

Article

Understanding Slovakian Gas Well Performance and Capability through ArcGIS System Mapping

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Abstract: There are two important territories in Slovakia with functioning gas well operations: the Eastern Slovak Lowland and the Vienna Basin. This article focuses on the creation of electronic monitoring and graphical mapping of the current technical conditions of gas wells in the Eastern Slovak Lowland. An analysis of the gas wells' current state in the terrain is available. The aim of the article is to draw attention to the current state of gas wells, such as the insufficient processing of gas wells, the lack of summary and uniform records concerning them, and the lack of an electronic system for monitoring the technical security of the wells. The scientific contribution of this article lies in its ability to interpret and address operational problems related to gas wells. Through analogy, the step algorithm expresses the possibility of also using gas wells for oil, geothermal and hydrogeological wells. The intention was to highlight the importance of the need to create a database for the security and strategic needs of the state regarding the storage of natural gas. As of yet, no computer or graphic system has been used in Slovakia to monitor, unify and clarify the actual technical condition of gas wells. Using the ArcGIS electronic and graphical software tool, the mapping and recording of gas wells was carried out in the area under investigation. The mapping was completed with the mentioned technical patterns. These patterns have the information found on individual gas wells. After the information is added to the database, this mapping can also be carried out in another important area with functioning gas wells, such as in the Vienna Basin, which could be another theme for further research in this area.

Keywords: natural gas; gas well; gas extraction; monitoring; mapping; ArcGIS software



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1. Introduction

Today, Slovakia is almost entirely dependent on the import of oil and natural gas. Despite the current situation, the history of oil production in Slovakia, which was previously part of Austria-Hungary and later Czechoslovakia, is one of the oldest in the world, and its origins date back roughly to the middle of the 19th century.

At the beginning, extraction from a geological point of view was situated in the area of the western and eastern part of the flysch belt of Slovakia. Over time, extraction in these territories declined, and in the period between the First and Second World Wars, almost completely disappeared. During the First World War, however, intensive exploration and then extraction began in the Vienna Basin area, and then in the 1960s in the East Slovak Neogene Basin area as well.

These extraction locations reached their maximum production in the 1960s and 1980s. The Vienna and East Slovak Basin were then gradually joined by the Danube Basin. These are rated among the traditional areas of oil exploration and continue to be some of the most promising exploration areas in Slovakia. These basins have a degree of oil exploration that is relatively uneven in terms of quality and volume [1,2].

The wells must be situated in suitable rock-bearing environments, e.g., in sandstones. Because of its structure, sandstone allows the accumulation of hydrocarbons such as oil and natural gas. For drilling applications in the evaluation of cases such as borehole instability and many other drilling problems, it is necessary to analyze the effects of bound tension and pore pressure in the bearing rocks [3,4].

It is useful to analyze the history of measurements and perform continuous optimization in order to reduce the number of measurements on wells where problems have not been registered for a long time and focus more on potential problematic wells [5].

In the territory of Slovakia, the largest Neogene basin is the Danube Basin. When compared to the Vienna Basin and East Slovak Basin, verified deep borehole source rocks contain less organic carbon and have a lower hydrocarbon potential. In Slovakia, the Vienna Basin is definitely one of the very important gas and oil regions, and important deposits with predominantly gasoline types of oil can be found in the East Slovak Basin (Figure 1).

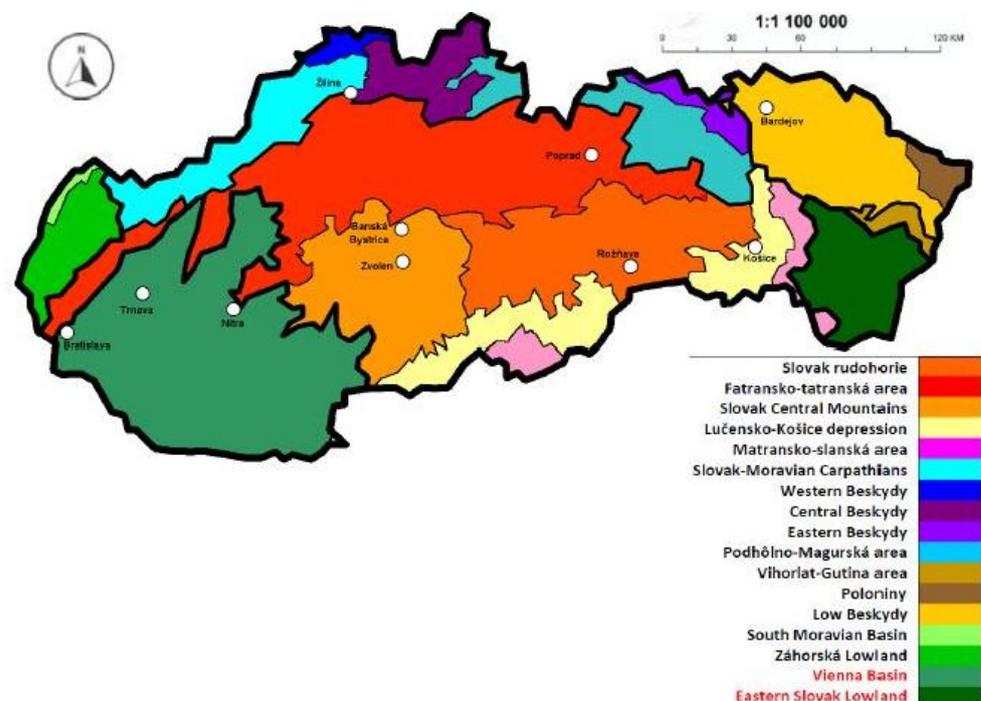


Figure 1. The Eastern Slovak Lowland and Vienna Basin [6].

