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Improving the national monitoring of groundwater chemical status by applying the R_u index

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Abstract

Two complementary proposals were given to improve the national monitoring of groundwater chemical status in the grouped groundwater body "Eastern Slavonia - Sava River Basin". The aim of this research was to ensure an even distribution of monitoring stations in the study area and systematic monitoring of groundwater quality in deeper parts of the aquifer system. This is important as the national monitoring stations are used to assess the status of a grouped groundwater body according to the methodology in accordance with the provisions of the Water Framework Directive as well as the Groundwater Directive. Based on hydrogeological and geological characteristics of the investigated area, an objective assessment of the representativeness of the monitoring stations, using the R_U index, was done. Representativity Index (R_U index) is used to measure monitoring network homogeneity expressed in percentages. The first proposal of improvement of the national monitoring of groundwater chemical status includes 11 monitoring stations, with a R_U index of 80.10%, two of which, as new observation wells, should be drilled at shallow depth of the aquifer system. Seven observation wells and two pumping wells around Gunja and Đakovo are part of the existing national monitoring system. The second proposal complements the first one and includes 17 monitoring stations, with a Ru index of 82.48%, six of which, as new observation wells, should be drilled at a greater depth of the aquifer system. These proposals would enable better confidence of groundwater chemical status and trend assessment, as well as more reliable determination of ambient background values of groundwater quality parameters. Implementing these proposals in practice and getting insight into new hydrogeochemical data from the deeper part of the aquifer system would give the possibility of delineating the grouped groundwater body "Eastern Slavonia – Sava River Basin" by depth into two new groundwater bodies, the shallower and deeper.

Keywords: groundwater monitoring, groundwater body, eastern Slavonia, alluvial aquifer system, R_U index, chemical status

1. Introduction

Monitoring of groundwater chemical status ensures a comprehensive overview of the chemical status of groundwater in the river basin district and allows determining the presence of a significant and persistently growing pollution trend. National groundwater monitoring includes surveillance monitoring, used to assess the long-term chemical status of groundwater in groundwater bodies, and operational monitoring, used to determine the chemical status of groundwater and/or to assess the risk at of failure to achieve good chemical status of groundwater bodies. Since national monitoring stations are used for assessing the chemical status of groundwater bodies, it is important that each monitoring station representatively presents area where it is located. An objective assessment of homogeneity of a monitoring network on a grouped groundwater body is ensured by applying the Representativity Index (R_U index) that should be 80% or higher (**Grath et al., 2001**).

In the investigated area of the grouped groundwater body "Eastern Slavonia - Sava River Basin" (**Figure 1**) the existing network of groundwater monitoring stations does not consider properly the representativeness of stations according to the conceptual hydrogeological model, R_U index, hydrogeological characteristics, or vertical delineation (**Nakić et al., 2016**; **Nakić et al., 2018**).

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In this paper, two proposals were given to improve the national monitoring of groundwater chemical status in the grouped groundwater body "Eastern Slavonia - Sava River Basin". The aim of this research was to ensure an even distribution of monitoring stations in the study area and systematic monitoring of groundwater quality in deeper parts of the aquifer system, based on geological and hydrogeological data, aquifer vulnerability and technical data from available observation and pumping wells.

