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EUWI+ EU WATER INITIATIVE FOR EASTERN PARTNERSHIP

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Delineation and characterisation of groundwater (GW) bodies, design of a GW monitoring network and development of a national methodology for assessment of GW natural resources in mountainous regions in the Hrazdan and Sevan river basin districts (Armenia) under the European Union Water Initiative Plus

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1. INTRODUCTION

- Delineation and characterisation of groundwater bodies in the Hrazdan and Sevan RBDs carried out in the scope of EUWI+ from May to November 2018 are presented. The works have been carried out for the rational management and maintenance of groundwater resources in the mentioned river basins in line with the Water Framework Directive (WFD).
- The described area occupies the central part of Armenia.
- Total area of studied RBDs is 6700 km^2 (without Lake Sevan).
- The lowest point on the territory is the lower stretch of Hrazdan River (820 m) and the highest point is the peak of Mount Aragats (4095 m).
- Depending on altitude, the average annual temperature varies from -2.7 to +11.5^{0}C.
- The average annual precipitation in the range of 250-929mm and evaporation in the limits of 213-434 mm.

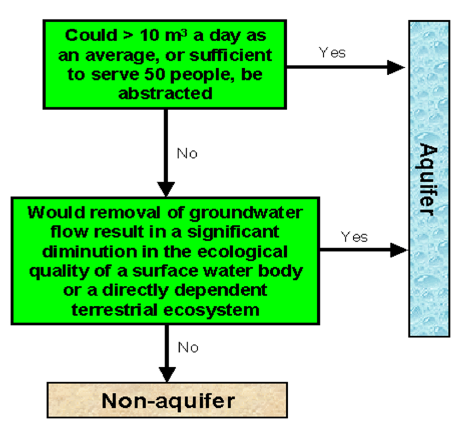


Figure 1. Aquifer Determining Scheme

2.METODOLOGY OF DELINEATION AND CHARACTERISATION OF GROUNDWATER BODIES

The Water Framework Directive's definition of aquifer requires two criteria to be considered in determining whether geological strata qualify as aquifers. If either of the criteria is met, the strata will constitute an aquifer or aquifers. In practice, the criteria mean that nearly all groundwater can be expected to be within aquifers. The following parameters have been taken into account for the delineation of groundwater bodies: groundwater feed, water movement, accumulation and discharge conditions, specifics of water-bearing horizons according to the filtering properties (water-solubility, water-abundance level), the amount of water used and the purpose of use. The delineation of water bodies is considered to be an iterative-long term process that is improved over time.

Article 7 of the WFD requires the identification of all groundwater bodies used, or intended to be used, for the abstraction of more than 10 m^3 of drinking water a day as an average. By implication, this volume could be regarded as a significant quantity of groundwater. Geological strata capable of permitting such levels of abstraction (even only locally) would therefore qualify as aquifers.

3. GROUNDWATER BODIES IN THE HRAZDAN AND SEVAN RIVER BASIN DISTRICTS

Specific features of groundwater bodies in the Hrazdan and Sevan RBDs are lithological composition, water movement, formation and accumulation environment (porous, fractured, fractured porous), source of feeding, location depth, nature of pressure, total discharge, chemical composition of water, actual water abstraction, associated aquatic ecosystems and dependent terrestrial ecosystems, existing pressures and other indicators.

4 hydrogeological complexes presented on the map which have a surface spread are grouped in 2 groups by water-bearing - permeability levels (Figure 2, Figure 3). These water-bearing complexes are of great practical importance. Due to limited surfaces, a small amount of water is formed in the local water-bearing complex composed by Upper Cretaceous sedimentary, mainly carbonate rocks. Here the mineral water bodies are also delineated.

Table 1. Groundwater Bodies of Hrazdan RBD

№	GWB Name	GWB Code, Number	GWB Total Discharge, l/sec	Total Mineralization of Groundwater, g/l	Type of Water Abstraction Structure	Count of monitoring sites: Operating	Proposed
1	2	3	4	5	6	7	8
1	Aragats-Mulki	2G-1	220	0.17- 0.48	wells	3	2
2	Argavand-Masis	2G-2	420	1.1 – 1.35	wells	14	-
3	Meghradzor	2G-3	23	0.65	wells	-	2
4	Arzakan	2G-4	11,4	0.5-0.62	wells	-	2
5	Aparan-Ashtarak	2G-5	2980	0.15-0.7	mainly springs, wells with insignificant discharge	2	4
6	Jrarat-Yerevan	2G-6	7409	0.18-0.98	mainly springs, wells with insignificant discharge (*400l/sec)	3	5
7	Mravyan-Solak	2G-7	14,5	0.28-0.50	springs	-	1
8	Lusagyugh-Aghavnadzor	2G-8	17	0.1-0.31	spring	-	1
9	Voghjaberd	2G-9	0.73	0.9	springs	-	2
10	Hankavan	2G-10	25.0	3.3 – 6.6	mineral water wells	-	-
11	Bjni	2G11	3	1.1 – 2.5	mineral water wells	-	-
12	Arzni	2G-12	13	2.1 – 11.7	mineral water wells	-	-
	Total in Hrazdan RBD		11136.63			22	19

