Geoelectrical Investigation of Aquifers in the Bodoc Site, Covasna County, Using the Vertical Electrical Sounding (VES) Method

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Abstract

Geoelectrical methods are reliable tools for the assessment of shallow aquifers and for understanding their structure and distribution in the subsurface. In the Bodoc site, Covasna County, geoelectrical methods were applied to investigate aquifers, aiming to determine their extent and physical characteristics. The studied perimeter is located near a carbonated mineral water capture and bottling facility, highlighting both the economic importance of local resources and the relevance of the performed geophysical investigations. The geoelectrical measurements were carried out as part of a study for investigating analogues for CO_2 geological storage and testing a new monitoring methodology for future anthropic CO_2 reservoirs. The Bodoc site was selected for this study due to its good resemblance to a safe CO_2 geological storage site, being a natural CO_2 reservoir. Within the study, six electrometry profiles were carried out, distributed across various areas within the Bodoc perimeter, each reaching a maximum depth of approximately 4.2 meters. The measurements were performed using the vertical electrical sounding (VES) technique, with the help of an AGI MiniSting™ R resistivity meter, applying the Schlumberger configuration. The acquired data were subsequently processed to generate 2D resistivity sections, which allowed for the interpretation of the electrical property distribution in the subsurface. The obtained results highlight variations in electrical resistivity, based on which it was possible to delineate distinct shallow geological units and to estimate the extent of the aquifers within the studied area. The interpretation of these results led to a better understanding of the local geological structure. Ultimately, the geoelectric method proved to be an efficient and reliable tool for investigating and characterizing aquifers, providing relevant information regarding their distribution in the subsurface. The study conducted in the Bodoc area confirms the utility of these methods in analyzing geological environments and highlights their application potential in diverse contexts, including studies on monitoring the geological storage of CO_2.

Keywords: *Electrometry, Aquifers, Bodoc, Analogues, CO_2*

1. Introduction

The geoelectrical method is widely used for both shallow and deep investigations. Over time, geoelectrical measurements have been successfully applied in the study of aquifers, archaeological sites, and deep investigations for hydrocarbons or CO_2 storage [1]. It is a simple geophysical method, among the most widely used in the context of civil engineering studies, which is why it is often chosen for investigating geological structures near the surface [2].

Geoelectrical measurements are based on analyzing the response of the geological medium to an electric current injected into the subsurface, this response being controlled by the properties of the layers that allow the electric current to pass through them [3]. In general, rocks can be good conductors, intermediate conductors, or poor conductors, depending on several factors [4]. The main factors controlling the flow of electric current through geological media are the fluids contained within the layers, their porosity, and the clay content in their composition [5]. Groundwater resources are vital both for ecological stability and for supporting human activities, playing a crucial role in ensuring drinking water supplies, irrigation, and the protection of natural habitats. Although they represent the primary source of freshwater in many areas, aquifers are highly vulnerable to contamination and overexploitation, which is why they require continuous monitoring and detailed studies. Thus, over the past two decades, geophysical techniques—particularly those based on electrical resistivity—have been increasingly used and improved, being appreciated for their effectiveness and non-destructive nature [6]. Moreover, integrating information obtained from electrometry with complementary techniques, such

as electromagnetic or seismic methods, provides a much clearer perspective on subsurface structure. Such a combined strategy facilitates not only the identification of aquifer boundaries but also the evaluation of their characteristics (such as the amount of water stored within layers), making a significant contribution to resource quantification and responsible management [7].

Due to the resistivity contrast between water-saturated layers and dry ones, the geoelectrical resistivity method is clearly a suitable choice for aquifer investigation. Within a research project aiming to develop a new environmental monitoring methodology for CO_2 geological storage based on the investigation of natural analogues, geoelectrical resistivity investigations were carried out in April 2025 at the Bodoc site, Covasna County, Romania. The objective of the geoelectrical survey was to investigate the lateral and vertical distribution of shallow water levels. Data acquisition was performed using the Vertical Electrical Sounding (VES) method, applied with the Schlumberger array configuration, a method recognized for its accuracy in determining vertical lithological variations. 2D models were generated following the processing of field-acquired data, representing the distribution of resistivity within the subsurface, clearly distinguishing the water-saturated zone from the vadose zone.