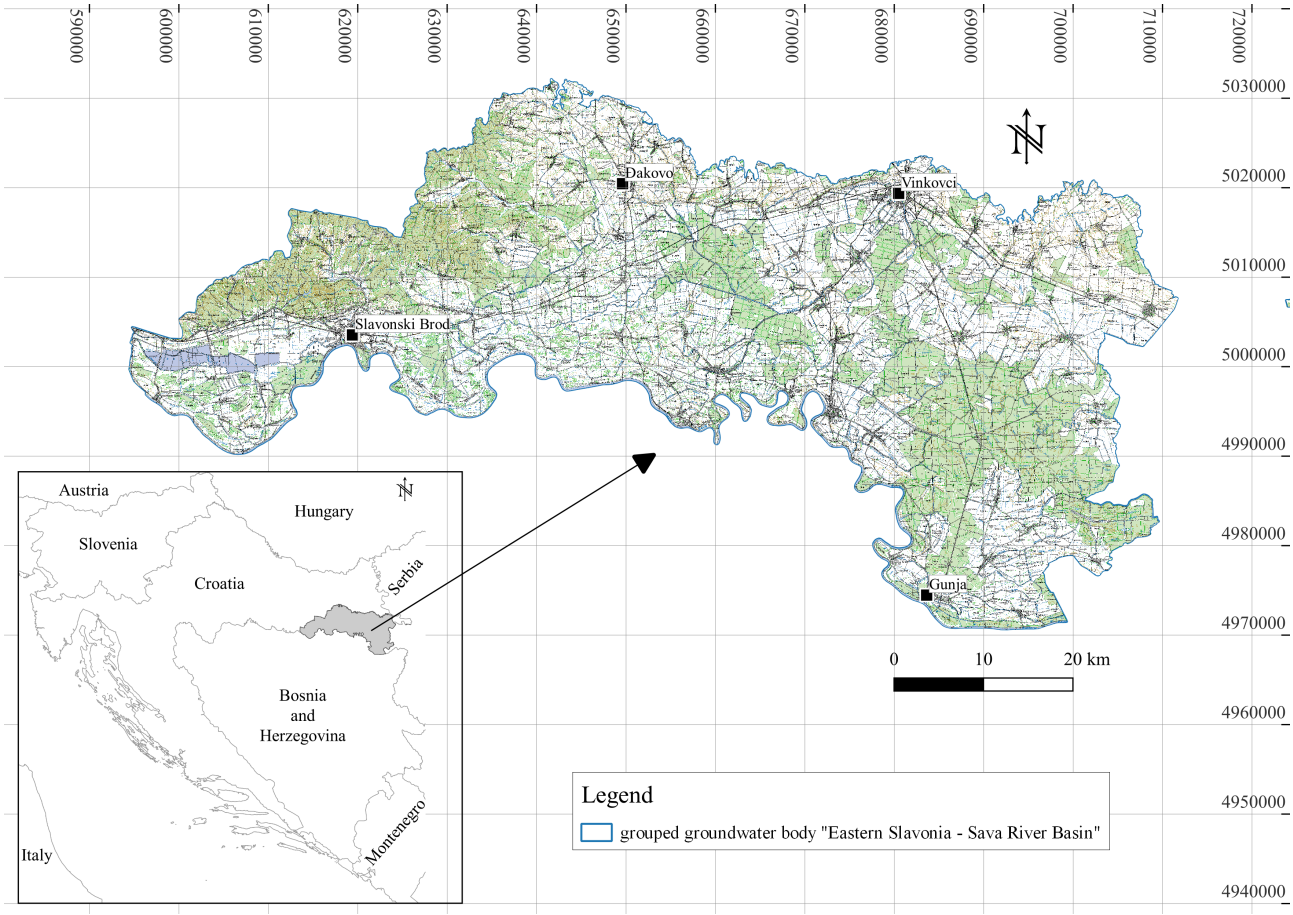

Figure 1: Grouped groundwater body "Eastern Slavonia - Sava River Basin"

2. Methods

As stated earlier, an appropriate and representative number of monitoring stations is the first prerequisite for objective assessment of groundwater chemical status. The first step for improving groundwater monitoring network is to collect the existing data in the investigated area. That includes all technical data from pumping and observation wells as well as all relevant geological and hydrogeological data (**Figure 2**). In addition, data on aquifer vulnerability was also used to locate new observation wells. Finally, the Representativity Index was used to make an objective assessment of existing and new monitoring networks representativity.

2.1. Collecting data

In 2021, the national monitoring of groundwater chemical status included 18 stations with a R_U index of 62.07%. For these stations, technical data were collected from “Đakovo water supply”, “Vinkovci water supply and sewerage” and “Croatian Waters”. A review of collected data found that for eight observation wells there is data on the depth and positions of the filter, for two wells there is data on depth and for one well there is data only on filter positions and well depth respectively. For other five wells, no data on the position and depth of the filter were available. In addition, data on filter positions were collected for another 19 pumping and observation wells in the investigated area.

Hydrogeological and geological data were collected from the literature review and include the following: lithological units in the investigated area (**Velić & Vlahović, 2009**); thickness of the Quaternary aquifer complex (**Hernitz, 1983**); total aquifer thickness (**Bačani, 1997; Miletić et al., 1975a; Miletić et al., 1975b; Nakić & Mayer, 2003**); aquifer productivity (**Brkić et al., 2009**) and aquifer vulnerability (**Brkić et al., 2009; Nakić et al., 2016**).

