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# APPLYING DATA ANALYSIS TECHNIQUES TO GROUNDWATER RESOURCES MANAGEMENT MODELLING: A CASE STUDY OF GROUNDWATER SOURCES "ZELENICA" AND "GORNJE POLJE" NEAR LOZNICA, SERBIA

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**Abstract**

One of the data science techniques is the data analysis, based primarily on various techniques and methods application in order to acquire, analyze, interpret and eventually visualize the data. The aim of these techniques is the translation of the raw data into the useful information. In this study, a comprehensive data analysis of accessible geological and hydrogeological settings of terrain in zones near "Zelenica" and "Gornje Polje" springs (alluvium of river Drina) near Loznica, has been performed. The lithologic-technical profiles of observation and of water-sampling objects have been analysed, and results, obtained by geophysical methods, subsequently interpreted. Besides, the grain size analysis test, aquifer tests, precipitations monitoring and water-level of Drina river monitoring at specified precipitation-/water-gauge were performed too. Obtained results are used as a starting point for creating the hydrogeological model (and hydrodynamic one afterwards) of the research area. The main tools used were Microsoft Excel software (for data preparation and analyzing) and Modflow code (for hydrogeological and hydrodynamic models creation).

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**Key words:** data analysis, hydrogeological model, hydrodynamic model, Microsoft Excel, Modflow code

**Introduction.** Appropriate management groundwater resources in contemporary society is a great challenge, especially if there are increased needs for water, threats from various pollution sources, climate changes impacts, etc. Traditional methods of water management data analysis are often limited in big datasets processing as well as in long-term changes prediction. Therefore, the data science techniques draw more attention, as they might improve the optimization process and decision making, improve the prognosis of various data types (for example, groundwater level [1]) enable faster analysis of big datasets [2], or better understanding of climate changes impact onto groundwater resources [3]. There are various data science techniques used in hydrogeological research, such as: machine learning (ML) for groundwater quality modelling [4], managed aquifer recharge [5], groundwater pollution risk combined with methods for vulnerability assessment [6]. For example, geostatistical methods can be combined with machine learning in groundwater quality management [7]. The efficiency of monitoring network composed of monitoring wells can be improved in various ways, e.g. by using statistical methods (time series analysis) and AI techniques [8], and by subsequent synthesis of hydrogeological research results.

Groundwater resources management modelling includes the use of mathematical and computational models and techniques for analysing and simulation applied in sustainable management of these resources. This way, it can contribute to preservation of their quality and quantity, primarily by mitigating their overexploitation, or to improve the protection from pollution, but their rational use for various purposes too, such as: water supply, industry, agriculture, etc. There are other approaches, such as the groundwater resources management by simulation modelling, which can be of crucial importance for later decision making and in defining management strategies because of its capability in predicting various scenarios of this management [9]. For example, modflow code has been proven effective in groundwaters simulation to the similar extent as the artificial neural networks [10].

Data analysis is another data science technique, based primarily on application of various techniques and methods for analyzing, interpretation and visualization of the data. Essentially, the purpose of this technique is to translate "raw data" into useful information using statistical and/or other logic techniques systematically. Such an approach integrates the use of GIS tools, databases and 3D modelling of groundwaters [11] for defining the appropriate strategy in water resources management.

In this study a comprehensive data analysis of the available geological and hydrogeological settings of the terrain has been performed in the area of Zelenica and Gornje Polje groundwater sources (the alluvium of river Drina) near Loznica.

The input data obtained in this way can further serve for different purposes, e.g. in creating the 3D hydrogeological model (and/or hydrodynamic model) of the terrain, as is discussed further in the text.

**Methodology.** The applied methodology is based on data analysis techniques. In general, data analysis may involve specific methods for data research, discovering templates, and subsequently drawing conclusions. The data analysis process includes the following stages [12]:

a) initial data analysis: data cleaning for the data quality assessment;
b) main analysis phase: answering the original research question;
c) final analysis phase: gives the final report draft on results of the performed analysis.

Various quantitative and qualitative data can be analyzed. The qualitative ones usually mean those characterized by the descriptive character, i.e. most often in the form of textual descriptions. Quantitative data are characterized by numerical character, and are used to express the quantity or intensity of a feature/phenomenon.

Data analysis of geological and hydrogeological settings in the zones of "Zelenica" and "Gornje Polje" sources, of lithologic-technical profiles of piezometers and wells (with interpretation of the results obtained by geophysical methods, and those related to granulometric content research of analysed material), aquifer tests, precipitation monitoring and water level of Drina river at designed pluviometry/water-gauge station, represent a starting basis for hydrogeological model creation of specified research area, which subsequently gets transformed into a hydrodynamic model.