Energy security, as one of the essential prerequisites for sustainable development, is an objective pursued by all countries in the world [7].

The dynamics of the world oil and gas market have changed drastically over the last decade. The discovery and extraction of large, new high-quality oil and gas reservoirs, combined with the involvement of states in the development of low-carbon alternative energies, lead to the fact that the global market is currently shaped not only by demand but also by supply. The volatility of oil prices creates uncertainty, which negatively affects decision-making processes in all energy sectors. The price of oil is the reference unit for the investment and development in the alternative energy sector. In the context of the Paris Climate Agreement, it is necessary to mitigate the impact of oil prices on the development of alternative energies [8].

The current global economy is also making progress by using oil and natural gas in several sectors of the economy. Their use is visible in the cosmetic, pharmaceutical, alimentary, chemical, and metallurgical industries, but especially in the energy industry.

Oil is not recyclable and is now more frequently substituted with alternative fuel in the energy industry. Currently, there is a trend in the energy industry towards the use of low-carbon energy.

An alternative solution to the use of low-carbon fuel sources is also natural gas. One of the possibilities of the efficient use of this energy source is its storage in excavated natural gas (NG) deposits [9]. Slovakia has the largest storage capacity of underground storage tanks in Central Europe.

Another possibility for obtaining natural gas from unconventional sources, especially from shale, is hydraulic fracturing, currently mainly used in Poland. Hydraulic fission (HF) techniques are particularly effective in stimulating hydrocarbon production from shale gas or oil formations [10,11].

Hydraulic fracturing and induced seismicity monitoring are operating procedures for the safe and effective production of oil and gas [12].

The aim of the article is to draw attention to the current state of wells, in which there is insufficient processing of gas wells, a lack of summary and uniform records concerning them, as well as a lack of an electronic system for monitoring the technical security of the wells. In the area of fuel production and use, oil derivatives are increasingly being replaced by fuels of plant origin such as biofuels, while many aggregates and mechanisms have also started to use electric drive. At present, the trend in energy is to force out aggregates burning hydrocarbon fuels because they produce a carbon footprint. Fossil fuels are exchanged in favor of alternative fuels such as biofuels. Nevertheless, the traditional hydrocarbon fuels will still be used in many other industry sectors.

In the territory of Slovakia, the largest extraction company is NAFTA a.s., which is also our largest natural gas storage company with a maximum annual storage capacity of approximately 2.5 billion m³. It operates in two exploration areas (Figure 2) with a total area of approximately 3050 km². NAFTA is currently the most important player in Slovakia's oil and gas exploration in the production sector. Table 1 has a list of valid exploration areas and permits for oil and gas extraction for 2020 used by the international energy company NAFTA Ltd., (London, UK). The original collection of gas centers where natural gas had been stored provisionally were replaced by new modern technology. Underground gas storage in the Slovak Republic represents the conversion of natural gas deposits to the conditions of the underground storage of natural gas. The technological equipment for gas processing, measurements as well as the control system have a very high technical level. The other companies such as Vermilion Slovakia Exploration s.r.o., Bratislava, Alpine Oil & Gas Slovakia s.r.o., Bratislava and ROMGAZ s.r.o., Bratislava are small shareholders in Slovakia (Table 1).

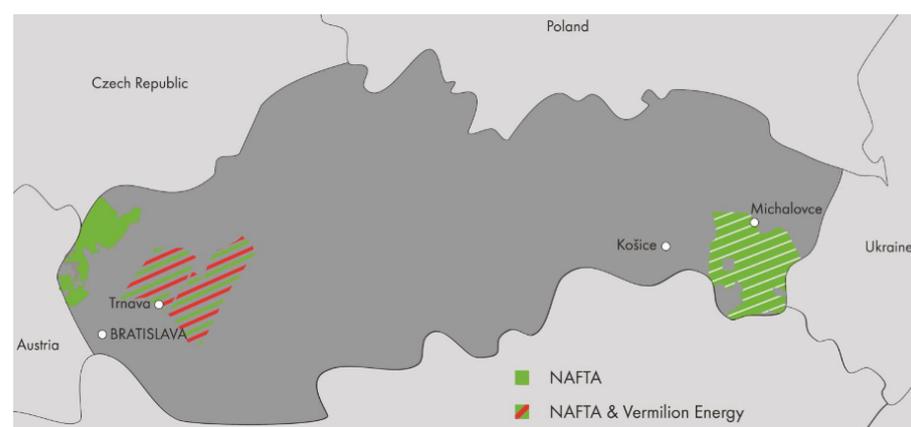


Figure 2. Exploration territories in the Slovak Republic [13].

Out of concern for the social interest, the national strategy is to store natural gas in underground storage facilities, as part of the sustainability of the country's energy potential for the future [2].

In recent years, it has been discovered that there are several operational problems in the fields around underground reservoirs. During mining, changes in the geological environment may occur that affect the mining process, e.g., compaction and sandblasting.

With increases in the understanding of mining procedures and methods, the work on underground gas storage facilities will become more efficient [14].

Well mapping allows the creation of efficient and safe gas reservoirs based on their properties, which is a way of locating wells during the development of oil and gas reservoirs and during extraction. Well modeling using an optimization algorithm automatically finds the most suitable well locations, can help increase efficiency, provide objective decision-making and reduce risk [15]. The exact identification of localized wells by mapping via ArcGIS software leads to the accurate localization of wells. The excavated boreholes with suitable geological conditions (e.g., porosity and the boundary of the deposit with impermeable layers) are potentially suitable for use as underground storage tanks.

The stochastic drilling approach with the usage of well property algorithms is used to find the optimal drilling depth measured in vertical wells in three-dimensional space. The algorithms created in such a way are then used to demonstrate the determination of the actual measured depth of the vertical wells [16].

