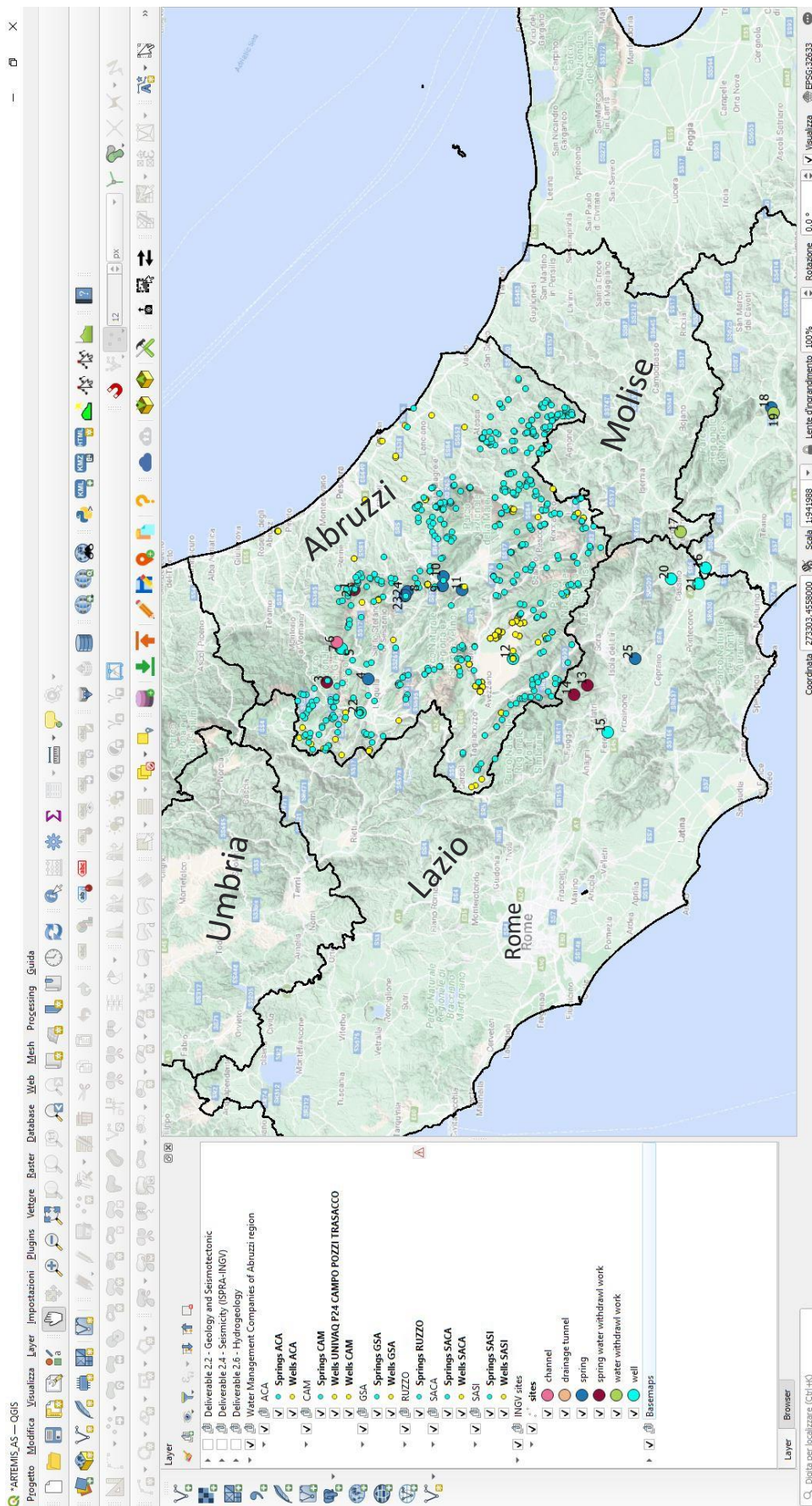


Figure 2.3: The structure of the QGIS project with the location of the potential sites for radon monitoring, represented by wells (in yellow) and springs (in blue), of the Abruzzi Water Companies

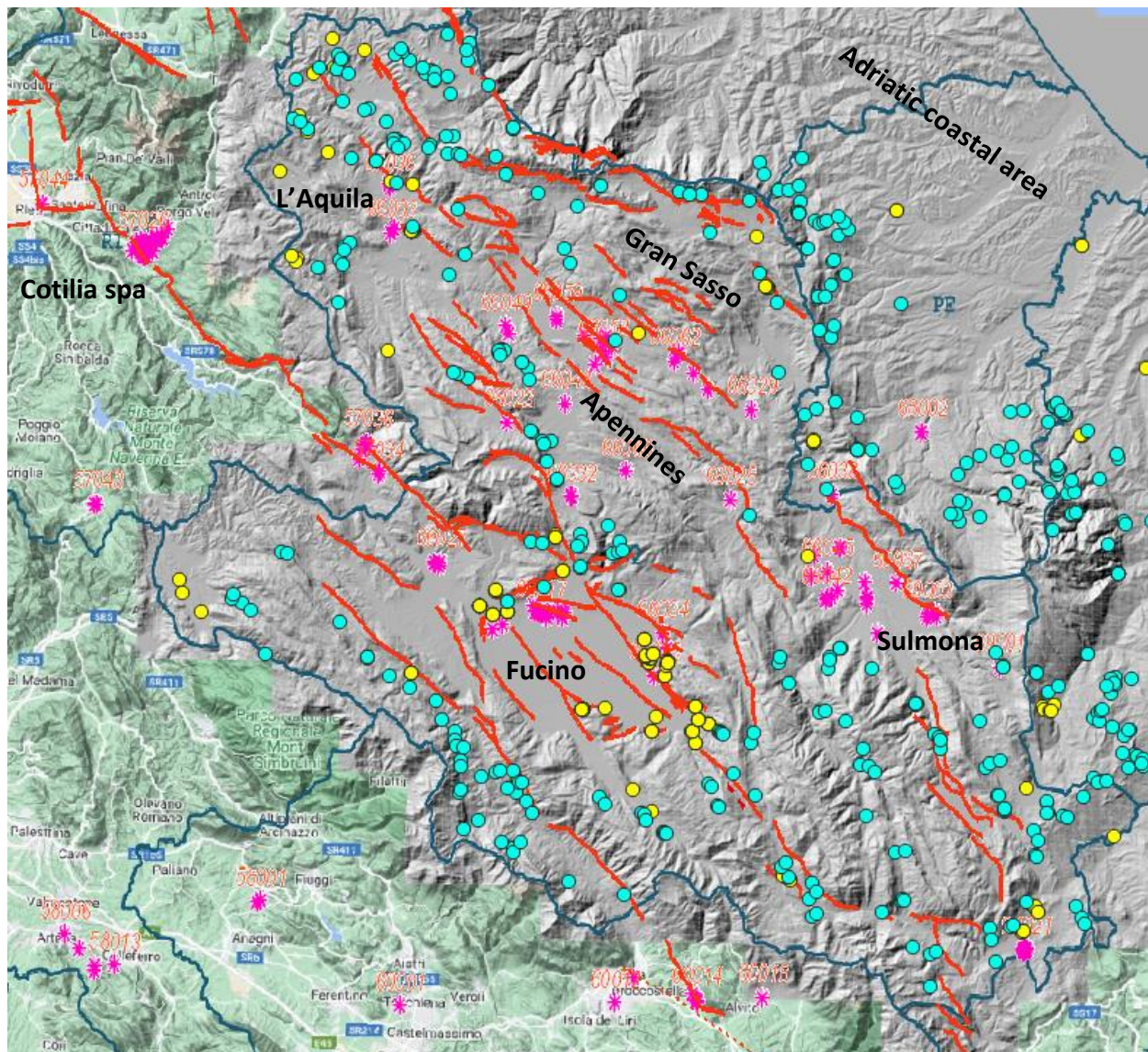


Figure 2.4: Sinkholes in carbonate-karst terrains and intermontane plains of Abruzzi (from WMS by ISPRA: <http://sgi2.isprambiente.it/arcgis/services/servizi/sinkhole/MapServer/WmsServer>). Note the significant occurrence of sinkholes in the main Abruzzi plains (L'Aquila, Sulmona and Fucino) and in the hydrothermal area of Cotilia spa. Red lines: seismogenic faults; dots: potential sites for radon monitoring (wells and springs in blue and yellow colours respectively)

At each point, in addition to the sinkhole code, there are general information (i.e. geographic coordinates, date of formation, municipality of location, genetic mechanism, soil use, geomorphological features, lithology, etc.).

The sinkhole is a geomorphological feature typical of karst terrains. It is a mainly subcircular depression or hole in the ground caused by some form of ground surface collapse. In central Italy the formation of many of these sinkholes, which sometimes occurs catastrophically, are due also to the upwelling of geogas (Nisio et al., 2007) (fig. 2.5). So, their location is quite interesting for radon monitoring within the artEmis project.

Again, L'Aquila, Sulmona and Fucino plains with the hydrothermal area of Cotilia spa (30 km west to L'Aquila), could be areas where select the potential sites for radon monitoring because, in addition to the occurrence of seismogenic faults and the significant springs, many sinkholes are placed (figs. 2.6-2.9).



Figure 2.5: Sinkhole at the hydrothermal area of Cotilia spa. Note the light blue colour of cold mineralized spring water because of the precipitation of calcite microminerals and the subcircular shape of the sinkhole due the collapse of underground cavities facilitated by the aggressive geogas upwelling through (active) faults (from Google Earth Pro)

