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Groundwater exploration in the Garachay river basin using vertical electrical sounding method

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Since Azerbaijan is located primarily in a semi-arid zone, water shortages have always been a problem. Beginning from the second half of the 20th century, rapid population expansion and economic growth have further increased water demand. The geophysical survey in the Garachay river basin using the Vertical Electrical Sounding aimed to provide high-quality fresh groundwater for the nearby settlements. The geological section was dissected in detail. It consists of 8—10 layers of alternating boulder-pebble rocks with thin clay layers. The geological section of the study area is plicatively differentiated. Each identified aquifer is underlain by an impermeable layer, in which rocks are mostly composed of clay. The thickness of the alluvial deposits changes between 1—12 m and their specific electrical resistivity were determined to be 50—450 Ohm·m. The resulting map shows an increase in the thickness of alluvial deposits from the northwest to the southeast. The main physical parameters, such as natural moisture content, density, the density of rocks under water, and filtration coefficient have also been determined. In the right-bank part of the study area, the sediment filtration coefficient varies between 1—3 m/day, while in the left-bank part, it ranges from 6 to 12 m/day. The constructed 3D models clearly demonstrate how the electrical resistivity of the rocks that make up the geological section decreases from the surface down. This is presumably due to an increase in natural rock moisture with depth or an increase in clay particles content in the deeper layers. All of this suggests that the study area is promising for fresh groundwater exploration.

Key words: electrical prospecting, geophysical research, specific electrical resistance, rock density, natural moisture.

Introduction. The geophysical study area is located in the Gabala district of the Azerbaijan Republic, on the left bank of the Garachay river, which practically dries up during the summer. The floodplain consists of gravel and pebble deposits with clay-sand aggregates and boulder inclusions. The maximum width of the floodplain in the study area is 135 m, and the minimum is 42 m.

It should be noted that geophysical and electrical exploration surveys were conducted for the first time in this area.

Based on the geostructural conditions, the study area belongs to the Greater Caucasus mountain-fold zone hydrogeological region of the pore-fracture water.

This area has a moderately warm climate with dry winters. The average annual air temperature is approximately 12 °C, and the annual precipitation is 550 mm, maximum during the warmer months. Evaporation potential is approximately 860 mm per year. Snowfall is limited to 25 days per year. The prevailing wind directions are northerly and northeasterly, with an average annual wind speed of approximately 1.4 m/s.

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As is well known, water on our planet consists of surface and groundwater, which form an inseparable single shell — the hydrosphere. Water consumption primarily requires freshwater with a soluble salt content of preferably no more than 1 g/l. Earth's reserves are estimated at approximately 35 million cubic kilometers, or more than 4 million cubic meters per person, 70 % of which is in solid form.

Fresh groundwater, which generally has high quality, accounts for approximately 10.5 million km^3, i.e. approximately 1/3 of the total fresh water reserve, but its exploitation is limited by its uneven distribution in the crust.

According to the Food and Agriculture Organization of the United Nations, the total annual water consumption is 4000 km^3. About 70—72 % of all freshwater withdrawals worldwide is used by agriculture. Roughly 12 % is consumed for municipal and about 16—20 % for industrial water supply worldwide. Rivers and lakes provide a major share of this water, though groundwater supplies about 25 % of all irrigation water [Richard, Engin, 2014; AQUASTAT, 2025]. Part of the water is in the lithosphere. Underground water should be considered an independent physical body in a vaporous, solid, and liquid-drop state [Hiscock, Bense, 2014].

By all accounts, water is the most valuable mineral in the world. Today water shortages are a major global problem. According to the United Nations World Water Development Reports, global water demand is projected to increase by 20 to 30 % by 2050 [Richard, Engin, 2014]. Therefore, the efficient use and exploration of fresh groundwater are highly relevant.

Since Azerbaijan is located primarily in a semi-arid zone, water shortages have always been a problem. Beginning from the second half of the 20th century, rapid population expansion and economic growth have further increased water demand. Therefore, hydrogeological and geophysical methods are used to search for underground water sources in various regions of the country. Geophysical exploration in the Garachay river basin is also related to this issue.

The purpose of conducting geophysical survey in the study area using the Vertical Electrical Sounding (VES) was to search for fresh groundwater for the nearby settlements.

