Interreg
Danube Region

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PANNONIAN.GW

Report on output SO1

Harmonisation of joint monitoring and modelling of groundwater system of Pannonian Plain (PANNONIAN. GW)

Content

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1 Introduction

Title of the first project output is: Groundwater monitoring network (SO1).

This report comprises activities during the first 6 months of the project implementation. All partners and ASPs were included in them. There were collected annual groundwater levels data in the period between 1990-2022. Partners were focused on the first mandatory output: **Groundwater (GW) monitoring network (SO1).** There were three groups of activities.

Activity A.1.1.

- Description of the state of groundwater monitoring network in Pannonian Plain included analysis of primary database.
- mapping of GW observation wells network
- report on recommendations for intensification of groundwater observation network to national responsible authorities.

Activity 1.1.2

- Groundwater table observations in Pannonian Plain
- Mapping of GW table on different temporal scales (decades)
- Report on standard statistical analysis by different tools to have more comprehensive insight of GW behaviour in the period 1990-2022
- Map of critical spots where is detected extreme lowering or any other extreme change of groundwater level
- Report on results as a platform for activities and outputs of the main project Special focused on the forestry, agriculture and nature

These two sets of activities are elaborated in this report, **Chapter 2** National groundwater observation networks and **Chapter 3** Statistical analysis.

Activity 1.1.3

List of target groups that should be addressed by the main project and report on target groups is not complete and it is still in the process. Due to delays in data acquisition results of statistical analysis were completed with delay, what resulted with time shortage for developing Activity 1.1.3. (**Chapter 4).** It is given as a draft version and this activity will be completed within the following days.

This entire report, together with 10 maps has been published on the official project website: **Chapter 5** consists of links to the official project website http://www.gfos.unios.hr/homepage/harmonization-of-joint-monitoring-and-modelling-of-groundwater-system-of-pannonian-plain . The wider audience interested in this problem can find results of project activities completed in the first 6 months of project implementation. All members of project team were involved in creation of this report.

March 10, 2025

2 National groundwater observation networks

2.1 National Groundwater Observation Network - Romania

The National Hydrogeological Network (NHN) is under the management of the National Administration of Romanian Waters and is the main provider of hydrogeological data necessary for the development of studies and research on the groundwater regime and assessment of the groundwater quantitative and qualitative status . Therefore, its organization on a given territory must correspond to both practical, economic and scientific purposes that may lead to the explanation of certain natural phenomena or anthropogenic interventions on the groundwater regime.

Currently, wells and springs from the National Hydrogeological Network quantitatively and qualitatively monitor the Romanian groundwater bodies that have been delimited in accordance with the Water Framework Directive 2000/60/EC. From the 143 delimited groundwater bodies, 124 groundwater bodies are included in the quantitative monitoring program (107 phreatic groundwater bodies and 16 deep groundwater bodies).

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The number of groundwater wells in the monitoring program has decreased, reaching from 4629 wells in 1979, to 3014 wells in 2006 and to 2956 in 2023. The causes that led to the decrease in the number of groundwater observation wells are mainly the destruction and clogging of some of them, as well as the lack of observers.

The National Hydrogeological Network is constantly modernizing through actions to automate the systematic measurements of groundwater level and flow. Starting with 2004, some of NHN groundwater observation wells have been equipped with an automatic system for measuring groundwater level and temperature. The purchased system consists of: a level transducer (pressure type) and temperature that is mounted in the well, equipped with a casing and connection cable, and a datalogger that allows the recording and storage of measurements made at the chosen time interval (from 1 minute to 24 hours). The system also includes software for data analysis (configuration and transfer).

For all groundwater monitoring wells (phreatic wells, deep wells and springs) the measurement and observation program is permanent. The activities and their standard frequency are presented in Table 2.11.

Table 2.1.1 The monitoring program of the NHN groundwater monitoring wells

Activity	Frequency	Observations
Manual hydrogeological measurements		
Phreatic groundwater well	10 / month	It is measured on the 3rd, 6th, 9th, 12th, 15th, 18th, 21st, 24th, 27th and 30th of each month.
Deep groundwater well	1 / month	
Groundwater flow rate - deep weel	1 / trimester	
Groundwater flow rate - spring	1 / month	
Temperature - phreatic groundwater well	5 / month	
Temperature - spring	1 / month	
Depth measurement - phreatic well	4 / year	It is measured on the last day of the trimester
Depth measurement - deep well	1 / year	Video monitoring during drilling inspection
Drainage of the phreatic groundwater well	1 / year	It is carried out in the wells set at the beginning of the year
Experimental pumping of the phreatic well	1 / year	It is carried out in wells established at the beginning of the year that meet pumping conditions
Automatic hydrogeological measurements		

Activity	Frequency	Observations
Phreatic groundwater well	1/day	
Deep groundwater well	1/day	
Temperature - phreatic groundwater well	1/day	
Temperature - deep groundwater well	1/day	

Within the PANNONIAN.GW project, a number of 1098 hydrogeological boreholes were identified that monitor the phreatic groundwater level. The distribution of the phreatic groundwater wells from the NHN identified in the Romanian study area is shown in Figure 2 (a, b and c).

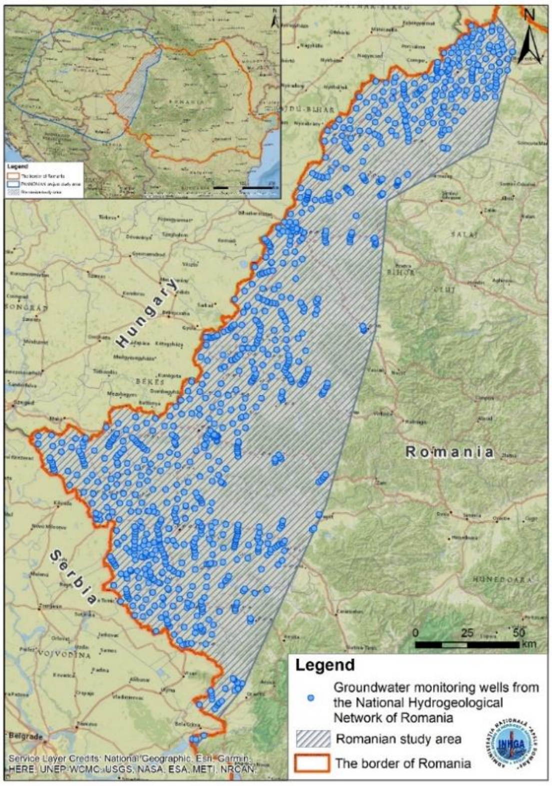

Figure 2.1.1a) The phreatic groundwater wells from the NHN identified in the Romanian study area

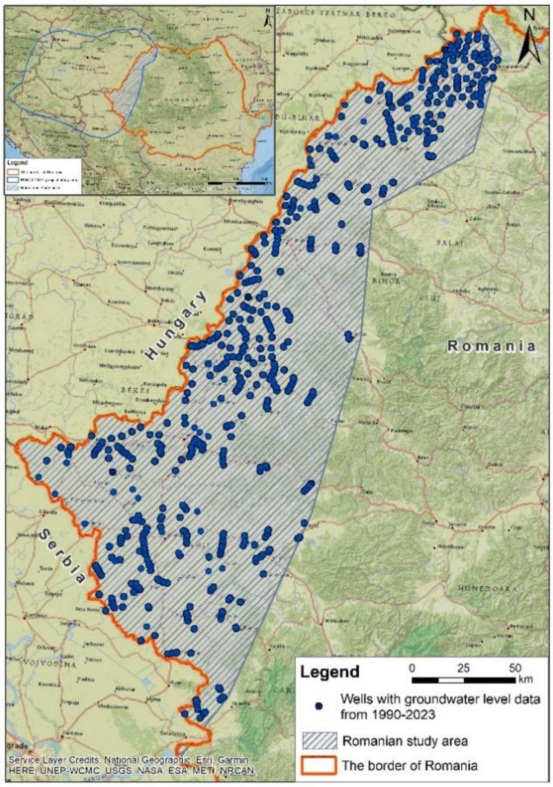

Figure 2.1.1b) The wells with groundwater levels data from 1990 - 2023

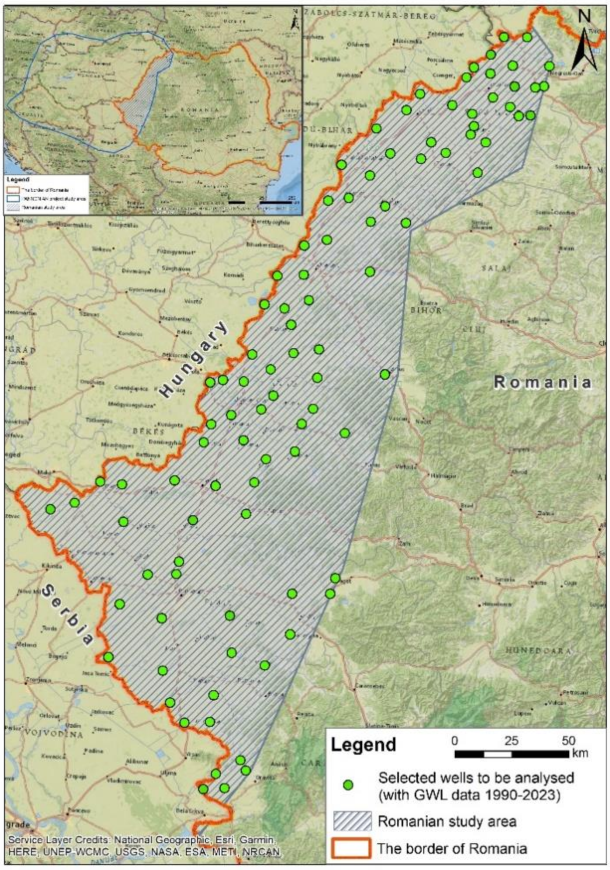

Figure 2.1.1c) The wells selected to be analyzed

Some of these wells from Figure 2.1.1a) monitored the phreatic groundwater level since the establishment of the National Hydrogeological Network. For others there are no monitoring periods due to various reasons (inaccessibility of the land, problems related to the improper functioning of the sensors, etc.) and others are recently executed and have a short monitoring period. Thus, from the total of 1098 wells identified in the first step of analysis, several 625 wells with a monitoring period for at least 30 years were selected (GWL monitoring period 1990-2023, Figure 2.1.1b). Having in mind the scope of the monitoring analysis, 625 were considered too many, so, in the second phase, had been selected several 96 wells (Figure 2.1.1c), uniformly distributed, to analyze the evolution of the groundwater level in Pannonian Plain.

2.2 National Groundwater Observation Network - Croatia

Institution responsible for groundwater monitoring network is Croatian Meteorological and Hydrological Service (DHMZ). It is a government body in Croatia. Among others it is responsible for establishing the infrastructure and measurements systems, as well as planning and maintenance of various national meteorological, hydrological and air quality monitoring stations and development and maintenance of various databases (meteorological, hydrological, air quality).

Establishing of groundwater monitoring network started in 1950, but its the most extensive development was in the 60s of the last century. Since than monitoring network continuously grows and the most recent observation wells were installed in 2021. In this moment there are 703 observation wells in operation. They are all located in the Danube River basin and in that sense they belong to the study area. In this app. 75 years of groundwater monitoring, the large number of observation wells have gaps in data series between 1990 and 1995 due to the war activities. Some of observation wells were destroyed in that period, and again established with better and modern equipment (Figure 2.2.1). There are two ways of groundwater level monitoring:

- manual measurements of current GW level twice per week (each Monday and Thursday). This kind of monitoring stations give annually 104-105 data.
- Continuous electronic automatic measurements of GW level. Afterwards, mean daily values are calculated as an arithmetic average of all values measured during one day. These data present average daily GW level. This kind of monitoring is established on 96 observation stations and they provide annually 365/366 data.

Process of GW monitoring network modernization started at the end of 90s, but there are still a large number of observation well monitored manually.

Croatian Meteorological and Hydrological Service (DHMZ) is not responsible for groundwater quality. Sampling of groundwater and lab analysis are responsibility of another state institution (Hrvatske vode, *eng*. Croatian Waters).
All basic data published on official web site https://meteo.hr/ can be downloaded free of charge. However, other information, data interpretation, models, prognosis and similar studies on demand must be paid. Also, data needed for scientific work are also provided free of charge.

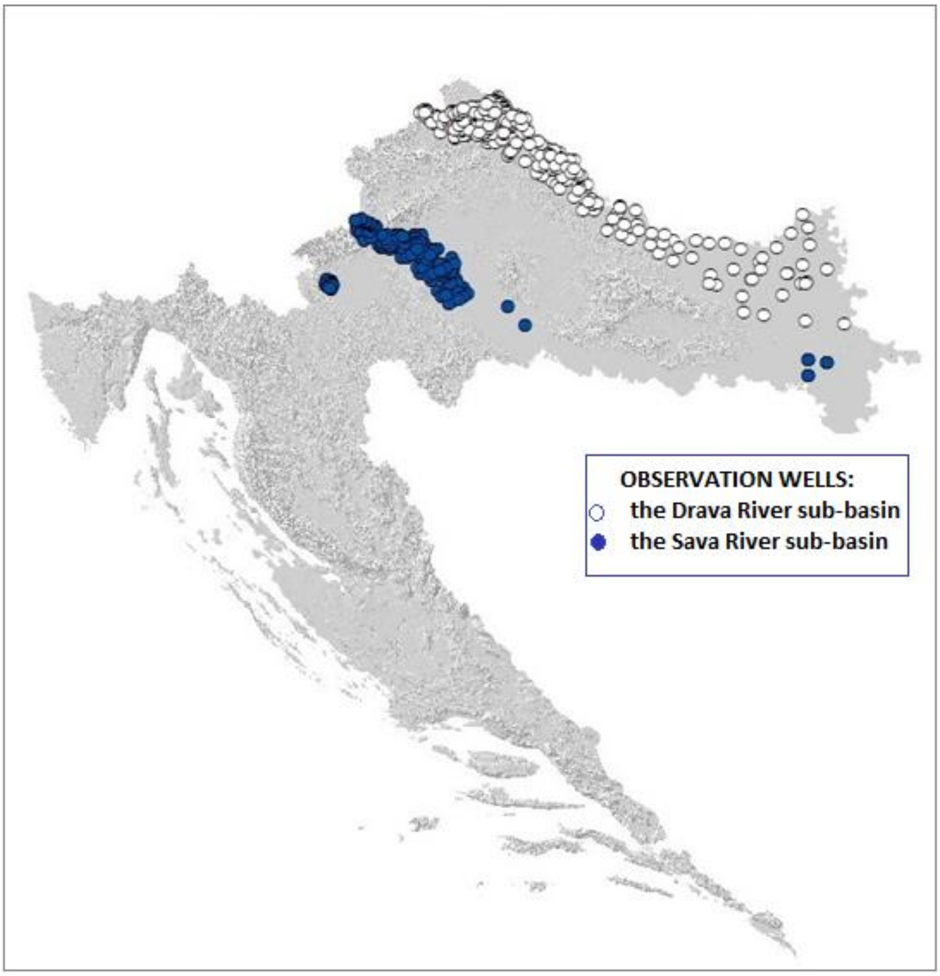

Figure 2.2.1 The network of groundwater wells identified by DHMZ in Croatia (https://meteo.hr/infrastruktura.php?section=mreze_postaja&param=hm&el=podzemne_hm)

2.3 National Groundwater Observation Network – Slovenia

Groundwater level monitoring data can be found on official website of Slovenian Environment Agency (ARSO) https://meteo.arso.gov.si/. Data is collected as part of the national monitoring programme. The website is regularly updated.

Data can be downloaded manually for monthly, annual and periodic statistics; however, the agency can be contacted directly (via email) to obtain full time series of individual monitoring stations (also free of charge). Tables with periodic statistics can be downloaded in the form of Excel files. The distribution of tables tracks the more abundant aquifers in 27 geographic areas. Each file contains sheets with groundwater level data of a given measuring point with monthly, annual and periodic values. Available from:

https://meteo.arso.gov.si/met/sl/watercycle/tables/monthly_statistic/

The groundwater quantity monitoring programme is based on the selection of optimal locations for the monitoring sites according to the conceptual hydrogeological conditions of the aquifers and the groundwater quantity assessment methodology. The monitoring network also takes into account the criteria of the length and continuity of the time series of historical observations, the technical suitability of the facility and the utilisation of groundwater and space.

Agency also publishes monthly bulletins with meteorological, agrometeorological and hydrological data, together with air and water quality data and seismic activities, as well as annual national assessments of groundwater quantity, both in PDF format.