The interpretation of dynamic and physical characteristics of a hydrogeological system leads to a hydrogeological model [13]. A hydrogeological system is defined by: input elements, environment characteristics, processes in observed area and output elements, whereby the input and output elements are mutually dependent. The two main characteristics of the hydrogeological system are its geometry, i.e. spatial distribution of aquifers, as well as their filtration characteristics. The formation of the hydrogeological model means the schematization of the hydrogeological system, because of the complexity of hydrogeological and hydrodynamic conditions, which means the schematization of: (1) flow area (outflow geometry), (2) porous medium characteristics (and of hydrodynamic condition of the outflow course), (3) outflow regime (based on what principles, features and distribution of factors affecting the outflow water regime are established), (4) water balance elements, (5) boundary conditions of the hydrogeological system (which is represented by the water inflow into the model and outflow from it), and (6) initial conditions (characterized by piezometer level values at initial moment).

The rock type is displayed in hydrogeological model, whereby the outflows and their mutual relationship and spatial distribution are particularly pointed out. Besides, the levels of groundwater released and the directions of the groundwater flow (i.e. the inflows and outflows in the hydrogeological system) are displayed. The next stage is the transformation of hydrogeological model into a hydrodynamic one, through the model geometry (spatial distribution of lithostratigraphic units and hydrogeological parameters of porous medium), initial and boundary conditions defining, and numerical method selection [14]. After creating the hydrogeological model, based on the presented hydrogeological characteristics of the research area, and performed analysis of the characteristics of the porous medium, the type of movement and the elements of the groundwater regime, the next step is its upgrade into a hydrodynamic model. The starting point in creation of a hydrodynamic model is the preparation of these bases and input data, followed by creating databases from the numerical values of the hydraulic parameters (being the input for hydrodynamic calculations). The main tool for input data preparation is usually Microsoft Excel software.

The appropriate numerical method of solving the differential equations, which is "behind" the software's code, is applied in case of 3D hydrodynamic model, depending on schematization and discretization. Regarding the software, besides the set of equations used to describe the analysed circulation, it includes also (1) numerical methods for their solving, (2) procedure of input parameters setting, and (3) selection and method of displaying the obtained results. The finite differences code most often used is Modflow, developed by the U.S. Geological Survey [15] and being continuously developed and improved over time. There are a number of graphic interfaces for hydrodynamic calculations in Modflow code, such as: "Groundwater Vistas" [16], "Visual Modflow" [17], "Processing Modflow" [18], "Modflow Surfact" [19] and "GMS – Groundwater Modelling System" [20]. After software selection, the further sequence has to be performed: (1) „import" of geometric properties of the analyzed area into the model, (2) discretization of space, (3) setting the hydrogeological parameters of the porous sediment, (4) boundary conditions setting, (5) initial conditions setting, and (6) temporal discretization – calculation interval. Thus, a hydrogeological model is being transformed into a hydrodynamic model.

**Case study.** The "Zelenica" and "Gornje Polje" groundwater sources are used for water supply of the city of Loznica (Serbia). There are 9 explorative and exploiting wells excavated at "Zelenica" spring (8 in exploitation), while "Gornje Polje" spring consists of 7 such objects. The same quaternary sandy-gravelly sediments (of 8 m avg. thickness) are captured in all wells at both springs (Fig. 1). The groundwater sources have no impact on each other. The water-tapping objects at both groundwater sources are located along the course of the Drina river. Wells at both groundwater sources are connected into a unique pressure pipeline. Water is being chlorinated before inletting into the water supply network.

**Results and discussion.** Geological and hydrogeological settings were analyzed in both planar and profile projection, in order to make a hydrogeological model and 3D outflow representation of the "Zelenica" and "Gornje Polje" ground-