The survey had the following objectives:

– detailed dissection of the lithological composition to a depth of 50 m;

– determination of the estimated thickness of the aquifer and alluvial deposits down to the first impermeable layer;

– identification of the probable thickness of the impermeable layer and its distribution across the study area.

To accomplish the objectives, the geophysical electrical survey method (four-electrode AMNB) VES was selected [Telford et al., 1990]. Fieldwork was conducted using ERA-MAX electrical survey equipment operating at alternating current (4.88 Hz).

In terms of seismicity, the degree of seismic intensity in the region is 8 based on the Medvedev-Sponheuer-Karnik scale. The current horizontal crustal movement is approximately 10 mm per year northward, with almost no vertical movement.

The natural radioactivity of rocks is very low, ranging from 6 to 8 μR/hour [Geological …, 2014].

Research methodology. Geophysical surveys were conducted in the floodplain of the Garachay river (a left-bank tributary of the Turyanchay river) along four profiles. The profiles were oriented from northeast to southwest. The coordinates of the VES observation points were determined using the global positioning system GPS. The locations of the profiles and VES points are shown in Fig. 1.

Since the survey studied the crust down to a depth of up to 50 m using the VES method, the distance between the current electrodes AB was 100 m, fulfilling the condition MN<<AB several times — a more frequent measuring setup [Vyzhva et al., 2013].

Earlier experimental surveys [Telford et al., 1990; Vyzhva et al., 2013] used the VES method to obtain a detailed geological section of the area and to determine more accurately the depths of individual lithological varieties. As a result, efficient dimensions