Monthly bulletins are available from:

https://www.arso.gov.si/o%20agenciji/knji%C5%BEnica/mese%C4%8Dni%20bilten/bilten2023.htm

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The annual national assessment of groundwater quantity status is based on the ARSO's databases for hydrological monitoring of groundwater and surface water, meteorological monitoring and records of water rights and water reimbursements. The annual national assessment includes data from 271 hydrological monitoring sites for surface and groundwater, 214 of which belong to the Danube River Basin.

Annual assessment available from:

https://www.arso.gov.si/vode/podzemne%20vode/

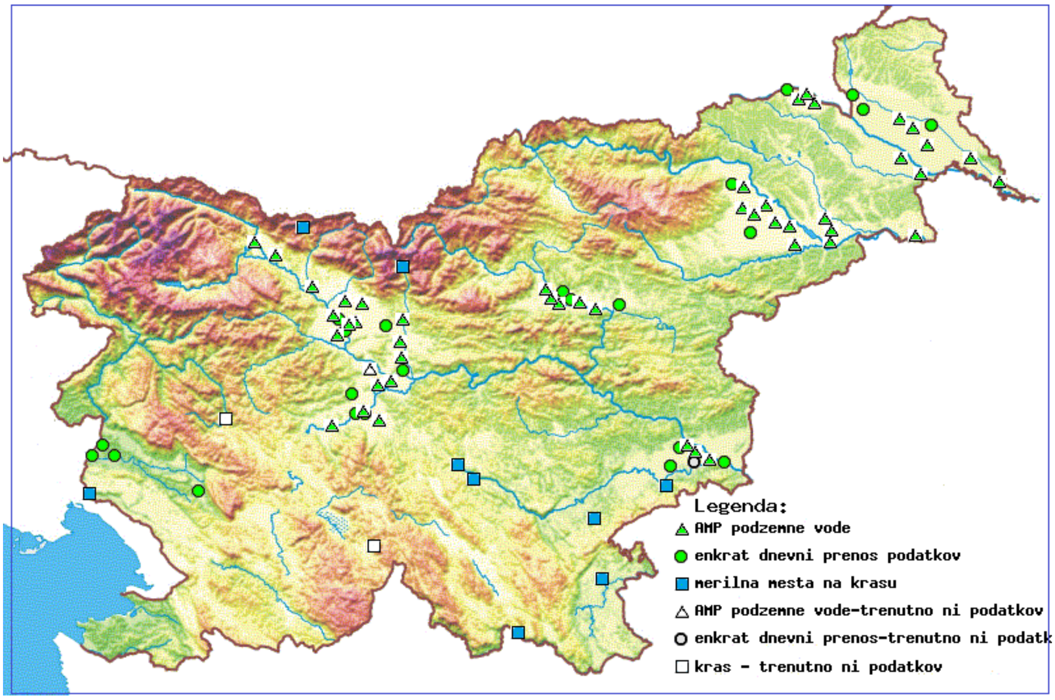

Figure 2.3.1 The network of groundwater wells in Slovenia (green triangle: automatic measuring station; green circle: daily measurement; blue square: karst measuring station; white icons: currently no dana vaialble) https://meteo.arso.gov.si/met/en/watercycle/groundwater-stations-data/

2.4 National Groundwater Observation Network – Serbia

Institution responsible for groundwater monitoring network in Serbia is Republic Hydrometeorological Service of Serbia (RHMZ). It is a government body . It was established in 19th century and then started meteorological measurements . Hydrological measurements started in 1920, but groundwater monitoring network was established later. RHMZ is responsible for development of the infrastructure and measurement systems, as well as planning and maintenance of various national meteorological and hydrological monitoring stations.

The first records of groundwater levels date from 1948. In 2023 there were 303 active observation wells. Almost half of them are used only for groundwater level monitoring, 143 wells . Network of 148 observation wells have measurements of groundwater level and groundwater temperature. Both zones are included in monitoring, phreatic groundwater bodies and deep groundwater bodies. There are different frequencies of monitoring. They vary between daily, monthly, two times per month and observations 3 times per month.

All groundwater level data are published on official website https://www.hidmet.gov.rs/ as annual bulletins and can be downloaded free of charge. However, other information, data interpretation, models, prognosis and similar studies on demand must be paid.

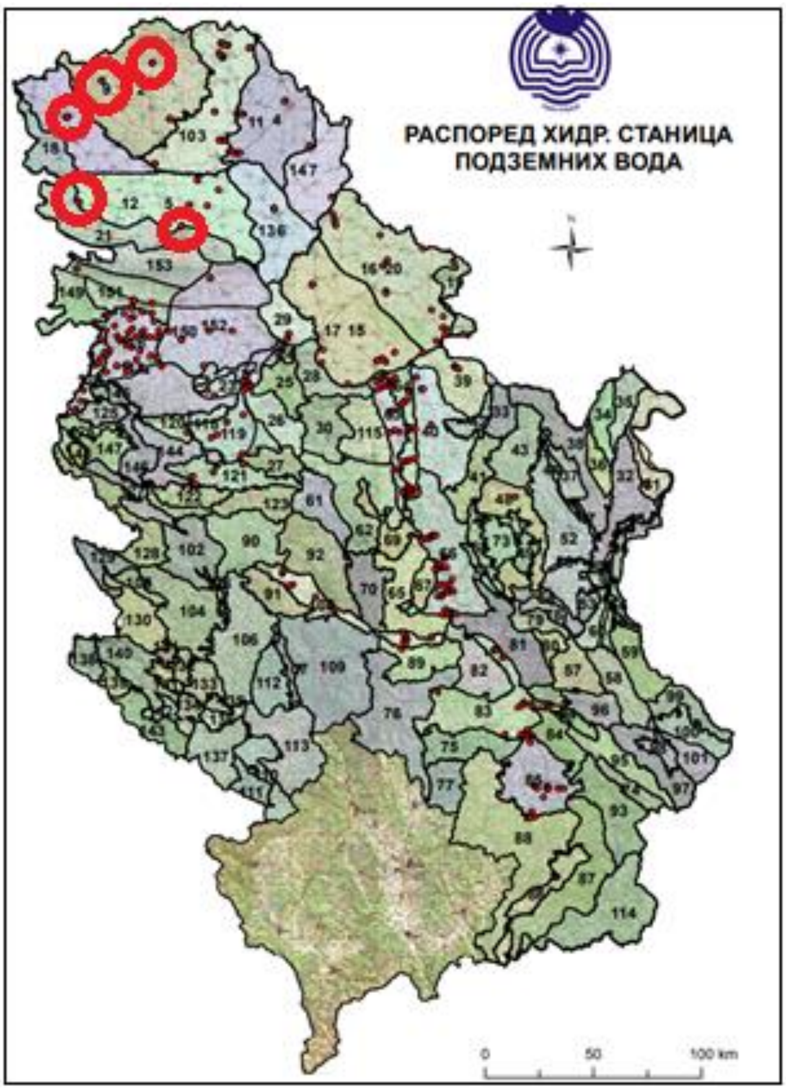

Figure 2.4.1 The network of groundwater wells identified by RHMZ in Serbia in 2023 with designated piesometers included in project area (https://www.hidmet.gov.rs/data/hidro_pod_godisnjaci/PODZEMNE%20VODE%202023.pdf)

2.5 National Groundwater Observation Network – Hungary

Groundwater level monitoring data can be found on official website https://geoportal.vizugy.hu/talajvizkutak/index.html . Entire Hungarian territory is located in Pannonian basin, so there are in total 1082 observation wells distributed on the lowland.

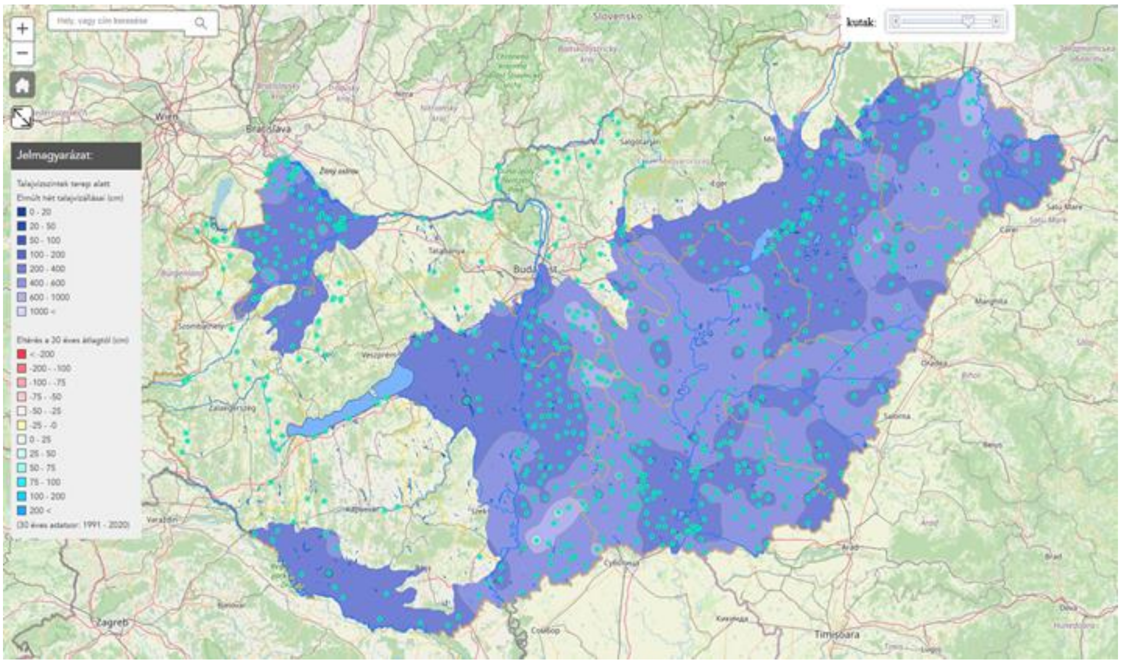

Figure 2.5.1 The network of Hungarian groundwater wells
https://geoportal.vizugy.hu/talajvizkutak/index.html

2.6 National Groundwater Observation Network – Bosnia and Herzegovina

Institution responsible for groundwater monitoring network in Bosnia and Herzegovina is Federal Hydrometeorological Service. Measurements of groundwater level have no long history- they started in 2019. Groundwater water level gauging stations are automatic with time step of measurement of 1 hour. Hydrometeorological service publishes annual bulletins with meteorological, and hydrological data, including groundwater level data. All values of given as characteristic: mean, minimum and maximum monthly and annual.

Figure 2.6.1 The network of groundwater wells in Bosnia and Herzegovina
https://www.fhmzbih.gov.ba/latinica/

2.7 Conclusions and Recommendations

2.7.1 Conclusions

The main task of this report is to define status of groundwater (GW) monitoring network in the countries of the Pannonian Plain included in this study.

General conclusion is that GW observation network is rather dense and distribution of GW observation wells over the area should not be an obstacle in analysis of groundwater level changes. Table 2.7.1 presents total number of observation wells in study region. It is not total number of all piezometers of national GW monitoring network, only part of national network belonging to Pannonian Plain. The total number is 3233 but only 419 observation wells were analysed (Figure 2.7.1). All of these 419 obs. wells have the same length of data series, 33 years (1990-2022). We reduced number of obs. wells because of the following reasons:

- Data series were not long enough (the main reason)
- Data series had one or more gaps of missing data for several years
- Data were not reliable (possible mistakes in measurements, not logical values)
- Concentration of several obs. wells in one nest (all observed data were same and there was no use of analysing them all)

Table 2.7.1 presents relationship between total number of obs. wells in Pannonian Plain and number of wells included in analysis.

Table 2.7.1 Groundwater observation wells of study area

	COUNTRY	TOTAL NUMBER OF OBSERVATION WELLS (Pannonian Plain) Map 1	OBSERVATION WELLS INCLUDED IN ANALYSIS (Map 2)
1	Romania	1098	96
2	Croatia	703	98
3	Serbia	303	5
4	Slovenia	41	20
5	Hungary	1082	200
6	Bosnia and Herzegovina	5	0
7	Slovakia	?	0
	TOTAL	**3233**	**419 (~13%)**

Experts involved in data analysis agreed that this number of obs. Wells is sufficient for analysis, and what is the most important they **are equally distributed** over study area (Figure 2.7.2). The GW observation wells from Bosnia and Herzegovina (located in the south part of the Pannonian Plaine, Figure 2.7.2.) were not involved in the study due to the short period of monitoring. The length of data series is only 4 years (2019-2022). Also, data from Slovakia did not arrive in time. Generally, lengths of data series are very variable. In all countries there are observation wells with data series of GW observations longer than 100 years. But the most intensive development occurred in the 60-ties of the 20th century.

Despite of problems with data acquisition, distribution of piezometers over study area is satisfactory what is presented in figures 2.7.1 and 2.7.2. These figures are published on the official project web site as Map 1 and Map 2.

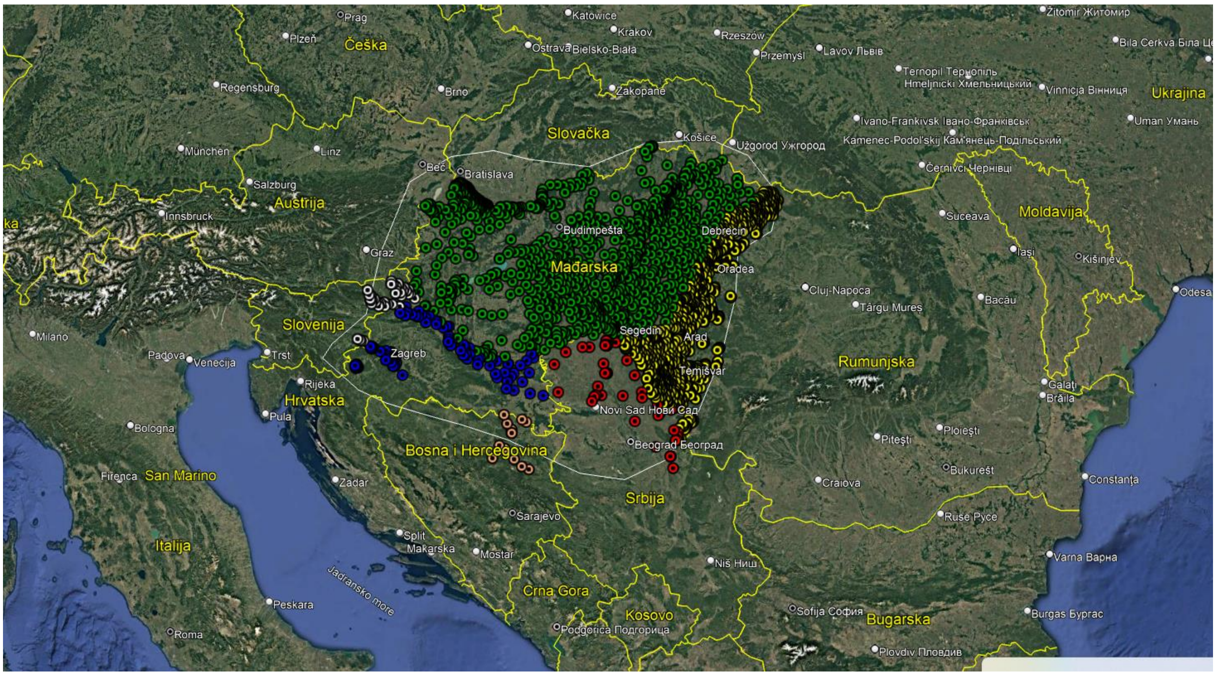

Figure 2.7.1 Presentation of complete GW observation network (Map 1)

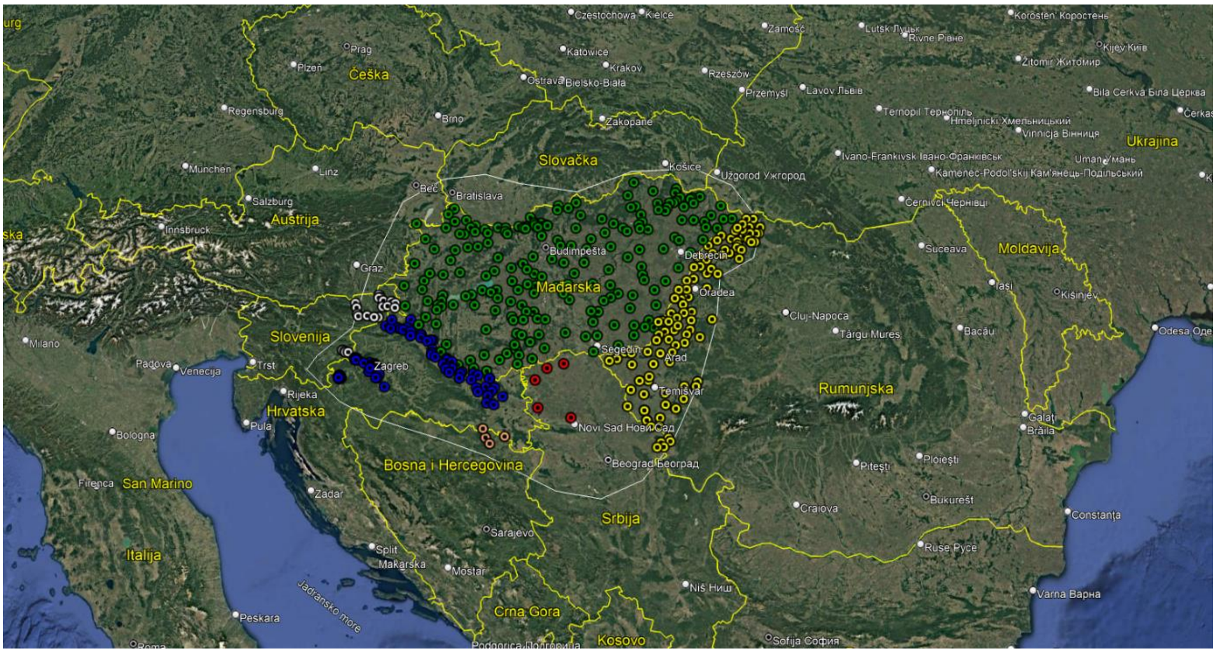

Figure 2.7.2. Presentation of reduced GW observation network (Map 2)

2.7.2 Recommendations

On the basis of analysis of national groundwater networks, we faced several problems. There are great variabilities in data availability. In some countries data access is too complicated and hardly possible. The problem is even greater if someone needs data of specific frequency or specific format. Some of countries in study area have publicly available data in the form of annual publications in .pdf format, not suitable for further data processing. We recommend:

- **simplification of data accessibility for scientific and practical application.**
- **improvement of co-operation between countries in this region regarding GW observation and data exchange**
- **Publishing data in more practical format (at least annual data).**

3 Statistical analysis

3.1 Methodology

Statistical analysis applied on observed data series of groundwater levels gave us more precise insight of groundwater changes over 33 years. Available data from countries included in project are observed on different time scale (hourly, daily, etc.). Data used in all statistical analysis are annual what was considered as acceptable for this level of research. Also, groundwater level, as a component of water balance has very slow dynamic.