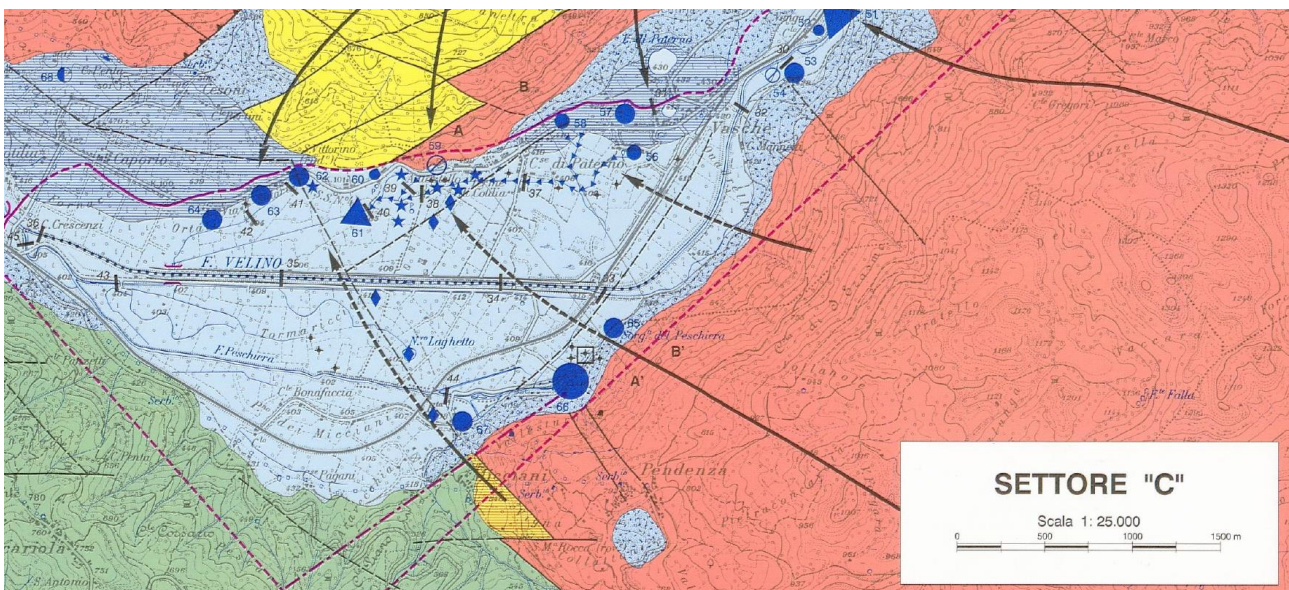


Figure 2.6: Hydrogeological map by Boni et al. (1995) of the hydrothermal area of Cotilia spa (30 km west to L’Aquila). In the hydrogeological map the springs (punctual spring: blue dot, linear spring: blue triangle) and geogas emissions point (blue star) are reported. In the alluvial plain (light blue area) many geogas emissions are widespread



Figure 2.7: The hydrothermal area of Cotilia spa (30 km west to L’Aquila) in which sinkholes by ISPRA database (<http://sgi2.isprambiente.it/arcgis/services/servizi/sinkhole/MapServer/WmsServer>) and seismicogenic faults by ITHACA database (<http://sgi.isprambiente.it/ithaca/viewer/index.html>) are reported. Note the sinkholes aligned along the seismicogenic fault which cross the Velino R. plain (Miccianni fault Auct.: MF)

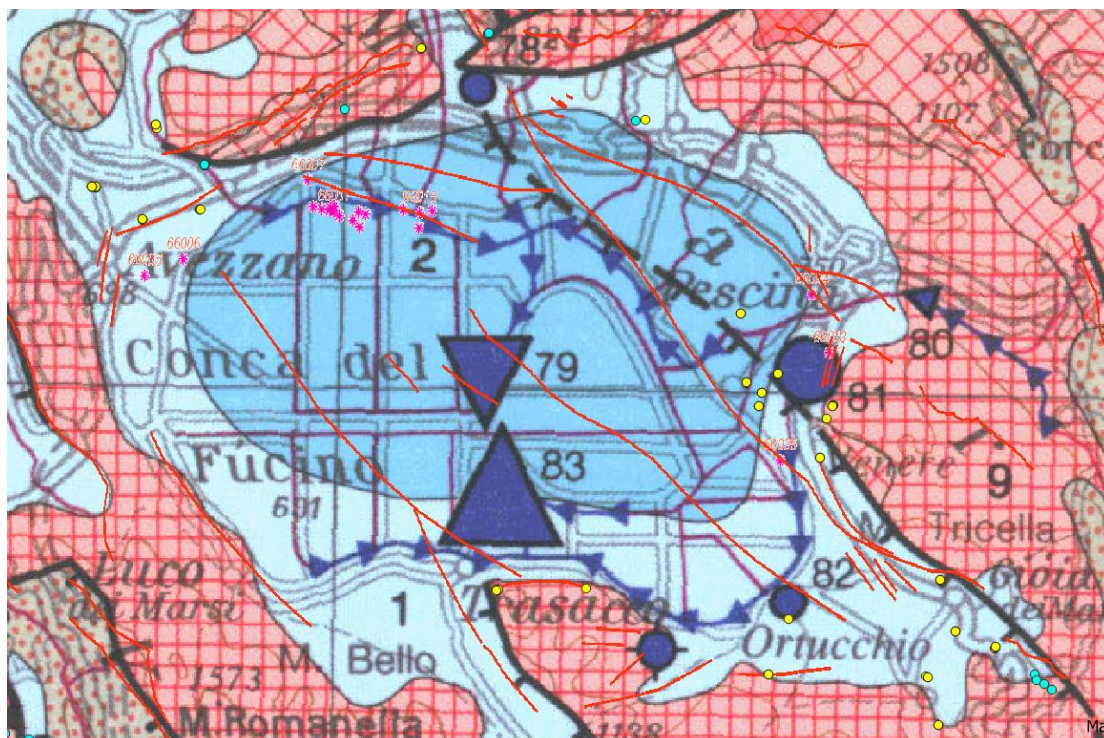


Figure 2.8: The Fucino plain (40 km south to L’Aquila). Hydrogeological map by Boni et al. (1995) with sinkholes by ISPRA database, seismicogenic faults (red lines) from ITHACA database and the springs (blue dots) and wells (yellow dots) of the Water Companies Note the abundance of sinkholes and springs sometimes aligned along the seismicogenic faults

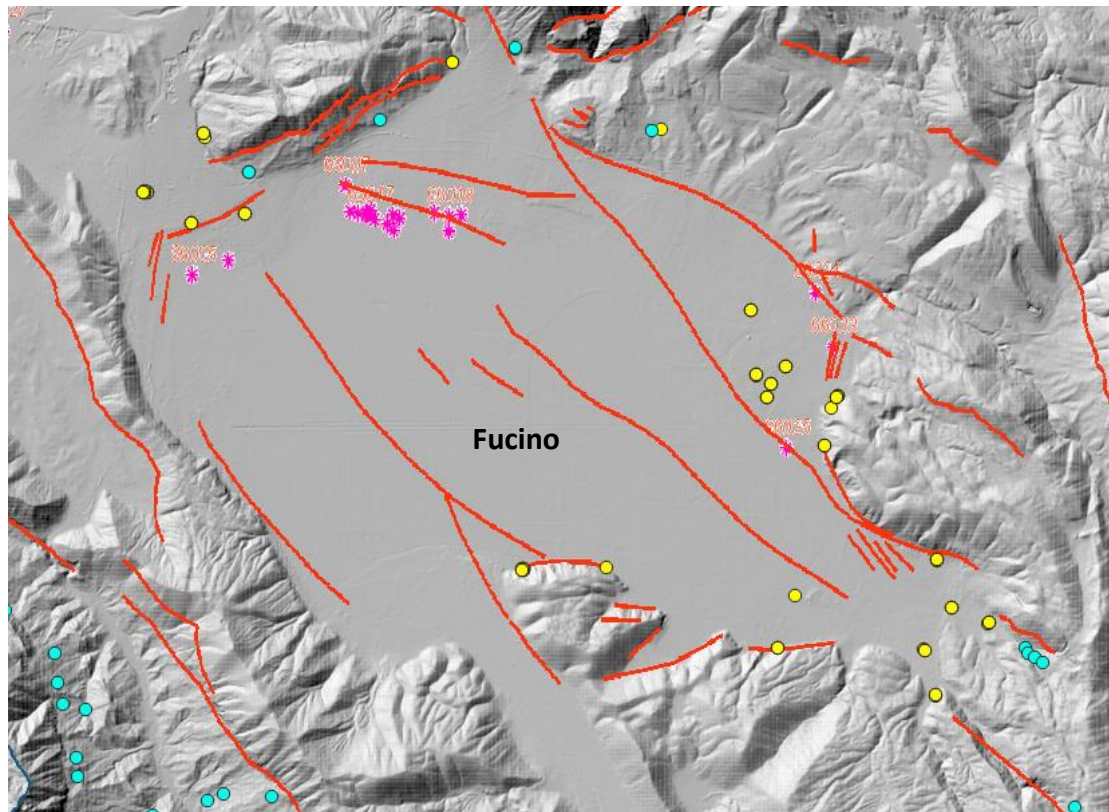


Figure 2.9: The Fucino plain (40 km south to L’Aquila). DEM with sinkhole by ISPRA database and seismogenic faults (red lines) from ITHACA database and the springs (blue dots) and wells (yellow dots) of the Water Companies. Note the abundance of sinkholes sometimes aligned along the seismogenic faults

The subfolder named "Hydrogeological maps" of the QGIS project holds several hydrogeological maps at regional scale: the two sheets of the “Hydrogeological scheme of central Italy” at 1:500,000 scale by Boni et al. (1986) (figs. 2.10-2.12) and the hydrogeological map of central-southern Italy by Celico (1983) (fig. 2.13).

In the hydrogeological map by Boni et al. (1986) many hydrogeological data and features are reported: the hydrogeological complexes (fig. 2.10), several hydrogeological sections (fig. 2.11), the punctual and linear springs with the spring altitude, the discharge values and the principal chemico-physical parameters (temperature, TDS) (fig. 2.12), the direction of the groundwater flowpaths, spring related to karst cave system, geogas leak associated with small springs, submarine springs, deep boreholes, the main geological elements such as undefined and extensional faults, thrusts, volcanic caldera border, minor volcanic apparatus. In the map the springs are also classified in cold and not mineralised (blue colour), cold and mineralised (yellow colour) and hot and mineralised (red colour). This latter category refers to hydrothermal groundwater circulation (fig. 2.12).