2. Case study

The geoelectrical measurements for the investigation of shallow groundwater at the Bodoc site, Covasna County, were conducted at the end of April 2025, during a period characterized by increasing precipitation. The perimeter chosen for the groundwater study is of great economic importance, being located above an aquifer containing deep-seated CO_2 accumulated as a result of post-volcanic processes. Through a migration process, this CO_2 reaches the near-surface via faults and fractures. A carbonated mineral water extraction and bottling plant is located in the northeastern part of the perimeter. The study area is characterized by a tiered relief, representative of the Eastern Carpathians segment where it is located. Its geographic setting encompasses elements of the Brașov Depression and the Olt–Baraolt River region, features previously documented in the specialized literature [8]. According to the Geological Map of Romania, Sheet 28 – Brașov, scale 1:200,000 [9], from a geological perspective, the near-surface Quaternary sediments are of the deluvial-proluvial type (sediments transported by the streams flowing from the Bodoc Mountains), consisting of gravels and boulders. Their thicknesses range from a few tens of centimeters up to several meters at lower altitudes, moving westward toward the Olt River. Beneath these Quaternary sediments lies a layer composed of shaly-sandstone and sandstone flysch (the Bodoc flysch), of Barremian-Aptian age, exceeding 500 meters in thickness, which continues beneath the Bodoc Mountains. The entire secondary hydrographic network is collected by the Olt River, which flows through the depression area along a north-south axis. From its left bank, it receives the influx of the Vașar, Talomir, Borviz, and Șute streams. The geoelectrical profiles were positioned according to relief variations to ensure that potential variations in the water table depth were intercepted. Therefore, four of the profiles were placed on higher ground to the left of the stream crossing the valley, while two of them were located near the lower bank, to the right of the stream, at a lower elevation compared to the first four (Figure 1). To enable the determination of the groundwater level distribution over the largest area possible, the profiles were laid end-to-end, with each line consisting of two geoelectrical profiles. The spatial positioning of the profiles and the measurement points along their entire length was recorded using a high-precision GPS device, specifically a Trimble R2 GNSS receiver.