Based on the above-mentioned information, we can demonstrate that it is possible to quickly identify deposits with good productivity and to identify the most promising areas with the presence of natural gas (according to Table 1). In the article, all available data and information obtained from the East Slovak Basin from the available gas wells are mapped and electronically processed into the summary registration and mapping system. The authors used the existing software, ArcGis, and showed the possibility of filling its database with the verified data and information from the existing wells. This information was not completely processed in the electronic form. This software more easily provides research into the technical characteristics of wells. The main aim is to show the newly realized approaches to the electronic registration and mapping of wells, which, in Slovakia, have not been mapped so far. This method of electronic evidence is possible to use to process data and information, as well as for geothermal wells.

We can use various automated systems and programming in other software such as DELPHI and MATLAB [17,18] to monitor, map and digitize information on the conditions of wells. For example, a computational fluid dynamics (CFD) simulation tool is used to build computational models, which together, creates modelling support for employees at the Centre for Renewable Resources at the Technical University of Košice [19].

Table 1. List of all valid exploration territories for oil and gas in Slovakia (2020), (source: elaborated by authors based on [13,20]).

Name of the Exploration Area	Keeper of the Exploration Area	Area [km ²]	Validity Up to
Bažantnica oil and natural gas	NAFTA a. s., Bratislava	451.4	14.05.2020
Beša natural gas	NAFTA a. s., Bratislava	770.45	26.09.2029
Gbelyoil and natural gas	NAFTA a. s., Bratislava	419.00	21.05.2020
Topoľčany natural gas	NAFTA a. s., Bratislava	1190.93	31.12.2024
Trnava natural gas	NAFTA a. s., Bratislava (50%), Vermilion Slovakia Exploration s.r.o., Bratislava (50%)	91.3	31.03.2028
Vienna Basin—north oil and natural gas	NAFTA a. s., Bratislava	146.51	28.06.2024
Svidník oil and natural gas	Alpine Oil & Gas Slovakia, s.r.o., Bratislava (66.67%), ROMGAZ s.r.o., Bratislava (33.33%)	34.22	01.08.2021

As we have demonstrated in the introduction, up until recently, information on the location and condition of historical oil and gas wells in Slovakia has been poorly recorded and archived, including important geological, fluid and hydrocarbon production information collected for each well.

As a result, this has hampered the efficient new exploration of oil and gas, has prevented the repurposing of historical wells for carbon or hydrogen storage or the assessment of geothermal resources, and has impaired the ability to effectively identify and remediate wells in poor condition that pose an environmental risk.

In this article we demonstrate how we have developed a new database and interrogation workflow utilizing ArcGIS technology that can address these concerns. We provide case examples of how the new system can be used to easily identify wells that require remediation, depleted gas reservoirs that can be repurposed for carbon storage, and areas of future hydrocarbon perspectivity.

2. Materials and Methods

For our research we have chosen gas wells in the territory of the East Slovak Lowland.

One model example of information inserted into the ArcGis database is from the Stretava 45 well. The individual steps show the process of creating the database and entering information into it. The valuation of the current status of all available wells was carried out. After a detailed analysis, it was found that in 2020, there were six active extractions of hydrocarbon deposits in the territory of the East Slovak Lowland. We considered all gas and oil wells in Slovakia, which are registered by NAFTA Ltd. (270 wells). There are 270 wells in these mining areas, of which 61 are drilled and equipped, 11 planned and 198 that have been plugged and abandoned. These wells were used to create a program for their records, electronic mapping and the collection of their basic information.

We entered the data of production wells, testing wells and exploration wells into the software database. The abandoned wells were no longer important when considering data entry into the database as they are excluded from the study.

After obtaining the measured data (the location, quantity, and state of oil and gas wells), the data were evaluated using the following analyses:

- (a) We analyzed up-to-date information on the status and number of gas wells in the selected territory. In the territory of the Slovak Republic, the production of oil, gasoline, and natural gas as well as the underground storage of natural gas in natural rock structures is localized in the districts of competence of the OBU (District Mining Office) in Bratislava and the OBU (Mining Office) in Košice. A list of all valid exploration territories in Slovakia for 2020 is given in Table 1.

Due to its suitable geological structure, the territory of Slovakia has several oil and gas deposits (Tables 2 and 3). This favorable geological structure is necessary for their formation, accumulation and subsequent extraction, or more precisely, for underground storage.

Table 2. List of currently valid extracted natural gas deposits, (source: elaborated by authors).

Natural Gas—14 Deposits	
From which 5 are mined deposits	
No.	Name of the deposit
1	Bánovce nad Ondavou
2	Trhovište—Pozdišovce
3	Stretava
4	Senné
5	Ptrukša

Table 3. Listing of the actual valid mined oil deposits, (source: elaborated by authors).

Oil (Gasoline)—6 Deposits	
From which 4 are mined deposits	
No.	Name of the deposit
1	Bánovce nad Ondavou
2	Trhovište—Pozdišovce
3	Stretava
4	Senné

However, not all the discovered deposits were extracted because they were not financially efficient. Extracted oil or gas deposits can be used for other extraction activities in Slovakia as well as in other countries. Depleted oil and gas reservoirs can be subsequently used for other activities such as gas storage, carbon storage, and the disposal of mine waste water, sulphide, CO₂ etc. [21,22].

Most of these suitable underground geological structures are used for the storage of natural gas, which are located mainly near the villages of Jakubov, Gajary, Suchohrad, Plavecký Thursday, Láb and Križovany nad Váhom.

An analysis of the current state of deposits was carried out from the total current number of natural gas deposits (Table 2) and oil (Table 3) located in the east of Slovakia in the East Slovak Basin.

