

Hydrogeological Research of Groundwater Through Integrated Geophysical Methods (Ert And Ves) in the White Drin Basin, Kosovo

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ABSTRACT

Sustainable management of groundwater resources requires accurate hydrogeological characterization and identification of aquifer structures in the groundwater. This study presents the integrated application of two geophysical methods – Electrical Resistivity Tomography (ERT) and Vertical Electrical Sounding (VES) – for the identification and characterization of aquifers in the Drin i Bardhë River Basin in Kosovo.

The research was conducted at 11 hydrogeological sites, including alluvial sediment environments, pro alluvial deposits and flysch formations. A total of 37.49 km of ERT profiles and 126 VES measurements were conducted, using the ARES and ARES II geophysical systems. Data analysis showed significant variations in electrical resistivity, with values <30–50 Ωm representing water-saturated clayey sediments, while the range 80–200 Ωm identifies sandy and gravelly aquifers with high permeability.

The results show that about 63% of the studied localities present high aquifer potential, while 27% present medium potential, mainly in areas with conglomerates and heterogeneous deposits. Only 10% of the localities resulted unproductive, due to the presence of shallow bedrock or flysch formations with low permeability. The thickness of the identified aquifers varies from 15 to 40 m, while in some sedimentary areas it reaches up to 60–70 m depth.

The integration of ERT and VES methods enabled the identification of buried fluvial structures (paleo-channels) and the determination of optimal areas for monitoring drilling. Based on the geophysical interpretation, 14 locations for monitoring wells were proposed, significantly reducing the risk of unproductive drilling.

The results demonstrate that the integrated use of geoelectrical methods constitutes a reliable and cost-effective approach for the hydrogeological characterization of sedimentary basins and for sustainable groundwater resource planning in regions with high geological complexity.

Keywords: Groundwater, Electrical resistivity tomography (ERT), Vertical electrical sounding (VES), Hydro geophysics, Aquifer characterization, White Drini Basin, Kosovo

Introduction

Geophysical methods have been widely used for identifying aquifers and characterizing subsurface hydrogeological structures [1,2].

Groundwater represents one of the most important sources of water supply for the population and economic activities in many regions

of the world [3]. In regions with continental climate and variability of precipitation, such as the Western Balkans, these sources play a strategic role in ensuring a sustainable water supply [4].

Geophysical methods have been widely used to characterize subsurface structures and identify aquifers due to their non-invasive nature and relatively low cost [5,6]. Electrical Resistivity Tomography (ERT) and Vertical Electrical Sounding (VES) are among the most widely used methods in hydro geophysics for identifying lithological changes and for defining water-saturated zones [7,8].

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Importance and Context of the Study

Groundwater constitutes the most important source of drinking water supply for the population and agriculture in the Republic of Kosovo. In the context of climate change and increasing water demand, sustainable management of these resources has become a strategic necessity. The Drin i Bardhë River basin, which lies in the western part of the country (Kosovo), represents one of the main water reserves. However, the lack of detailed hydrogeological data, especially at depth, has made the assessment of the water potential and quality of the watersheds difficult.

According to data from the Ministry of Environment and Spatial Planning (MESP), the need to establish a groundwater monitoring network has been highlighted as a national priority. This study is being carried out within the framework of the Kosovo Environmental Program (KEP), funded by the Swedish International Development Agency (SIDA), with the specific aim of strengthening institutional capacities for the implementation of the European Union Water Framework Directive.

Hydrogeological Issues

Previous research, including European Union projects (2009/2010), has identified 14 groundwater bodies, but has suggested the need for more in-depth exploration/study of the geological structures. The study area is characterized by great lithological complexity, where karst formations, flysch layers and alluvial sediments are chaotically interwoven due to past tectonic activity. This complexity makes existing conceptual models incomplete, while random drilling without prior investigations poses a high financial and technical risk.