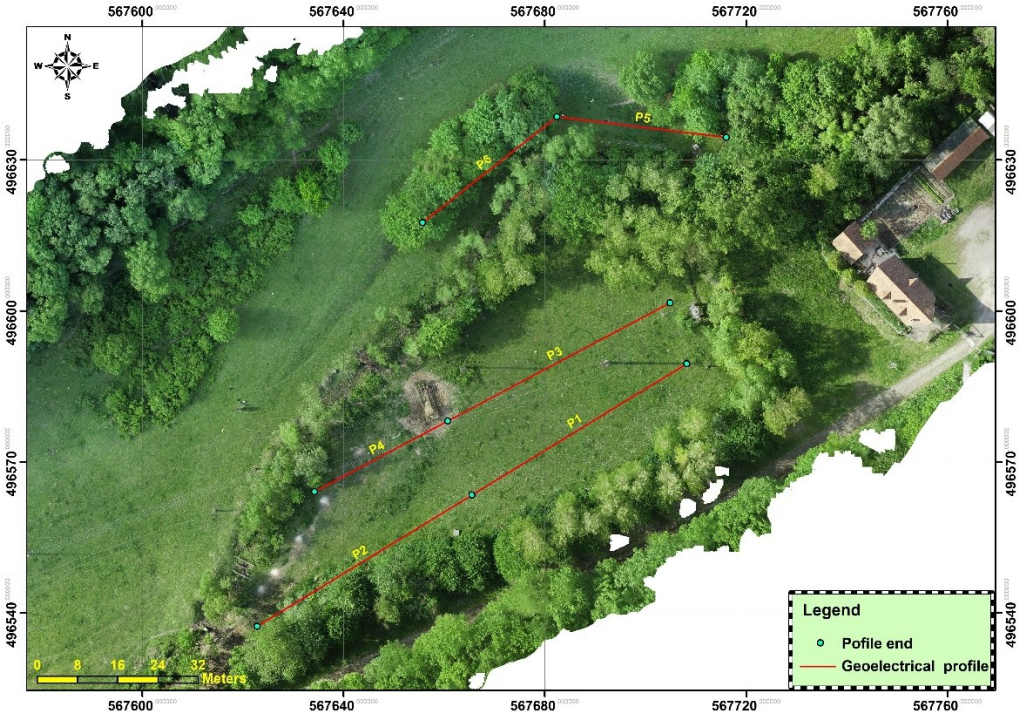

Fig. 1: Site layout plan of the Bodoc site where the six geoelectrical profiles were carried out (shown in red on the map).

The geoelectrical measurements were conducted using the MiniSting™ R resistivity meter, a high-performance instrument designed for determining the resistivity of geological formations. The measurement system consists of four electrodes, two of which are used to inject the electric current into the ground (AB), while the other two are used to measure the potential difference (MN). The metal electrodes are connected to the device via insulated cables, which ensure the transmission of the current and the recording of the electrical signal. A 12V battery was connected to the resistivity meter to supply the electrical current to be injected into the subsurface through the electrodes. The device operates on a single acquisition channel, allowing measurements to be taken at a specific point using a fixed electrode configuration. The depth of investigation is controlled by varying the distance between the

current injection electrodes, which allows the method to be adapted for both shallow studies and deeper investigations. The configuration used is simple and efficient, being easy to implement in the field and suitable for a wide range of geophysical applications.

The Schlumberger electrode array is typically the most common configuration for measuring resistivity via VES [2]. The measurement setup at the Bodoc Site consisted of placing the resistivity meter at the central point of the VES, namely halfway between the AB and MN electrodes. The MN electrodes were kept in a fixed position throughout the duration of the measurements, being placed laterally relative to the resistivity meter, at a distance of 1 m from it and 2 m apart from each other (Figure 2). Depending on the maximum target depth for the investigation, the distance between the AB electrodes was progressively increased by 2 m increments for each measurement level, thereby ensuring the investigation of increasingly greater depths. For each VES, the measurements were performed in 5 depth steps, which involved expanding the AB distance five times. The maximum investigated depth was approximately 4 m.

Fig. 2: Conducting VES measurements using the MiniSting™ R resistivity meter.

Depending on the terrain morphology, the profiles were positioned so that measurements could be repeated in subsequent years, establishing a monitoring process for the lateral and vertical distribution of groundwater. Due to obstacles such as vegetation, anthropogenic elements, or sudden and significant relief variations, the profiles varied in length. Consequently, profiles P1, P2, and P3 were each 50 m long, with 16 VES points conducted per profile. Profile P4 was 30 m long and consisted of 6 VES points, while profiles P5 and P6 were 40 m long, each consisting of 8 VES points. For all six profiles, a 2 m spacing was maintained between the VES points. The primary parameter determined during the electrometric measurements is the apparent resistivity. It is designated as "apparent" because the boundaries of geological layers and anomalies generated by fluids or objects are not highlighted with sufficient resolution to establish their exact position and depth directly from the raw measurements. Therefore, the term apparent resistivity is used instead of true resistivity. The true resistivity, along with the geometry of the structures producing the anomalies, can be subsequently determined through the processing and interpretation of the field data. The processing of the field data acquired via the VES method was performed through 2D modeling using the inversion technique. The apparent resistivity values obtained in the field were processed using the EarthImager 2D software (AGI), which constructed a subsurface model through successive parameter adjustments, ensuring that the differences between the calculated and measured values were minimized. The final model resulting from the inversion describes the true resistivity distribution, which serves as the basis for the subsequent geological interpretation [10]. By applying this method, a significantly more detailed image of the water table, layer boundaries, and lithology of the study area was obtained.