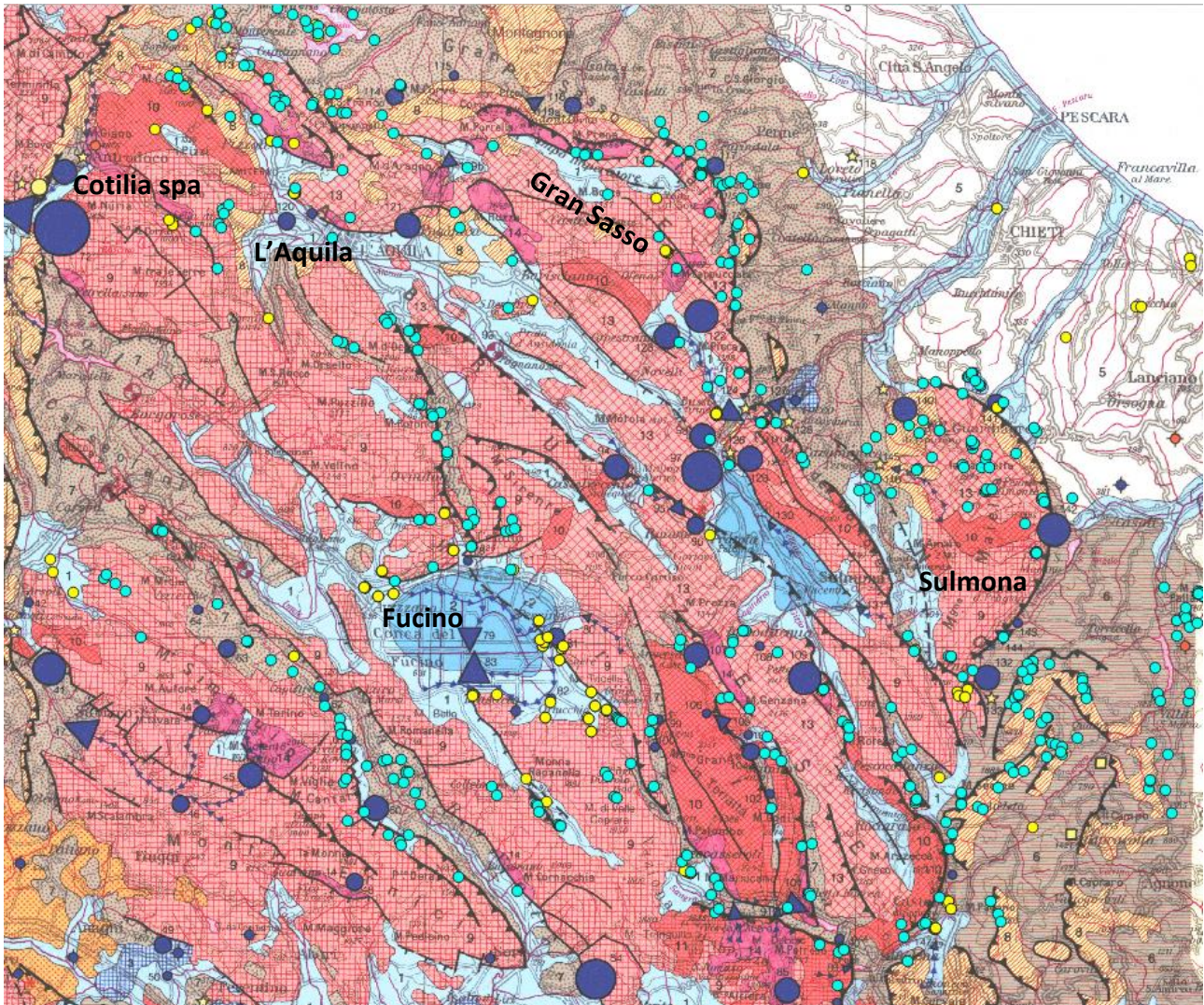


Figure 2.10: Part of the hydrogeological scheme of central Italy by Boni et al. (1986) with the location of the potential sites (wells: yellow dots; springs: light blue dots). The red, brown and light blue areas correspond to the regional carbonate aquifers, the regional terrigenous aquiclude and the local aquitard (detrital multilayer aquifer) of the intermontane plains and the alluvial valleys, respectively. The blue dot and triangle refer to the punctual and linear spring and their symbol dimension is proportional to the discharge values. The black lines refer to the main faults and thrusts

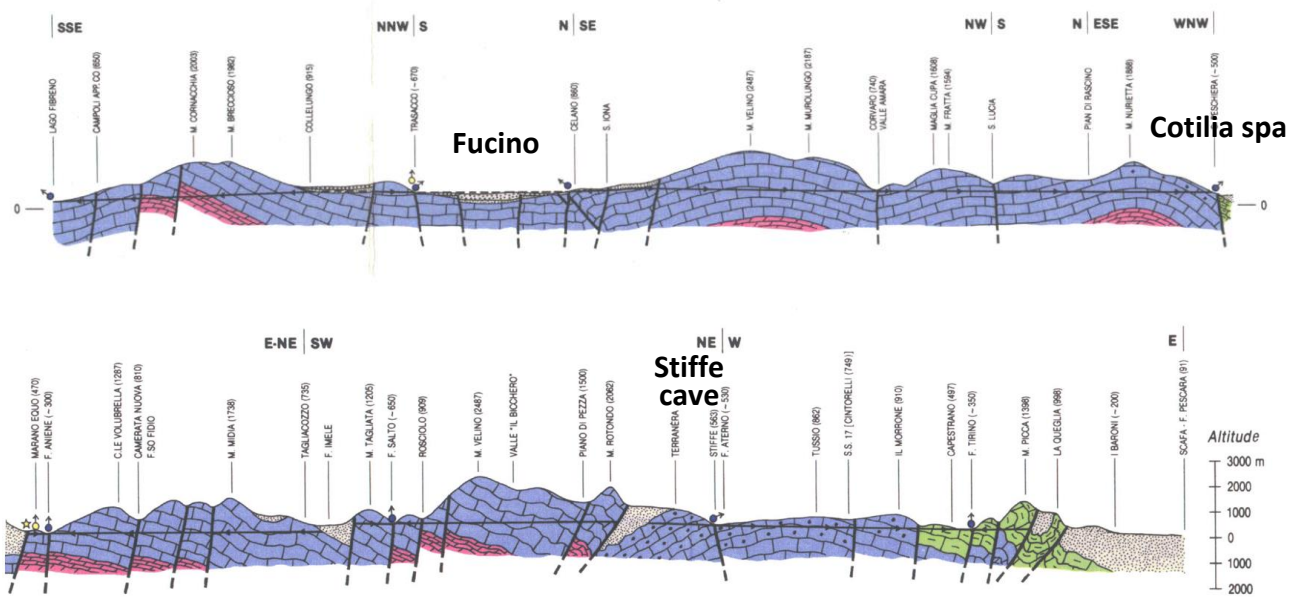


Figure 2.11: Hydrogeological sections crossing the Abruzzi region by Boni et al. (1986). The blue and green, black dotted and violet areas correspond to the regional carbonate aquifers, the regional terrigenous aquiclude and the dolomitic regional aquiclude, respectively. The dark blue dots and lines refer to the springs and the water table

PORTATA MEDIA MISURATA • MEASURED MEAN DISCHARGE (m ³ /s)							SALINITÀ (TDS) g/l	TEMPERATURA °C
0.1 – 0.5	0.5 – 1.0	1 – 3	3 – 6	6 – 10	10 – 15	15 – 20		
							<0.75	<20
							>0.75	<20
							>0.75	>20

Figure 2.12: Legend of the punctual springs in the hydrogeological map by Bono et al. (1986)

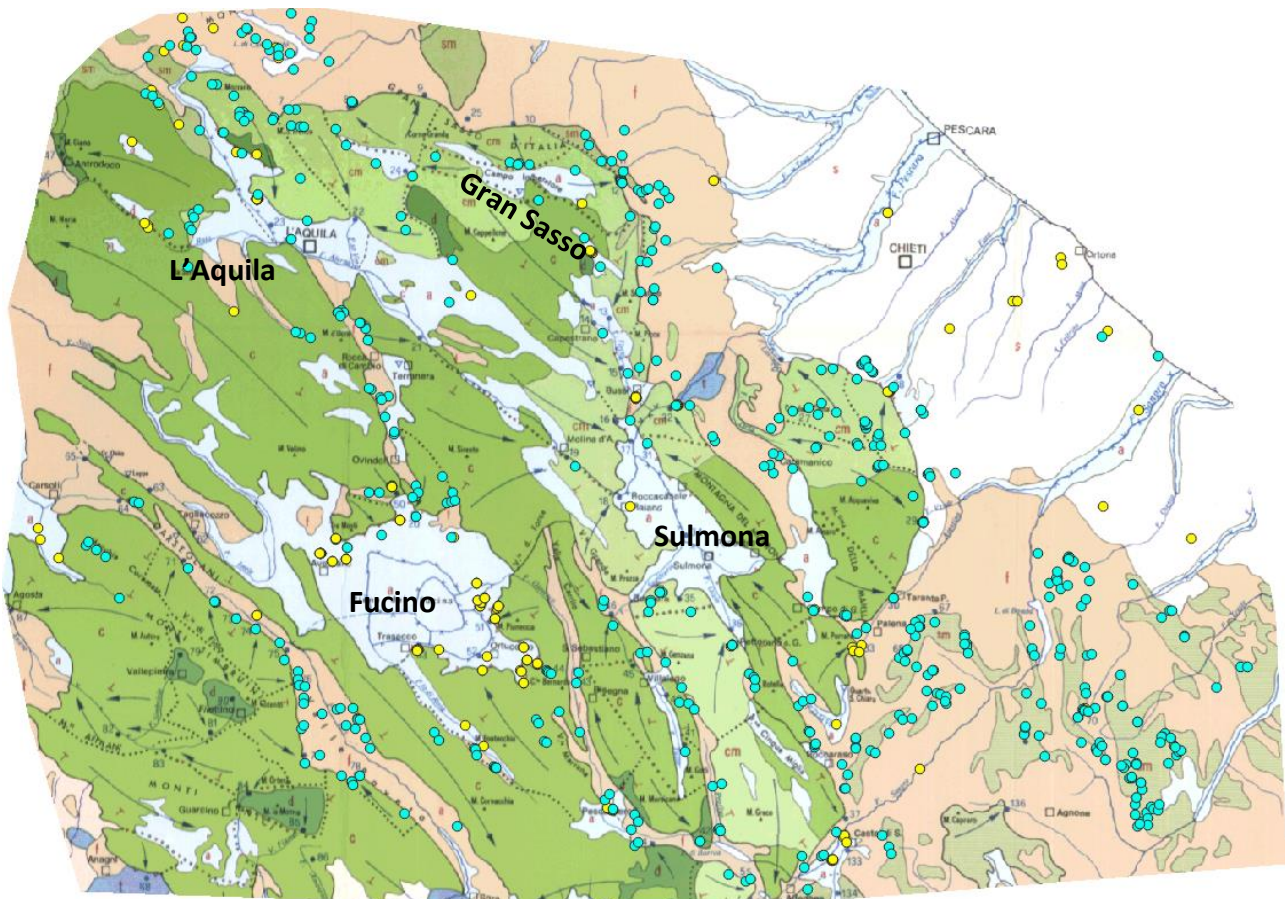


Figure 2.13: Part of the hydrogeological scheme of central-southern Italy by Celico (1983) with the location of the potential sites (wells: yellow dots; springs: light blue dots). The green, light brown and light blue areas correspond to the regional carbonate aquifers, the regional terrigenous aquiclude and the local aquitard (detrital multilayer aquifer) of the intermontane plains and the alluvial valleys, respectively

The hydrological map by Boni et al. (1986) conversely contains meteorological data (air temperature and rainfall) and hydrometric data (river discharge). Further, in this map, the water budget of the main hydrogeological systems and the groundwater resources are estimated and reported in tables. In specific tables are also reported the base flow of the main rivers and the effective infiltration of the aquifers.

The hydrogeological setting with the springs, the seismogenic faults and the sinkholes of the intermontane plains of the Abruzzi region (L'Aquila Fucino and Sulmona) considered the main interesting areas in which the potential sites can be selected are reported (figs. 2.14-2.16).

Further, in the QGIS project is also stored the hydrogeological scheme of the Gran Sasso Massif at 1:150,000 scale by Petitta and Tallini (2002) (fig. 2.17).

This map is representative of the more emblematic carbonate-fissured aquifer of the Abruzzi region which can be considered a case-study area within the artEmis project because the Gran Sasso aquifer feeds several significant springs and is crossed by many seismogenic faults (fig. 2.17).