The Role of Geophysics

Applied geophysics offers a non-intrusive and cost-effective solution for subsurface (groundwater) exploration. Geoelectrical methods, particularly electrical resistivity tomography and vertical electrical probing, have proven to be the most efficient tools for lithological separation and identification of water-saturated zones, based on differences in the electrical conductivity of rocks.

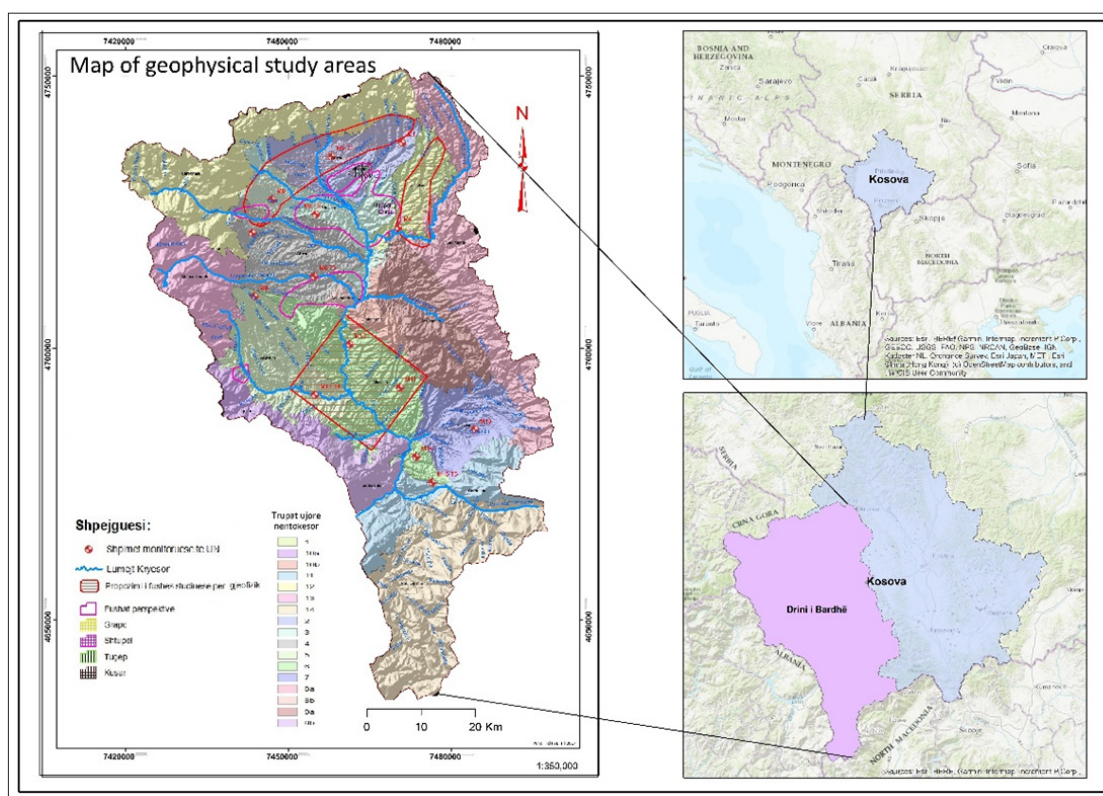


Figure 1: Spatial position of the study area

Study Objectives

This scientific paper has as its main goal the hydrogeological characterization of the Drin i Bardhë basin through a multidisciplinary geophysical approach.

The specific objectives are:

- **Determining Watershed Geometry:** Quantitative measurement of the thickness of useful sediments (sand, gravel) and the depth to impermeable bedrock (clay or hard rock).
- **Identification of Potential Water Zones:** Localization of layers with electrical resistivity characteristic of fresh groundwater, distinguishing between water-saturated clays and dry sandy layers.
- **Lithological Characterization:** Description of the internal structure of the basin, identifying horizontal and vertical changes in geological material (heterogeneity).
- **Drilling Optimization:** Providing technical recommendations for the placement of monitoring wells, minimizing the risk of unproductive drilling and ensuring optimal representation of various watersheds.
- **Training and Knowledge Transfer:** Increasing the capacities of local staff in the field of applied geophysics and data interpretation.