Figure 2. Overview map with monitoring sites within Hrazdan RBD

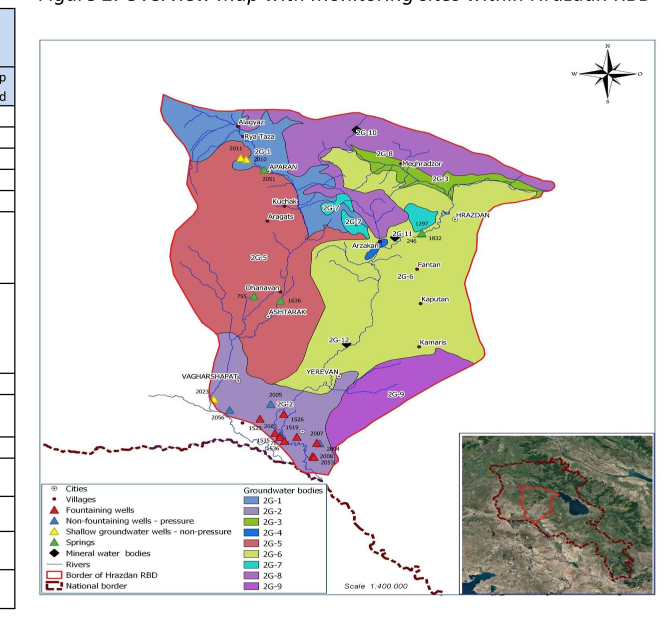


Table 2. Groundwater Bodies of Sevan RBD

№	GWB Name	GWB Code, Number	GWB Total Discharge, l/sec	Total Mineralization of Groundwater, g/l	Type of Water Abstraction Structure	Count of monitoring sites: Operating	Proposed
1	2	3	4	5	6	7	8
1	Dzknaget-Areguni	3G-1	35	0.16	springs	-	2
2	Lchashen-Gavar-Shatjrek	3G-2	4771.3	0.44	wells	2	6
3	Shorja-Sotk	3G -3	16.1	0.54	springs	-	2
4	Vardenis or Masrik	3G-4	960	0.32	spring-well	9	5
5	Sevan (Gavar)	3G-5	10.0	3.5	mineral water wells	-	-
6	Lichk	3G-6	74,0	3.9 – 4.2	mineral water wells	-	-
	Total in Sevan RBD		5866.4			11	15