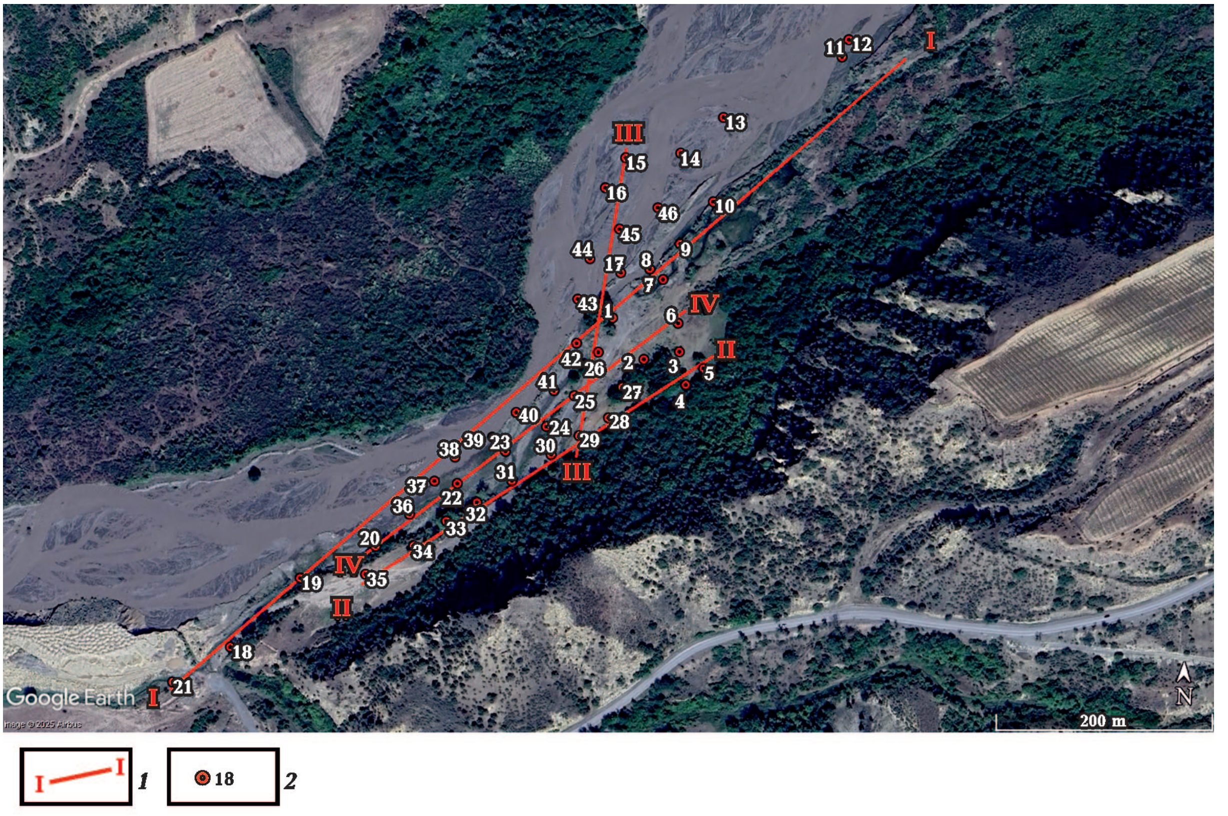

Fig. 1. Satellite image of the study area and the location of geophysical profiles in the floodplain of the Garachay river: *1* — geophysical profile lines, *2* — VES points with their numbers.

of the current line AB and the potential line MN/2 were adopted.

For the purpose of grounding the AB current line, metal electrodes (length 1.0 m, diameter 0.02 m) were used, while brass electrodes were used on the MN potential line. The current electrodes were connected to each other with GCSCPL (G — geophysical, C — cable, SC — steel-copper conductive, P — polyethylene insulation, L — lightweight) wire, and the potential electrodes were connected with GSP-2 (Geophysical Signal and Power Cable with two wires) wire [Salamov et al., 2025].

During field measurements, an alternating current source was used for the AB current line. To obtain high-quality measurements in the current line, an alternating current intensity of 100 mA was achieved, resulting in measured potential values ΔU varying in the range of 0.1 to 1000 mV. The measurements indicated that the quality of the fieldwork complied with the current instructions for the electrical exploration method [Telford et al., 1990; Vyzhva et al., 2013],

$$\rho_{\text{a.e.r}} = K_{\text{VES}} \frac{\Delta U}{I}. \qquad (1)$$

The values of apparent electrical resistance ($\rho_{\text{a.e.r}}$) of rocks comprising the geological section of the study area were calculated using formula (1), where K is the correction factor of the VES survey setup, ΔU (mV) is the measured values of the potential difference, and I (mA) is the intensity of the current density in the current line [Telford et al., 1990].

Overall quality control of fieldwork is achieved through independent control soundings, comprising 5 % of the total number of VESs. The quality of measurements at the i-th spacing of AB/2 is determined by the discrepancy ε (in %) between the primary ρ_{ai} and control $\rho_{\text{a}}^{(\text{c})}$ measurements, where:

$$\varepsilon = \frac{\rho_{\text{ai}} - \left(\rho_{\text{ai}} + \rho_{\text{ai}}^{\text{c}}\right)/2}{\left(\rho_{\text{ai}} + \rho_{\text{ai}}^{\text{c}}\right)/2} 100\% .$$

The uncertainty between the main and control measurements should not exceed 5 %, which is acceptable [Salamov et al., 2025].

Based on the calculated apparent electrical resistivity values of the rocks, ρ_a curves were constructed and interpreted, and the specific electrical resistivity ($\rho_{s.e.r.}$) of the rocks was determined.

Based on the data, the predicted vertical $\rho_{a.e.r}$ sections of rocks were constructed. Geoelectric sections were constructed based on the $\rho_{s.e.r.}$ values, converted into predicted lithological-geophysical sections.

We have conducted similar studies in other regions of the Republic [Salamov et al., 2020, 2023, 2025; Gasimov et al., 2025].

Surfer 15, CorelDRAWX6, and ZOND-2 software packages were used to process the field geophysical data.

Discussion. On the left bank of the Garachay river, gravel and pebble deposits with inclusions of sand and boulders are widespread. The right bank portion of the site is dominated by clay deposits with inclusions of gravel and sand.

Vertical sections of $\rho_{a.e.r}$ and geoelectric sections based on $\rho_{s.e.r}$ were compiled, and the latter were converted into expected lithological-geophysical sections (Fig. 2).