Study Area and Geological Conditions

The area of interest is located in the northern and central part of the Drin i Bardhë river basin, which covers a significant area of western Kosovo. The relief varies from wide alluvial valleys to low hills, while the Drin i Bardhë river constitutes the main element of surface and groundwater drainage.

The geology of the region is the result of the evolution of the Tethys Ocean and the collision of the African European tectonic plates. According to the Kosovo Mining Authorities, the stratigraphic sequence includes:

- **Palaeozoic Formations:** They appear as a deep basement, composed mainly of schist and crystalline granite, which in most cases serves as an impermeable base for groundwater.
- **Mesozoic Formations:** Dominated by ophiolites (serpentinites) and limestones. The karst developed in these areas creates opportunities for deep aquifers, but with irregular distribution.
- **Neogene and Quaternary Formations:** These are the main object of investigation. They include Pliocene sediments (clays, sands, lignite) and Holocene alluvial deposits (gravels, sands, muds) that were deposited by the river and its tributaries. The thickness of these sediments varies considerably, reaching up to 100 meters in the deep valley areas.

The main aquifers in the area are of the porous type, located in the alluvial sediments of the river valleys. Water accumulates in the empty spaces between the grains of sand and gravel. The static water level varies depending on the topography and the amount of precipitation, while the direction of groundwater flow generally follows the slope of the valley towards the main river.

The geology of the region is the result of the tectonic evolution of the Tethys zone and includes a complex combination of sedimentary and magmatic formations. The stratigraphic sequence includes Palaeozoic, Mesozoic, and Neogene and Quaternary deposits, which have been identified as the main aquifer formations in the region [4].

Holocene alluvial sediments, composed of gravel and sand, represent the most productive aquifers due to their high porosity and permeability [3].

Research Methodology

To achieve the set objectives, a combination of two complementary geoelectrical techniques was used. Electrical resistivity tomography is an effective method for identifying lithological changes and for characterizing aquifers in sedimentary basins [9,10].

Electrical Resistance Tomography (ERT)

The Electrical Resistivity Tomography (ERT) method is based on measuring the electrical resistance of subsurface materials by injecting an electric current and measuring the resulting potential [5]. Variations in electrical resistivity are directly related to the lithological composition, porosity, and water content of the sediments [6].

This method consists of injecting electric current into the ground through a system of electrodes and measuring the resulting

voltage, where these methods have their own principles (see Figure.2).

- **Physical Principle:** The electrical resistivity of rocks depends on their clay content, porosity, and degree of water saturation. Clays have low resistivity, while dry gravel has high resistivity.
- **Implementation:** 2D profiles were performed using the ARES II instrument. The Wenner-Schlumberger configuration was chosen due to its good vertical resolution and significant depth of investigation. The spacing between the electrodes was 5 meters, allowing an effective depth of investigation of about 60 meters.
- **Processing:** The data is processed with inversion algorithms to create realistic models of subsurface resistivity distribution.

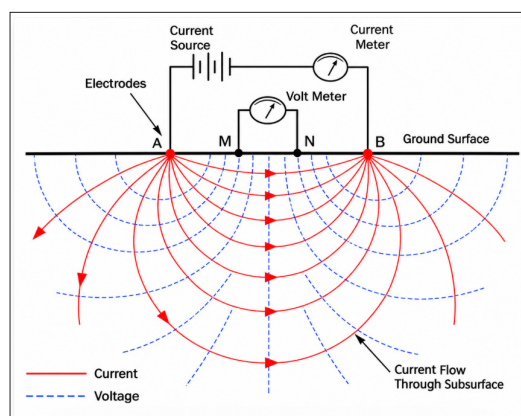


Figure 2: Principles of the ERT method

Data interpretation was performed through numerical inversion methods, which enable the construction of two-dimensional models of subsurface resistivity distribution [7].