So, we applied several basic statistical test such as: homogeneity test, trend test and comparison of average annual groundwater levels between decades (the 1st decade is 1990-1999, the 2nd decade is 2000-2009 and the 3rd is 2010-2022). Groundwater fluctuation is strongly related to precipitation. In order to understand GW movement over longer time period there is Figure 3.1, which presents annual anomalies in precipitation in reference period 1990-2020. In the 90-ies, the most of years had negative anomaly app. -5%, then we have period of more rainy years with positive anomaly up to + 8%.

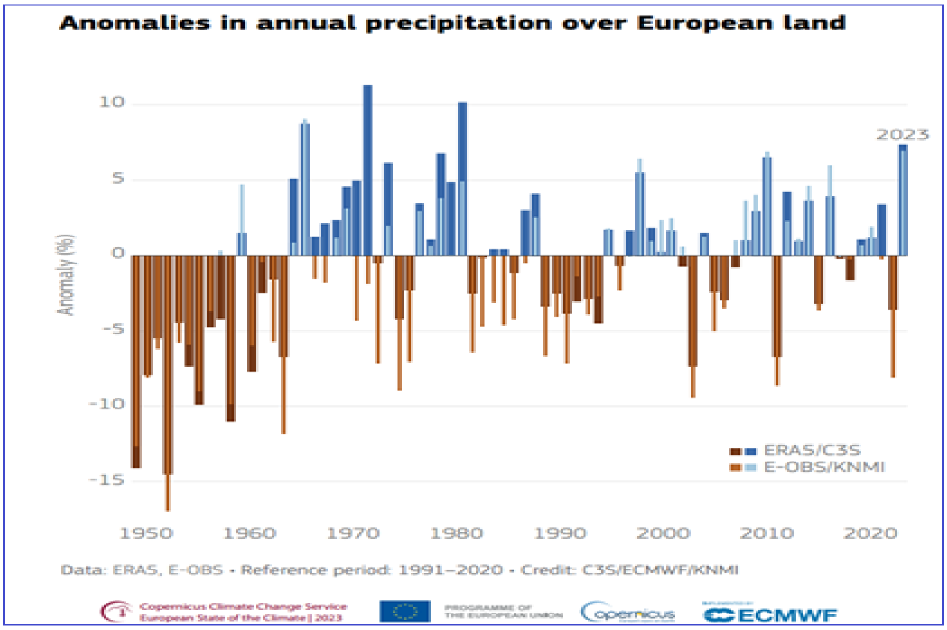

Figure 3.1 Annual European precipitation anomalies (1950-2020)

https://climate.copernicus.eu/esotc/2023/precipitation

3.1.1 Homogeneity test

Homogeneity tests enable us to determine if a series may be considered as homogeneous over time, or if there is a time at which a change occurs. One of very common test, widely used is The Standard Normal Homogeneity Test (SNHT), developed by Alexandersson, 1986. Homogeneity test are recently oftenly used to detect changes in meteorological and hydrological parameters caused by climate change. In this specific case all GW observation series (1990-2022) were tested by SNHT and we detect:

- Does groundwater level observed 33 years in some obs. well has significant change or not
- When change occurred
- Is change positive (increasing) or negative (decreasing)

Results are presented in tables and map.

3.1.2 Trend test

Linear regression has been applied on all data series in order to detect linear relationship between two variables – groundwater change over time. There are two possibilities which can occur: positive and negative. The first one means increasing trend of groundwater levels and the second decreasing. Results are given by tables.

To have more accurate interpretation of trend test, a nonparametric trend test proposed by Mann (1945) then further studied by Kendall (1975) and improved by Hirsch et al (1982, 1984) was applied. Two hypothesis are tested by M-K test:

- the null hypothesis for these tests is that there is no trend in the series.
- there is trend in the series which can be positive trend or negative

The Mann-Kendall tests are based on the calculation of Kendall's tau measure of association between two samples, which is itself based on the ranks with the samples.

3.1.3 Comparison of average GW levels per decades

In the climate change analysis data observed during longer time period are divided into decades. This approach is oftenly used in order to compare different parameters in longer time period. So, we compared average groundwater levels between decades (the 1st decade is 1990-1999, the 2nd decade is 2000-2009 and the 3rd is 2010-2022). Also, this method is very useful for detection of climate change impacts on meteorological and hydrological features of some area.

3.2 Statistical analysis- Romania

Time series of 96 observation wells in Romania, actually in part of Romania which belongs to Pannonian Plain are presented in Figure 3.2.1.a), Figure 3.2.1.b), Figure 3.2.1.c) and Figure 3.2.1.d). They present Banat water basin (Fig. 3.2.1. a), Mures water basin (Fig. 3.2.1.b), Crisuri water basin (Fig. 3.2.1.c) and Somes-Tisa water basin (Fig. 3.2.1.d). Annual GW levels over period of 33 years does not show significant change.

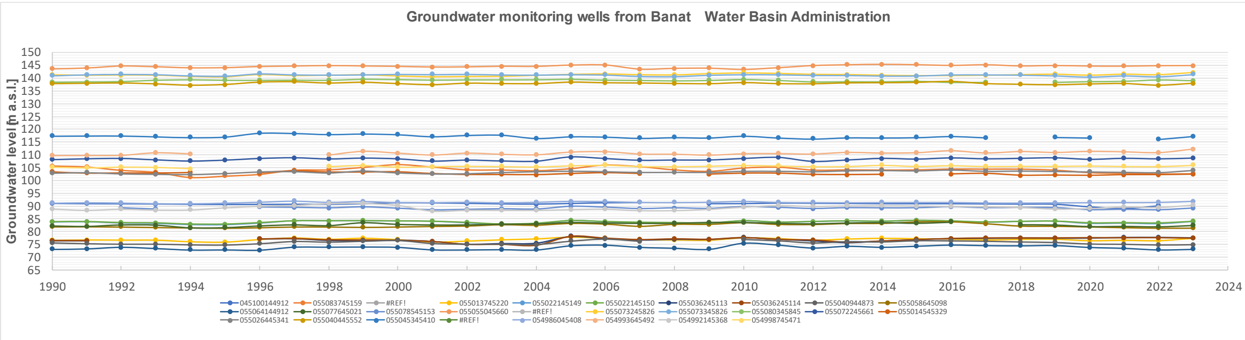

Figure 3.2.1.a) Groundwater change of obs. wells in the Banat water basin (1990-2022)

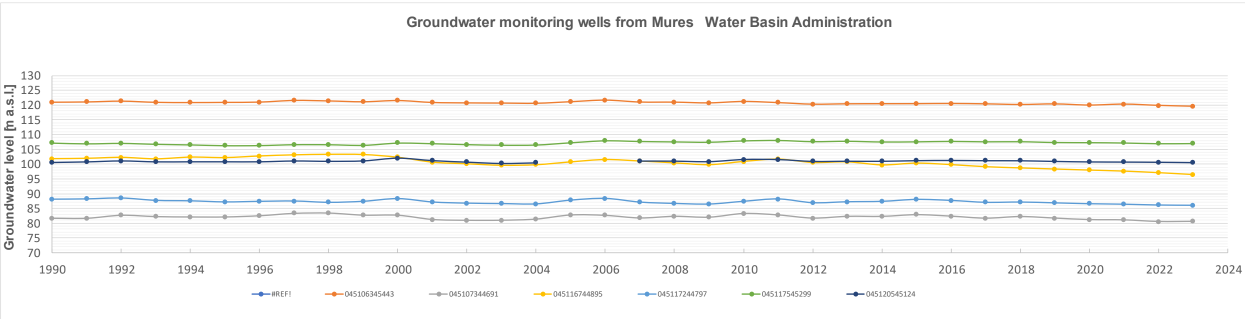

Figure 3.2.1.b) Groundwater change of obs. wells in the Mures water basin (1990-2022)

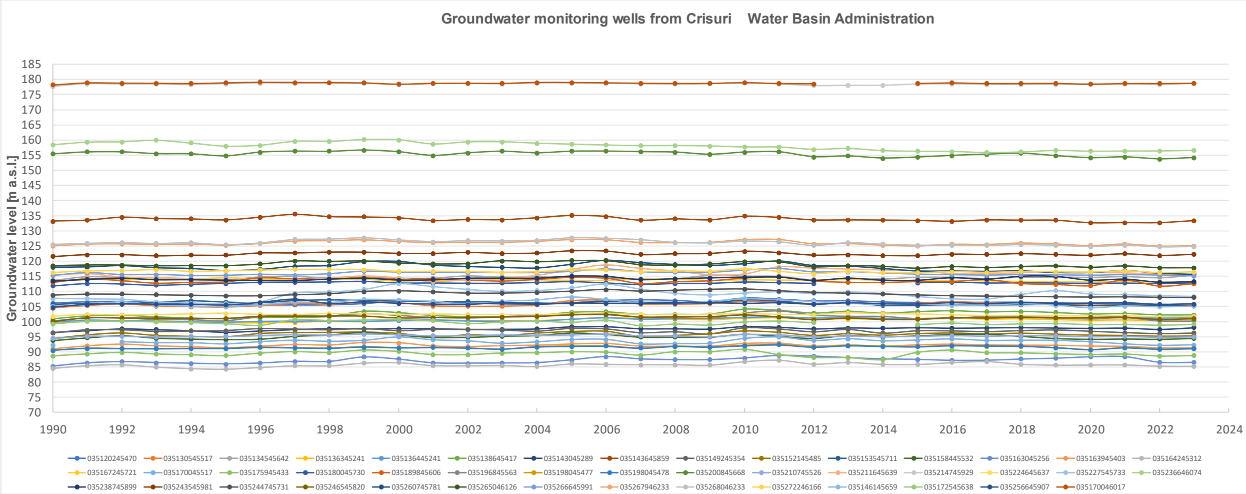

Figure 3.2.1.c) Groundwater change of obs. wells in the Crisuri water basin (1990-2022)

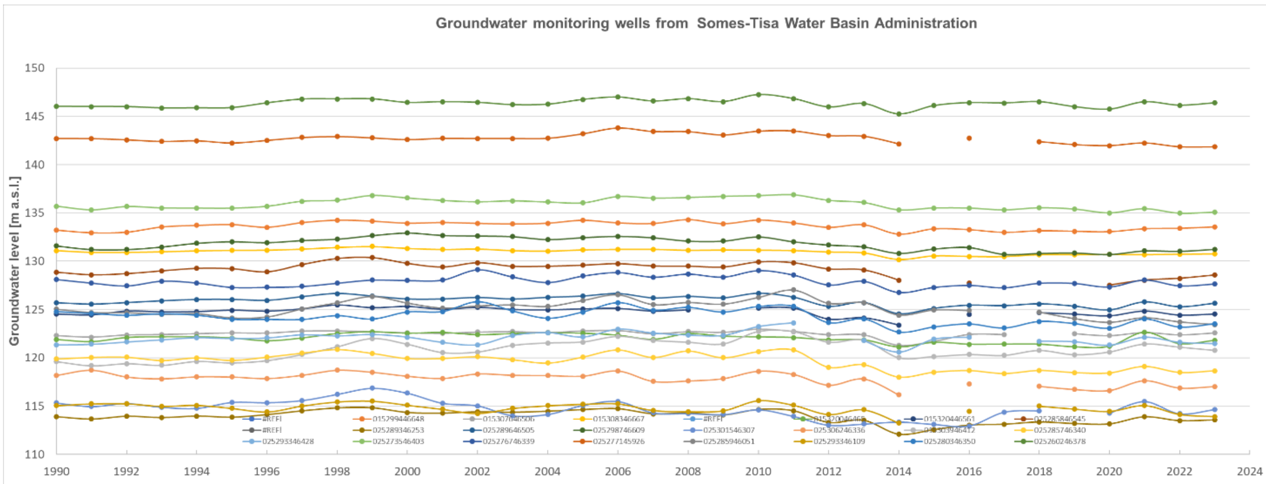

Figure 3.2.1.d) Groundwater change of obs. wells in the Somes-Tisa River basin (1990-2022)

Further analysis of homogeneity of data series confirmed that almost half obs. wells have homogeneous data. Standard Normal Homogeneity Test (SNHT), showed that the most of data series are homogeneous. In Figure 3.2.2 shows calculation results. If computed p-value is greater than the significance level alpha=0.05, data are considered to be homogeneous, in this case 46 observation wells have homogeneous data in the period 1990-2022. The most of non-homogeneous data series are in the Crisuri water basin and Somes-Tisa water basin (right figure).

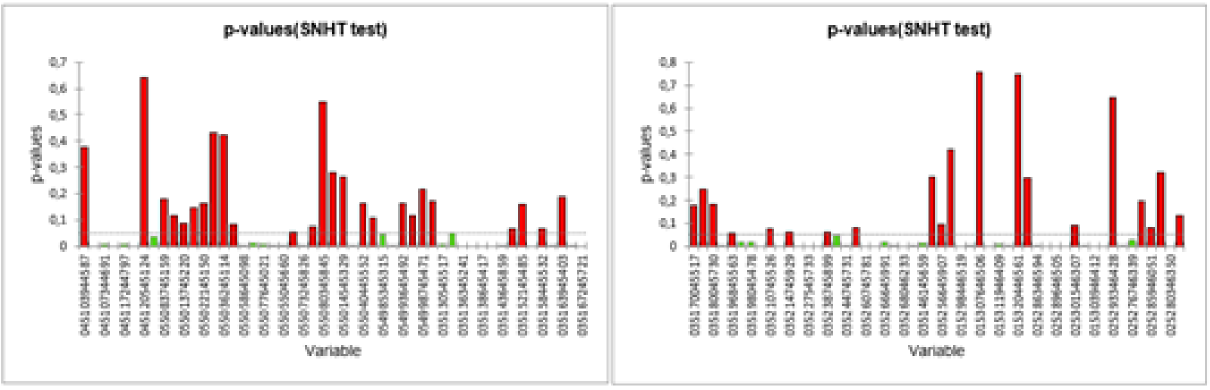

Figure 3.2.2 Results of SNHT for 98 obs. wells in Romania

Results of SNHT presented in more detail are given in Table 3.2.1. The most of non-homogeneous data series (NH), have negative change of average annual GW levels with break year after 2012. Also, some obs. wells have non-homogeneous with positive change of average annual GW levels with earlier break year, in the nineties or beginning of 21st century. Results of homogeneity test is presented on the Map 3.