Figure 3. Overview map with monitoring sites within Sevan RBD

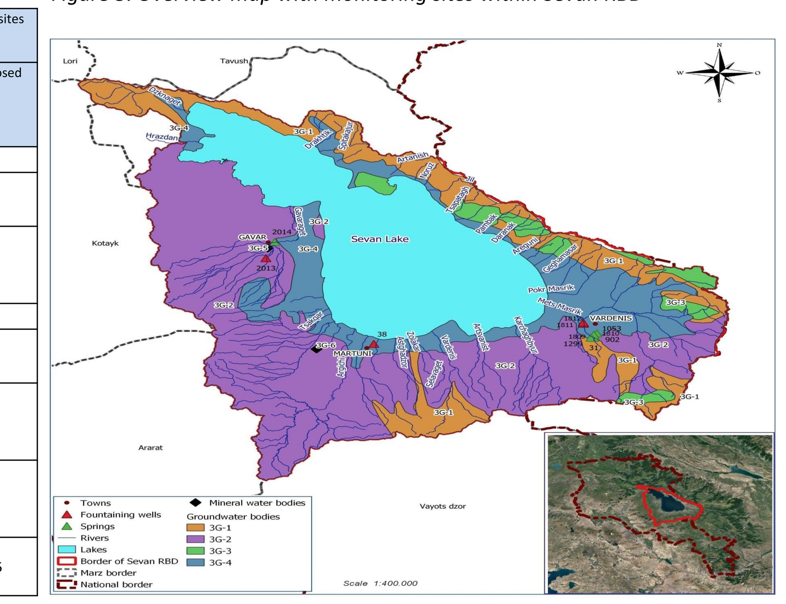


Table 3. Example of a characterization sheet of a groundwater body

N	Parameter	Value
1	GWB code	2G-1
2	GWB name	Aragats-Mulki
3	GWB area (km²)	149
4	Aquifer – Pressure situation	Pressure and non-pressure
5	Individual GWB or group of GWBs	Group
6	Transboundary	No
7	GWB thickness, m, min-max	50.0 – 58.0
8	Discharge and average annual fluctuation l/sec	333
9	Depth to GW level Min–Max, Mean [m]	(-7.0) – (-8.4)
10	Aquifer – Petrography, lithological description	0.0 – 55.0 pebble-river pebble, rock debris, sand, non-aquifer (Q_{IV}); 55.0 – 70.0 dacite tuff, dacite, non-aquifer (Q_3); 70.0 – 92.0 clay, solid, water impermeable (Q_3); 92.0 -123.0 pebble, rock debris, sand, water-bearing, 1-st pressure water- bearing horizon (Q); 123.0 – 145.0 clay, water impermeable (N_2^3-Q); 145.0 – 172.0 pebble, rock debris, sand, water-bearing, 2-nd pressure water-bearing horizon (N_2^3-Q); 172.0 – 200.0 clay, water impermeable (N_2); 200.0–210.0 limestone, corroded, non-aquifer (K_2)
11	Hydraulic conductivity (kf), Min–Max, Mean [m/s]	18 – 25
12	Transmissivity (T), Min–Max, Mean [m²/s]	900 – 1450
13	Daily groundwater abstraction [>10 m³/day]	Yes
14	Number of abstraction wells/springs	Wells 9 (nine)
15	Purpose of abstraction	Drinking water supplies
16	Total groundwater abstraction l/sec	220.0
17	Aquifer – Geochemistry (main cations and anions)	HCO_3^- and Na^+K^+
18	Main recharge source	Precipitation
19	Annual precipitation [mm]	564 – 920
20	Associated aquatic ecosystems	The Kasakh River
21	Prevailing human pressures	Agricultural and livestock
22	Land use	As arable land and pasture
23	GWB chemical status	Good
24	GWB quantitative status	Good
25	Confidence level of information	Good
26	GWB chemical trend	Good

Purpose of the Assessment of the available groundwater resources in mountainous regions

The purpose of the programme relates to the development of a methodology for the assessment of the various types of groundwater resources in mountainous regions (beside intermountain basins) on the pattern of the two RBDs in Armenia:
according to the EU WFD: available groundwater resources
according to the local regulations: usable groundwater resources, the strategic groundwater resources and the national water reserves

Groundwater resources, reserves and evaluation methodology

Quantitative assessment of groundwater resources
- Groundwater resources
  - Natural
  - Artificial
- Groundwater reserves
  - Exploitable

For the quantitative assessment of groundwater resources in hydrogeology, concepts such as **groundwater resources** and **groundwater reserves** were adopted. Groundwater resources are divided into **natural** and **artificial**, but groundwater reserves are divided into **exploitable** .

Groundwater natural resources

Groundwater natural resources in the Republic of Armenia mainly consist of
1. spring 2. drainage 3. deep runoff

Groundwater natural resources
- usable water resource – 50 %
- strategic water resource – 20 %
- national water reserve – 30 %

Based on groundwater natural resources, the following types of groundwater resources were evaluated
Usable groundwater resources are the amount of water in the watershed or other territories, the long-term operation of which does not lead to the depletion or pollution of groundwater.
Strategic groundwater resources are the amount of water needed to meet basic human needs and to maintain water ecosystems in emergencies (droughts, environmental disasters, etc.).
The national water reserve is the difference between the natural groundwater resources and the amount of usable and strategic resources.

Artificial resources

Besides natural resources, **artificial resources** are being formed under anthropogenic pressures. **Artificial resources** are variable depending on the efficiency of the hydro-technical constructions and can be minor. Therefore, the process of groundwater exploitation must be justified by natural resources.