Vertical Electrical Survey (VES)

This method is used to obtain in-depth information at a single point, and this method also has its own principles (see Figure 3).

- **Implementation:** 126 measurements were performed at 11 locations using the ARES instrument. The configuration used was Schlumberger, with active electrode spacing up to 160 meters.
- **Interpretation:** The apparent resistivity curves are interpreted to determine the number of layers, their thickness and their true resistivity. This method serves for the quantitative calibration of TRE profiles.

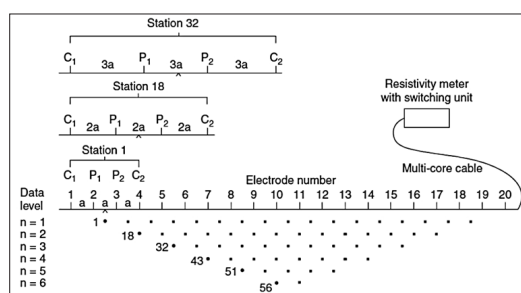


Figure 3: Principles of the VES method

The graphical data (curved line) VES are obtained in the case of the Schlumberger configuration, which is most used, by fitting

the apparent resistivity values ρ_z in relation to the length of the space AB/2. The apparent resistivity for individual separation points is determined using the relation:

$$\rho_z = k * U / I$$

Where:

- I is the circulating current introduced into the ground by electrodes A and B.
- U is the voltage between the measuring electrodes M and N.
- k is the configuration constant according to the relation $k = \rho * AM * AN / MN$

The curves of the vertical electrical graph can be changed by effects that do not correspond to the theoretical assumptions of the method. In our case we can speak of:

- Resistive inhomogeneities in the horizontal direction;

- Resistive anisotropy (is a method of increasing image quality on computer graphics surfaces that are in a tilted state);
- Grounding of electrodes;
- Uneven contact resistance on individual electrodes;
- Non-planar topography;
- Continuous changes in the studied resistance of the environment in the vertical direction.

VES method is used to determine vertical resistivity changes and identify geological layers at depth [11].

Instruments and Software Used

For the security and accuracy of the data, certified devices, ARES and ARES II models, were used, which are distinguished by their high resistance to external electrical noise (see Figure. 4).



Figure 4: ARES Units (Equipment Used)

Results and Discussion

The results of this study are consistent with previous studies showing that the electrical resistivity range between 80 and 200 Ωm corresponds to sandy and gravelly aquifer sediments [1,12]. These results are also consistent with previous studies in hydro geophysics, which show similar resistivity ranges for aquifer sediments in alluvial basins [6,8].

For the needs of the project, the following sub-localities were selected, defined and researched in the Drini i Bardhë river basin: Zaqishtë, Dejnë, Moglicë, Qyshk, Vitomiricë, Kovragë, Çitak, Buçan, Tërstenik, Jelloc and Burojë.

Table 1: Geophysical Survey Data by Locality

No.	Location	Length of Profiles (km)	No. of VES Measurements	Configuration	Max. Depth of Investigation (m)	Dominant Geological Type
1	Zoqishtë	3.2	12	Wenner-Schlum.	60	Alluvial Sediments
2	Dejnë	2.8	10		60	Pro alluvial Cone
3	Moglicë	3.0	11		60	River Terrace
4	Qyshk	4.1	14		60	Fluvial sediments
5	Vitomiricë	3.5	12		60	Alluvial Valley
6	Kovragë	2.9	10		60	Neogene sediments
7	Çitak	3.1	11		60	Tectonic Contact
8	Buçan	4.5	15		60	Deep Basin
9	Tërstenik	3.3	11		60	Erosion Valley
10	Jelloc	3.0	10		60	Flysch Formation
11	Burojë	3.0	10		60	Sandy Sediments
TOTAL	37.49 km	126				

The geophysical survey in the Drin i Bardhë River Basin focused on identifying vertical and horizontal electrical resistivity variations, which reflect the lithological structure and groundwater distribution. The following presents the synthesized data from 11 localities, divided according to dominant hydrogeological characteristics [13-16].