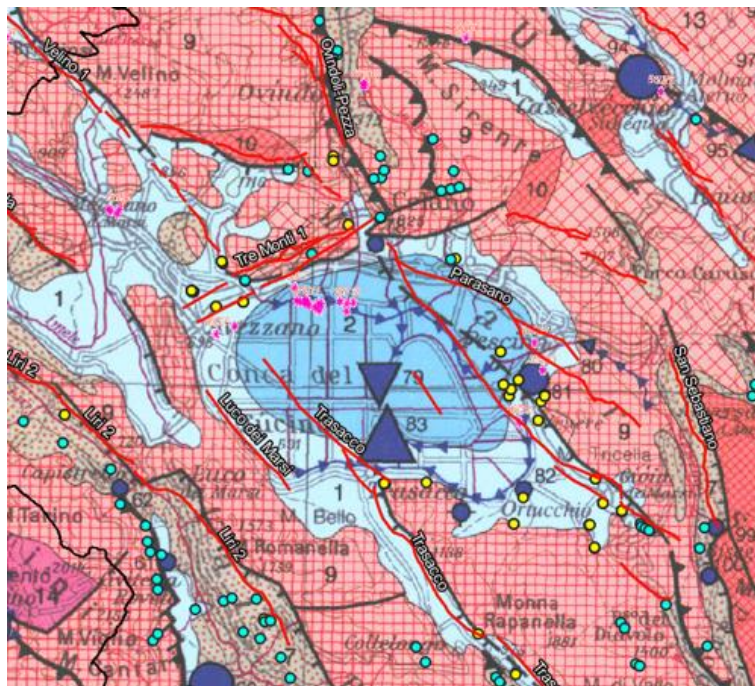


Figure 2.14: The hydrogeological setting of Fucino plain from the “Hydrogeological scheme of central Italy” by Boni et al. (1986). The location of wells (yellow dots) and springs (light blue dots) is shown. The red lines are fault from the fault database of Carafa et al. (2022), while pink stars are sinkholes from the ISPRA WMS service (<http://sgi2.isprambiente.it/arcgis/services/servizi/sinkhole/MapServer/WmsServer>)

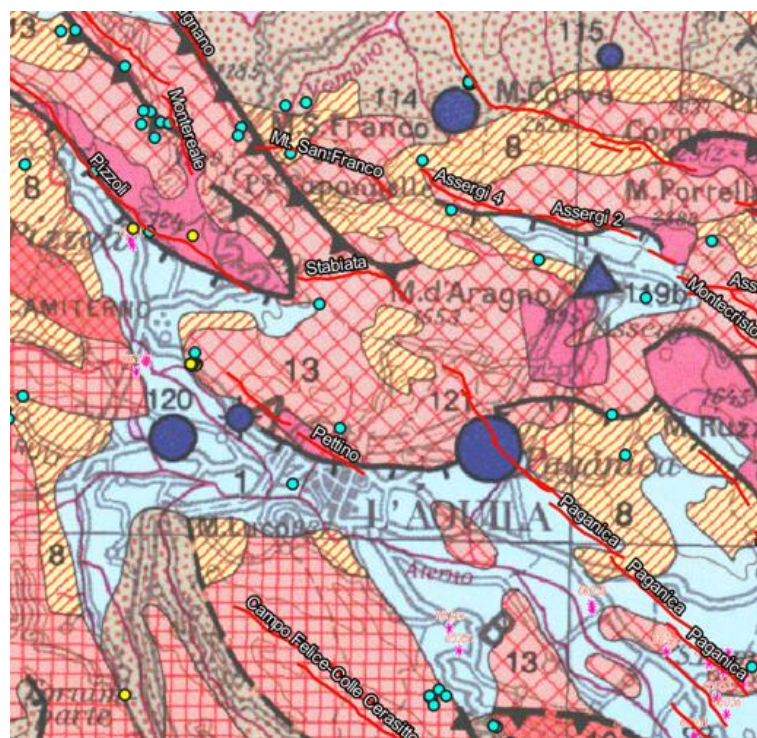


Figure 2.15: The hydrogeological setting of L'Aquila plain from the “Hydrogeological scheme of central Italy” by Boni et al. (1986). The location of wells (yellow dots) and springs (light blue dots) is shown. The red lines are fault from the fault database of Carafa et al. (2022), while pink stars are sinkholes from the ISPRA WMS service (<http://sgi2.isprambiente.it/arcgis/services/servizi/sinkhole/MapServer/WmsServer>)

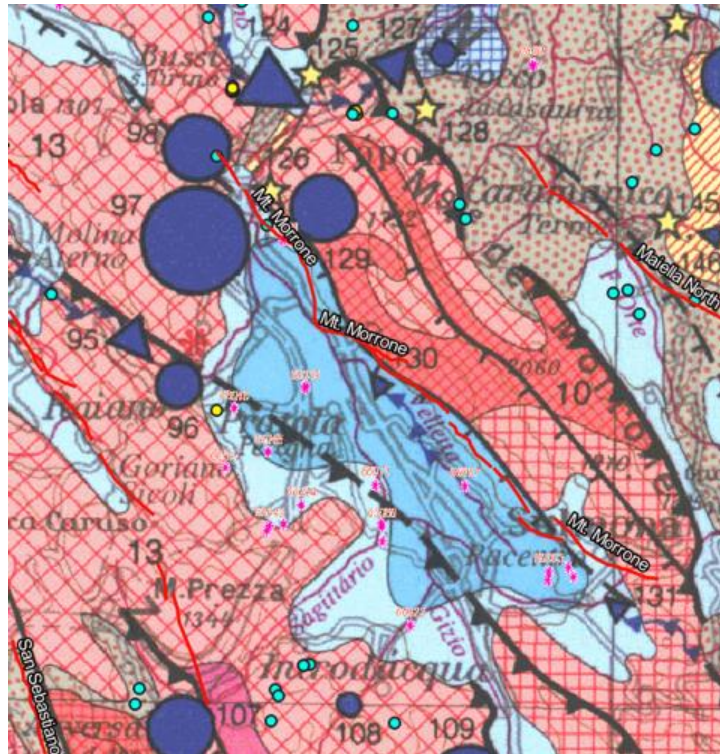


Figure 2.16: The hydrogeological setting of Sulmona plain from the “Hydrogeological scheme of central Italy” by Boni et al. (1986). The location of wells (yellow dots) and springs (light blue dots) is shown. The red lines are faults from the fault database of Carafa et al. (2022), while pink stars are sinkholes from the ISPRA WMS service (<http://sgi2.isprambiente.it/arcgis/services/sinkhole/MapServer/WmsServer>)

Moreover, within the Gran Sasso core aquifer, the LNGS Underground Nuclear Physics laboratory are located. Potential sites for radon monitoring within the LNGS laboratory can be selected because previous studies have proved that they are hydrosensitive with respect to the seismicity (De Luca et al., 2016; 2018) and do not show hydrological noise due to shallow processes because LNGS laboratory are located at great depths with 1000 meters of rock above it.

In the Gran Sasso map, several hydrogeological complexes were classified and mapped (Petitta and Tallini, 2002) (fig. 2.17). The calcareous complex (n.6, light green colour, in the map) prevails. It is represented by mainly stratified limestones locally interlayered with dolomitic limestones. The complex n. 6 has a high permeability, due to fracture network and karst features and holds the Gran Sasso groundwater. Dolomitic lithologies (n. 7, violet colour, in the map) act as regional aquiclude and are placed only at the base of the calcareous complex so sustaining the Gran Sasso groundwater located within the calcareous complex. Marly and calcareous-marly lithologies (n. 4 and 5, dark green colour, in the map) act as local aquiclude and aquitard and are placed conversely in the upper part of the calcareous complex (n. 6) in the NW and central sector of the Gran Sasso aquifer. These hydrogeological complexes (n. 4-7) pertain to the Meso-Cenozoic pre-orogenic formations attributable to shallow-water carbonate platform (with relative reef edge), slope to basin and deep-water basinal lithofacies.

The upper Miocene sandstone and clayey-marly lithologies, corresponding to syn-orogenic foredeep turbidite deposits (n. 3, light brown, in the map) represent the regional aquiclude. They border the above-mentioned carbonate aquifer (n. 6, 4, 5), above all in the northern Gran Sasso slope.

Southward the Gran Sasso aquifer is bounded by the post-orogenic Plio-Quaternary detrital continental deposits (n.1 and 2, light blue and light yellow, respectively in the map) filling up the intermontane plains

and pertain to mainly lacustrine, fluvial, glacial, and slope lithofacies. In many cases, this boundary is not totally free of discharge and small volumes of groundwater partially flow into the permeable detrital-clastic sediments so favouring their recharge by the carbonate aquifer.