Groundwater exploitable reserves

Groundwater exploitable reserves: the amount of groundwater that can be obtained from a particular area by technically cost-effective water intake facilities at a given operating mode and at a water quality that meets the requirements during the entire estimated period of water consumption

Evaluation of the available groundwater resources in the Hrazdan and Lake Sevan RBDs according to the EU WFD

As boundary conditions the following requirements were highlighted:
a) at least 50% of the river's multi-year average natural runoff should remain as an ecological flow;
b) the available groundwater resource should be no more than half of the renewable groundwater resource.
Available groundwater resources were evaluated in two different ways. However, the obtained results were not satisfying and these two methods are not acceptable.

Available resources

Method 1
Available groundwater resource = groundwater renewable resource - 50% of the river's flow + surface flow component in the river.

In the Hrazdan RBD, calculations showed that the available groundwater resource is more than half of the renewable groundwater resource, sometimes up to 90%.
In the Sevan RBD, the calculated available groundwater resource exceeded the renewable groundwater resource up to 3 times

Method 2
Available groundwater resource = groundwater renewable resource - 50% of the river's flow.

In this case, null and negative values were obtained in Sevan RBD

As a result, the **usable resources** are taken as **available** resources instead of the 2 proposed methods

Water balance formula

Water balances were calculated using the following formula

$X = Y + Z \pm W$, where

X – precipitation on the watershed or calculation area, mm or mln. m^3/year
Y – river's flow rate at gauging point/measuring section, mm or mln. m^3/year
Z – evaporation, mm or mln. m^3/year
± W – inflow (+) or outflow (-) ,mm or mln. m^3/year

This method requires the following parameters:
1. Restored river flow.
2. Precipitation and evaporation
3. The spring flow rate
4. Baseflow rate
5. Flow rate of the groundwater discharging in the river
6. Groundwater deep runoff

Water balance formula

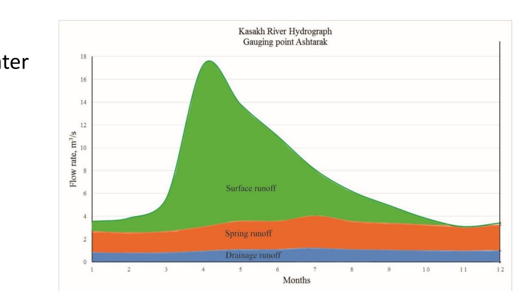
1. river runoff = surface runoff + groundwater runoff (without deep runoff)
2. groundwater runoff = springs runoff + drainage runoff (baseflow) + deep runoff
3. deep runoff = precipitation - (river runoff + evaporation)

It is known that during the operation of the water-table aquifer, the drawdown ($S_{allowable}$) is not allowed to be more than 0.5 - 0.7 of the aquifer average thickness (H)

Hydrograph separation

The following data are required for the hydrograph separation in the mountain regions:
- the flow rate of the rivers in the water gauging points;
- the quantity of water that is used for various purposes upstream of the gauging point (water supply, irrigation, diversion canals, etc.), which is not accounted for in the river flow rate.
- the long-term average monthly flow rate of the natural springs

The Kasakh river's flow will be taken as an example for the partitioning of the river's flow at to the "Ashtarak" gauging point:
1. Determination of the river's restored flow
2. Determination of the springs' flow
3. Determination of the variation factor K $\quad K_n = \frac{W_n}{W_{11}} = \frac{W_n}{2.15}$
4. Determination of the drainage flow $\quad D_n = R_n - W_n$
5. Determination of the river's groundwater flow $\quad G_n = B_n + W_n$
6. Determination of the river's surface runoff $\quad S_n = R_n - G_n$