Before discussing the results for each site, it is necessary to establish a correlation between the electrical resistivity values (Ωm) and the geological environment. Unlike dry materials, water-saturated sediments exhibit a decrease in resistivity [14-19].

Table 2: Lithological Classification Based on Electrical Resistivity Values

Values resistance (Ωm)	Lithological interpretation	Hydrogeological situation	Geological material
< 30	Clay / Saturated clay	Impermeable / Restrictive	Valley clay, alluvial mud
30 – 80	Wet sand / Covered gravel	Potential Aquifer	Fluvial sediments, fine sand
80 – 200	Coarse gravel / Coarse sand	Good Aquifer	Pro alluvial cones, river terraces
> 400	Hard rock / Dry sediments	Impervious / Basement	Limestone, Flysch, Granite, Palaeozoic Basement

These areas represent the greatest interest for new drilling. They are characterized by large thicknesses of sediments with medium resistance [20-25].

Since there are 11 locations and due to the large volume of data, we have presented the modelling and maps of only three measurement locations: Buçan, Zaqishtë and Dejne. The measurements at Buçan showed a deep sedimentary structure, typical of closed basins.

ERT Profile Analysis: At depths of 0-15 m, low values (20-40 Ωm) were recorded, indicating the presence of surface clays. The most significant change occurs at depths of 20-60 m, where the resistivity increases to values of 80-150 Ωm , indicating water-saturated sandy layers [26-30].

Interpretation: This structure indicates a semi-closed aquifer, where the clay layer above protects the water from external contamination.

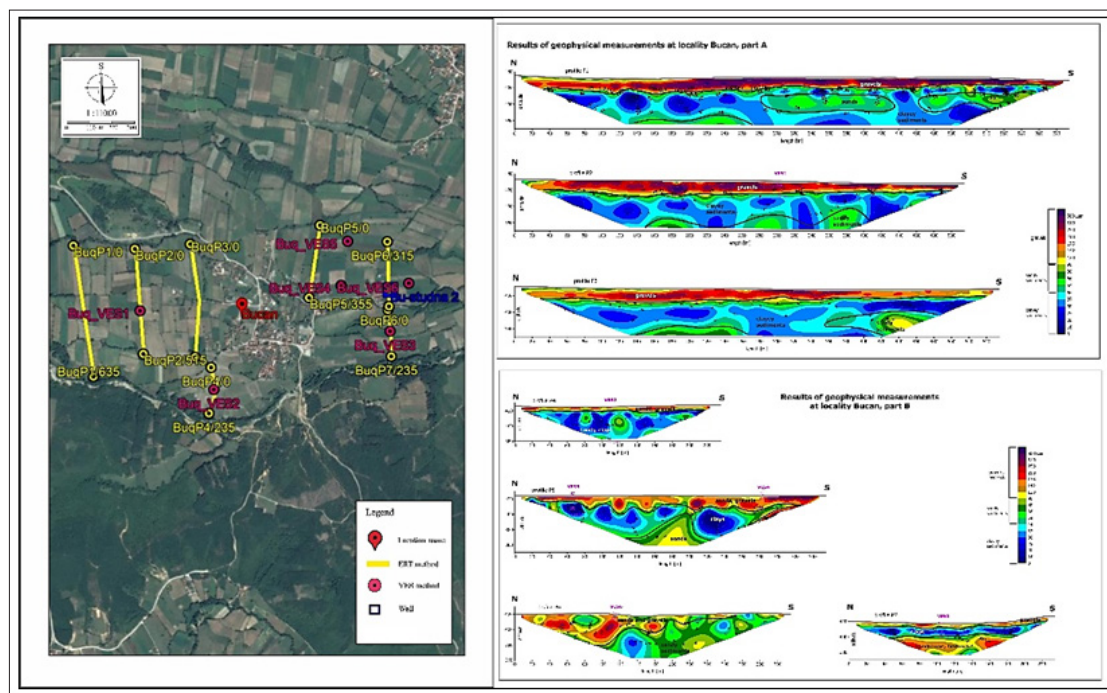


Figure 5: 2D ERT and VES profile at the Buçan location

Figure 5 shows a 2D cross-section with a depth of 0-60m. Blue colour dominates the surface (clay), while green and yellow colours appear at depths >20m, indicating the presence of a sandy aquifer.