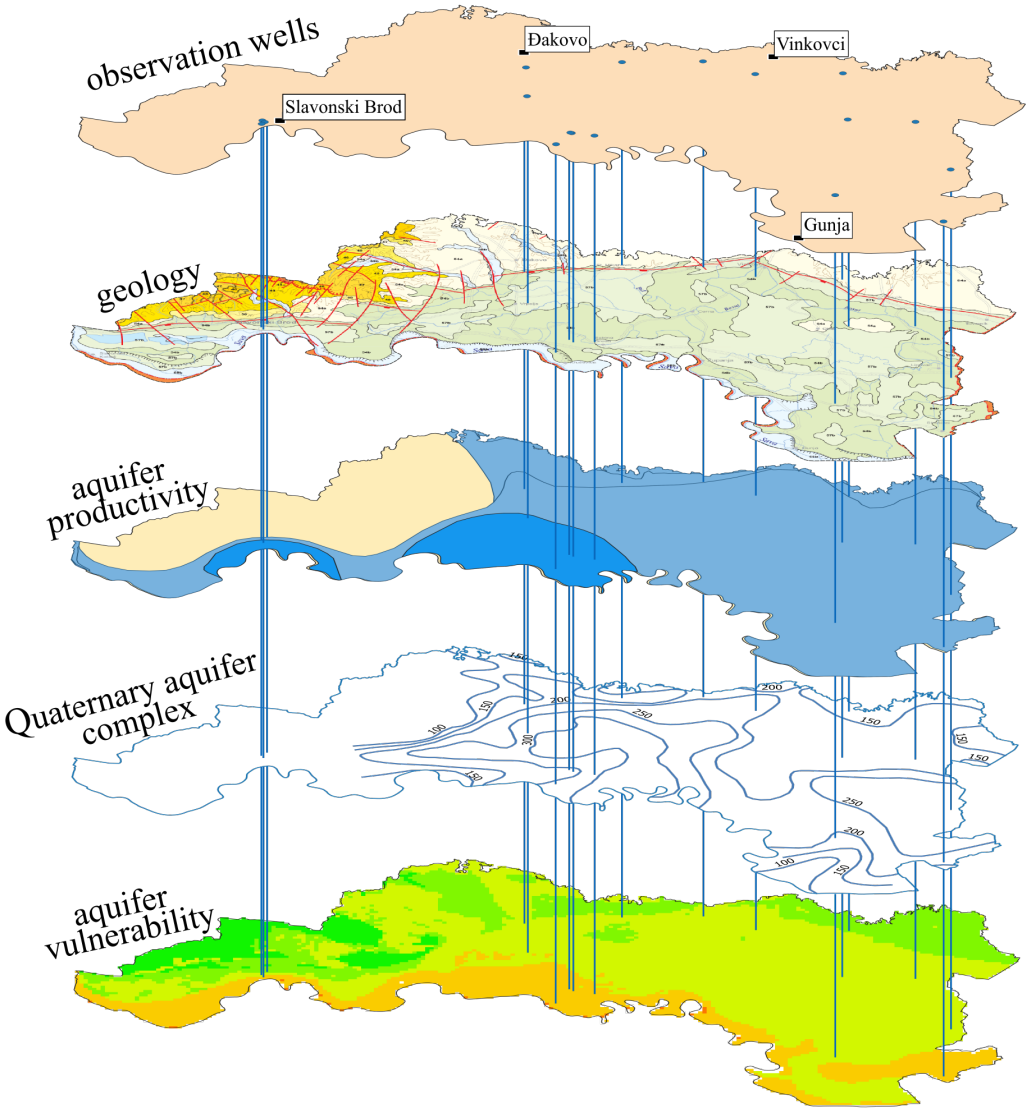

Figure 2: Data used to improve groundwater chemical status monitoring network in investigated area

2.2. R_U index

To assess the homogeneity of monitoring stations in the grouped groundwater body "Eastern Slavonia - Sava River Basin", the R_U index was used. It is defined as the average minimum distance between any location in the area to the closest sampling site and expressed as percentage of the average minimum distance for an optimal network (**Grath et al., 2001**). It is calculated according to the **Equation 1** (**Grath et al., 2001**).

$$R_U = \frac{37{,}7}{dist_{ave}\sqrt{\frac{k}{Area}}}\ [\%] \qquad [1]$$

Where are:
k – number of sites,
$dist_{ave}$ – average minimum distance between any location in the area to the closest sampling site,
Area – size of the area.