3. Results

Prior to the actual processing, the data were filtered and sorted in Excel; spikes from erroneous values were removed to ensure data integrity, thereby providing a correct baseline for the processing stage. At this stage, the profile geometry was defined (the spacing between VES points and the distances for the MN and AB electrodes), along with the depths at which the measurements were conducted. After importing the filtered data file into EarthImager 2D, a separate file containing the elevation data for each electrode position was also loaded. The software generated a pseudosection representing the apparent resistivity values measured in the field. The horizontal axis represents the distances at which the injection electrodes were placed, while the vertical axis displays black dots corresponding to the depth measurements of each individual VES (Figure 3). The calculated pseudosection represents the apparent resistivity values obtained through measurement simulation, which is used for comparison with the field data to refine the model. The final 2D models obtained following the inversion are displayed in Figures 4–8, representing all six profiles. The resistivity scale is shown on the right side of the images, where low values are represented in blue and high values in red.

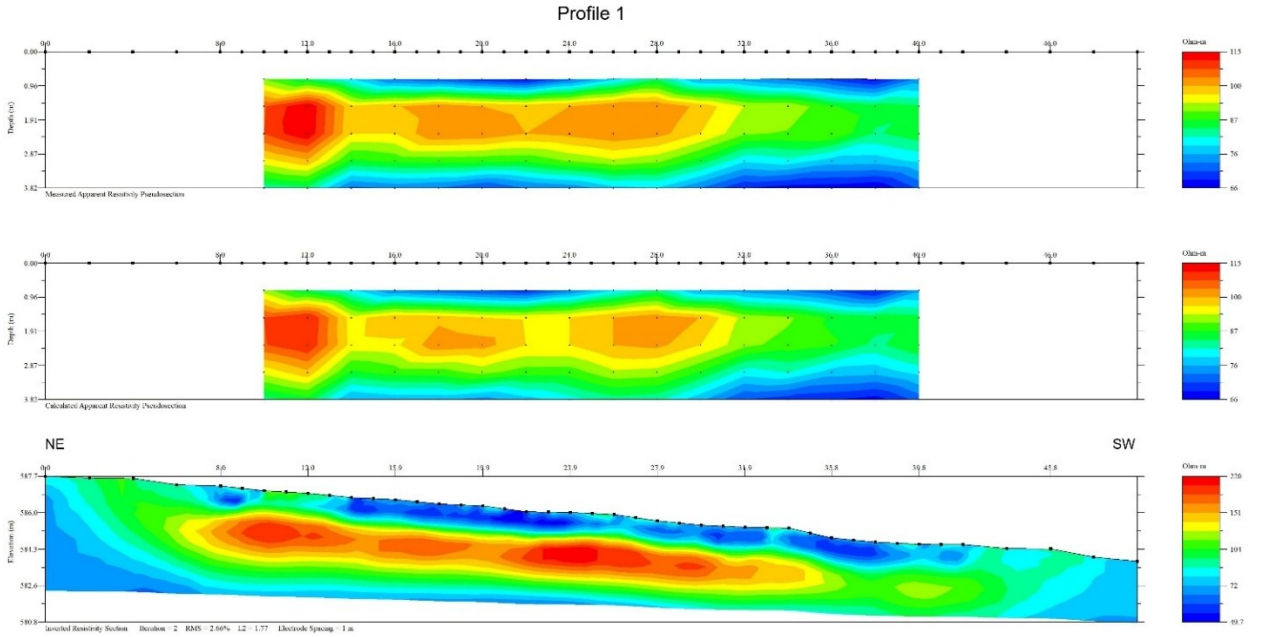

Fig. 3: The two pseudosections, the upper one representing the measured apparent resistivity, and the second one the apparent resistivity calculated by the software. The resistivity section (profile 1) in the lower part represents the final result obtained after inversion, with resistivity values ranging between 40.5 and 266 Ω·m.