Research at the Zaqishtë site presents a classic valley structure. VES analysis: Vertical survey curves show an initial decrease in resistivity (valley clay layer) and a gradual increase at depth, corresponding to the transition from clay to fluvial gravel [31-33].

Aquifer Geometry: The thickness of useful sediments is estimated to be around 25-30 meters.

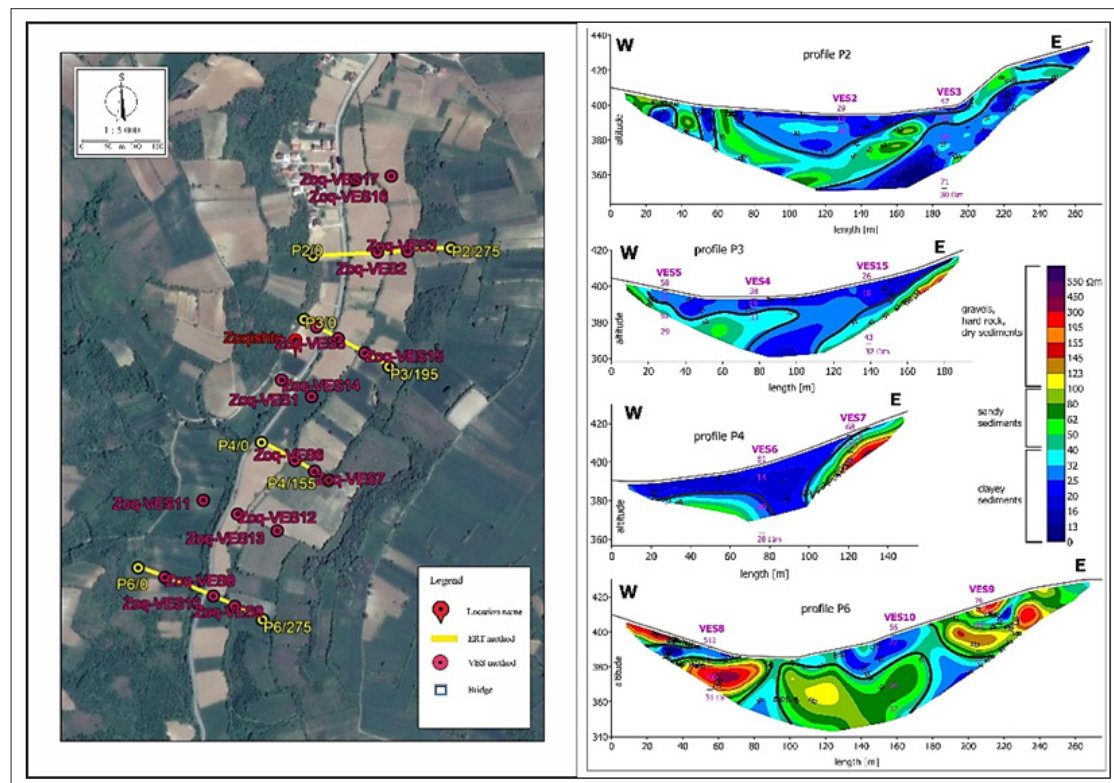


Figure 6: 2D ERT and VES profile at the Zaqishtë location

Logarithmic Pgraph showing the apparent resistivity curve (a) and the length AB/2. The curve shows three layers: Surface Clay, Sand Aquifer, and Basement [34-36].

The localities of Dejnë and Moglicë, these areas are located at the outlet of mountain rivers.

Results: The presence of large blocks of rock (conglomerates) causes high resistivity anomalies (> 300) even at depth. This creates difficulties in distinguishing between dry gravel and solid rock [37].