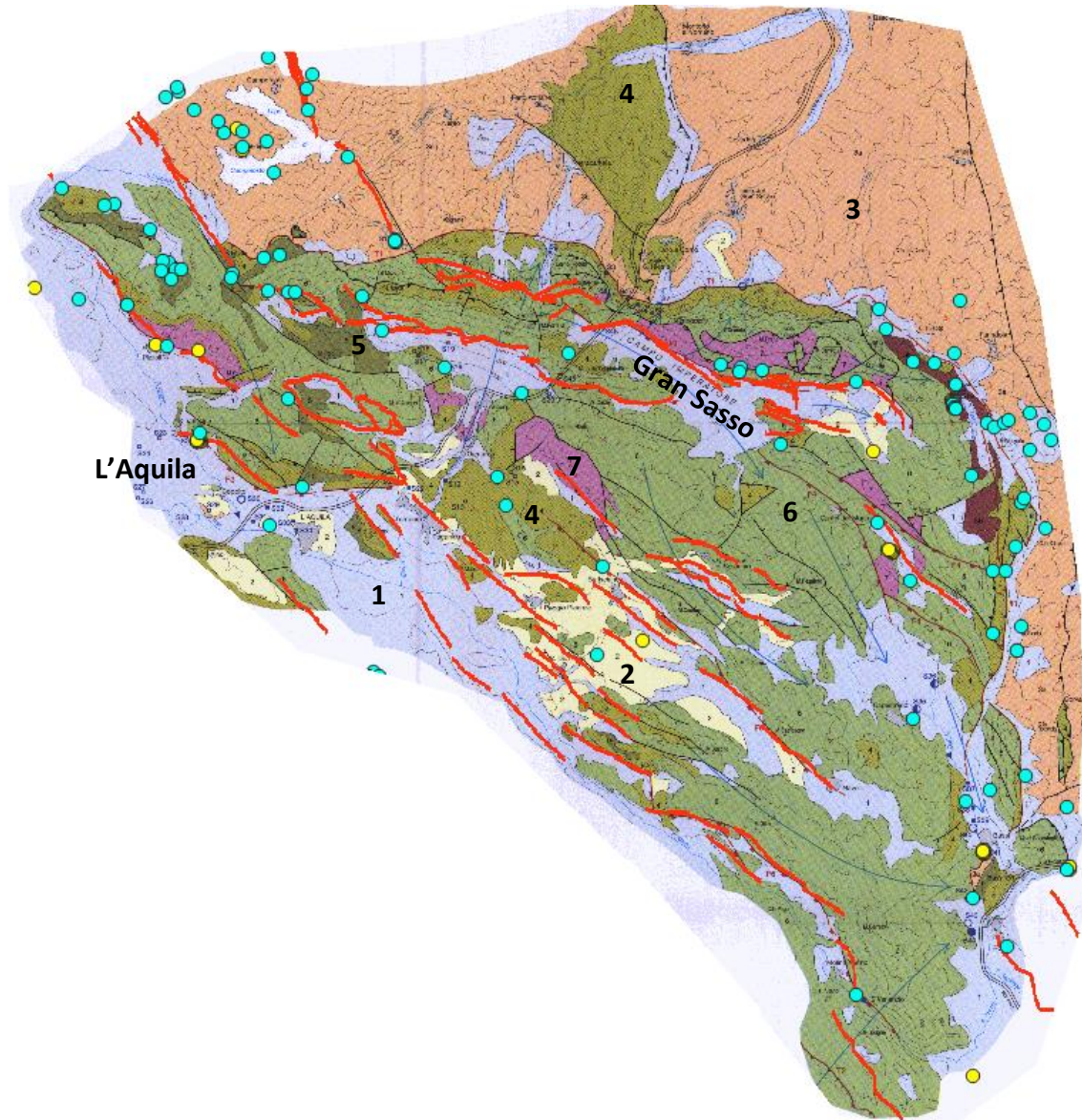


Figure 2.17: The hydrogeological scheme of the Gran Sasso massif by Petitta and Tallini (2002) with the location of the potential sites (wells: yellow dots; springs: light blue dots). The green, light brown and light blue areas correspond to the carbonate aquifer, the terrigenous aquiclude and the local aquitard (detrital multilayer aquifer) of the intermontane plains and the alluvial valleys, respectively. The red lines refer to the seismogenic fault of the ITHACA database by ISPRA (<http://sgi.isprambiente.it/ithaca/viewer/index.html>)

Further, in the map by Petitta and Tallini (2002) the discharge values, the main ions, temperature, electrical conductivity, and stable water isotopes ($\delta^2\text{H}$ and $\delta^{18}\text{O}$) of the main springs are reported too (fig. 2.18).

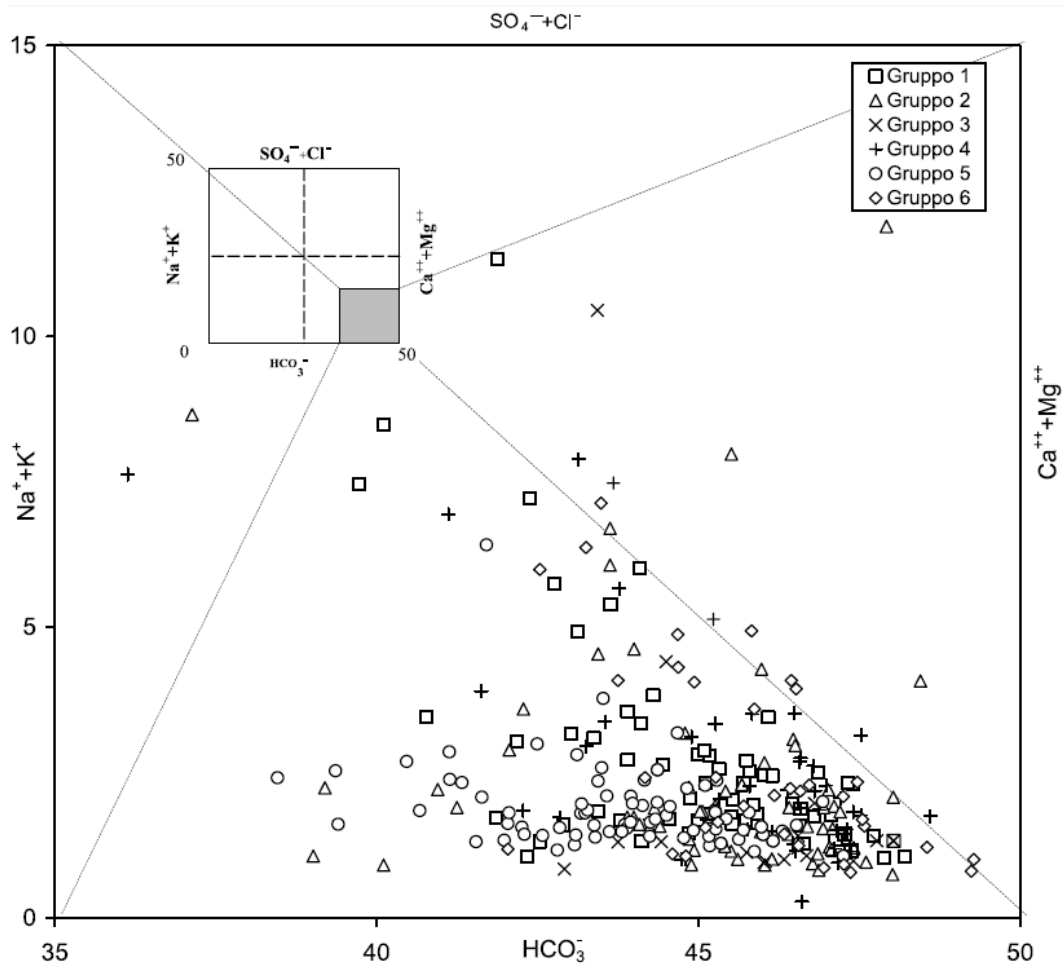


Figure 2.18: Langlier-Ludwig square diagram in which the hydrochemical data of the Gran Sasso springs are reported (Petitta and Tallini, 2002). Note that since groundwater flows in calcareous aquifer, its chemistry is mainly calcium-bicarbonate type as can be seen in the Langlier-Ludwig diagram

In synthesis, the main interesting areas in which the potential sites could be selected are the principal intermontane plains of Abruzzi region (L'Aquila Fucino and Sulmona), the Cotilia spa and the Gran Sasso core aquifer, because these areas are near significant seismogenic faults and high discharge springs are widespread. Moreover, the Cotilia spa and the Gran Sasso core aquifer are possibly hydrosensitive with respect to the seismicity because the first is an hydrothermal area and for the latter, studies proved this behaviour (De Luca et al., 2016; 2018).

2.1 References

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extension://efaidnbmnnnibpcajpcglclefindmkaj/https://aset.acs.beniculturali.it/dm_0/00/high/biblio/pdf/Quaderno-4_2.pdf (accessed 4.21.23)

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Petitta, M., Tallini, M., 2002. Idrodinamica sotterranea del massiccio del Gran Sasso (Abruzzo): indagini idrologiche, idrogeologiche e idrochimiche (1994–2001) [Underground hydrodynamics of the Gran Sasso massif (Abruzzo): hydrological, hydrogeological and hydrochemical investigations (1994–2001)]. *Boll. Soc. Geol. D'It.* 121, 343–363

3 GIS map and database of hydrogeology of Ionian Islands and Gulf of Corinth

This section describes the workflow and the structure of the developed GIS databases and the corresponding maps about the hydrogeological setting of central Ionian Islands and Gulf of Corinth, Greece. It includes details about the data compiled for the developed databases (hydrolithological formations and locations of water resources of the selected areas), along with the descriptions concerning the structure of the related databases. Examples of maps with the hydrogeological characteristics for both the central Ionian Islands and Gulf of Corinth using the associated shapefiles, are also given.

The primary input for the construction of the hydrogeological GIS database and the respective maps for both the selected areas is the georeferenced hydrolithological map of Greece in 1:1.000.000 scale (Ministry of Development and Investments, 1996), in which the characterization of the geological formations of the selected areas is made on the basis of their permeability (alluvial, karstic and non-permeable formations). In detail, the mapped areas covering both the central Ionian Islands (Lefkada and Kefalonia) and the Gulf of Corinth are georeferenced and stored in the artEmis hydrogeological GIS database in .tiff format. Additionally, already published maps of various hydrogeological characteristics provided by Spyrou et al. (2022) for the central Ionian Islands and by Voudouris et al. (2005) for the Gulf of Corinth are also georeferenced and stored in the artEmis hydrogeological database via the QGIS software.

Further, the available shapefiles containing information about various water resources of the selected areas are compiled from the portal <http://geodata.gov.gr/en/dataset> (Athanasίου et al., 2011; last accessed on April 2023). Specifically, the series of the compiled shapefiles includes:

1. *The water sub-basins of Greece shapefile*

This dataset contains the sub-basins comprising the water basins of Greece, including both the selected areas (central Ionian Islands and Gulf of Corinth). The thematic layer of sub-basins includes the fields provided for both in accordance with the Inspire Directive and with the Community Directive on water (2000/60/EC).

2. *The hydrographic network of Greece shapefile*

This dataset contains the hydrographic network of Greece, including both the selected areas (central Ionian Islands and Gulf of Corinth).

3. *The Greek rivers and stream shapefile*

These data include mapped water surfaces of the rivers and streams of Greece, including both the selected areas (central Ionian Islands and Gulf of Corinth) and were created under Community Directive on water (2000/60/EC).

4. *The groundwater sources of Greece shapefile*

This dataset contains the boundaries of the Groundwater of Greece, including both the selected areas (central Ionian Islands and Gulf of Corinth). Groundwater is all water which is below the surface of the ground in the saturation zone and in direct contact with the ground or subsoil.

The maps are prepared by using the Digital Elevation Model (DEM) of Greece provided by the Copernicus Land Monitoring Service (<https://land.copernicus.eu/imagery-in-situ/eu-dem>; last accessed on April 2023) for the construction of the geomorphological base maps of selected areas.

3.1 Hydrogeology GIS database and maps of central Ionian Islands

The central Ionian Islands, Lefkada and Kefalonia, are mainly covered by the permeable carbonate formations of Ionian and Paxos Zones and more recent alluvial sediments resulting in a complex hydrogeological setting which is characterized by alluvial and karstic groundwater aquifers.

From a hydrolithological point of view, Lefkada Island is composed by both granular alluvial sediments with medium to high permeability (formations with dark and light yellow colors, respectively in Figure 3.1) and medium to high permeability karstic formations (formations with green and blue colors, respectively in Figure 3.1) as it is derived from its georeferenced hydrolithological map.

On the other hand, Kefalonia Island is mainly covered by the carbonate formations of Paxos and Ionian Zones. This fact is highlighted also in its georeferenced hydrolithological map (Figure 3.2; formations with light blue color), in which an extended development of high permeability karstic aquifers network covering almost the entire island is shown.