Table 3.2.1 Results of SNHT for Mures, Banat, Crisuri and Somes-Tisa water basins-Romania

COUNTRY	CODE	H/NH	BREAK YEAR	TENDENCY
MURES R.BASIN ROMANIA	045103944587	H		
	045106345443	NH	2012	NEGATIVE
	045107344691	NH	2020	NEGATIVE
	045116744895	NH	2017	NEGATIVE
	045117244797	NH	2019	NEGATIVE
	045117545299	NH	2005	POSITIVE
	045120545124	H		
ROMANIA BANAT R.BASIN	055083745159	H		
	055102645214	H		
	055013745220	H		
	055022145149	H		
	055022145150	H		
	055036245113	H		
	055036245114	H		
	055040944873	H		
	055058645098	NH	2002	POSITIVE
	055064144912	NH	2005	POSITIVE
	055077645021	NH	1999	POSITIVE
	055078545153	NH	1996	NEGATIVE

	055055045660	NH	2012	POSITIVE
	055061445393	H		
	055073245826	NH	2005	POSITIVE
	055080345845	H		
	055072245661	H		
	055014545329	H		
	055026445341	NH	2004	POSITIVE
	055040445552	H		
	055045345410	H		
	054985345315	NH	2017	NEGATIVE
	054986045408	NH	1996	POSITIVE
	054993645492	H		
	054992145368	H		
	054998745471	H		
ROMANIA CRISURI R.BASIN	035120245470	H		
	035130545517	NH	1997	POSITIVE
	035134545642	H		
	035136345241	NH	2005	POSITIVE
	035136445241	NH	2005	POSITIVE
	035138645417	NH	2005	POSITIVE
	035143045289	NH	1998	POSITIVE
	035143645859	NH	2012	NEGATIVE
	035149245354	H		
	035152145485	H		
	035153545711	NH	2014	NEGATIVE
	035158445532	H		
	035163045256	NH	2005	POSITIVE
	035163945403	H		
	035164245312	NH	1999	POSITIVE
	035167245721	NH	2017	NEGATIVE
	035170045517	H		
	035175945433	H		
	035180045730	H		
	035189845606	NH	2018	NEGATIVE
	035196845563	H		
	035200845668	NH	2012	NEGATIVE
	035210745526	H		
	035211645639	NH	2005	POSITIVE
	035214745929	H		
	035224645637	NH	2017	NEGATIVE

	035227545733	NH	1997	POSITIVE
	035236646074	NH	2010	NEGATIVE
	035238745899	H		
	035243545981	NH	1996	POSITIVE
	035244745731	NH	2015	NEGATIVE
	035246545820	H		
	035260745781	NH	2015	NEGATIVE
	035265046126	NH	2012	NEGATIVE
	035266645991	NH	2015	NEGATIVE
	035267946233	NH	2012	NEGATIVE
	035268046233	NH	2012	NEGATIVE
	035272246166	NH	2012	NEGATIVE
	035146145659	NH	2014	NEGATIVE
	035172545638	H		
	035256645907	H		
	035170046017	H		
ROMANIA SOMES-TISA R.BASIN	015298446519	NH	2012	NEGATIVE
	015299446648	NH	2014	NEGATIVE
	015307646506	H		
	015308346667	NH	2013	NEGATIVE
	015311946409	H		
	015320046465	NH	2012	NEGATIVE
	015320446561	H		
	025285846545	H		
	025286346594	NH	2014	NEGATIVE
	025289346253	NH	2012	NEGATIVE
	025289646505	NH	2012	NEGATIVE
	025298746609	NH	2013	NEGATIVE
	025301546307	H		
	025306246336	NH	2018	NEGATIVE
	015303946412	NH	1998	POSITIVE
	025285746340	NH	2012	NEGATIVE
	025293346428	H		
	025273546403	NH	2014	NEGATIVE
	025276746339	NH	2012	NEGATIVE
	025277145926	H		
	025285946051	H		
	025293346109	H		
	025280346350	NH	2012	NEGATIVE
	025260246378	H		

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However, M-K test applied on complete data series gave us information about existence and significance of trend. Similar as in SNHT criteria for existence of significant trend according to M-K test is computed p-value which has to be is greater than the significance level alpha=0.05, if trend does not exist (Figure 3.2.3). Figure presents all 96 observed wells divided into two groups and approximately 60% of them have no significant trend level. Also, half of the locations with statistically significant trend have decreasing trend. The most of them are located Somes -Tisa water basin.

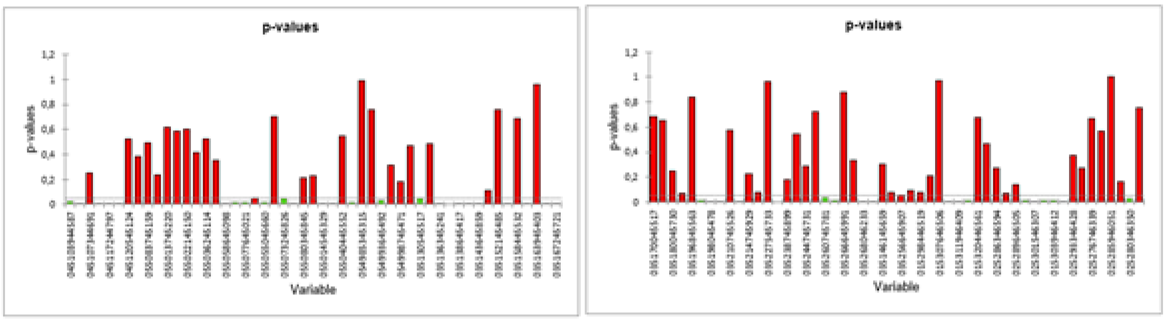

Figure 3.2.3 Results of Mann- Kendall trend test

These two analysis give us information on existence of non-homogeneity, break year, direction of GW change (decreasing or increasing) and significance of trend of annual GW levels.

Next analysis is comparison of average annual GW levels of 3 decades. Values of average annual GW levels per each decade for Romanian water basins and other basins of Pannonian Plain included in study are presented in Maps 4, 5 and 6.

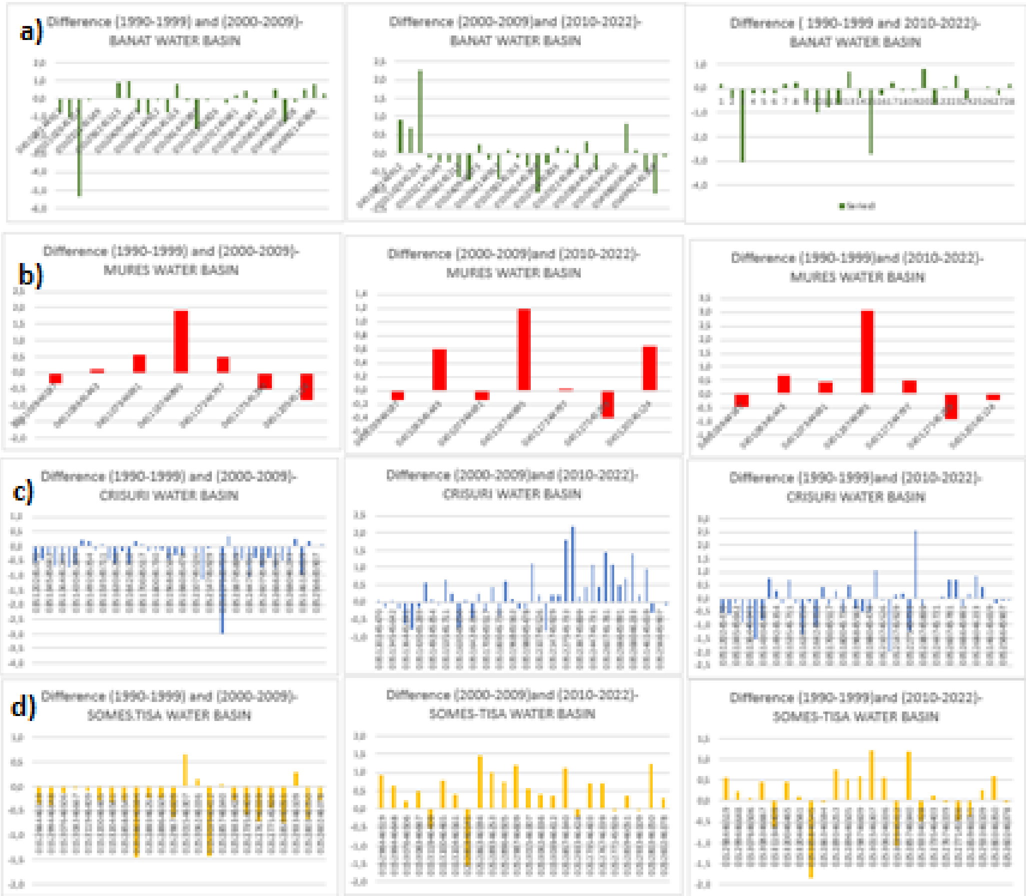

Figure 3.2.4 Differences in average GW levels for Mures, Banat, Crisuri and Somes-Tisa water basins--Romania

Almost all of observation wells have negative differences in average GW levels between the 2nd and the 1st decade except Mures water basin (Fig. 3.2.4 a)). Different results are obtained by calculation of differences between average GW levels of the 3rd and the 1st decade (Fig. 3.4 ., right column). The most of obs. wells have positive change of average GW levels in the Mures water basin and Somes-Tisa. Banat water basin and Crisuri water basin have mostly negative differences. Only differences in average GW levels between the 3rd and the 2nd decades are mostly positive what implies that period between 2000 and 2010 (the 2nd decade) had more precipitation (middle column). These results are correlated to precipitation pattern presented in Figure 3.1.

Results of differences in average GW levels between decades for Romania, are presented on Maps 7, 8 and 9, together with results calculated for other countries included in research.

3.3 Statistical analysis of GW levels - Croatia

Time series of 98 observation wells in Croatia, actually in part of Croatia that belongs to Pannonian Plain are presented in Figure 3.3.1.a) and Figure 3.3.1.b). Total number of observation wells included in analysis consists of 48 obs. wells in the Drava River basin (Fig. 3.3.1.a) and 50 obs. wells in the Sava river basin, Fig 3.3.1.b). Over period of 33 years it is not visible any significant change in annual data of GW levels.

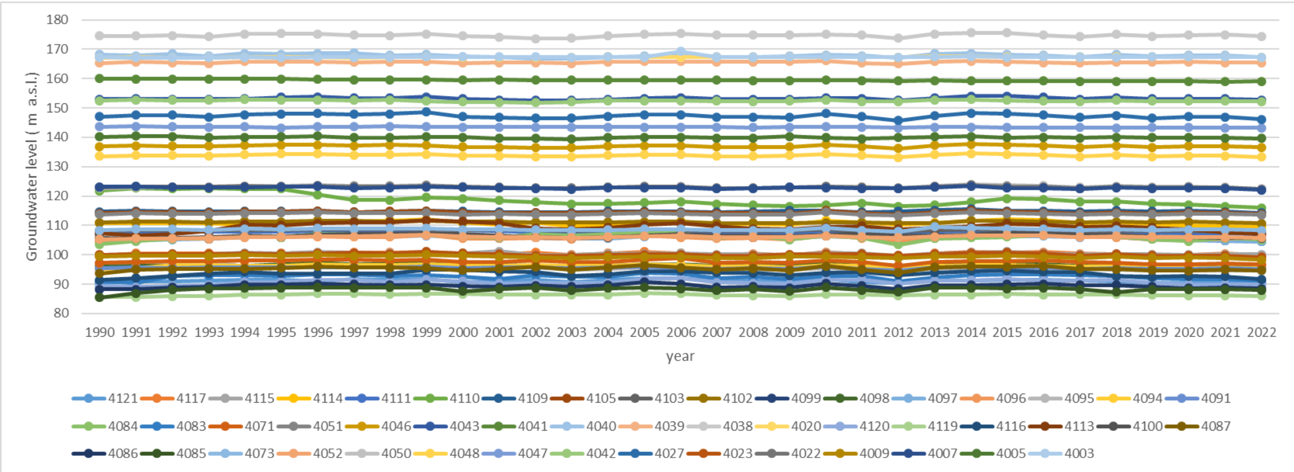

Figure 3.3.1 a) Groundwater change of obs. wells in the Drava River basin (1990-2022)

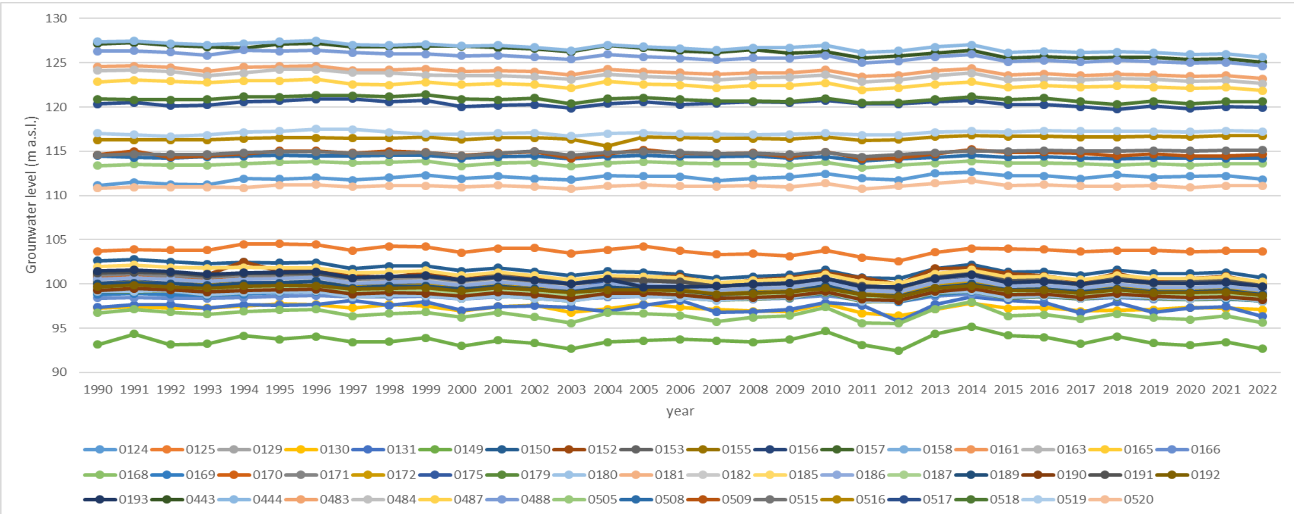

Figure 3.3.2.b) Groundwater change of obs. wells in the Sava River basin (1990-2022)

Further analysis of homogeneity of data series confirmed that most of obs. wells have homogeneous data. Standard Normal Homogeneity Test (SNHT), showed the most of data series homogeneous. In Figure 3.3.3 are results of calculation. If computed p-value is greater than the significance level alpha=0.05, data are considered to be homogeneous, in this case 16 observation wells have homogeneous data in the period 1990-2022. The most of non-homogeneous data series are in the Sava River Basin (right figure).

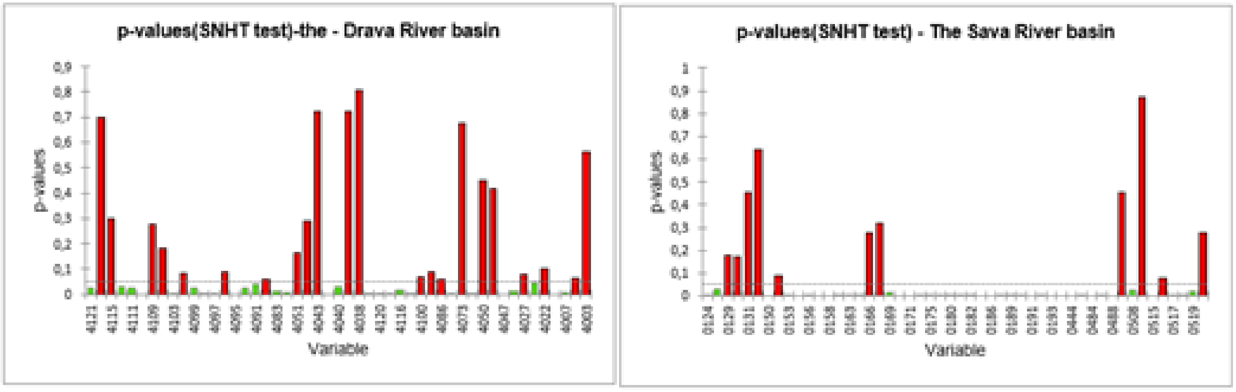

Figure 3.3.3 Results of SNHT for 98 obs. wells in Croatia- the Drava and the Sava River basins

Results of SNHT presented in more detail are given in Table 3.3.1. The most of non-homogeneous data series (NH), have negative change of average annual GW levels with break year in 2000 or later. Also, eight obs. wells have non-homogeneous with positive change of average annual GW levels with break year in the nineties. Results of homogeneity test are presented on the Map 3.