Discussion: The aquifer here is in the pores between the rocks. Drilling with protective columns is difficult and medium depth (30-40 m) is recommended to capture the water-bearing layer [38-41].

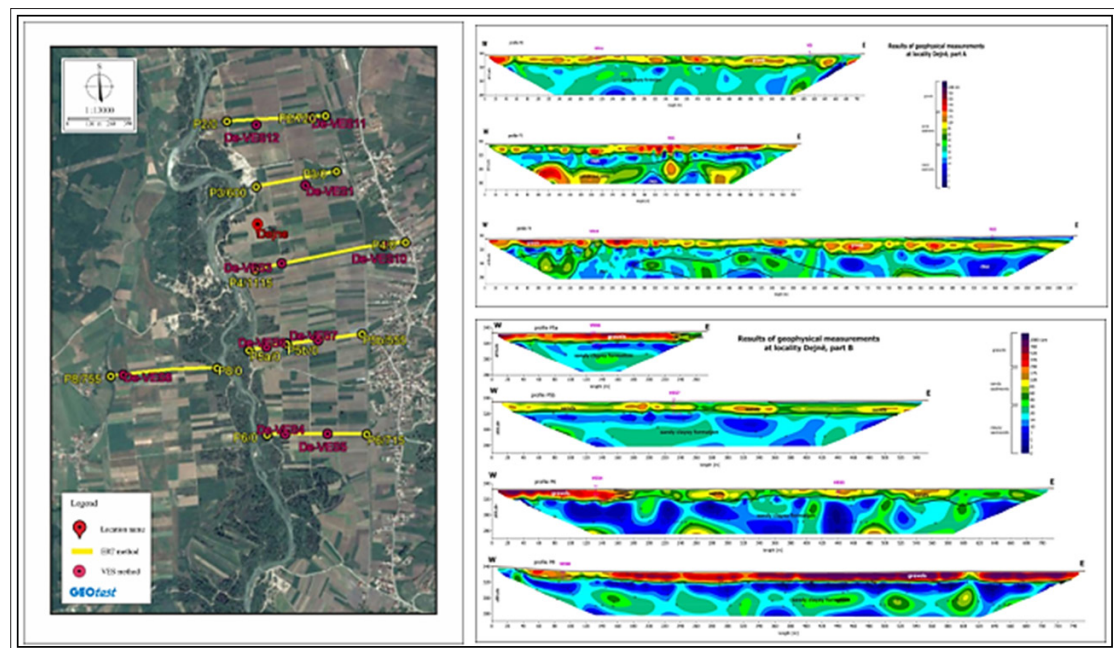


Figure 7: 2D ERT and VES profile at the Denjë locality

A key finding of this study is the importance of using both methods simultaneously. Role of ERT: The ERT method was crucial to see the continuity of the layers. For example, at the Qyshk locality, ERT revealed a "paleo-channel" (ancient, buried river) that could not be identified with isolated VES. If drilling were done 10 meters away from this channel, the well would lack water [42-45].

Role of VES: The VES method was faster and provided quantitative data on absolute depth. It served to calibrate the ERT images. The identification of paleo-channels in some localities is consistent with the findings of other studies showing that buried fluvial structures constitute important groundwater reservoirs [4].

Table 3: Drilling Recommendations from Geophysical Survey Results

Location	Electrical Resistance (Ωm)	Lithological Interpretation	Water Potential	Recommendation (Drilling Depth)
Zoqishtë	30 – 150	Surface: Clay; Depth: Gravel/Sand	High	45 – 50 m
Dejnë	50 – 400	Stone and gravel conglomerates	Middle	30 – 40 m
Moglicë	20 – 120	Clay on wet sandstone	Middle	35 – 45 m
Qyshk	15 – 100	Fine sand and old deposits	High	50 m
Vitomiricë	25 – 80	Clay/Sandstone Alternating (Stratification)	High	55 m
Kovragë	10 – 60	Dominant clay with thin layers of sand	Low	30 m
Çitak	100 – 800	Broken rock (Flysch) with little sediment	Very Low	Not recommended
Buçan	20 – 150	Gray clay, Coarse sand (Confined aquifer)	Very High	60 – 70 m
Tërstenik	40 – 300	Coarse alluvial gravel	Medium - High	35 m
Jelloc	> 1000	Basement rocks (Impervious)	No Potential	0 m (Do not drill)
Burojë	50 – 200	Loose sandstone and conglomerate	High	40 m