The above mined oil deposits (Table 3) are located in Eastern Slovakia. Currently, the total production of oil in our territory is symbolic and accounts for only 1% of domestic consumption. The amount of mined oil and gasoline, which is around 58,000 tons and 10,500 tons per year, respectively, is not sufficient for the needs of the country, so oil has to be purchased abroad.

More important are natural gas deposits, which produce one million m³ per year, while geologically suitable mined deposits are mainly used in Slovakia for the underground storage of natural gas, and are among the most important in Central Europe.

Table 4 gives an overview of the hydrocarbon deposits and the oil and gas wells in the extraction territory of the Eastern Slovak Lowland.

Table 4. Actual state and number of wells in the territory of the Eastern Slovak Lowland, (source: elaborated by authors).

No.	Name of Hydrocarbon Deposits	Realized Wells	Abandoned Wells	Planned Wells
1	Bánovce nad Ondavou	10	28	0
2	Pavlovce nad Uhom	10	46	2
3	Pavlovce nad Uhom I.	13	36	2
4	Pozdišovce I.	12	39	1
5	Kapušíanske Kľačany	14	42	6
6	Trebišov	2	7	0
	Total	61	198	11

Table 4 shows that abandoned wells are largest in number and are also in the last, irreversible phase in the life of the gas and oil well. Liquidation shall be taken if there is no use of the well or if its further use would be inefficient from an economic point of view. Abandoned wells can be used for waste storage, the pumping of mining water, heating with heat pumps, or heating through the usage of low-level heat. The wells are controlled, plugged and abandoned if they are filled with special cement mixtures.

These wells have to then be deepened and cleaned, and then undergo the installation of underground equipment [23,24].

(b) We gathered and collected the necessary technical data and relevant information from 2020 available in the annual reports published by NAFTA a.s.

- (c) We obtained and processed the collected data from the Information System of Geodesy, Cartography and Cadaster in the Slovak Republic (ISGKK).
- (d) We verified the collected data using a functional algorithm, where 270 wells were processed, which will provide basic information about these wells simply by searching for them. ArcGIS software was used for recording, monitoring and mapping, from which the electronic and graphical records of gas wells were obtained. The selection of well parameters (depth, diameter of casings, casing wall thickness, the type and composition of the lower part of the well, material quality, the type of joint, etc.) were decided based on the amount of available information about the wells and locations of the wells in the East Slovak Basin.

ArcGIS is a geographic information system (GIS) for working with maps and geographic information maintained by the Environmental Systems Research Institute (ESRI). It is used for creating and using maps, compiling geographic data, analyzing mapped information, sharing and discovering geographic information, using maps and geographic information in a range of applications, and managing geographic information in a database [25–27].

3. Results

In the contents of the methodology, we analyzed all the indicators necessary to create an algorithm for solving the status of wells in the electronic system. A clear database of technical overground and underground information about wells was created. After the creation of the database, an image base was visualized in ArcGIS software and used to form the map based on the Slovak Republic.

The background of the map made it possible to filter different information and make a selection according to the selected parameters.

As a support for the creation of the algorithm, we used the monitoring of the well and a database created by us that contained all the basic data obtained about individual wells. These data are listed as follows:

- Hydrocarbon deposits;
- Location;
- Type of well;
- Completion of the well;
- Pumping tests;
- Underground correction of the well;
- Sample of further usage;
- Liquidation well;
- Photo documentation;
- Further obtained information.

The process of the creation of the algorithm is visualized by the map base of the area in which we were interested, as shown in Figure 3.

The methodology of the sequence of the creation of geographical maps consists of the following main steps:

- (a) Opening the ArcMap tool and creating a digital geographical map base of the area of interest (Figure 3);
- (b) Creating the geographical names in the format “.shp”, from the source geoportal.sk (Figure 4);
- (c) Opening the ArcCatalog system module, which is necessary for the organization of the geographic database and the creation of polygon mining areas with a system file (Figure 5);
- (d) Marking the mining areas and wells on a map base, where the wells were placed in the individual mining areas (Figure 6);
- (e) Creating a file and inserting information about individual wells (Figure 7);
- (f) Conducting the final search based on the selected well (Figure 8).