Table 3.3.1 Results of SNHT for in Croatia- the Drava and the Sava basins

COUNTRY	CODE	H/NH	BREAK YEAR	TENDENCY
	4121	NH	2019	NEGATIVE
	4117	H		
	4115	H		
	4114	NH	2020	NEGATIVE
	4111	NH	2002	NEGATIVE
	4109	H		
	4105	H		
	4103	NH	2017	NEGATIVE
	4102	H		
	4099	NH	2020	NEGATIVE
	4098	NH	2019	NEGATIVE

CROATIA THE DRAVA R.BASIN	4097	NH	2019	NEGATIVE
	4096	H		
	4095	NH	1994	NEGATIVE
	4094	NH	2019	NEGATIVE
	4091	NH	2011	NEGATIVE
	4084	H		
	4083	H		
	4071	NH	2007	NEGATIVE
	4051	H		
	4046	H		
	4043	H		
	4041	NH	2003	NEGATIVE
	4040	NH	2000	NEGATIVE
	4039	H		
	4038	H		
	4020	NH	2013	POSITIVE
	4120	NH	1994	POSITIVE
	4119	NH	1994	POSITIVE
	4116	NH	1993	POSITIVE
	4113	NH	1994	POSITIVE
	4100	H		
	4087	H		
	4086	H		
	4085	NH	1992	POSITIVE
	4073	H		
	4052	NH	1994	POSITIVE
	4050	H		
	4048	H		
	4047	NH	2015	NEGATIVE
	4042	NH	1999	NEGATIVE
	4027	H		
	4023	NH	2019	NEGATIVE
	4022	H		
	4009	NH	2001	NEGATIVE
	4007	NH	2001	NEGATIVE
	4005	H		
	4003	H		
	0124	NH	1994	NEGATIVE
	0125	NH	2006	NEGATIVE
	0129	H		
	0130	H		

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CROATIA THE SAVA R.BASIN	0131	H		
	0149	H		
	0150	NH	2000	NEGATIVE
	0152	H		
	0153	NH	2002	NEGATIVE
	0155	NH	2000	NEGATIVE
	0156	NH	1997	NEGATIVE
	0157	NH	2000	NEGATIVE
	0158	NH	2000	NEGATIVE
	0161	NH	2000	NEGATIVE
	0163	NH	2000	NEGATIVE
	0165	NH	2000	NEGATIVE
	0166	H		
	0168	H		
	0169	NH	2003	NEGATIVE
	0170	NH	2000	NEGATIVE
	0171	NH	2000	NEGATIVE
	0172	NH	2000	NEGATIVE
	0175	NH	2004	NEGATIVE
	0179	NH	1997	NEGATIVE
	0180	NH	1997	NEGATIVE
	0181	NH	2006	NEGATIVE
	0182	NH	2000	NEGATIVE
	0185	NH	2000	NEGATIVE
	0186	NH	2000	NEGATIVE
	0187	NH	1997	NEGATIVE
	0189	NH	2000	NEGATIVE
	0190	NH	1997	NEGATIVE
	0191	NH	2000	NEGATIVE
	0192	NH	2000	NEGATIVE
	0193	NH	2000	NEGATIVE
	0443	NH	2009	NEGATIVE
	0444	NH	2015	NEGATIVE
	0483	NH	2000	NEGATIVE
	0484	NH	1999	NEGATIVE
	0487	NH	1997	NEGATIVE
	0488	NH	2002	NEGATIVE
	0505	H		
	0508	NH	2009	NEGATIVE
	0509	H		
	0515	NH	2014	POSITIVE

	0516	H		
	0517	NH	2017	NEGATIVE
	0518	NH	2003	NEGATIVE
	0519	NH	2013	NEGATIVE
	0520	H		

However, M-K test applied to complete data series gave us information about existence and significance of trend. Similar to the SNHT criteria for existence of significant trend according to M-K test is computed p-value which must be greater than the significance level alpha=0.05, if trend does not exist (Figure 3.3.4). In the Drava river basin the most of obs. wells do not show statistically significant trend in GW levels. On the contrary, in the Sava river basin more than 80 % of obs. wells show statistically significant negative trend.

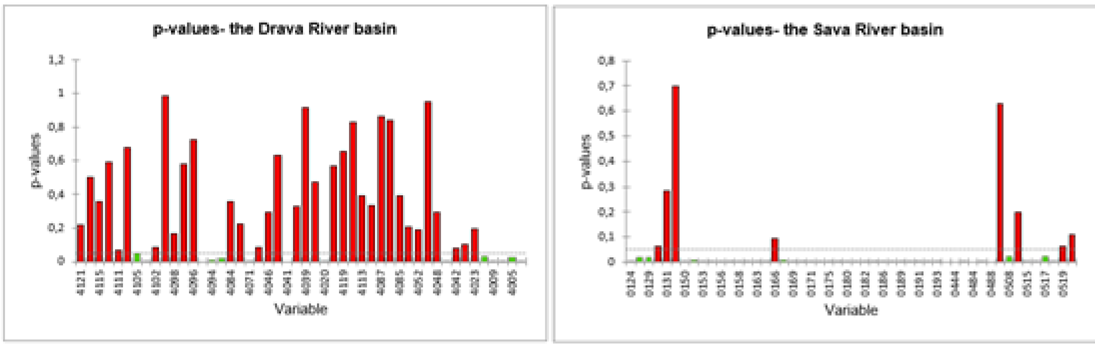

Figure 3.3.4 Results of Mann- Kendall trend test

These two analysis give us information on existence of non-homogeneity, break year, direction of GW change (decreasing or increasing) and significance of trend of annual GW levels.

Next analysis is comparison of average annual GW levels of 3 decades. Values of average annual GW levels per each decade for Croatian river basins and other basins of Pannonian Plain included in study are presented in Maps 4, 5 and 6.

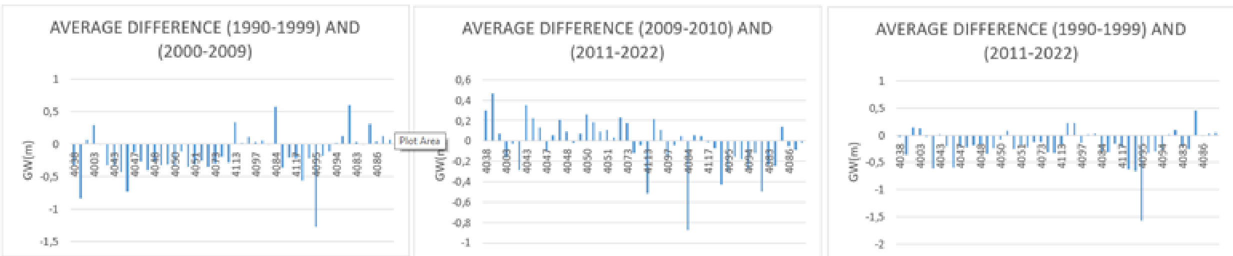

Figure 3.3.5 Differences in average annual GW levels between decades-the Drava river basin

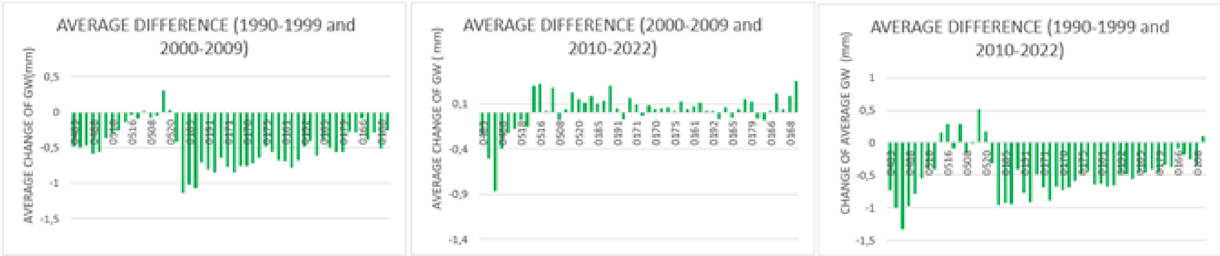

Figure 3.3.6 Differences in average GW levels between decades- the Sava river basin

Almost all of observation wells have negative difference in average GW levels between the 2nd and the 1st decade (Fig. 3.3.5 and Fig. 3.3.6). The similar result has calculation of differences in average GW levels between the 3rd and the 1st decade (Fig. 3.3.5 and Fig. 3.3.6). Only differences in average GW levels between the 3rd and the 2nd decades are mostly positive what implies that period between 2000 and 2010 (the 2nd decade) had more precipitation (middle figure). These results are correlated to precipitation pattern presented in Figure 3.1.

Results of differences in average GW levels between decades for Croatia, are presented on Maps 7, 8 and 9, together with results calculated for other countries included in research.

3.4 Statistical analysis of GW levels - Slovenia

Time series of 21 observation wells in Slovenia, actually in part of Slovenia that belongs to Pannonian Plain are presented in Figure 3.4.1. Over period of 33 years it is not visible any significant change.

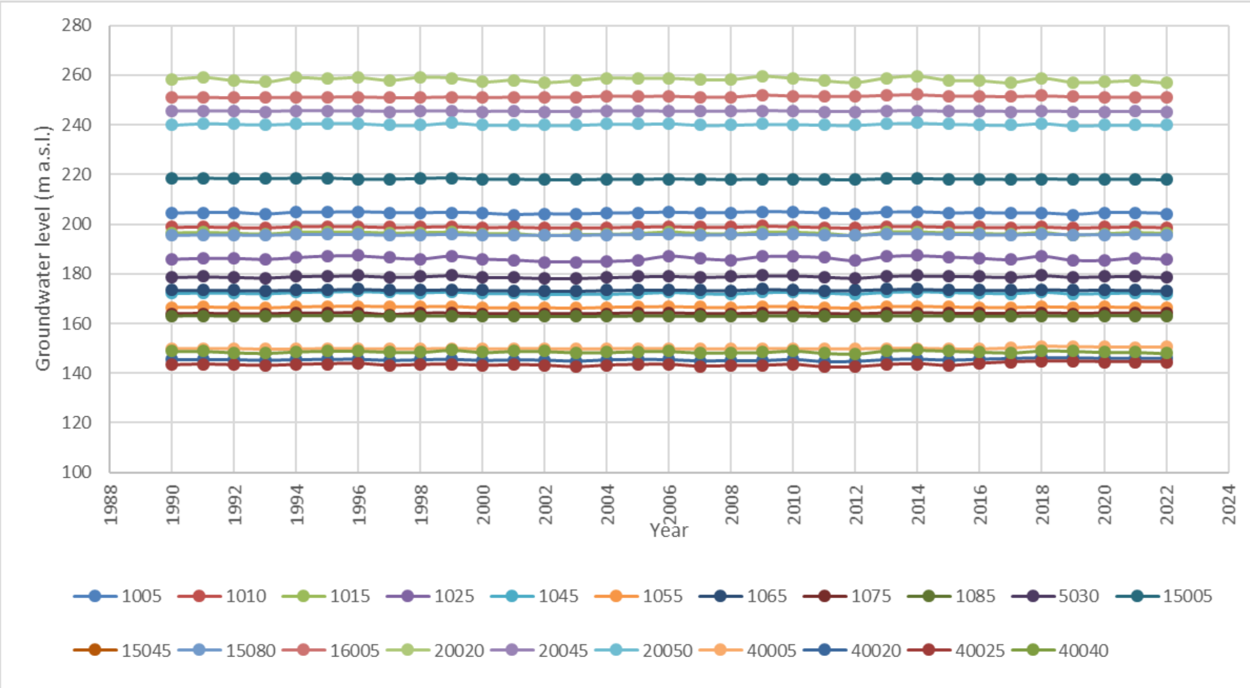

Figure 3.4.1 Groundwater change of obs. Wells in Slovenia (1990-2022)

Further analysis of homogeneity of data series confirmed that most of obs. wells have homogeneous data. Standard Normal Homogeneity Test (SNHT), showed the most of data series homogeneous. In Figure 3.4.2 are results of calculation. If computed p-value is greater than the significance level alpha=0.05, data are considered to be homogeneous, in this case 16 observation wells have homogeneous data in the period 1990-2022.

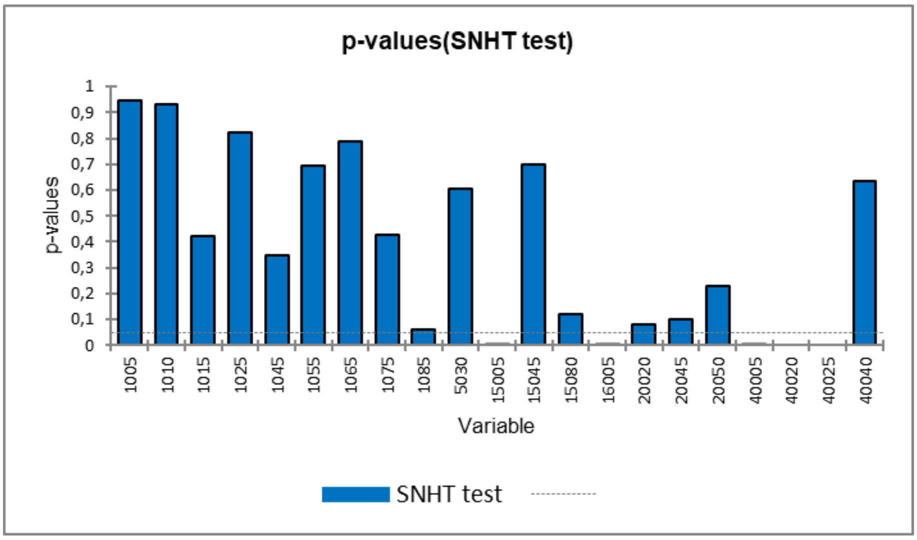

Figure 3.4.2 Results of SNHT for 21 obs. wells in Slovenia

Results of SNHT presented in more detail are given in Table 3.4.1. Besides many homogeneous data series (H), only one is non-homogeneous (NH) with negative change of average annual GW levels starting in 2000. Also, four obs. wells have non-homogeneous with positive change of average annual GW levels starting in 2004, 2017 and 2018. Generally, prevail homogeneous groundwater level. One of the reasons is higher altitude and more precipitation.

Table 3.4.1 Results of SNHT for Slovenia

COUNTRY	CODE	H/NH	BREAK YEAR	TENDENCY
SLOVENIA	1005	H		
	1010	H		
	1015	H		
	1025	H		
	1045	H		
	1055	H		
	1065	H		
	1075	H		
	1085	H		
	5030	H		
	15005	NH	2000	NEGATIVE
	15045	H		
	15080	H		
	16005	NH	2004	POSITIVE
	20020	H		
	20045	H		

	20050	H		
	40005	NH	2018	POSITIVE
	40020	NH	2017	POSITIVE
	40025	NH	2017	POSITIVE
	40040	H		

However, M-K test applied to complete data series gave us information about existence and significance of trend. Similar to the SNHT criteria for existence of significant trend according to M-K test is computed p-value which must be greater than the significance level alpha=0.05, if trend does not exist (Figure 3.4.3). Results of homogeneity test is presented on the Map 3.

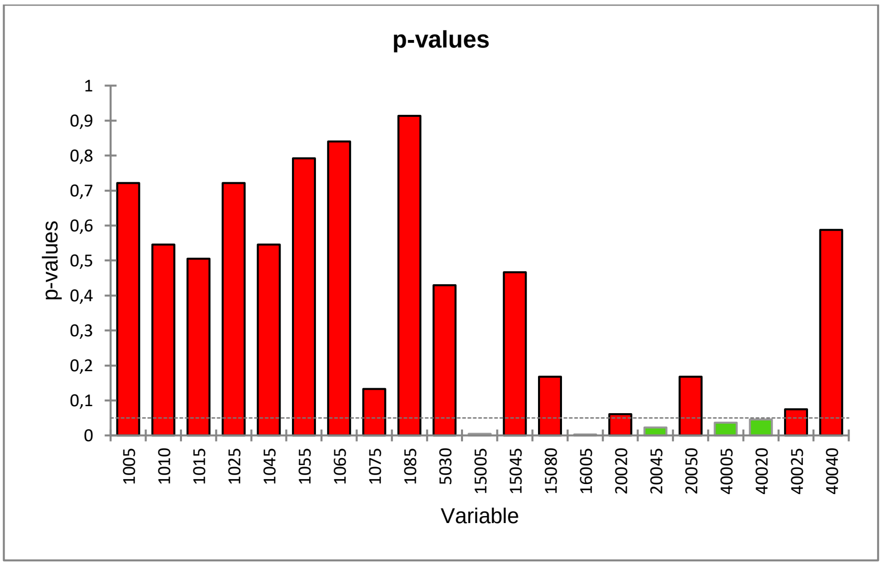

Figure 3.4.3 Results of Mann- Kendall trend test

These two analysis give us information on existence of non-homogeneity, break year, direction of GW change (decreasing or increasing) and significance of trend of annual GW levels.