The wide coverage of alluvial and karstic formations in both Lefkada and Kefalonia Islands, resulting in an extended network of various types of water sources (e.g., springs and lagoons and karstic elements, depicted with the light blue and yellow squares in Figure 3.3, respectively). Spyrou et al. (2022) compiled, evaluated and categorized the water sources of central Ionian Islands, based on a certain number of criteria.

Figure 3.3 shown a snapshot of the QGIS software workspace, in which the GIS Hydrogeological database of central Ionian Islands, along with the georeferenced map of their spatial distribution of the categorized water sources provided by Spyrou et al. (2022) is stored.

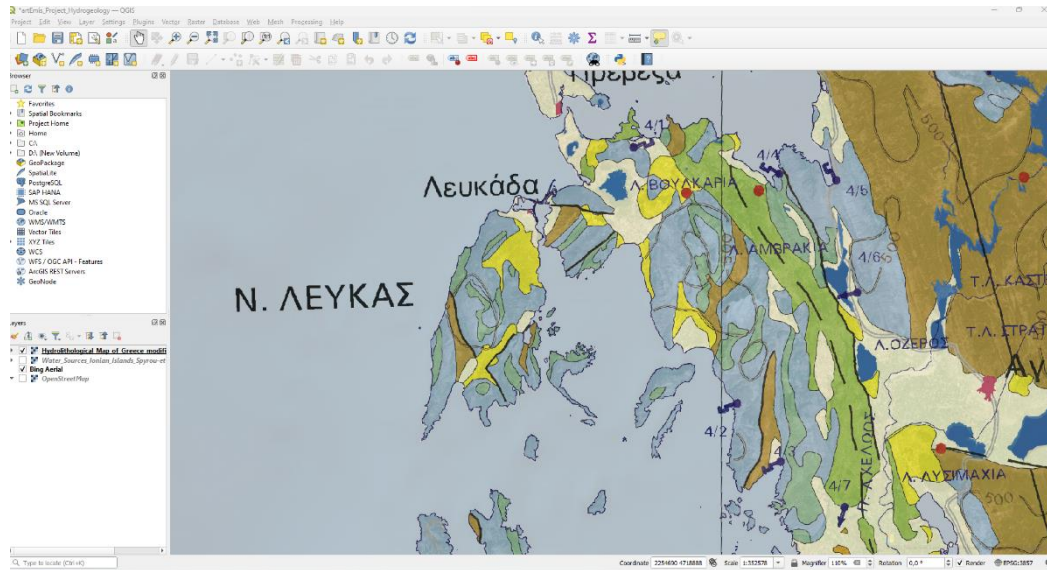


Figure 3.1: Snapshot of the QGIS workspace showing the georeferenced hydrogeological map of Lefkada Island taken from hydrogeological map of Greece, which is stored in the Hydrogeological GIS Database (dark and light yellow colors indicates the medium to high permeability alluvial formations, green and blue colors the medium to high permeability karstic formations. Whereas the brown color depicts the limited extension of the non-permeable formations)

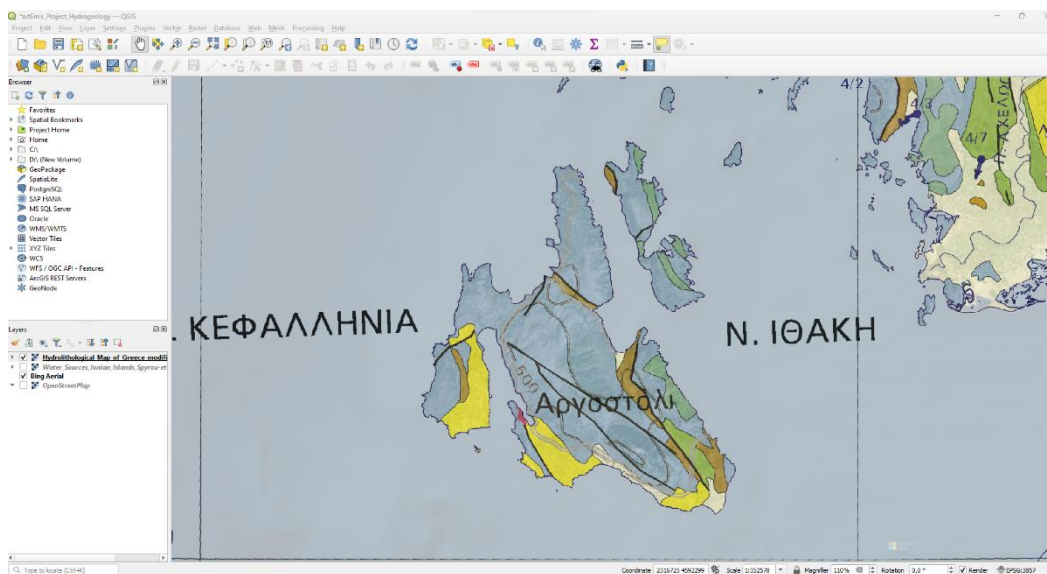


Figure 3.2: Snapshot of the QGIS workspace showing the georeferenced hydrogeological map of Kefalonia Island taken from hydrogeological map of Greece, which is stored in the Hydrogeological GIS Database (dark and light yellow colors indicates the medium to high permeability alluvial formations, green and blue colors the medium to high permeability karstic formations. Whereas the brown color depicts the limited extension of the non-permeable formations)

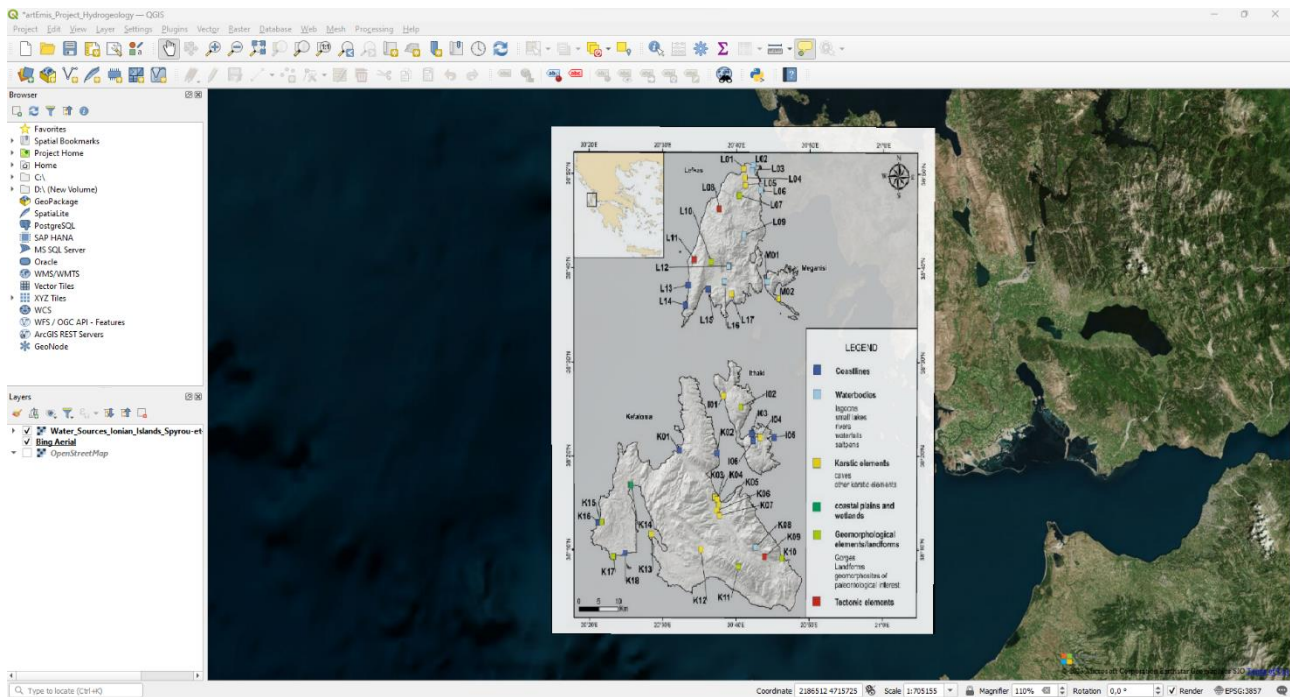


Figure 3.3: Snapshot of the QGIS workspace showing the georeferenced map of central Ionian Islands in which the spatial distribution of the water sources taken by Spyrou et al. (2022), which is stored in the Hydrogeological GIS Database. The different colored symbols depicted the various types of water sources according to the inset legend

3.2 Hydrogeology GIS database and maps of Gulf of Corinth

The area of Gulf of Corinth has a complex geological structure, composing by formations belonging to Pelagonian, Parnassos, Pindos and Gavrovo – Tripolitsa zones from its Easternmost to its Southernmost margins, along with a large amount of Quaternary and Plio-Pleistocene sediments. In terms of hydrolithology, in the area both alluvial and karstic permeable formations, especially along its southern coastline (Figure 3.4). Non-permeable formations are also extended in a large scale in its northwest margin.

Figure 3.4 shown the aforementioned hydrogeological setting, as derived by the georeferenced hydrolithological map of the Gulf of Corinth, using as input the hydrolithological map of Greece. The extracted georeferenced map of Corinth Gulf is stored as .tiff file format in the respective GIS Hydrogeological database.

As it is derived from the hydrolithological map of the study area, both granular alluvial and karstic aquifers, hosted in formations with medium to high permeability. The groundwater resources of Gulf of Corinth are distributed in both the northern and the southern coastlines.

Figure 3.5 shown an example of the development of a hydrogeological map of Gulf of Corinth with the use of QGIS software, containing the information about the location of the boundaries of the groundwater resources extended in the study area (dark blue shaded areas) using the respective shapefile (Groundwater_Resources.shp), along with the mapped water surfaces of the rivers and streams (light blue solid lines in map of Figure 3.5) flowing within the Gulf of Corinth, using the respective shapefile (Rivers_and_Streams.shp), as well.