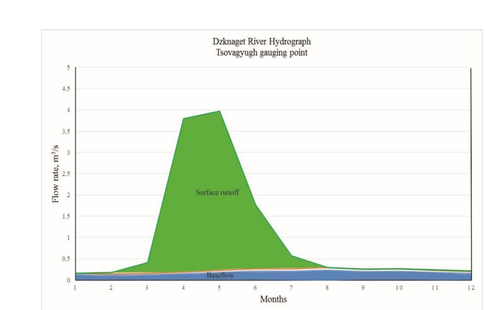
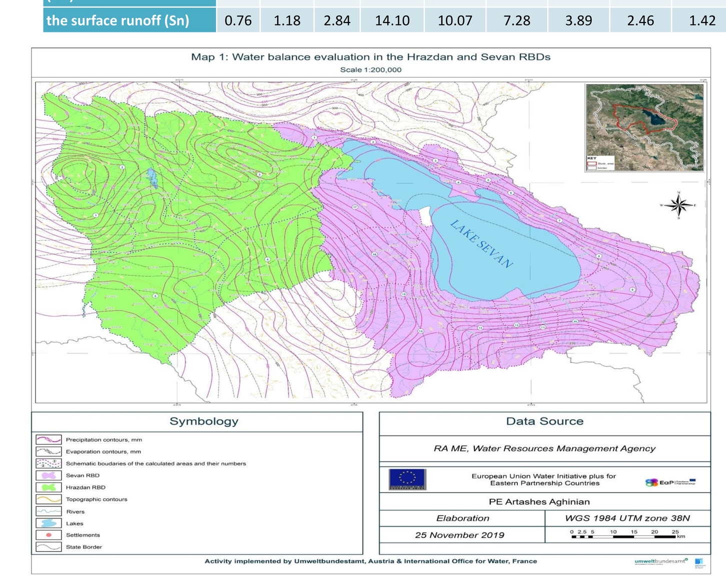
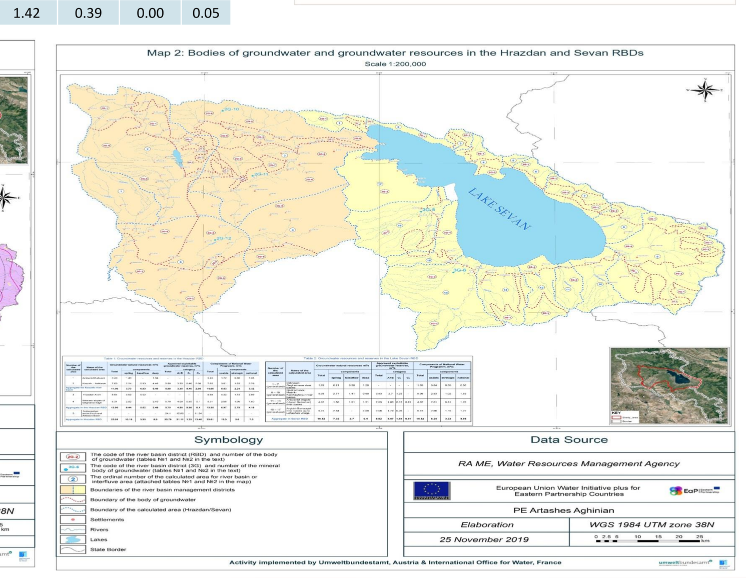


Table 4. Separation of the Kasakh river flow at Ashtarak gauging section

Component of the river flow	Average long-term recovered monthly flow rate, m³/s: I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
the river flow (Rn)	3.55	3.85	5.61	17.32	13.78	10.99	8.08	6.17	4.94	3.8	3.22	3.42
the spring runoff (Wn)	1.86	1.78	1.85	2.15	2.48	2.48	2.8	2.48	2.35	2.28	2.15	2.25
variation coefficient (Kn)	0.87	0.83	0.86	1.00	1.15	1.15	1.30	1.15	1.09	1.06	1.00	1.05
the drainage flow (Bn)	0.93	0.89	0.92	1.07	1.23	1.23	1.39	1.23	1.17	1.13	1.07	1.12
River's groundwater flow (Gn)	2.79	2.67	2.77	3.22	3.71	3.71	4.19	3.71	3.52	3.41	3.22	3.37
the surface runoff (Sn)	0.76	1.18	2.84	14.10	10.07	7.28	3.89	2.46	1.42	0.39	0.00	0.05





Projection of groundwater resources in line with the latest IPCC scenarios

Table 5: IPCC projected scenarios for the Hrazdan and Sevan River Basin Districts, high emission scenario (A_2) and a rapid stabilization scenario (B_2)

Hrazdan RBD, A2 scenario			
	2040	2070	2100
Temperature,%	1.7	3.2	4.7
Precipitation,%	0	-	-
River flow,%	-2-3	-6-7	-15-20
Hrazdan RBD, B2 scenario			
Temperature,%	1.3	2.6	3.3
Precipitation,%	0	-	-
Sevan RBD, A2 scenario			
	2030	2070	2100
Temperature,%	1.7	3.2	4.7
Precipitation,%	-2-6	6-17	10-27
River flow,%	-6%	-	-
Armenia, A2 scenario			
River flow,%	11.9	24	24.4

According to Table 5, the rivers' flow in Hrazdan RBD will decrease in a range of 2-20 % by various scenarios. Taking into consideration the groundwater flow is in direct correlation with river's flow, the groundwater available resources are projected up to 2100 for various scenarios according to the projected rivers flow.