The term "optimal network" is represented as a theoretical network with an optimal triangular pattern of sites for which R_U index will be 100**% (Grath et al., 2001)**. In real conditions, as previously mentioned, the Representativity Index needs to be 80% or higher for the network of monitoring stations to be considered homogeneous (**Grath et al., 2001**).

3. Results and discussion

The first proposal to improve network of groundwater monitoring stations includes 11 stations, and the R_U index is 80.10%. Out of a total of 11 stations, seven of them are part of the existing national monitoring system, which would certainly contribute to cost rationalization if this proposal was implemented. These are the stations marked in green in **Figure 3**. Two stations include the existing water wells for public water supply in Gunja and Đakovo (marked in purple in **Figure 3**), which should be included in the monitoring program to increase better spatial coverage and R_U index. Within this proposal, two new stations should be established, i.e., new observation wells would have to be drilled. One station would be in the zone of the productive aquifer (third map from the top on **Figure 2**) in the far west, and the other in the centre of the eastern part of the investigated area (marked in blue in **Figure 3**). Productive and non-productive aquifers can be distinguished in the observed area, whereby productive aquifers are divided into primary and secondary aquifers. Primary aquifers have high hydraulic properties, while secondary aquifers have lower hydraulic properties with spring yields less than 20 l/s. In the area of unproductive aquifers, the yields of the springs are less than 5 l/s. Existing stations (observation wells and pumping wells) would cover most of the grouped groundwater body and productive aquifer distribution areas, while new wells were proposed due to the lack of monitoring stations in parts of investigated area. Both new proposed stations contribute to the even distribution of points and increase the R_U index and should contribute to get a new hydrogeological data of the aquifer system. No detailed hydrogeological data were available in the western part of the investigated area. In the eastern part of the observed area, the thickness of the Quaternary aquifer complex is between 150 and 200 m and more detailed hydrogeological data were used for more precise site selection (**Bačani, 1997**).

The first proposal and consequently the second proposal include observation and pumping wells in their monitoring networks. Both types of monitoring stations are included to rationalize the costs of eventual implementation of the proposal since the collected data can be compared. This refers to the results of chemical analysis of groundwater for the purposes of national monitoring, which are used in the overall assessment of the chemical status of a grouped groundwater body. Since the primary purpose is to comply with the guidelines for assessing the status of grouped groundwater bodies in accordance with EU legislation, the only requirement for valid chemical analysis is that the sampled groundwater is not pre-conditioned. For this reason, it is possible to use pumping wells in the monitoring system.