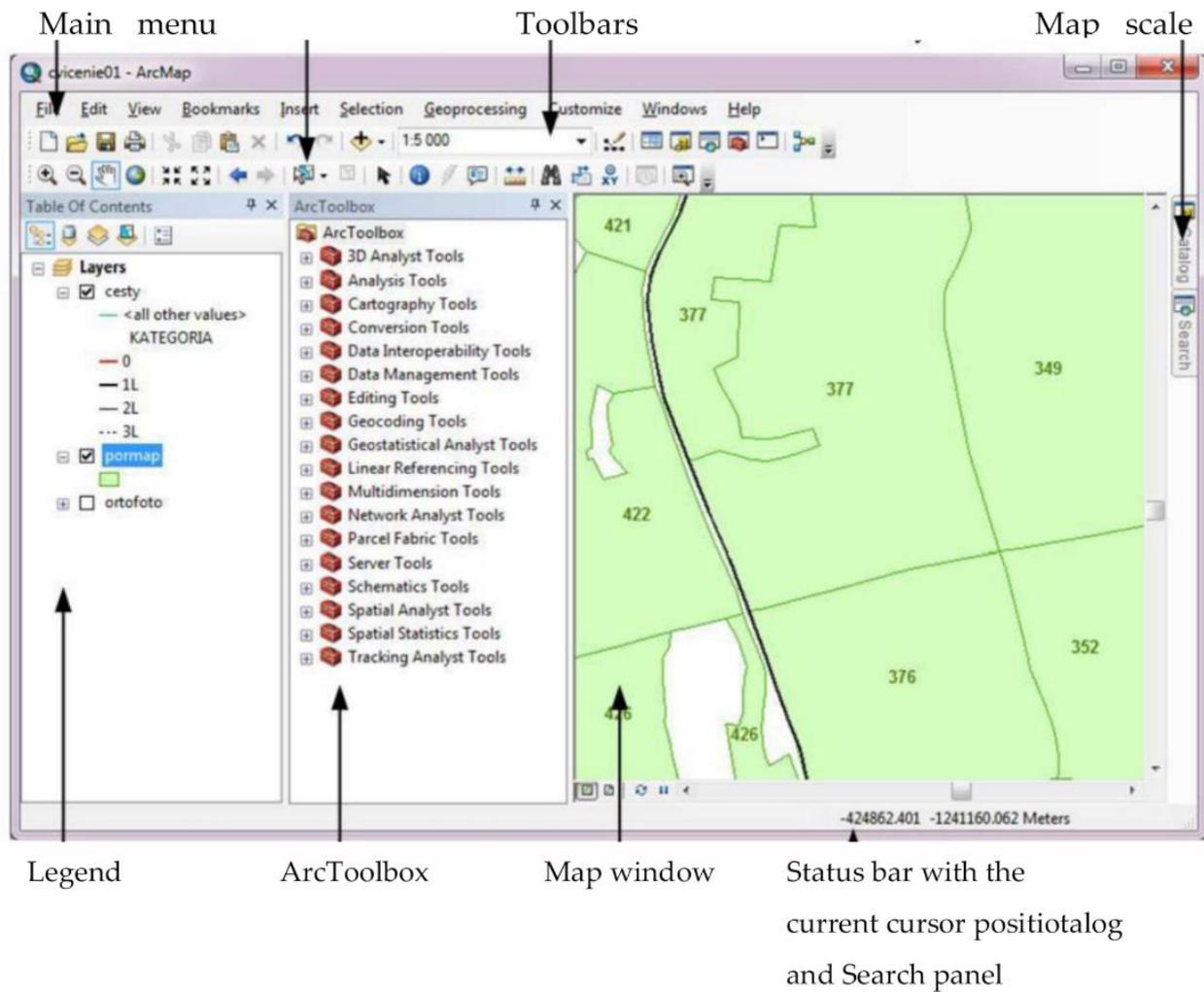


Figure 3. The process of the creation of the algorithm maps, (source: elaborated by authors).

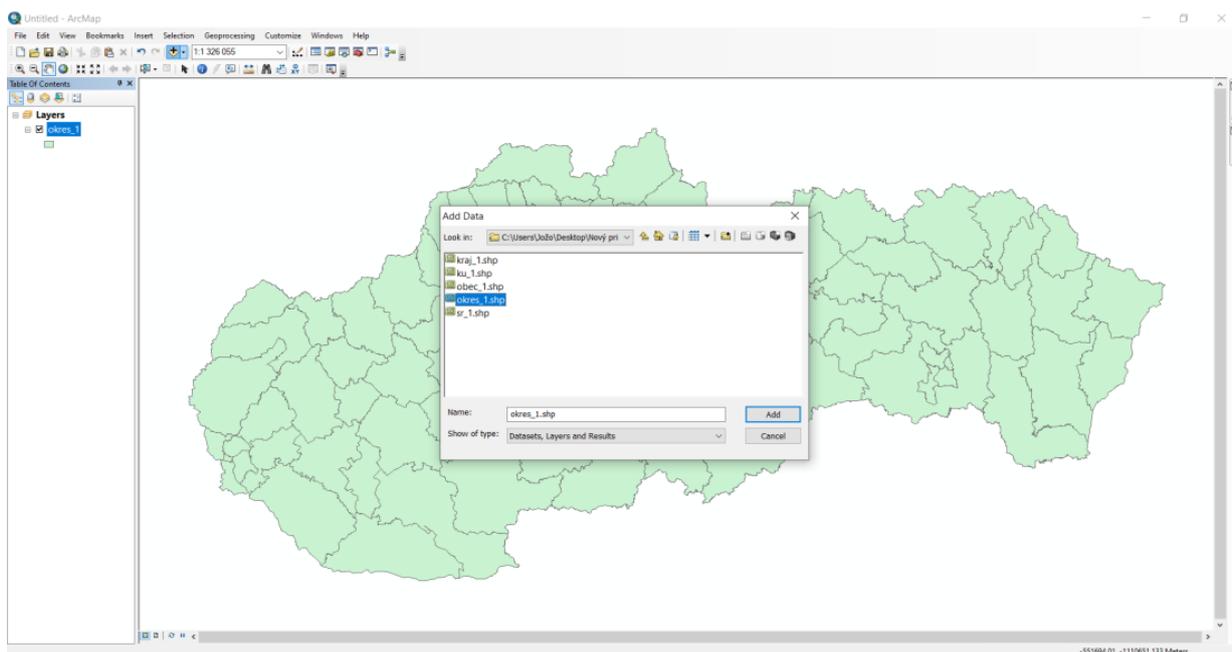


Figure 4. Inserting geographical districts and names, (source: elaborated by authors).