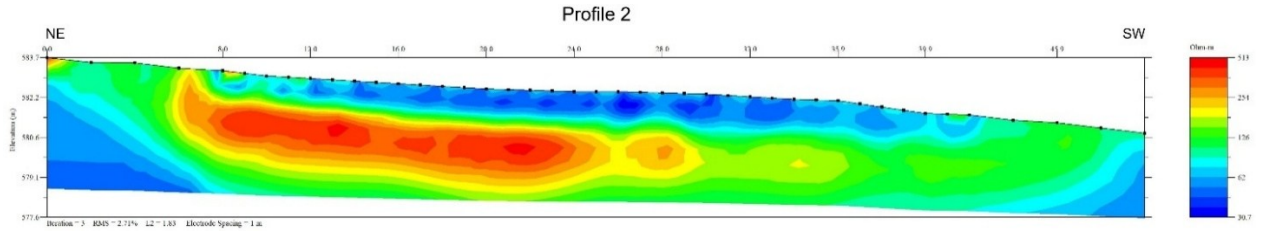

Fig. 4: Resistivity Profile 2, continuing from Profile 1 (Figure 3), with resistivity values ranging between 30.7 and 513 Ω·m.

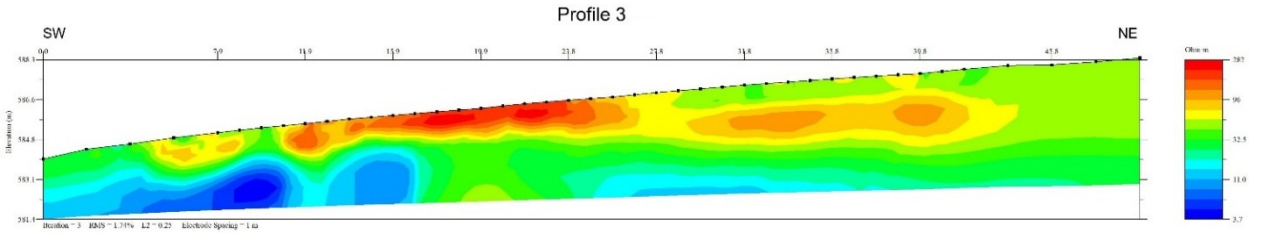

Fig. 5: Resistivity Profile 3, with resistivity values ranging between 3.7 and 282 Ω·m.

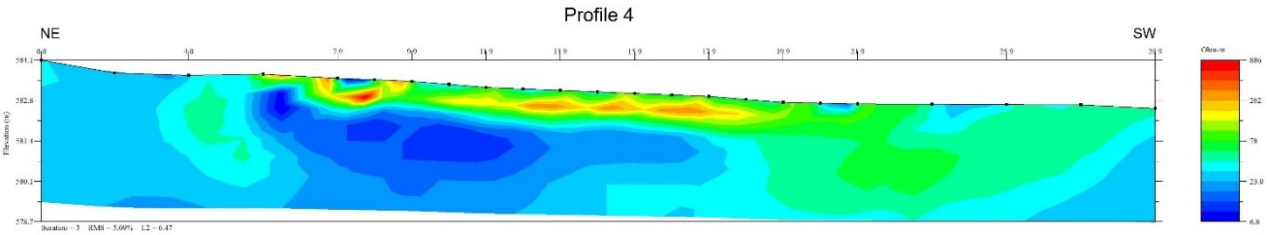

Fig. 6: Resistivity Profile 4, continuing from Profile 3 (Figure 5), with resistivity values ranging between 6.8 and 886 Ω·m.

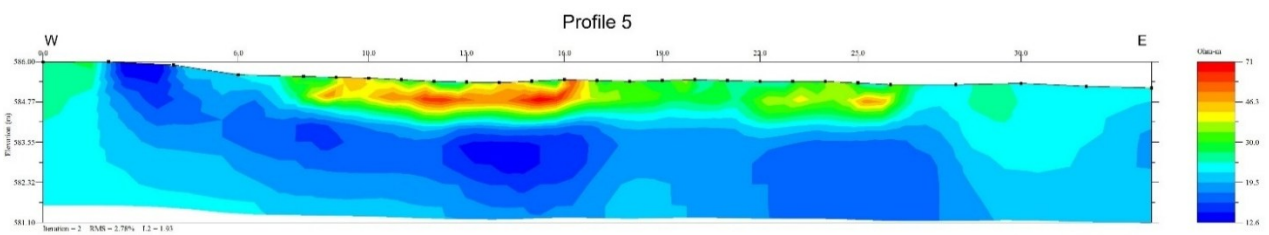

Fig. 7: Resistivity Profile 5, with resistivity values ranging between 12.6 and 71 Ω·m.