Conclusion and Recommendations

The geophysical research carried out in the Drin i Bardhë River Basin constitutes a fundamental contribution to the knowledge of the hydrogeological structures of this region, moving from a superficial perception to an in-depth quantitative model. Through the integrated application of Electrical Resistivity Tomography and Vertical Electrical Sounding, this study has managed to determine clear relationships between the physical parameters of the subsurface and the accumulation of groundwater. The results have demonstrated that the variability of electrical resistivity is a reliable indicator for the distinction of lithology, where areas with values below 30 Ωm have been consistently identified as impermeable clay environments, while the interval between 50-150 Ωm has indicated the presence of water-saturated sandy and gravelly sediments. Accordingly, high resistivity values, above 400 Ωm , have confirmed the presence of bedrock or dry sediments, qualifying these areas as unproductive for drilling.

From a geometric point of view, the study has proven the existence of a considerable thickness of useful sediments in the Buçan and Zaqishtë localities, where the aquifers reach depths of up to 60-70 meters, confirming the presence of paleo-fluvial channels that represent the main water reserves. On the other hand, in areas such as Jelloc and Çitak, the depth of the research has shown that the basement is located close to the surface, significantly limiting the water potential. A crucial finding of this work has been the confirmation that the use of only one-dimensional methods in terrains with high heterogeneity leads to interpretation errors, while the integration of two-dimensional methods was necessary for the detection of lateral and contact structures, offering a much higher scientific reliability for decision-making. It has also been found that the safest water accumulators are located under protective clay layers, while the areas of pro alluvial cones, due to their direct hydraulic connection to the surface, are more sensitive to pollution.

The results of the study show that the integration of ERT and VES methods constitutes an effective approach for the identification and characterization of aquifers in sedimentary basins. Geophysical analysis showed that most aquifers in the Drini i Bardhë basin are located in alluvial and Neogene sediments with a thickness of 15–40 m.

The integration of two-dimensional and one-dimensional methods significantly improves the reliability of hydrogeological interpretation and reduces the risk of unproductive drilling.

Recommendations

Based on the interpretations and discussions developed, a series of technical and management measures are proposed for the responsible authorities. In the first place, the drilling priority should be oriented towards areas with maximum sediment thickness, where the Buçan and Zaqishtë localities emerge as the most favourable options for drilling depths between 45 and 75 meters, guaranteeing a low risk of failure. On the other hand, the Jelloc locality is not recommended for drilling interventions due to the presence of impermeable rock near the surface. For areas with heterogeneous characteristics, such as Dejnë and Moglicë, increased technical care is advised during drilling due to the presence of stone blocks, as well as more limited depths of around 30-40 meters.

To meet the requirements of the Water Framework Directive, it is essential that new monitoring wells are equipped with automated measuring instruments to assess the dynamics of aquifer recharge. Qualitative monitoring is equally important, especially in agricultural areas such as Vitomirica, to prevent the intrusion of nitrates and pesticides. Since geophysical interpretation remains somewhat indirect, it is strongly recommended to compare lithological profiles obtained from future drilling with ERT models, as well as to develop further

studies through isotopic analysis and numerical modelling of water flow.

Finally, to ensure the sustainability of these resources, it is recommended to declare "Water Resources Protected Areas" around localities with high potential, implementing strict control over construction and agricultural activities within safety ranges, thus guaranteeing an integrated and long-term management of groundwater in the White Drini basin.

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