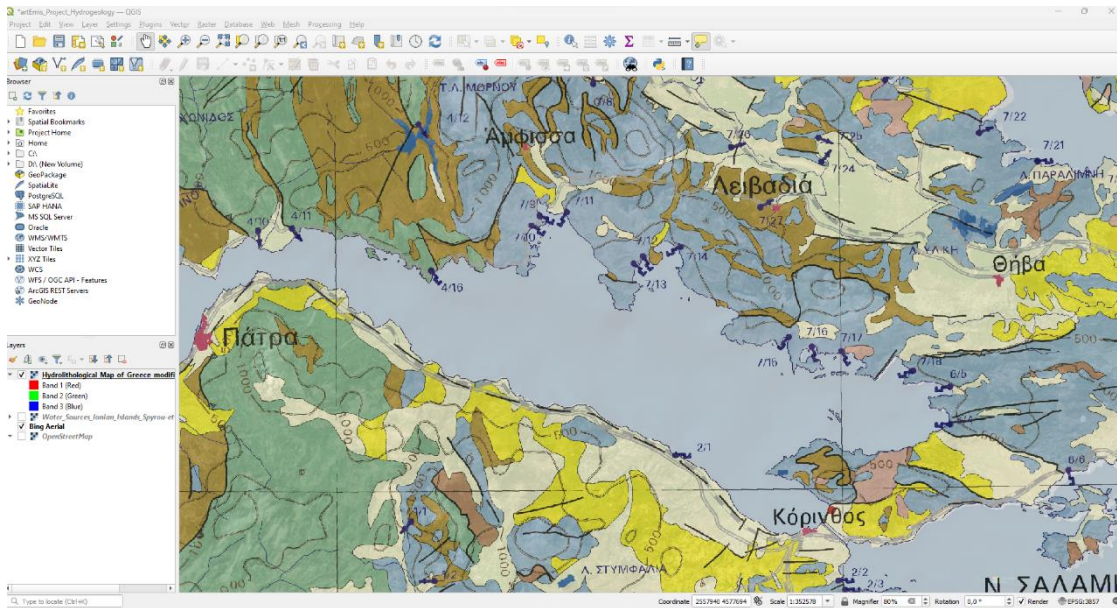


Figure 3.4: Snapshot of the QGIS workspace showing the georeferenced hydrogeological map of Gulf of Corinth taken from hydrogeological map of Greece, which is stored in the Hydrogeological GIS Database (dark and light yellow colors indicates the medium to high permeability alluvial formations, green and blue colors the medium to high permeability karstic formations. Whereas the brown colors depict the limited extension of the non-permeable formations)

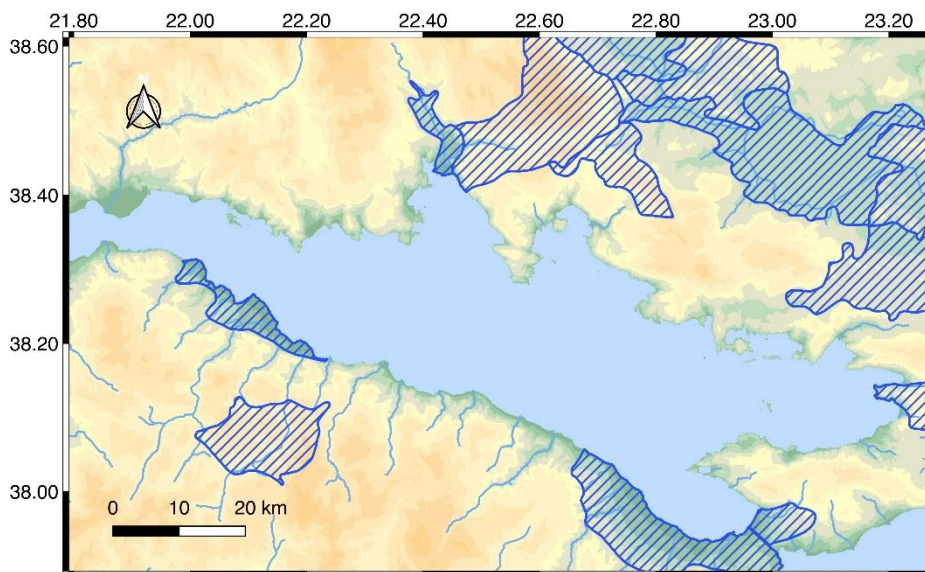


Figure 3.5: Geomorphological map of Gulf of Corinth showing the boundaries of its groundwater sources (dark blue shaded areas), along with the rivers and water streams (light blue solid lines) flowing within the study area, using the respective shapefiles compiled from the <http://geodata.gov.gr/en/dataset> portal

3.3 References

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4 GIS map and database of hydrogeology (Swiss Alps and Bedretto lab)

4.1 Swiss Alps

In this section, the maps and database of hydrogeology of Switzerland that are used in the QGIS project are described.

Most of the official swisstopo geospatial data have become freely available in recent years. For a quick overview or creating maps they can be displayed in any standard GIS Program such as QGIS as WMS (Web Mapping Service; <https://wms.geo.admin.ch/>). However, for calculations based on the geodata, they can be downloaded (often in various file formats, including shapefiles, Geodatabase (.gdb), and GeoPackage (.gpkg).

A very broad overview of the hydrogeological conditions in Switzerland is given in Fig. 4.1 (BAFU 2023b). In Switzerland, the hydrogeologic conditions can be assigned basically to three types of aquifers: i) Unconsolidated aquifers, ii) fissured aquifers, and iii) Karst aquifers.

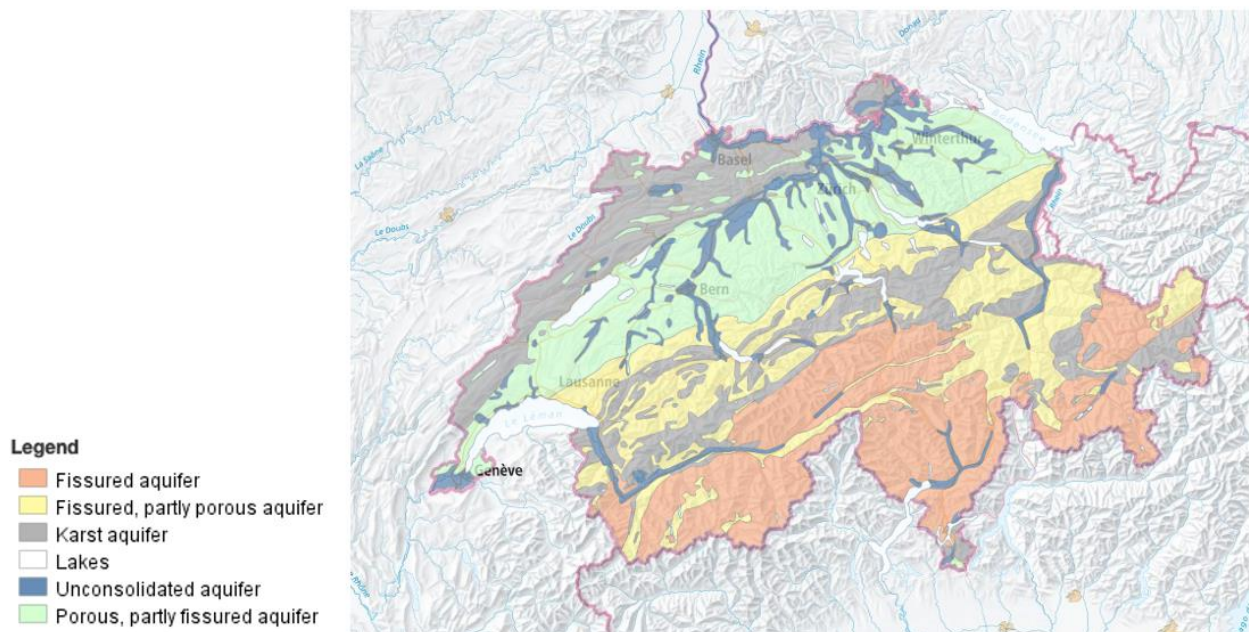


Figure 4.1: Hydrogeological Overview of Switzerland (data: BAFU 2023b)

An important dataset we use is the hydrogeological map of Switzerland 1:500'000 (Fig. 4.2, BAFU 2023a; Schürch et al. 2007). Apart from geological and tectonic information, it contains information regarding ground water. Important for our project may be the shapefiles “points exfiltration”.

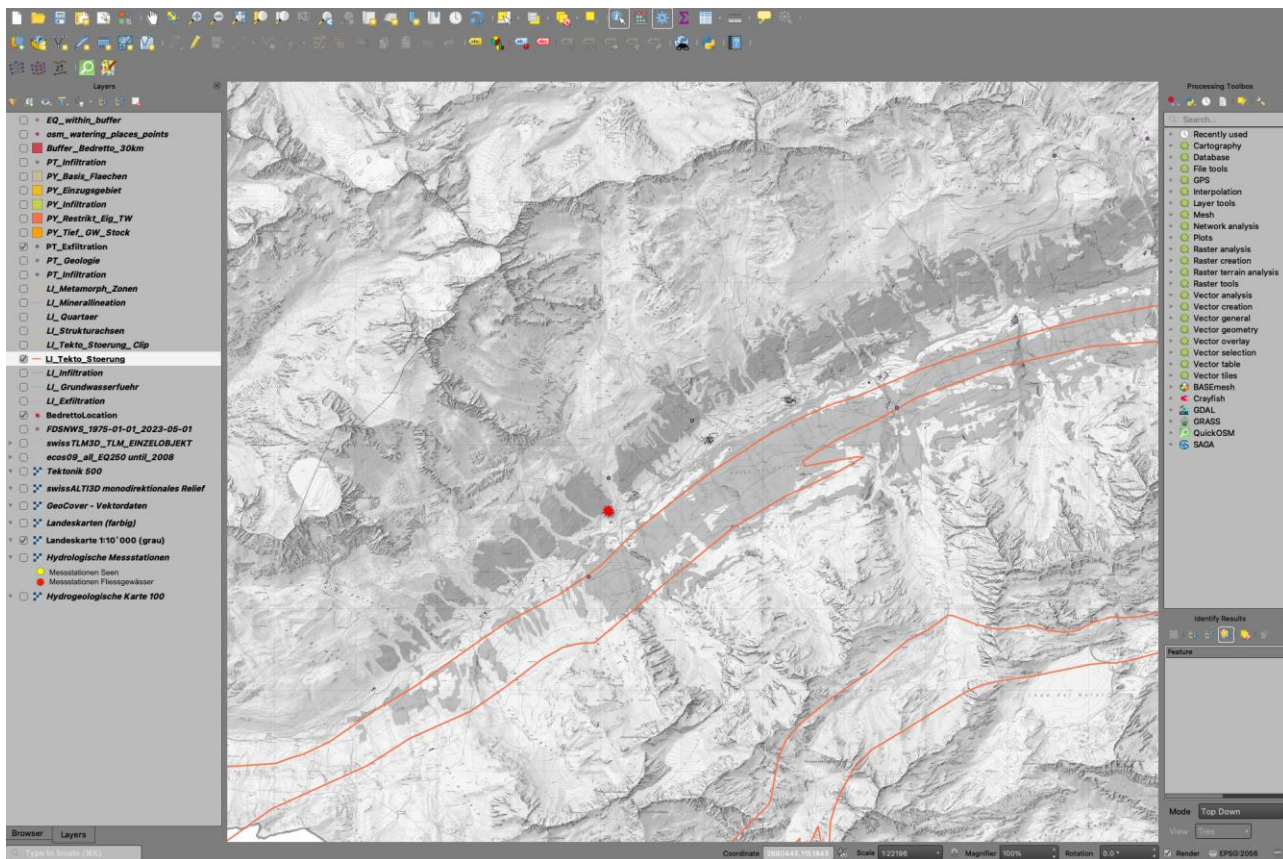


Figure 4.2: Extract from the hydrogeological map of Switzerland for the Bedretto Tunnel (red star) region. Purple dots indicate point exfiltration