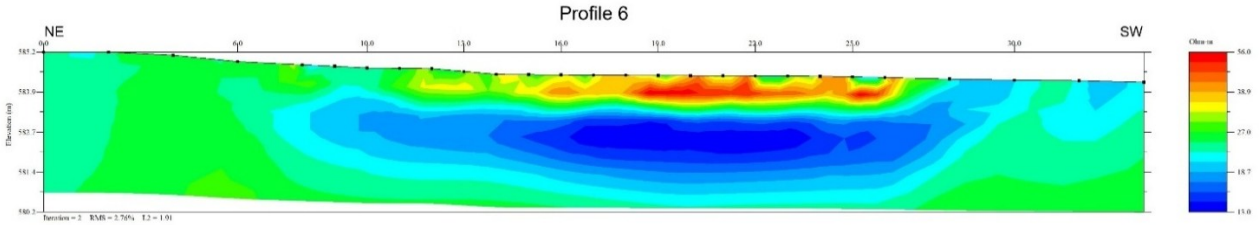

Fig. 8: Resistivity Profile 6, continuing from Profile 5 (Figure 7), with resistivity values ranging between 13 and 56 Ω·m.

From the analysis of the geoelectrical profiles presented above, a significant contrast in resistivity values is initially observed across each profile. Profiles 1 and 2 highlight high resistivity values within the first approximately 4 meters of depth, followed by a sharp decrease. This variation most likely indicates the transition from the vadose zone to water-saturated levels (groundwater hosted within the layers). Profile 3 also exhibits high resistivity values in the shallow zone, particularly in the northeastern part, where the terrain elevation is higher (588.3 m). In this area, the high-resistivity interval shows greater thickness. As the altitude decreases, this interval thins out, and low resistivity values appear increasingly closer to the surface, suggesting proximity to the watercourse. Continuing from Profile 3, Profile 4 is characterized by low resistivity values located near the surface, as it is positioned at lower elevations (with a minimum of 581.8 m). Profiles 5 and 6, situated at lower altitudes than the previous ones, exhibit low resistivity values starting from the surface. This aspect is most likely determined by the proximity to the stream and the high degree of saturation of the geological layers.

4. Conclusions

The geoelectrical investigations conducted at the Bodoc site proved effective in highlighting the spatial distribution of shallow groundwater, as well as its relationship with local geomorphological conditions. The resistivity models obtained through 2D inversion clearly demonstrate the contrast between the vadose zone, characterized by high resistivity values, and the water-saturated layers, associated with significantly lower values. In areas located at higher altitudes, the vadose zone is thicker, and high resistivity values are maintained over more extensive depth intervals. Conversely, towards low-lying areas and near the watercourse, low resistivity values appear closer to the surface, reflecting a higher degree of saturation. This trend is consistently observed across all profiles, representing the influence of the relief on subsurface hydrogeological conditions. The profiles located near the stream highlight low resistivity values even at shallow depths, suggesting a high degree of saturation. The study also demonstrates the applicability of the Vertical Electrical Sounding (VES) method, using the Schlumberger configuration, for investigating the hydrostatic level at shallow depths. Although the investigation depth was relatively limited (approximately 4 m), the method provided sufficient resolution to identify the primary hydrogeological characteristics. Overall, the results confirm that geoelectrical methods are reliable for groundwater monitoring. The profile configuration and the feasibility of repeating measurements provide the framework for future monitoring campaigns, contributing to the long-term evaluation of subsurface fluid dynamics.

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