Next analysis is comparison of average annual GW levels over 3 decades. Values of average annual GW levels per each decade for Slovenia and other countries of Pannonian Plain included in study are presented in Maps 4, 5 and 6.

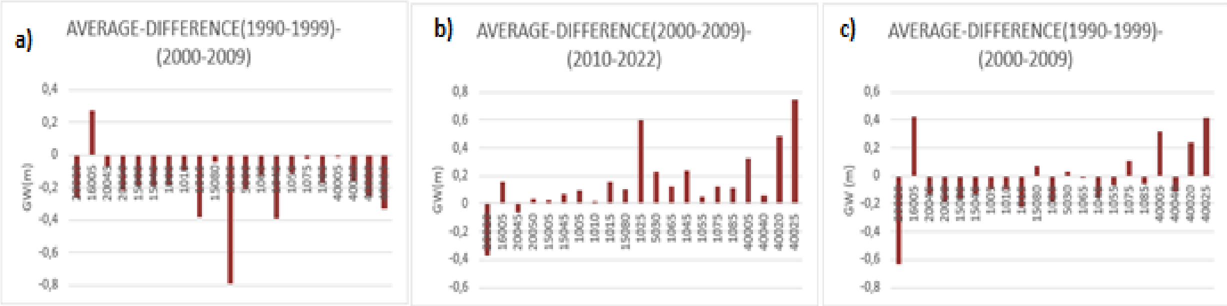

Figure 3.4.4 Differences in average GW levels between decades

The most of observation wells have negative differences in average GW levels between the 2nd and the 1st decade (Fig. 3.4.4a). The similar result has calculation of differences in average GW levels between the 3rd and the 1st decade (Fig 3.4.4c). Only differences in average GW levels between the 3rd and the 2nd decades are mostly positive what implies that period between 2000 and 2010 (the 2nd decade) had more precipitation (Fig 3.4.4b). These results are correlated to precipitation pattern presented in Figure 1.

Results of differences in average GW levels between decades for Slovenia, are presented on Maps 7, 8 and 9, together with other results calculated for other countries included in research.

3.5 Statistical analysis of GW levels - Serbia

Time series of 5 observation wells in Serbia, actually in part of Serbia which belongs to Pannonian Plain are presented in Figure 3.5.1. Over period of 33 years it is not visible any significant change in annual data.

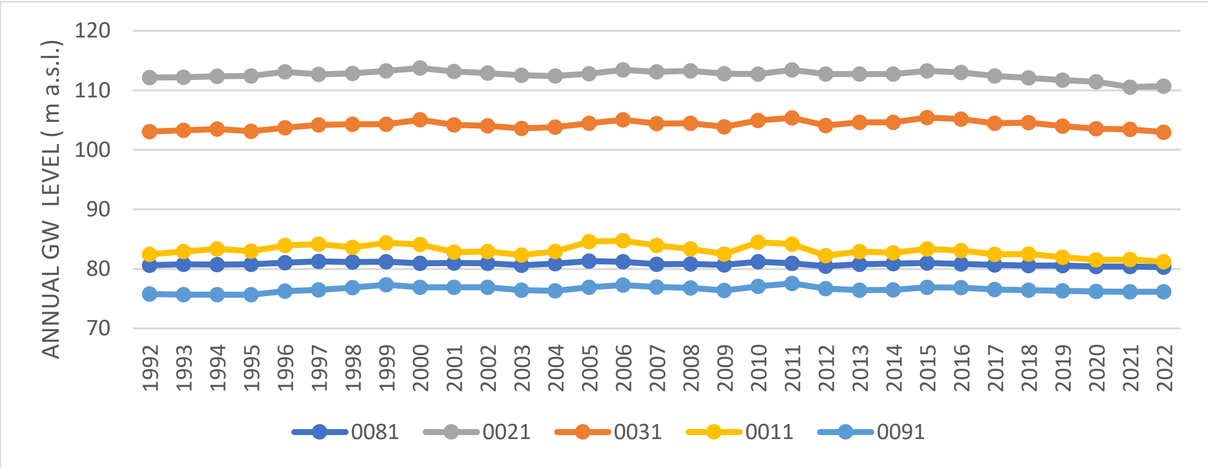

Figure 3.5.1 Groundwater change of obs. Wells in Serbia (1990-2022)

Further analysis of homogeneity of data series confirmed that all obs. wells have non-homogeneous data. In Figure 3.5.2 are results of calculation. If computed p-value is greater than the significance level alpha=0.05, data are considered to be homogeneous, in this case 5 observation wells have homogeneous data in the period 1990-2022.

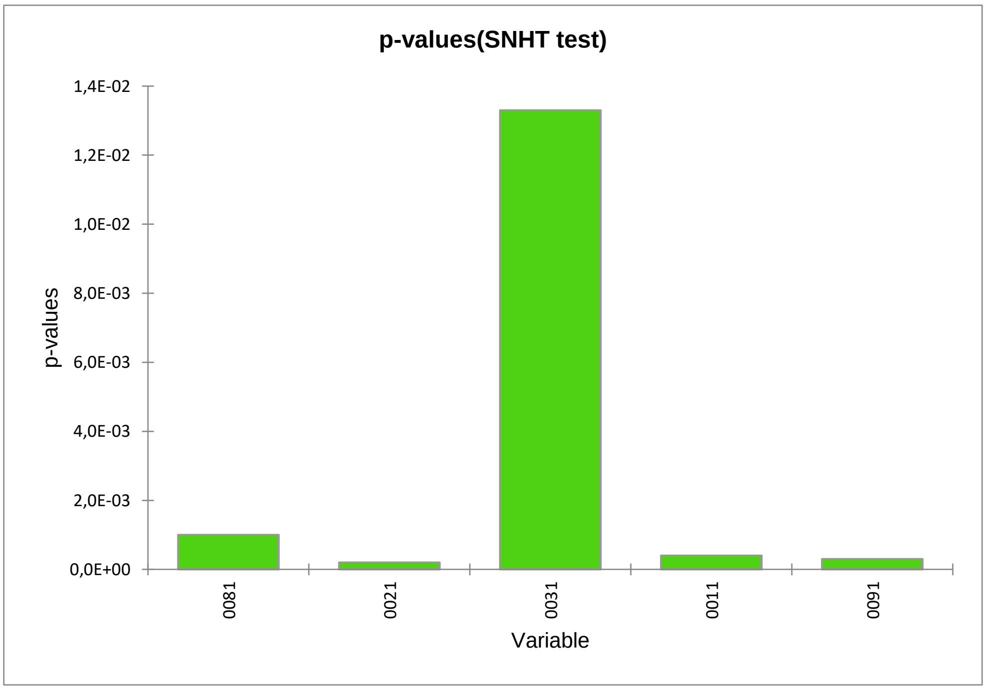

Figure 3.5.2 Results of SNHT for 5 obs. wells in Serbia

Results of SNHT presented in more detail are given in Table 3.5.1. There are no non-homogeneous data series (NH). There are three data series with negative change (starting in 2017, 2018 and 2019) and two with positive change of average annual GW levels (staring in the late nineties).

Table 3.5.1 Results of SNHT for Serbia

COUNTRY	CODE	H/NH	BREAK YEAR	TENDENCY
SERBIA	0081	NH	2018	NEGATIVE
	0021	NH	2019	NEGATIVE
	0031	NH	1997	POSITIVE
	0011	NH	2017	NEGATIVE
	0091	NH	1996	POSITIVE

Just for illustration, Fig. 3.5.3 presents result of SNHT for one obs. well – change of average annual GW of one obs. well (0011) in the period 1990-2016 and 2017-2022. On the annual basis there is negative change over 1.5 m. Results of homogeneity test are presented on the Map 3.

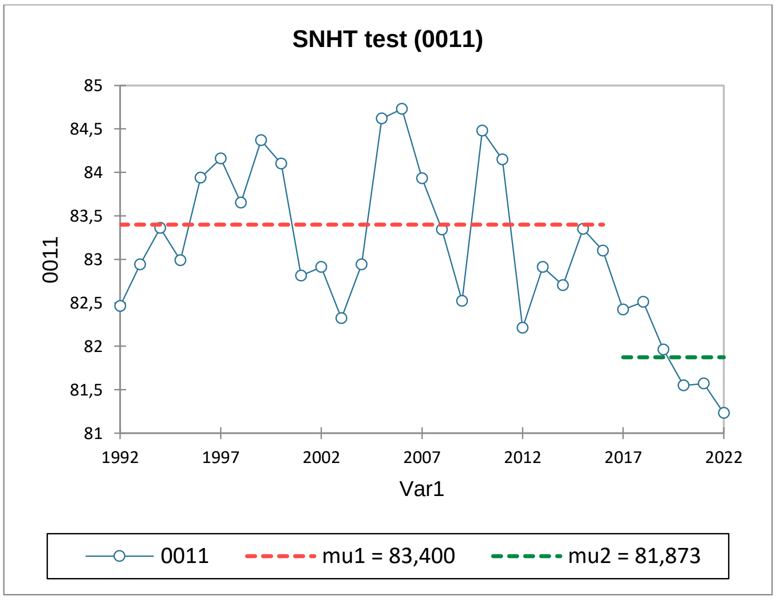

Figure 3.5.3 Results of SNHT for one specific obs. wells in Serbia

However, M-K test applied on complete data series gives us information about existence and significance of trend. Similar to the SNHT criteria for existence of significant trend according to M-K test is computed p-value which must be greater than the significance level alpha=0.05, if trend does not exist (Figure 3.5.4). Results of homogeneity test are presented on the Map 3.

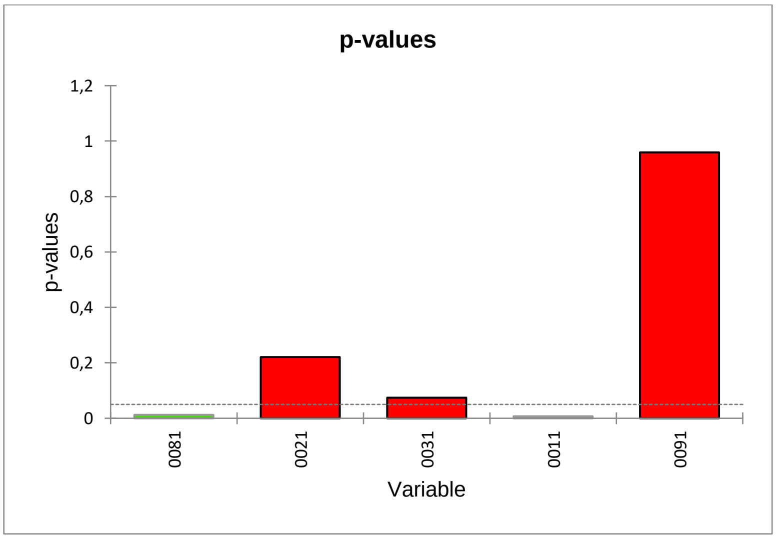

Figure 3.5.4 Results of Mann- Kendall trend test

These two analysis give us information on existence of non-homogeneity, break year, direction of GW change (decreasing or increasing) and significance of trend of annual GW levels. Among all non-homogeneous data series, only three of them have statistical significance (0021, 0031 and 0091).

Next analysis is comparison of average GW levels aver 3 decades. Values of average annual GW levels per each decade for Slovenia and other countries of Pannonian Plain included in study are presented in Maps 4, 5 and 6.

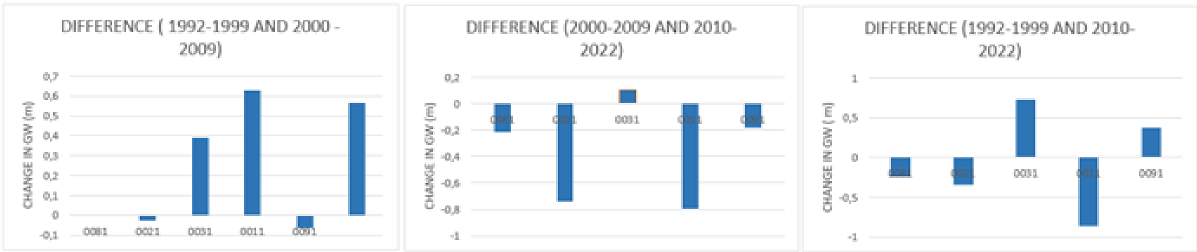

Figure 3.5.5 Differences in average GW levels between decades

The most of observation wells have positive differences in average GW levels between the 2nd and the 1st decade (Fig. 3.5.5, left). However, differences in average GW levels between the 3rd and the 1st and the 3rd and the 2nd decade have mostly negative changes (Fig 3.5.5 , middle and right).

Results of differences in average GW levels between decades for Serbia, are presented on Maps 7, 8 and 9, together with other results calculated for other countries included in research.

3.6 Statistical analysis of GW levels - Hungary

Time series of 200 observation wells in Hungary. This is the biggest number comparing to other countries involved in analysis because entire Hungarian territory belongs to Pannonian Plain. Data series of all obs. wells are presented in Figure 3.6.1.a), Figure 3.6.1.b) and Figure 3.6.1.c). Over period of 33 years it is not visible any significant change in annual data.

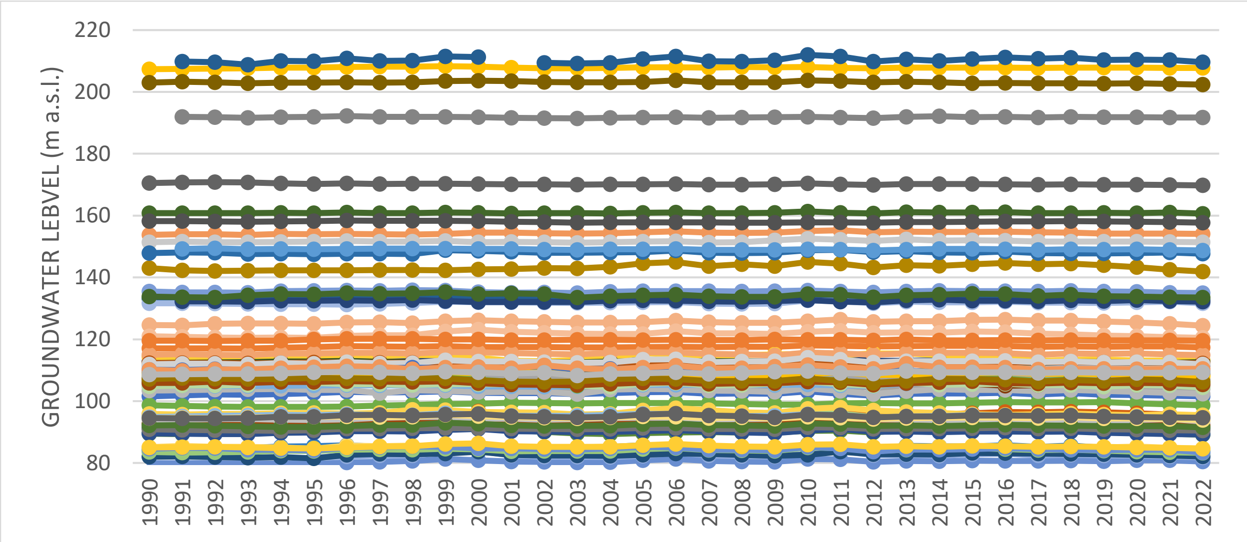

Figure 3.6.1.a) Groundwater change of 70 obs. wells in Hungary (1990-2022)