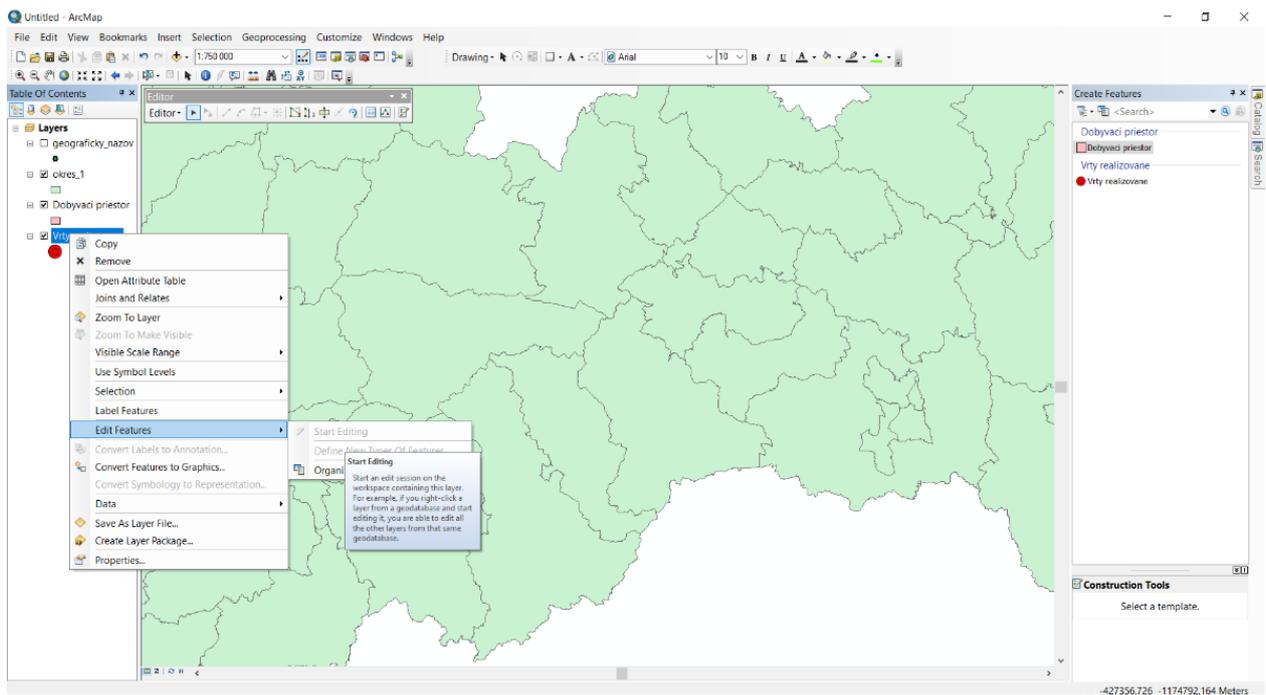


Figure 5. Creating layers for mining areas, (source: elaborated by authors).

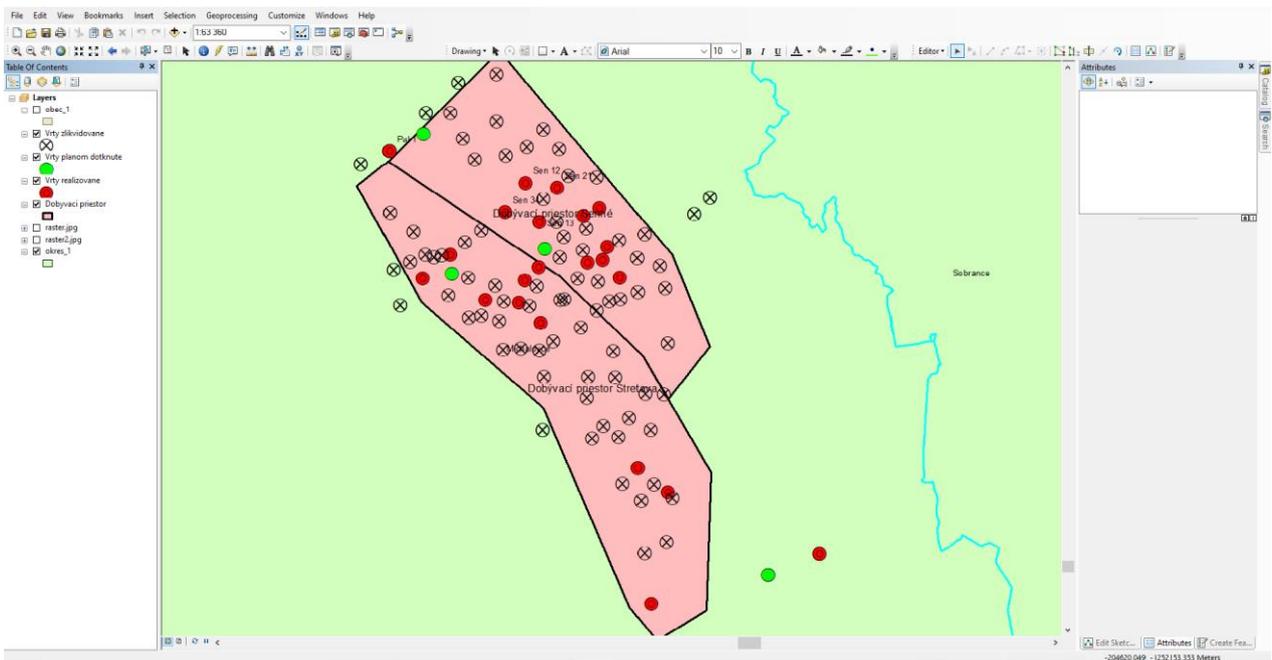


Figure 6. Placement of the wells in mining areas, (source: elaborated by authors).