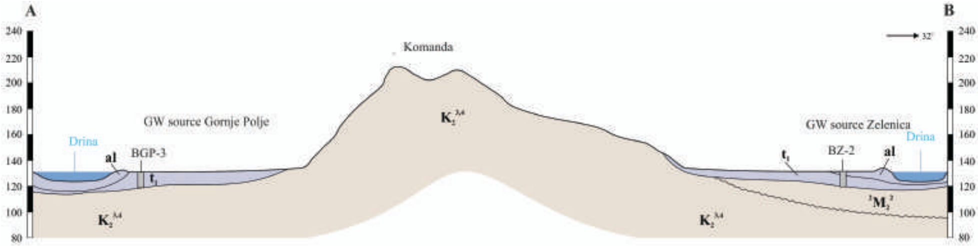


Fig. 1. Hydrogeological cross-section of the research area

water sources. Besides the hydrogeological map and hydrogeological cross-section, the lithologic-technical profile of monitoring and water-tapping objects was analyzed, and results of the performed geophysical research thoroughly interpreted. The research area dimensions were $3200 \times 3800$ m, involving the surface area of 12.16 km$^2$. Lithologic components and their profile elevation ranges are given in Table 1. By analyzing the granulometric content of the materials obtained from investigative drilling, hydraulic conductivity values were calculated. Values of the other hydraulic parameters of porous medium were also defined (by exhaustion tests performed in the spring wells) as follows: specific storage – Ss, specific yield – Sy, hydraulic conductivity – K, total porosity – n. Their values are listed in Table 1.

Table 1

Characteristics of the lithologic components and values of the hydraulic parameters of porous medium

| Lithologic components | Sandy-loamy and powdery sediments | Sandy-gravelly sediments | Marly clay |
|---|---|---|---|
| At elevation ranges (m) | 135–130 | 130–120 | 120–80 |
| Model layer | Less permeable | Aquifer | Water-resist |
| K (m/s) | $1.3 \times 10^{-4} - 7.7 \times 10^{-6}$ | $1.0 \times 10^{-1} - 10 \times 10^{0}$ | $5.4 \times 10^{-4} - 2.0 \times 10^{-7}$ |
| Ss (1/m) | $1.89 \times 10^{-3} - 2.38 \times 10^{-4}$ | $4.57 - 9.4 \times 10^{-6}$ | $1.89 \times 10^{-3} - 2.38 \times 10^{-4}$ |
| Sy (%) | 2–6 | 21–28 | 2–6 |
| n (%) | 34–57 | 24–39 | 34–57 |

The data that were measured and analyzed represent parameters that are entered as boundary conditions ("rivers", "recharge", "well") in the model. As the research area is intersected by Drina river, the boundary condition named as "river" was specified in the model. Water-level was monitored at "Radalj" water-gauge over the entire year of 2023. On the other hand, the precipitation monitoring at "Loznica" pluviometer was performed over the same period. The "recharge" boundary condition was specified as the initial value of effective infiltration which was assessed to 15% of mean monthly precipitation level. A diagram comparing

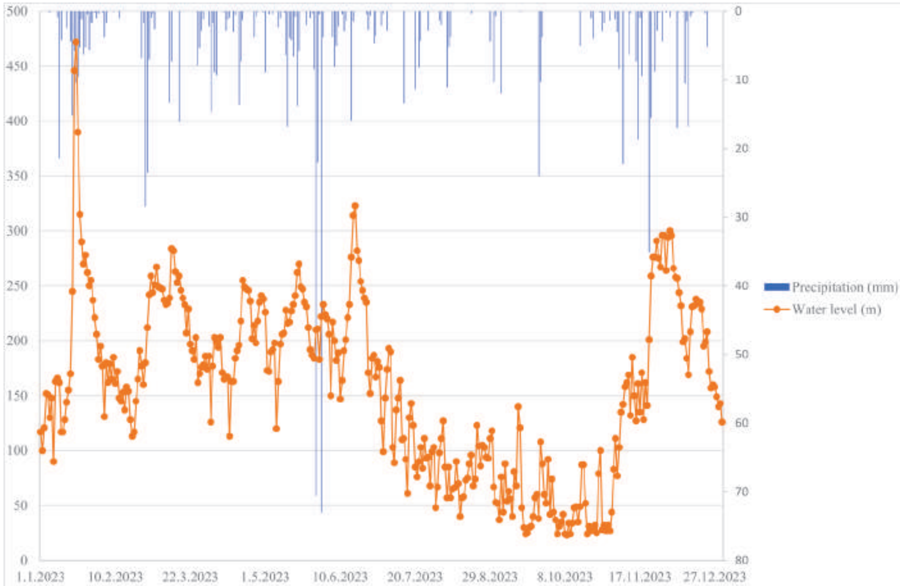


Fig. 2. A comparative view of the water-level of Drina river and the daily precipitation level

the Drina water-level and the precipitation level is shown in Fig. 2.