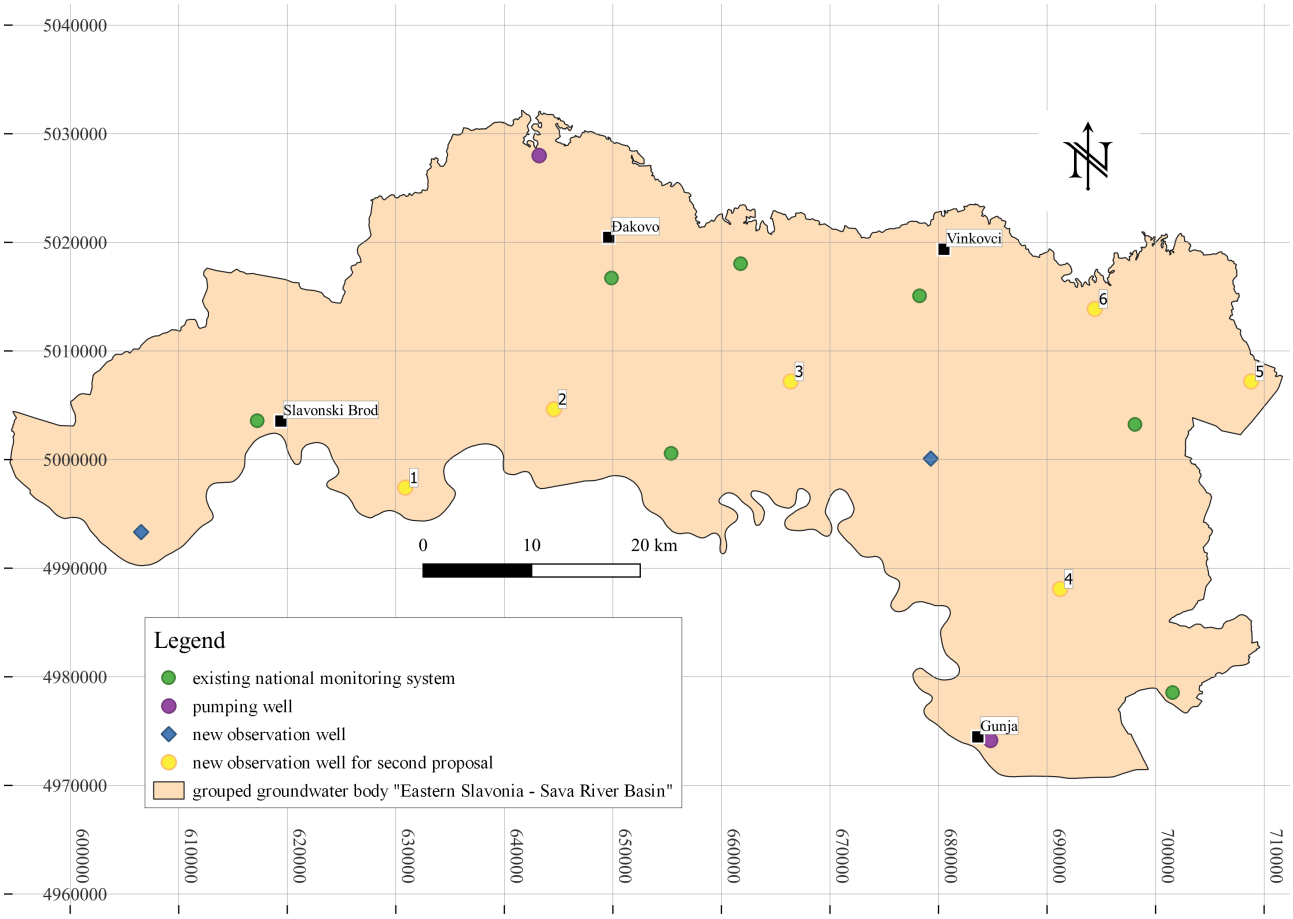

Figure 3: The proposal of improvement of the national groundwater monitoring network

The second proposal complements the first proposal and includes in total 17 stations, with an R_U index of 82.48%. In this proposal, six new observation wells are proposed (marked in yellow in **Figure 3** with marks 1 to 6), which would need to be drilled to a depth greater than 100 m. The new wells should reach deeper sandy aquifers, which probably differ from the shallower gravelly and coarse-grained sandy layers in terms of lithological composition and groundwater chemical composition. The layout of the wells follows zones of moderate and increased vulnerability of aquifers. At the location of wells 1, 5 and 6, the bottom of the Quaternary aquifer complex lies at a depth of 150 m; at the location of well 2 it lies at a depth of 250 m; at the location of well 3 it lies at a depth over 300 m, and at the location of well 4 it lies at depths between 200 and 250 m. The total thickness of aquifers at locations of well 2 and 3 is between 70 and 100 m; at location of well 4 its thickness is from 50 to 75 m, while at locations of wells 5 and 6 aquifers its thickness is less than 50 m (**Bačani, 1997; Hernitz, 1983**). Therefore, in addition to the R_U index, lithology, thickness of the Quaternary aquifer complex, total aquifer thickness, aquifer productivity and aquifer vulnerability were used for the preparation of the monitoring proposal. The results of chemical analysis of groundwater are also available for stations from the existing national monitoring system. However, these data were not used since the wells were located in a shallower part of the aquifer system that has already been well explored and described in the literature. Any data from chemical analysis from the proposed wells that cover a deeper part of the aquifer system could be used in the future to further improve the monitoring system in this area.