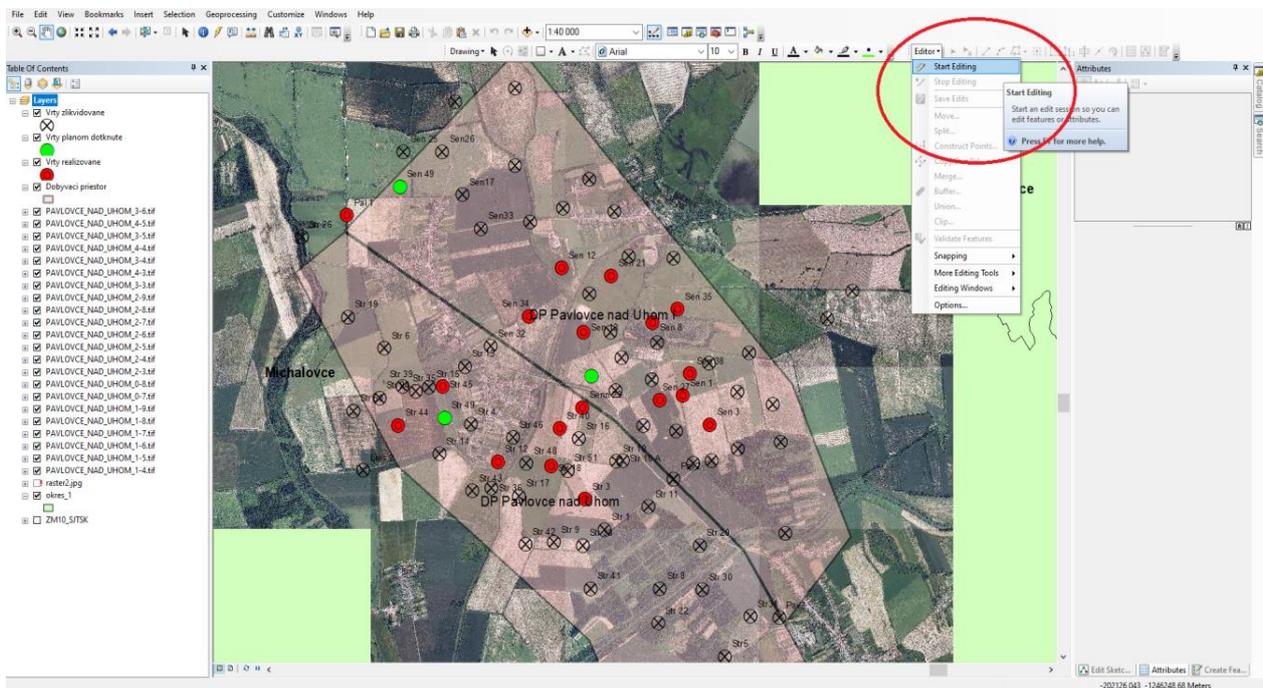


Figure 7. Entering the detected technical specifications and data, (source: elaborated by authors).

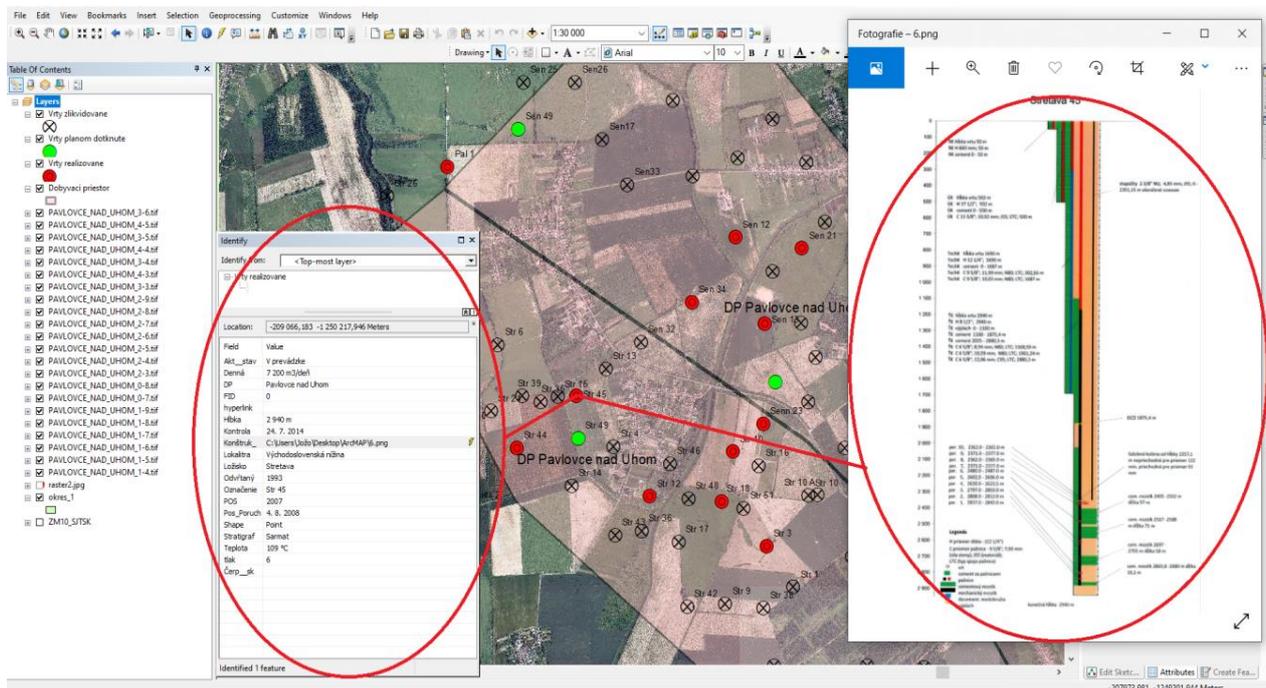


Figure 8. Preview of how to view basic information about the Stretava 45 well, (source: elaborated by authors).

The first step was to open ArcMap, one of the basic ArcGIS tools for creating digital geographic maps. This was followed by downloading and inserting the background map of the Slovak Republic in .shp format from the ZBGIS Map Client application, available on the geoportal.sk website.