The impact of the exploitation wells was simulated by the boundary of prescribed flux ("well"). The values of the well capacities at the groundwater sources

Table 2

Results of regime monitoring at the wells of Zelenica and Gornje Polje groundwater sources

| Well (label) | $H_{stat}$ (m) | $Q_{max}$ (l/s) | $H_{din}$ (m) | $Q_{aver}$ (l/s) |
|---|---|---|---|---|
| B3-1 | 0.77 | 44.60 | 5.66 | 30.60 |
| B3-2 | 2.88 | 43.30 | 9.22 | 30.30 |
| B3-3 | 2.66 | 47.10 | 8.48 | 30.8 |
| B3-4 | 0.74 | 43.60 | 7.92 | 28.0 |
| B3-7 | 0.92 | 48.80 | 6.77 | 29.10 |
| B3-8 | 1.35 | 43.80 | 8.00 | 28.60 |
| BGP-1 | 4.00 | 21.90 | 8.10 | 15.70 |
| BGP-2 | 4.30 | 22.60 | 8.32 | 15.90 |
| BGP-3 | 3.11 | 22.10 | 7.03 | 15.60 |
| BGP-4 | 4.15 | 20.20 | 8.40 | 15.00 |
| BGP-5 | 3.07 | 20.70 | 7.83 | 14.90 |
| BGP-6 | 3.08 | 23.30 | 8.49 | 15.30 |
| BGP-7 | 2.60 | 22.40 | 7.06 | 14.70 |

were registered every seven days in 2023. The maximum weekly and (average) annual capacities of wells were registered at "Zelenica" and "Gornje Polje" groundwater source. The screen constructions of the wells are given with the real dimensions on which they were built. Quanitative characteristics of the groundwater ssources are listed in Table 2 (H – the static and the dynamic water level, Q – flow capacity of the well).

The next step, after synthesizing the previous data, is to input them into the appropriate software program for a 3D presentation of the hydrogeological model and the hydrodynamic model of the aquifer regime (Fig. 3). Accordingly, the model includes the extraction of lithological members with their top and bottom elevations, data on hydrogeological parameters, data on recorded groundwater levels, data on wells and their operation and the groundwater balance.

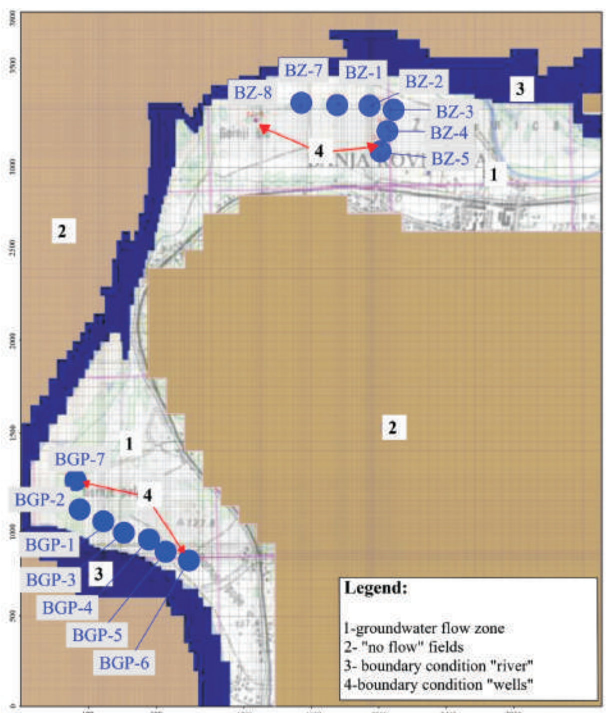


Fig. 3. Plan-view discretization of the broader area of the Zelenica and Gornje Polje groundwater sources with defined boundary conditions

Through software analysis, diagrams are obtained that show changes in groundwater levels over time, the dependence of measured and calculated groundwater levels, the correlation dependence of calculated and measured piezometric levels, and possibly a comparative presentation of the effects of different solution variants. On the other hand, the output maps from the software include: the distribution of the flow area in plan and profile, 3D block diagrams of the hydrogeological model, spatial discretization of the flow area, profiles with model layers, maps of the terrain surface and the bottom of each model layer, maps with initial values of hydrogeological parameters for each model layer, maps with boundary conditions for each model layer, groundwater balance maps as a result of model calibration and comparative maps of measured and calculated groundwater levels. After the model is completed, the software program also enables the calculation of various statistical indicators such as root mean square error, mean absolute error, coefficient of determination ($R^2$), residuals, among others.

**Conclusion.** The integration of data analysis techniques offers an important step in improvement of strategic decisions optimization process in the area of groundwater resources management, both in quantitative and in qualitative sense. The fact that a reliable basis for subsequent hydrodynamic model design can be created by processing and analyzing a wide range of data emphasizes the particular importance of this approach – first of all by the improvement in its accuracy, calibration and validation. The aforementioned models enable simulation of the dynamic processes along with various management scenarios evaluation, wherefore it makes possible to implement the provisions of a rational use, monitoring network optimization, more precise risk assessments and water resources protection.

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