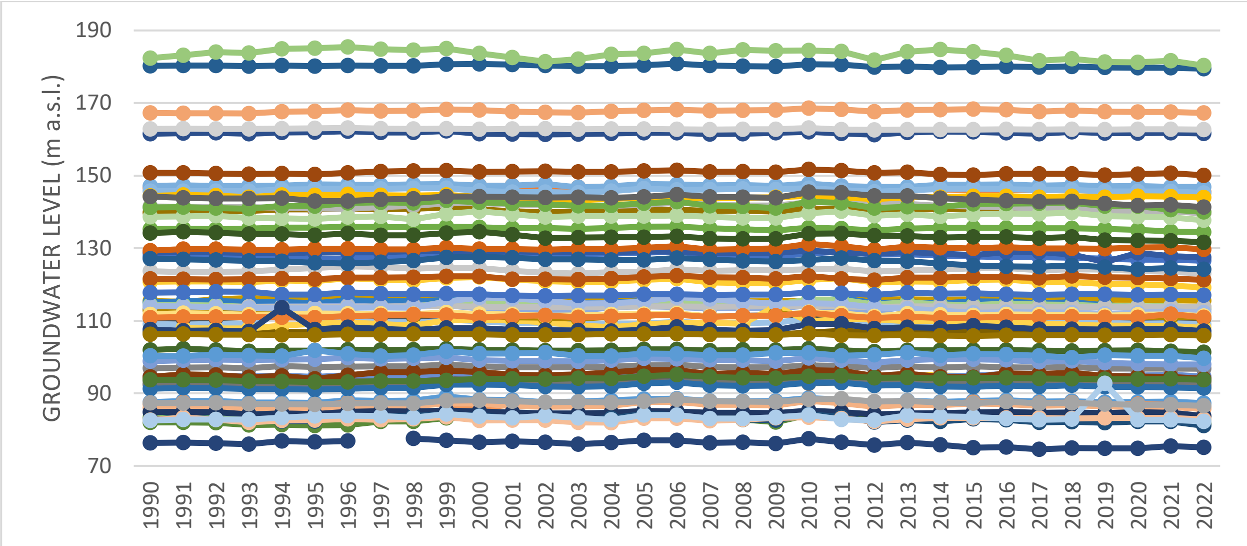

Figure 3.6.1.b) Groundwater change of 65 obs. wells in Hungary (1990-2022)

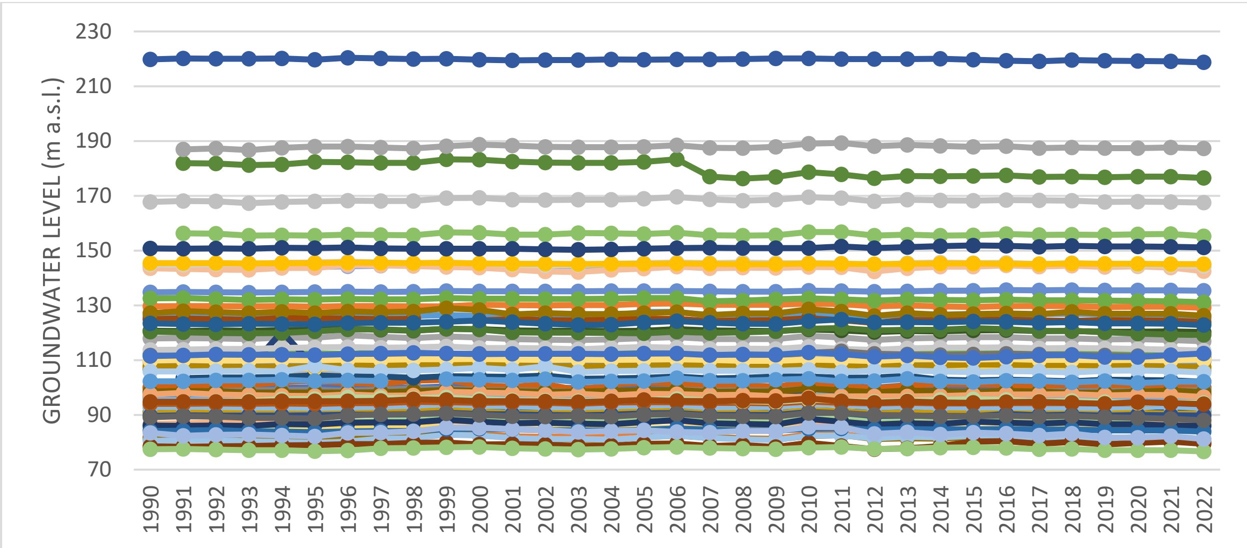

Figure 3.6.1.c) Groundwater change of 65 obs. wells in Hungary (1990-2022)

Further analysis of homogeneity of data series confirmed that most of obs. wells have non-homogeneous data. Standard Normal Homogeneity Test (SNHT), showed the most of data series are non- homogeneous. In Figure 3.6.2 are results of calculation. If computed p-value is greater than the significance level alpha=0.05, data are considered to be homogeneous, in this case 87 observation wells have homogeneous data in the period 1990-2022. The most of data series from Hungary are non-homogeneous.

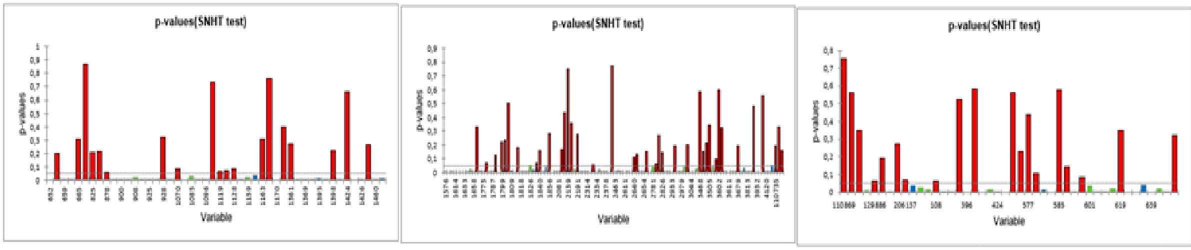

Figure 3.6.2 Results of SNHT for 200 obs. wells in Hungary divided in 3 groups

Results of SNHT presented in more details are given in Table 3.6.1. The most of non-homogeneous data series (NH), has negative change of average annual GW levels with break year in the beginning of 21st century or later. Also, 37 obs. wells have non-homogeneous with positive change of average annual GW levels with break year in the nineties. Results of homogeneity test are presented on the Map 3.

Table 3.6.1 Results of SNHT for Hungary

COUNTRY	CODE	H/NH	BREAK YEAR	TENDENCY
	652	NH	1997	POSITIVE
	656	H		
	659	NH	2002	NEGATIVE
	660	NH	2021	NEGATIVE
	665	H		
	666	H		
	825	H		
	864	H		
	878	H		
	890	NH	2020	NEGATIVE
	900	NH	2000	NEGATIVE
	903	NH	2001	NEGATIVE
	908	NH	2020	NEGATIVE
	921	NH	2019	NEGATIVE
HUNGARY	925	NH	2019	NEGATIVE
	926	NH	2002	NEGATIVE
	928	H		
	1068	NH	2007	NEGATIVE
	1070	H		
	1074	NH	2012	NEGATIVE
	1085	NH	2001	NEGATIVE
	1095	NH	2000	POSITIVE
	1096	NH	2015	POSITIVE

	1110	H		
	1119	H		
	1127	H		
	1128	H		
	1135	NH	2012	NEGATIVE
	1159	NH	2007	NEGATIVE
	1160	NH	1999	NEGATIVE
	1163	H		
	1164	H		
	1170	NH	2014	NEGATIVE
	1176	H		
	1361	H		
	1365	NH	2019	NEGATIVE
	1369	NH	2020	NEGATIVE
	1389	NH	2019	NEGATIVE
	1395	NH	2019	NEGATIVE
	1396	NH	2019	NEGATIVE
	1398	H		
	1403	NH	2019	NEGATIVE
	1424	H		NEGATIVE
	1425	NH	2015	NEGATIVE
	1426	NH	2007	NEGATIVE
	1440	H		
	1460	NH	2017	NEGATIVE
	1569	NH	2014	NEGATIVE
	1576	NH	2012	NEGATIVE
HUNGARY	1594	NH	2015	NEGATIVE
	1607	NH	2011	NEGATIVE
	1614	NH	2017	NEGATIVE
	1622	NH	2019	NEGATIVE
	1624	NH	2016	NEGATIVE
	1633	NH	2012	NEGATIVE
	1644	NH	2014	NEGATIVE
	1653	NH	2014	NEGATIVE
	1658	NH	2012	NEGATIVE
	1659	H		
	1663	NH	2012	NEGATIVE
	1775	NH	1998	POSITIVE
	1778	H		
	1783	NH	2014	NEGATIVE
	1787	NH	2003	NEGATIVE

	1794	H		
	1798	NH	1998	POSITIVE
	1799	H		
	1801	H		
	1805	H		
	1809	NH	1999	POSITIVE
	1812	NH	2013	NEGATIVE
	1813	H		
	1818	NH	1999	POSITIVE
	1820	NH	1999	POSITIVE
	1821	NH	1999	POSITIVE
	1826	H		
	1829	NH	1999	POSITIVE
	1838	H		
	1840	H		
	1847	NH	2012	NEGATIVE
	1855	NH	1998	POSITIVE
	1856	H		
	1858	NH	2012	NEGATIVE
	1860	NH	1997	POSITIVE
	2081	NH	1999	POSITIVE
	2092	H		
HUNGARY	2134	H		
	2139	H		
	2147	H		
	2176	NH	2021	NEGATIVE
	2191	H		
	2227	NH	2017	NEGATIVE
	2286	NH	2012	NEGATIVE
	2314	NH	2011	POSITIVE
	2319	NH	1997	POSITIVE
	2325	H		
	2334	NH	2000	POSITIVE
	2342	NH	2019	NEGATIVE
	2353	NH	1998	NEGATIVE
	2378	NH	1996	POSITIVE
	2430	NH	2015	
	2441	H		
	2463	NH	2015	NEGATIVE
	2588	NH	2019	NEGATIVE
	2608	NH	2016	NEGATIVE

	2611	NH	2014	NEGATIVE
	2616	NH	2014	NEGATIVE
	2634	NH	1999	POSITIVE
	2640	H		
	2649	H		
	2653	NH	2020	NEGATIVE
	2654	NH	2020	NEGATIVE
	2688	H		
	2771	NH	1999	POSITIVE
	2781	H		
	2783	H		
	2820	H		
	2826	H		
	2927	NH	1996	POSITIVE
	2932	NH	2019	NEGATIVE
	2933	NH	2002	NEGATIVE
	2945	H		
	2954	NH	2017	NEGATIVE
	2979	NH	1997	POSITIVE
	2984	NH	2020	NEGATIVE
	3038	H		
	3044	NH	2007	NEGATIVE
	3453	NH	2015	NEGATIVE
	3462	NH	2003	NEGATIVE
	3468	H		
	3469	H		
	3491	H		
	3505	H		
	3588	NH	2017	NEGATIVE
	3599	H		
	3602	H		
	3605	H		
	3607	NH	2002	NEGATIVE
HUNGARY	3611	NH	2013	POSITIVE
	3674	NH	1994	NEGATIVE
	3676	NH	1994	NEGATIVE
	3679	H		
	3685	NH	1994	NEGATIVE
	3687	NH	1994	POSITIVE
	3813	NH	1995	POSITIVE
	3858	NH	2019	NEGATIVE

	3859	H		
	3932	NH	2016	NEGATIVE
	4033	NH	1999	POSITIVE
	4062	H		
	4120	NH	2012	NEGATIVE
	4330	NH	2017	NEGATIVE
	110692	NH	2015	POSITIVE
	110735	H		
	110843	H		
	110859	H		
	110869	H		
	110877	H		
	110890	H		
	129845	NH	2014	NEGATIVE
	129886	H		
	129936	H		
	161015	NH	2000	NEGATIVE
	161022	H		
	206137	H		
	80	NH	1994	POSITIVE
	87	NH	2020	NEGATIVE
	94	NH	2020	NEGATIVE
	108	H		
	143	NH	1995	NEGATIVE
	206	NH	2017	NEGATIVE
	258	H		
	396	NH	2001	NEGATIVE
HUNGARY	405	H		
	412	NH	2011	POSITIVE
	422	NH	2020	NEGATIVE
	424	NH	2000	NEGATIVE
	434	NH	2000	NEGATIVE
	436	H		
	445	H		
	577	H		
	579	H		
	580	NH	2009	POSITIVE
	582	NH	2019	NEGATIVE
	585	H		
	589	H		
	591	NH	1994	POSITIVE

	594	H		
	601	NH	2019	NEGATIVE
	608	NH	1996	POSITIVE
	613	NH	1999	POSITIVE
	614	NH	2021	NEGATIVE
	619	H		
	625	NH	2014	POSITIVE
	630	NH	2004	POSITIVE
	635	NH	1994	POSITIVE
	639	NH	1999	POSITIVE
	644	NH	2021	NEGATIVE
	645	NH	1996	POSITIVE
	647	H		

However, M-K test applied on complete data series gave us information about existence and significance of trend. Similar to the SNHT criteria for existence of significant trend according to M-K test is computed p-value which must be greater than the significance level alpha=0.05, if trend does not exist (Figure 3.6.3). The most of obs. wells do not show statistically significant trend in GW levels.

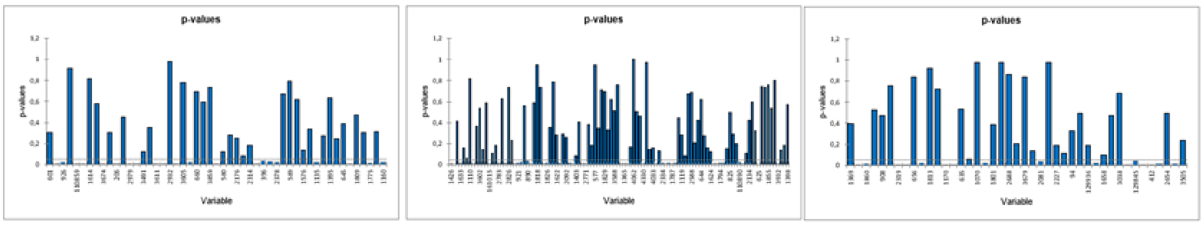

Figure 3.6.3 Results of Mann- Kendall trend test

These two analysis give us information on existence of non-homogeneity, break year, direction of GW change (decreasing or increasing) and significance of trend of annual GW levels.

Next analysis is comparison of average annual GW levels over 3 decades. Values of average GW levels per each decade for Hungarian obs. wells and other basins of Pannonian Plain included in study are presented in Maps 4, 5 and 6.

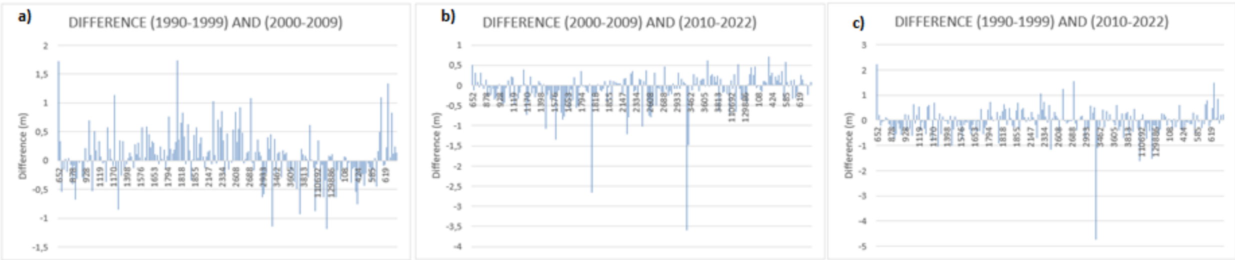

Figure 3.6.4 Differences in average GW levels between decades - Hungary

Almost all of observation wells have positive differences in average GW levels between the 2nd and the 1st decade (Fig. 3.6.4.b) and Fig. 3.6.4. a)). Much different result has calculation of differences in average GW levels between the 3rd and the 1st decade (Fig. 3.6.4 c) and Fig. 3.6.4.a)). Similar results are obtained by calculation of difference in average GW levels between the 3rd and the 2nd (Fig. 3.6.4.b). However, the range of difference is much bigger. Negative values are mostly over -0.5 m with the most extreme value of -4.7m.

Results of differences in average GW levels between decades for Hungary, are graphically presented on Maps 7, 8 and 9, together with results calculated for other countries included in research.

3.7 Impacts of GW changes on agriculture and environment

Previous analysis proved changes in GW table over the Pannonian Plain. In some regions changes are positive, in others they are negative. Both can have undesirable impacts on agriculture, forestry and nature, especially if they keep their trends over a longer period. Part of this report is brief elaboration of possible consequences on agriculture and environment. Due to the complexity of processes in water-soil-vegetation nexus in nature, more comprehensive study is required throughout the main project. Obtained results are platform for activities and outputs of the main project with special focus will be on the forestry, agriculture and nature.

3.7.1 GW level impacts on agricultural crops

Groundwater level fluctuations have very specific impact on agricultural crops. The main reason for that impact is developing of root system, the same as it's deepness as well as tolerant of some crops on high groundwater level (meadow). Roth plant system besides the water and nutrients needs the air, so, groundwater table has the significant role in normal development of plants. While water is present in the soil, there were an anaerobic condition, which are not convenient for developing normal biochemical process which are not good for degradation of organic matter as well as accessibility of the essential nutrients. In soil conditions with a high groundwater level, the soil structure for seed preparation is not good, especially in spring what is the result inconvenient „water-air- soil “regime.

The tolerant groundwater level for different agricultural crops is: for meadows, and pastures from 20 to 30 cm, vegetable crops (onion, tomato, haricot bean, potato, cabbage) from 50 to 60 cm, field crops (maize, winter wheat, sunflower, soyabean) from 110 to 120 cm, and different fruits approximately.