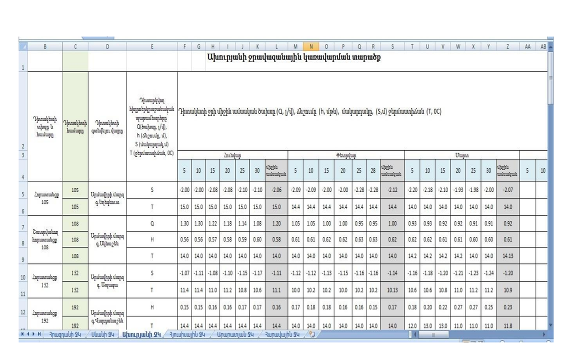
4. GW MONITORING NETWORK

There are 33 hydrogeological monitoring sites in the studied RBDs, 22 of which are in Hrazdan RBD, and 11 in the Sevan RBD.

Hydrogeological monitoring network: 33 points
- Hrazdan RBD: 22 points
  - natural springs: 6 points
  - boreholes: 16 points
  - sampling points: 8
- Sevan RBD: 11 points
  - natural springs: 5 points
  - boreholes: 6 points
  - sampling points: 6

Discharge measurements are conducted by dimensional method (10 l, 12 l, 16 l and 50 l), rectangular weirs (20 x 40 cm and 30 x 50 cm sizes) and triangular weirs (H=20 cm)and hydrometric current meter

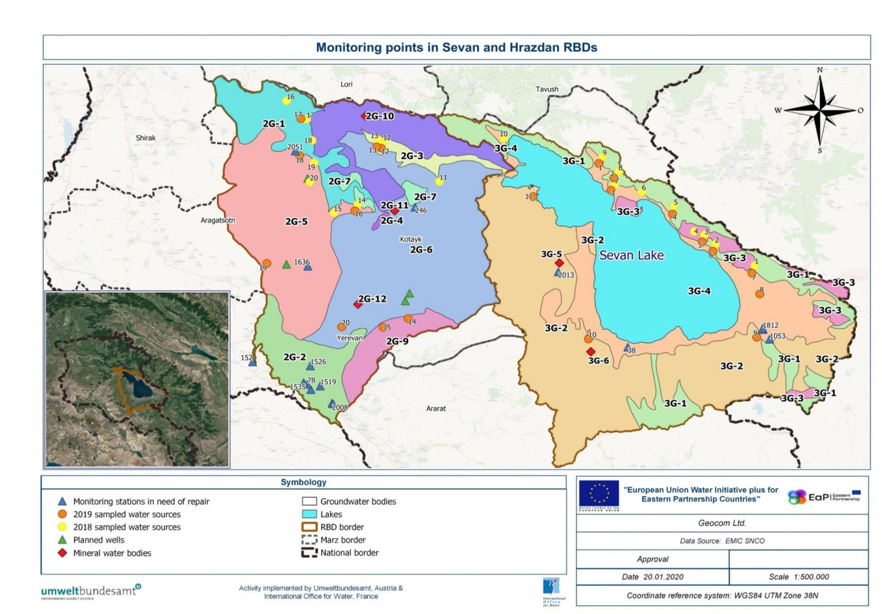
Level measurement Groundwater level is measured by electrical level meters (in non-fountaining wells) and pressure meters (in fountaining wells).



The density of the monitoring network in the Hrazdan and Sevan RBDs with complicated climatic and hydrogeological conditions is 1 point per 203 km^2.

5. HYDROGEOLOGICAL FIELD STUDIES

- In the Hrazdan and Sevan RBDs, from 2018 to 2019, the staff of the "Environmental Monitoring and Information Centre" SNCO along with EUWI+ representatives, owing to EU support and financing, have conducted hydrogeological field studies of 20 groundwater sources (natural water outlets and boreholes). They have studied geological-hydrogeological conditions of water sources, bodies of groundwater, water physical and chemical characteristics (taste, smell, color, temperature, flow rate, water level, etc.) during field trips. Water samples have been taken for laboratory analyses. We recommend to include these water sources into the hydrogeological observation network in case of available funds.
- To avoid possible negative consequences over time and to promote the sustainable management of water resources, it is necessary to expand the monitoring network in the area between the wells' zone of the intermountain basins and the zones of the pre- mountain springs.



CONCLUSION

In order to avoid shortcomings, to improve the quality of the monitoring and processing and transfer of samples, the following steps are necessary:
- Automation of monitoring, operative transfer and processing of results;
- Increasing the number of monitoring sites;
- Identification of anthropogenic factors with negative impact on groundwater resources and implementation of respective measures on impact neutralization.

Implementing partners

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