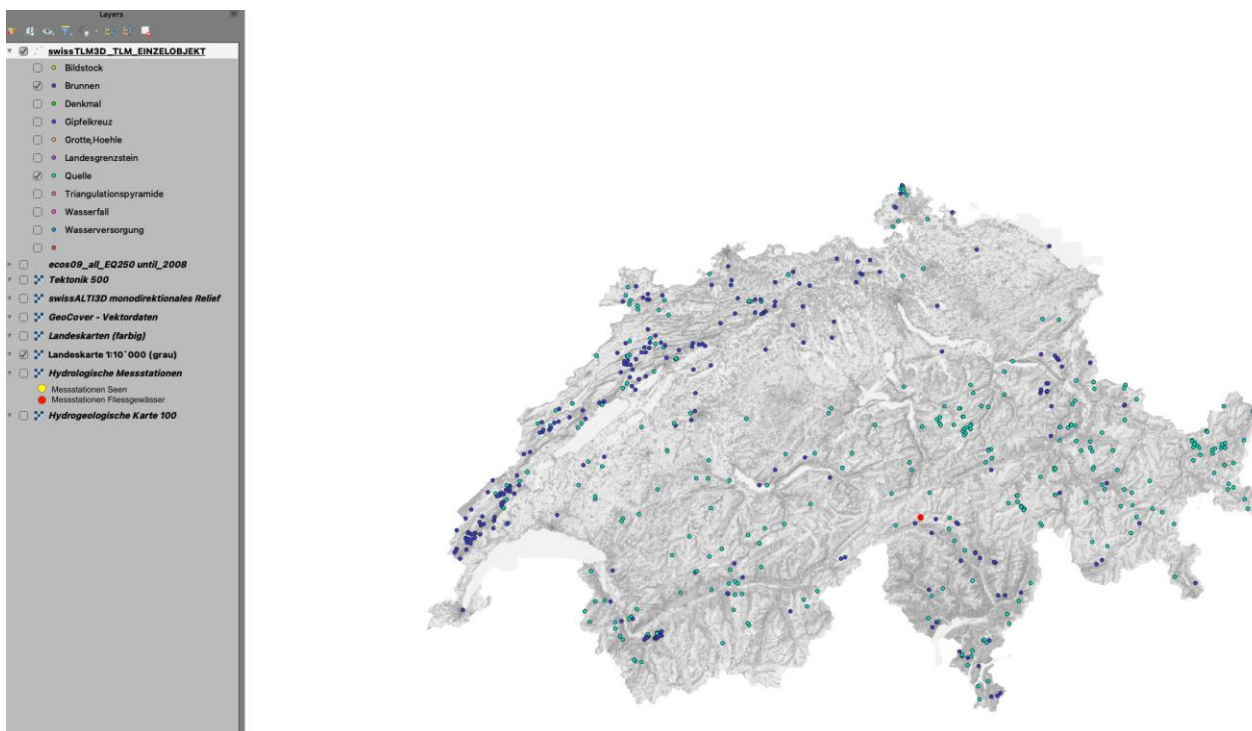


Figure 4.3: Fountains and Sources from the SwissTLM dataset (Swisstopo 2023)

We use publically available data on fountains (“Brunnen”) and sources (“Quellen”) from the SwissTLM dataset (Fig. 4.3; Swisstopo 2023b). In addition we use the open street map dataset (OSM 2023) to extract the locations of the “watering_places” (Fig. 4.4).

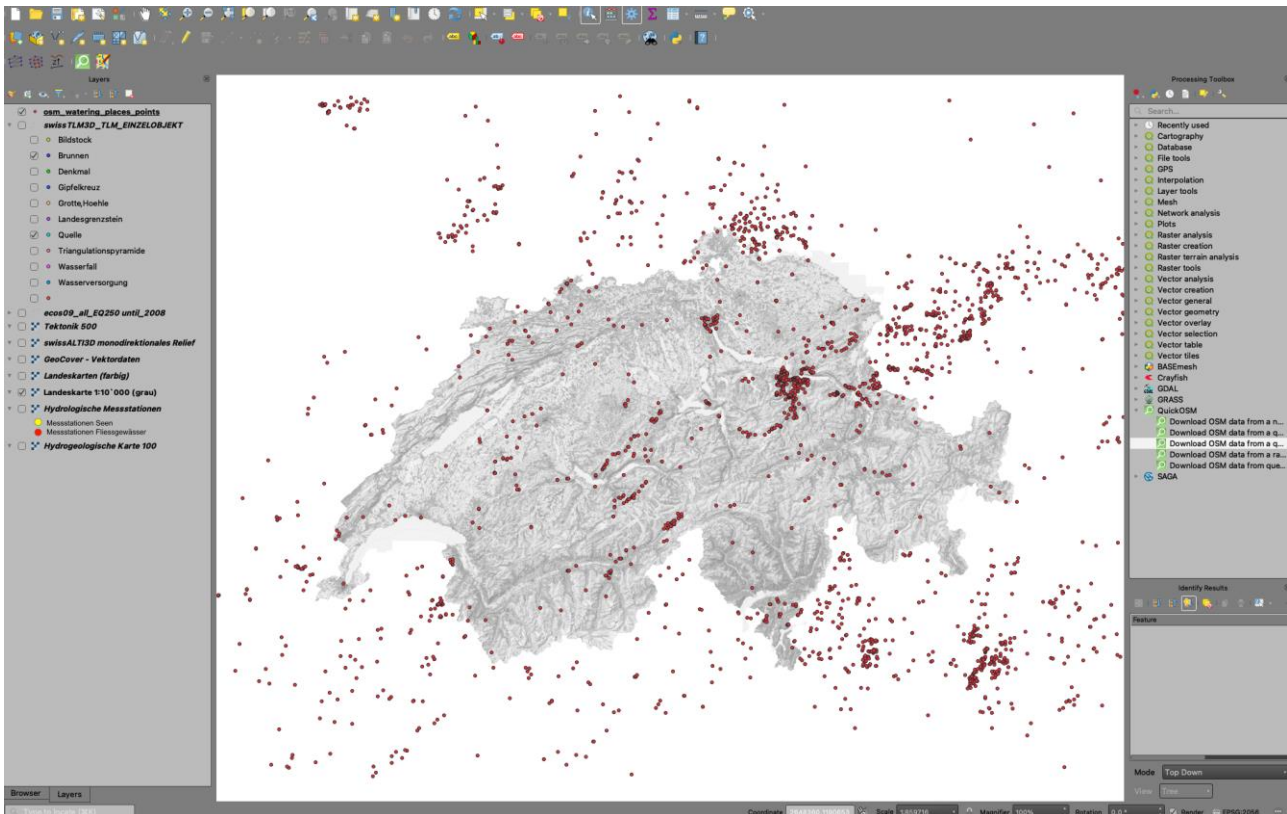


Figure 4.4: Watering points from the OpenStreetMap dataset (OSM 2023)

4.2 Bedretto tunnel

In the Bedretto tunnel, sampling locations are mainly described in tunnel meters (TM), where TM0 refers to the Tunnel entrance near the village of “Ronco”. The sampling locations in the tunnel will be manually georeferenced based on the tunnel meters. In order to compare our Rn measurement data to other geophysical and geochemical monitoring data, we aim at placing the radon sensors in the Bedretto Tunnel at existing sampling locations (e.g. Arnet, 2021a and b).

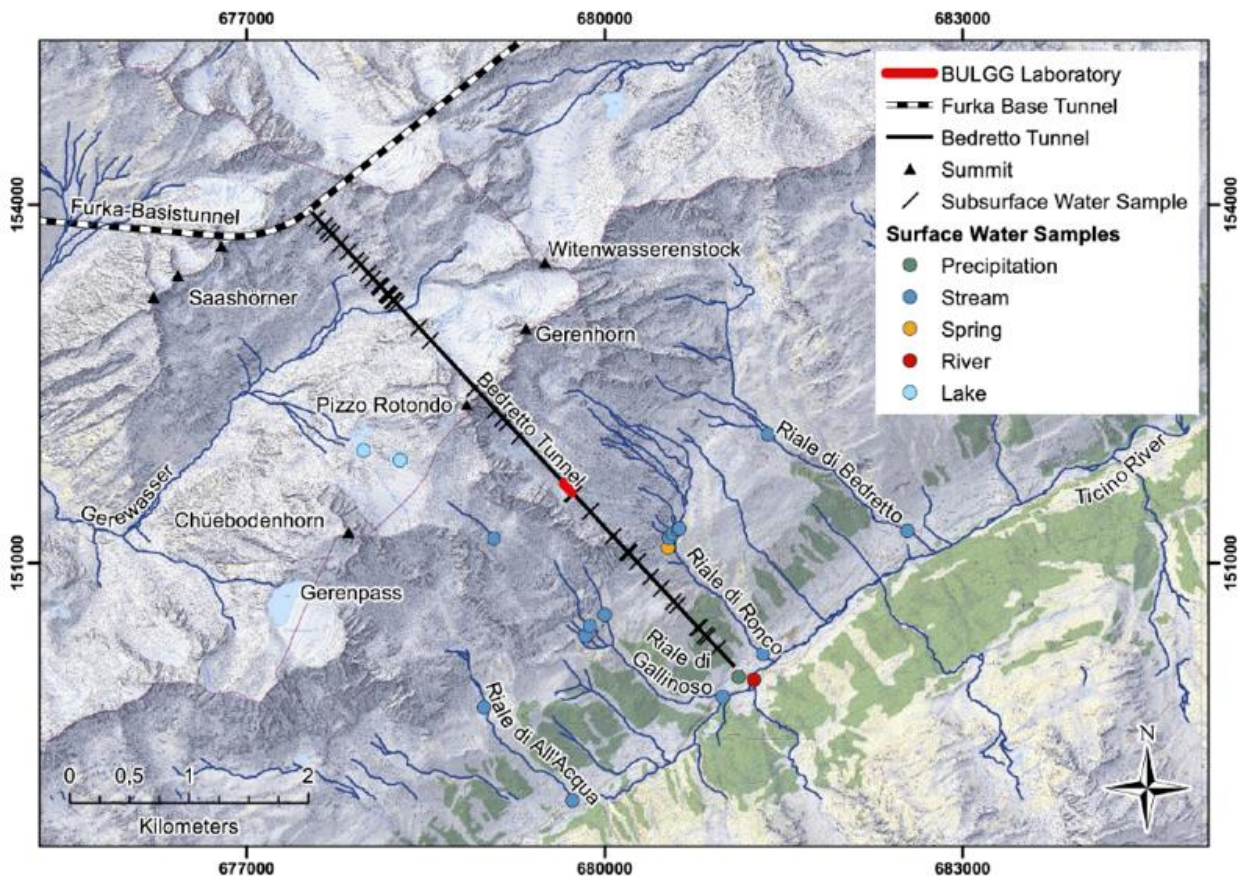


Figure 4.5: Subsurface water sample sites in the Bedretto tunnel from Arnet (2021a). Map from Arnet (2021a)

4.3 References

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