However, capillary rise of the groundwater is also important factor which have an impact on the water accessibility in dry periods of the year. Capillary rise of the water in the soil is result of the soil capillary potential. Water moves through the soil from higher to lower humidity through pores. Capillary rise of groundwater depends on the mechanical composition of the soil (percentage of the sand, gravel of clay in soil particles). In the light, sandy and sandy loam soils the capillary rising of soil water level is smaller, but in the heavy, clay soils are the highest, respectively. So, the water rising up by capillary potential from groundwater to upper soil layers in the plant root zone which is very desirable in the dry period of our climate conditions (from July to September) and very useful for growing plants. Constant and irreversible lowering of groundwater table reduces moisture of the soil originated by capillary rise. Consequently, water requirement in summer periods increases and irrigation implementation becomes essential for crop production. Groundwater level fluctuations have very specific impact on agricultural crops.

3.7.2 GW level impacts on the environment

Groundwater is a fundamental component of environmental stability, influencing entire ecosystems by regulating soil moisture, sustaining surface water bodies, and supporting diverse habitats. Its availability and fluctuations shape key environmental processes, particularly in wetlands, floodplain forests, and riverine systems. These environments are not only biodiversity hotspots but also essential for maintaining water quality, nutrient cycling, and climate resilience. Changes in groundwater levels—whether due to natural variability or human activities—can disrupt these delicate balances, leading to habitat degradation, species loss, and altered hydrological dynamics.

Wetlands are among the most productive ecosystems globally, acting as natural water filters, carbon storage sites, and nutrient-rich areas. Their dependence on groundwater stems from their hydrology—stable groundwater levels ensure constant soil moisture, prevent desiccation, and support the survival of specialized species adapted to wet conditions. Groundwater-fed wetlands in the Danube River Basin are particularly sensitive to fluctuations in water levels, and their degradation can lead to biodiversity loss and a reduction in key ecological services.

Floodplain forests, located along rivers and wetland areas, are also highly sensitive to changes in groundwater levels. These forests serve as natural flood buffers, slow down soil erosion, and provide habitats for a diverse range of species. They include priority habitat HT 91E0* (alluvial forests) and HT 91F0 (riparian mixed forests), which are closely linked to and dependent on natural river dynamics. These forest types help regulate groundwater levels by storing excess water during floods and gradually releasing it, ensuring long-term soil moisture balance. Many of these forests are designated under the Natura 2000 network due to their ecological importance. Stable groundwater levels help maintain natural flood regimes, which are essential for soil renewal and the regeneration of vegetation.

Beyond their direct influence on wetlands and floodplain forests, groundwater is also a vital source of water for rivers and lakes during dry periods. Maintaining a balance between natural infiltration and groundwater extraction is crucial for ecosystem preservation. Over-extraction of groundwater can lead to reduced water levels in rivers and wetlands, while disruptions in the hydrological cycle can cause irreversible changes in ecosystems.

River ecosystem and wetland restoration projects play a key role in protecting biodiversity and ensuring the long-term stability of the shallow groundwater system. Sustainable water management is not only important for protecting individual species and ecosystems but also for maintaining the environmental processes that support life across the broader region. The long-term protection of groundwater and related ecosystems requires an integrated approach, including sustainable water use, the conservation of natural aquifers, and the restoration of degraded habitats. The preservation of wetlands, floodplain forests, and other groundwater-dependent ecosystems is a crucial step in safeguarding biodiversity and environmental stability.

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The groundwater system plays a crucial role in maintaining the ecological balance, particularly in wetlands, floodplain forests, and riverine ecosystems, which are vital for biodiversity in the Danube Basin. These ecosystems provide important services—such as water filtration and purification, flood regulation, and carbon storage—and serve as habitats for numerous species of plants and animals, including migratory birds, rare fish species, and specialized flora.

In the Pannonian Plain over the past three decades, significant changes in groundwater levels have been recorded, and maps depicting conditions from 1990 to 2022 indicate three main trends presented in Figure 4.1.1. Red areas denote a decrease in groundwater levels (especially near the Hungary-Romania border and in the upper course of the Sava River). Yellow areas indicate an increase in levels, and green areas show stable levels. Decreased groundwater levels in red zones represent a serious threat to ecosystems such as wetlands, floodplain forests, and riverine systems. The stable soil moisture provided by groundwater and periodic floods is crucial for preserving these habitats. Drying of such areas can lead to the loss of species adapted to moist conditions, reduced biodiversity, and a disruption of the natural balance. Conversely, increased groundwater levels (yellow areas) can result in excessive soil moisture, which undermines soil quality and affects the stability of riverine ecosystems, wetlands, and floodplain forests. Excessive soil saturation can impair the ability of plants to breathe properly, impacting their growth and the overall health of the ecosystem.

Stable groundwater levels (green areas) ensure the consistent soil moisture needed to preserve these sensitive ecosystems. Additionally, the restoration of river ecosystems through wetland habitat restoration projects plays an important role in preserving biodiversity and protecting the shallow groundwater system. Sustainable management of these areas contributes not only to the conservation of the groundwater system itself but also to all the ecological services that these systems provide—from flood regulation and water purification to carbon storage.

Changes in groundwater levels have profound ecological consequences in the Danube Basin, and protecting and restoring these natural systems is crucial for the long-term preservation of nature and biodiversity in the region.

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4 Conclusion

Title of the first output of PANNONIAN.GW project is **Groundwater monitoring network** and project team was dealing with it 6 months. Results of groundwater monitoring on annual basis presented in this chapter give an overview of processes in the subsurface of the Pannonian Plain. It is situated in the middle part of the Europe with number of countries sharing it. In this project most of them participated but not all of them. The first problem we faced is difference in data availability and possibilities of their usage. So, our primary recommendation is improvement of coordination between countries in this region (page 17).

Application of basic statistical analysis on over 400 observation wells relatively well distributed over Pannonian Plain show great variability in GW levels in the period between 1990 and 2022. Results presented in previous chapter are focused on homogeneity test, Mann-Kendall trend test and differences of average GW level between decades. They prove decreasing of GW levels in some parts of the study area. However in some parts are designated increasing of GW.

Results are obtained on the annual time scale what means that we can expect much more variations on the shorter time basis such as season. Further modelling of these changes on shorter time scale, such as season, will be one of the main tasks of the main project. Certain areas, in the Sava river basin in Croatia and area on the North-East (border region between Hungary and Romania) show rather significant concentrated decrease of GW starting in the first decade of 21st century. These specific locations can be considered as critical spots and they are presented in Map 10 (Figure 4.1.1). Besides two previously mentioned regions with significant GW decreasing, there are numerous separated spots spread all over Plain and they need more attention in the main project.

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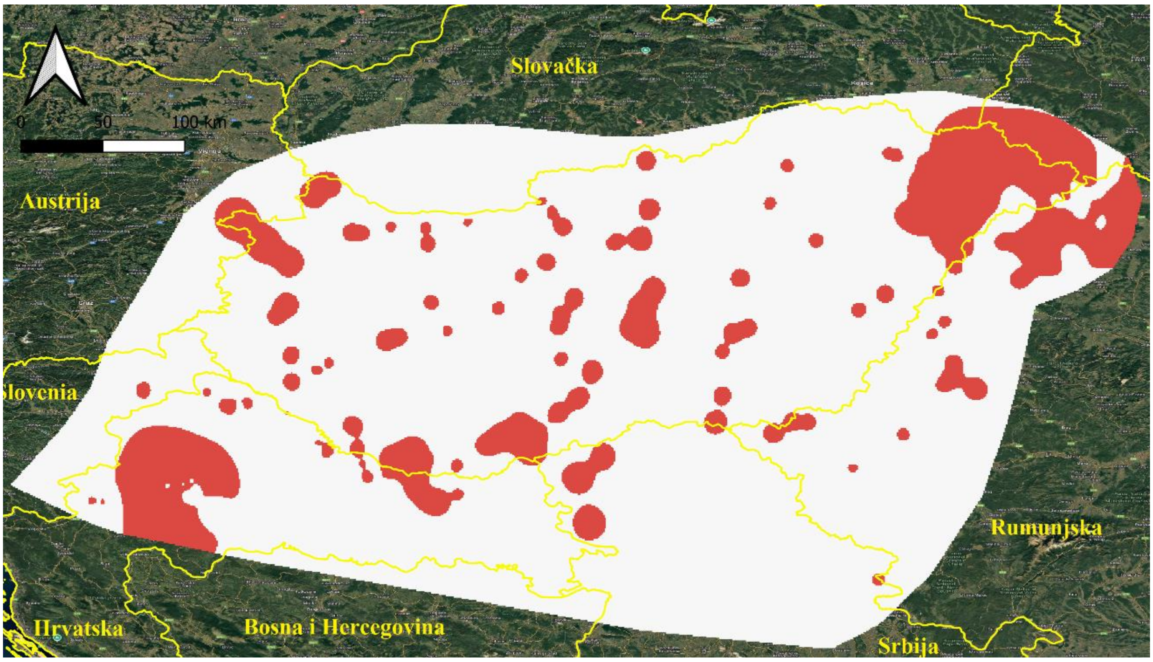

Figure 4.1.1 Example of GW lowering in the Somes-Tisa river basin in Romania (Map 10)

What are the other causes of GW decreasing , besides climate change is still question without an answer. It is also one of the tasks of main project.

Just for illustration, Figure 4.1.2. and Fig.4.1.3. shows results of SNHT for two observation wells in the the Somes-Tisa river basin in Romania and the Sava river basin in Croatia.

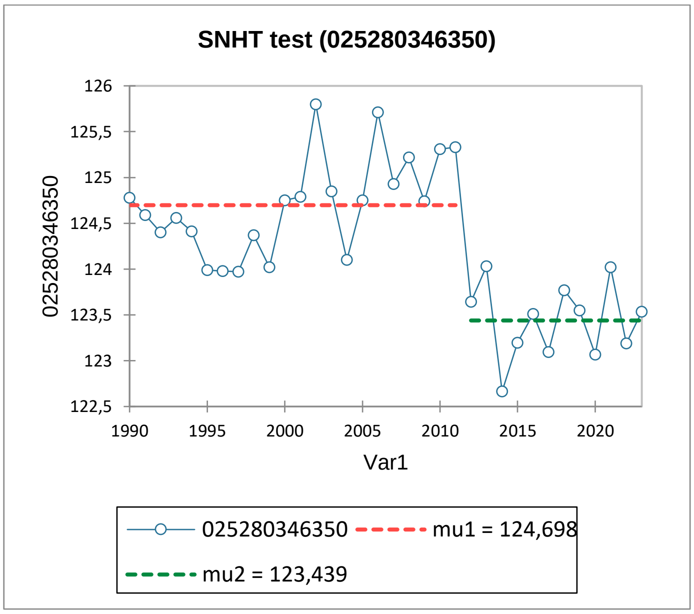

Figure 4.1.2 Example of GW lowering in the Somes-Tisa river basin in Romania

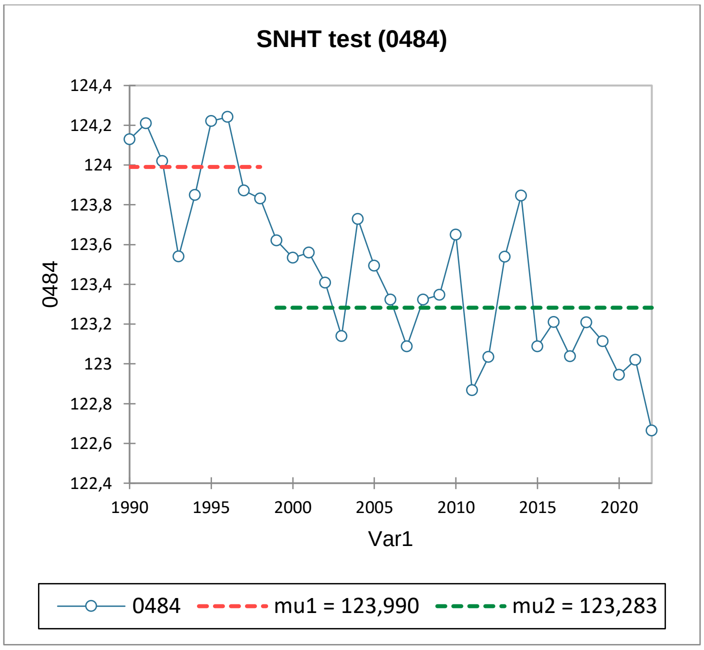

Figure 4.1.3 Example of GW lowering in the Sava river basin in Croatia

4.1 Description of the target groups addressed by the future project and their needs

In the first half of the project implementation project team was focused on collecting of large amount of data and their processing. It was very demanding process and took much more time, much more than we expected. As it was elaborated before, there are great differences in data availability. Some of data series were received few weeks ago what had a great impact on achieving all planned outcomes.

Also, thousand of data serries were statistically analysed.

These are main reasons why last activity, A.1.3   Description of list of target groups which should be addressed by the main project and report on target groups is not complete and it is still in the process. It is still on the level of sketch and will be developed in the next month together with the implementation on the second output: Groundwater table in   Pannonian Plain- main project (SO2).

In order to promote project PANNONIAN.GW and introduce wider audience so far it is presented:

1. Annual meeting of Croatian Society of Hydrology (February 21, 2025)
2. Project presentation is applied for presenting on Annual meeting of Croatian chamber of civil engineers (June, 2025)
3. Project description is in preparation for publishing in to Croatian journal of civil engineering „Građevinar”
4. Project results are planned to be submit as scientific article to international journal (June, July 2025)

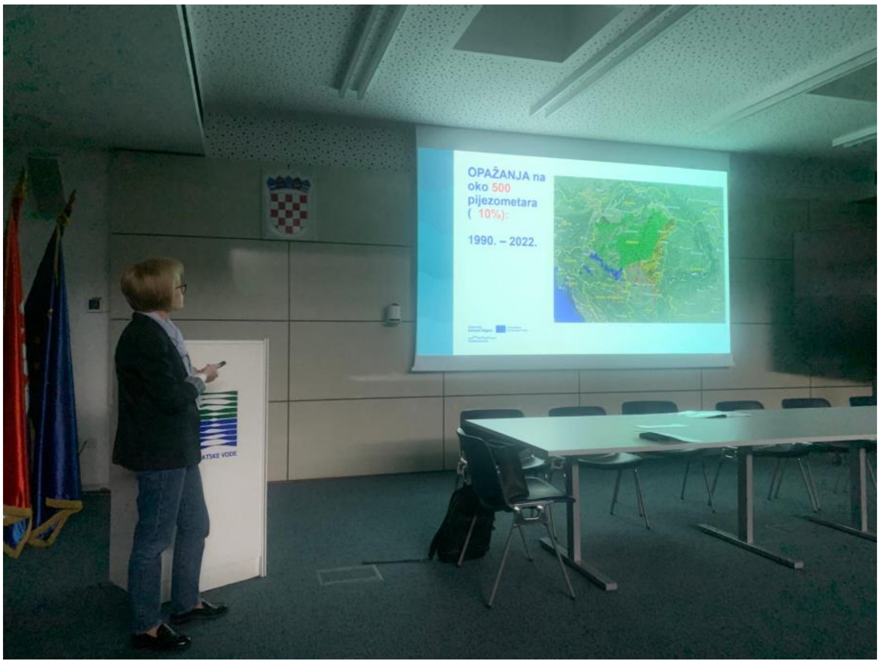

Figure 4.1.4. Project presentation on Annual meeting of Croatian Society of Hydrology

Target groups addressed by the future project will be searched among :

- Professional associations (national and international level) – activities already started
- Institutions for education and research
- Scientific audience (international)
- National sectoral agencies in the fields of agriculture, forestry, meteorology, hydrology and environment
- Non-governmental agencies

5 List of websites

On the official project website http://www.gfos.unios.hr/homepage/harmonization-of-joint-monitoring-and-modelling-of-groundwater-system-of-pannonian-plain there are results achieved in the first 6 months of the project implementation sorted as eleven separate links:

Report on output SO1 (March, 2025)

Map 1: Total GW monitoring network of the Pannonian Plain

Map 2: Reduced GW monitoring network of the Pannonian Plain

Map 3: Homogeneity of observed annual GW levels (1990-2022)

Map 4: Average annual GW level in the period 1990-1999

Map 5: Average annual GW level in the period 2000-2009

Map 6: Average annual GW level in the period 2010-2022

Map 7: Differences in average GW levels between the 2nd and the 1st decade

Map 8: Differences in average GW levels between the 3rd and the 2nd decade

Map 9: Differences in average GW levels between the 3rd and the 1st decade

Map 10: Critical spots