Such a spatial arrangement of groundwater monitoring stations would enable comprehensive chemical monitoring of groundwater laterally as well as vertically in the grouped body of groundwater "Eastern Slavonia - Sava River Basin". After drilling new observation wells and the establishment of improved groundwater monitoring network, a new chemical and hydrogeological data would be gathered, based on which conclusions could be made about the hydrogeochemical characteristics of deeper aquifers. In addition, it would be possible to assess the suitability of delineating the grouped groundwater body "Eastern Slavonia – Sava River Basin" by depth into two new groundwater bodies, the shallower and deeper.

4. Conclusions

This paper analyses the representativity of the national groundwater monitoring network in the grouped groundwater body "Eastern Slavonia - Sava River Basin". The new proposal is done using hydrogeological and geological data of the investigated area: the thickness of the Quaternary aquifer complex, total thickness of aquifers, aquifer productivity, aquifer vulnerability, technical data on drilled wells and R_U index.

Two monitoring proposals have been made for this purpose; the first one, which ensures the coverage of the area of the grouped body more evenly, and the second proposal that complements the first proposal, enabling more comprehensive monitoring of deeper aquifers.

These two proposals would enable an adequate assessment of groundwater quality in this grouped body with high reliability according to the methodology for assessing the condition of grouped groundwater bodies **(Croatian Waters, 2016)**, a relevant chemical trend assessment as well as a more precise determination of ambient background values of groundwater parameters in the investigated area. The implementation of the first proposal would increase the representativeness of the monitoring network, and at the same time rationalizing investment costs. The implementation of the second proposal would enable the assessment of the possibility of delineation of the grouped groundwater body "Eastern Slavonia - Sava River Basin" in depth into two new groundwater bodies, shallower and deeper.

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Sažetak

Unapređenje nacionalnog monitoringa kemijskog stanja podzemnih voda primjenom R_U indeksa

U ovome radu prikazani su prijedlozi za poboljšanje nacionalnog monitoringa kemijskog stanja podzemnih voda na grupiranom tijelu podzemne vode "Istočna Slavonija - sliv Save". Cilj ovog istraživanja bio je osigurati ravnomjernu distribuciju monitoring postaja na istraživanom području i omogućiti sustavno praćenje kakvoće podzemnih voda u dubljim dijelovima vodonosnika. Na temelju hidrogeoloških i geoloških karakteristika istraživanog područja izvršena je objektivna procjena reprezentativnosti monitoring postaja, korištenjem RU indeksa. Prvi prijedlog poboljšanja uključuje 11 monitoring postaja, s Ru indeksom od 80,10%, od kojih bi dvije nove bušotine trebale biti izvedene u plićem dijelu vodonosnog sustava. Sedam pijezometara i dva izvorišta u Gunji i Đakovu dio su postojeće infrastrukture za praćenje kemijskog stanja podzemne vode. Drugi prijedlog nadopunjuje prvi i uključuje 17 monitoring postaja, s Ru indeksom od 82,48%, od kojih bi šest novih bušotina trebalo izvesti u dubljem dijelu vodonosnog sustava. Ovi prijedlozi omogućili bi veću pouzdanost prilikom ocjene kemijskog stanja podzemnih voda i relevantniju procjenu trenda, kao i pouzdanije određivanje pozadinskih vrijednosti parametara kakvoće podzemnih voda. Provedba ovih prijedloga u praksi i stjecanje uvida u nove hidrogeokemijske podatke iz dubljeg dijela vodonosnog sustava potencijalno bi omogućili delineaciju grupiranog tijela podzemne vode „Istočna Slavonija – sliv Save“ po dubini na dva nova tijela podzemne vode, pliće i dublje.

Ključne riječi: monitoring podzemnih voda, tijelo podzemne vode, istočna Slavonija, aluvijalni vodonosni sustav, R_U indeks, kemijsko stanje

Author’s contribution

Borna-Ivan Balaž (mag. ing. geol., univ. spec. oecoing., environmental geology) provided the interpretation and presentation of the results. **Krešimir Pavlić** (PhD, Assistant Professor, geophysics, hydrology) provided the interpretation and analysis of the results. **Zoran Nakić** (PhD, Full Professor, hydrogeology) provided the presentation of the results and overview of the research area. **Jasna Kopić** (PhD, hydrogeology) provided the interpretation of results and technical data of wells on the observed area.