The second step was to download and insert the geographical names in the “.shp” format (Figure 4 from the source geoportal.sk).

In the third step, the ArcCatalog system module was opened to organize and manage the geographic database, as well as used to connect the system file. In order to form

polygon-type mining areas, a new layer (also using the “.shp” format) was created and added to the same folder (Figure 5). In a similar way, individual wells were created, which were of the point type.

After creating all the necessary layers, in step four we marked the mining areas and wells on the map base. The wells were inserted exactly according to the individual valid mining areas, and their items/categories can be seen in the table (Figure 6).

The last step was to fill the individual wells with all the basic technical information and well parameters. This was done using the top bar via the Start Editing function as shown in Figure 7.

The result of processing the data on wells was the creation of clear gas well recordings. The advantage for the user is the speed of obtaining available data according to the name of the searched well.

Alternatively, through the legend on the right side of the screen, the user can choose which hydrocarbon deposits he or she is interested in. The user then clicks on the type of well he or she wants to be displayed in the given hydrocarbon deposits. Then, the user clicks on the selected well, as shown in Figure 8 (Stretava 45 well), where he or she will see all the basic information available on the searched well.

This will show the user a clear table with windows and then he or she will be able to open photo documentation of the well.

Similarly, the user will be able to view information about pumping tests and underground repairs of the wells, as well as information on the disposal of wells and the possibilities for their further use via internet links [28].

4. Discussion

In the operation of wells by individual companies, it is a priority to have clear and accessible information about the current state of individual wells. The electronic monitoring and recording of wells allows wells to be kept under constant control. This helps companies respond in an appropriate manner to changes in wells, such as those caused by weather conditions, mechanical damage, and especially operational changes. It contributes to their smooth operation and prevents abrasion or well damage.

Another shortcoming is inaccurate legislation with a lack of solutions to the issue of well remediation after mining.

A number of obligations are unclear, such as who has the obligation to rehabilitate the territory after mining, how often the territory is to be controlled, or in what state the well is deemed to have been properly disposed of.

Each well requires regular monitoring on the surface, but mainly below the surface. This will prevent unplanned downtime due to poor technical conditions. Figure 9 shows an example of the unsatisfactory condition of a gas well at its mouth.

Figure 10 shows the correct surface and subsoil technical condition of the gas well, which is equipped with all safety devices (reinforced panel area, fencing, camera system, GPS system, information boards with basic data) and complete technical equipment (well completion) necessary for its safe operation.

Each gas well shall be subject to a so-called underground repair of the well after a certain period of operation or on the basis of its actual technical condition and production in order to continue to operate safely. Electronic records of its technical condition will also contribute to this.

The benefit of our algorithm and the work progress is to create fast and transparent monitoring of wells (i.e., well records and information about wells).

Thus, the result of the formed program is the recording of wells, where the user can find his or her sought-after well by name. Alternatively, through the legend on the right side of the screen, the user can choose what hydrocarbon deposits he or she is interested in and click on the type of well he or she wants to be displayed in those hydrocarbon deposits. The user will then click on the chosen well and then will be shown all available information about that well.

First, the user will see a table with basic information about the well. Second, the user will be able to open the photo documentation of the well. Next, it will be possible to consult the pumping tests, the underground repair of the well and the possibility of further use or disposal via internet links. All information and images entered can be edited, amended or supplemented according to the current technical condition with the possibility of comparing their status in the history of the program.



Figure 9. Example of the unsatisfactory condition of a gas well at its mouth, (source: elaborated by authors).



Figure 10. Correct overhead technical equipment of a gas well at its mouth, (source: elaborated by authors).

5. Conclusions

There is currently no systematic and consistent approach in Slovakia when deciding on the necessity and priorities of remediation measures of the wells implemented. There are no clearly defined criteria for assessing the importance of addressing them. There is a lack of public programs for the disposal of old wells after oil and gas extraction and for other environmental burdens. This should be done based on the objective evaluation according to the state of pollution and according to the evaluation of environmental risks.

The disposal of underground wells and underground spaces represents not only a technical but also an economically demanding task. This requires a combination of technical knowledge from the use of materials and the creation of open spaces with an emphasis on high environmental protection [29]. The modification of legislation would eliminate the potential threat of burdens to the environment.

In the case of the overall technical and electronic equipment of gas wells, the well can be considered safe for operation and control as shown in Figure 10. The benefit of this processing is to check the records in the actual operation of the well. Therefore, the purpose of this proposed electronic register is to simplify the search and control of the current technical status of wells.

Another benefit is to detect possible defects in well damage or accidents, which has a positive impact on the safety and technical security of the wells and, thus, on its service life and environmental quality.

The mapping created by us using ArcGIS software is unique in Slovakia in such a way that it allows an overview of individual wells and allows users to find out their current technical condition [30]. The purpose was to inform the general public about the latest developments in the subject under examination.

The results presented and the differences between our findings and the literature data obtained in some other studies indicate the need for further research.

The scientific use of the article resides in the ability to interpret technical problems and methods of processing and using information on gas wells. On this basis, gas companies can quickly and safely assess and evaluate the suitability of selected wells. Furthermore, it is possible to use them as storage devices, such as for the underground storage of natural gas. The database is processed based on the step algorithm offered by ArcGIS software. The database leads to a clear overview of the technical conditions of the wells, on the basis of which they can evaluate the overall safety of well operation. The interpretation of these data can provide gas companies with the strategic needs of the state and create additional capacity in the storage of natural gas in the Slovak Republic. The algorithm interpreted in the article is applicable not only to gas wells but also to oil, geothermal and hydrogeological wells.

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