Some expected physical parameters were also determined, and maps of the apparent and specific resistivity, rock density, under-

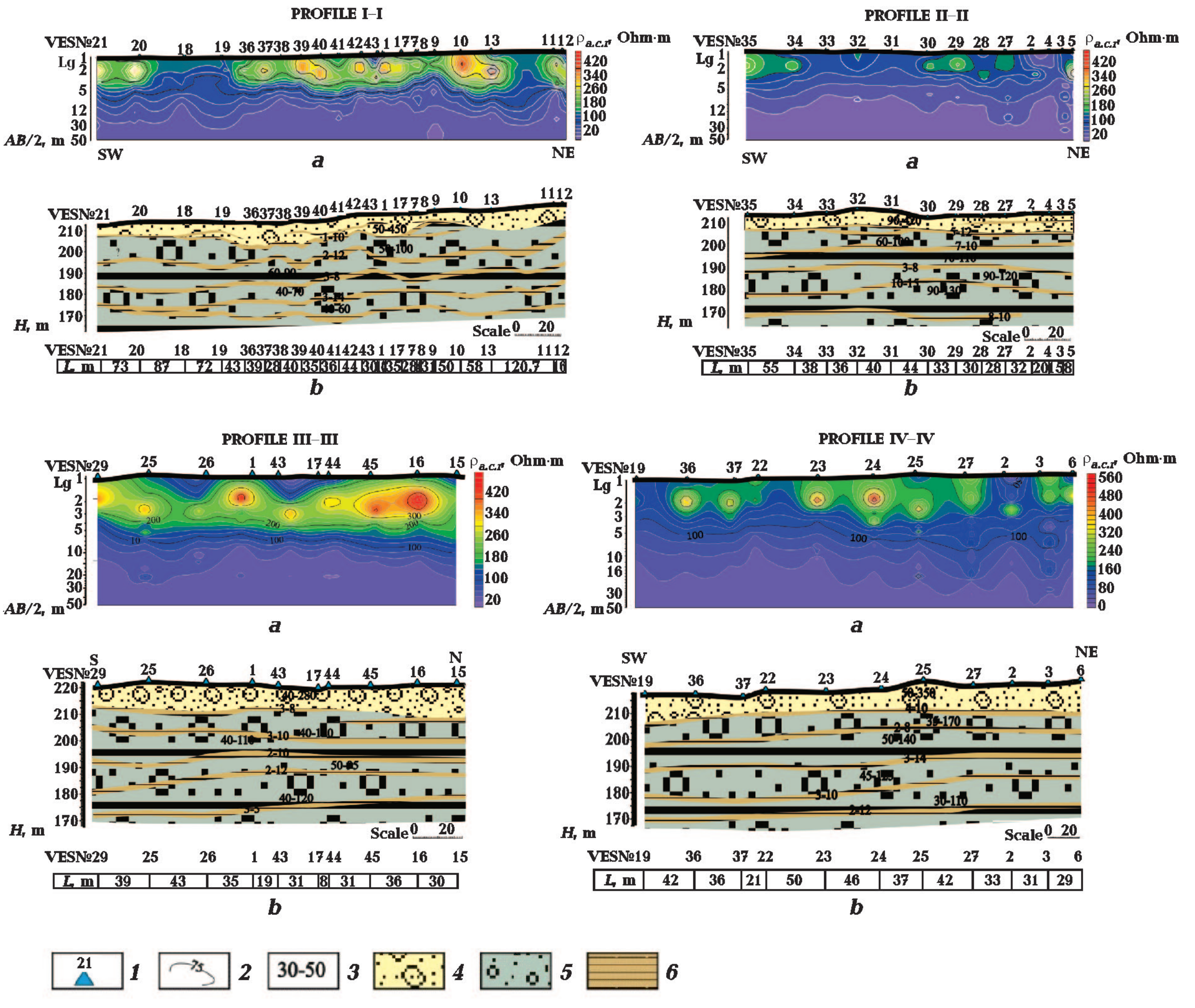

Fig. 2. Sections of the apparent (*a*) and specific (*b*) electrical resistivity of the study area: *1* — VES points and their numbers; *2* — $\rho_{a.e.r.}$ isolines; *3* — $\rho_{s.e.r.}$ values; *4* — alluvial deposits; *5* — rocks with inclusions of boulders and pebbles with sand filler; *6* — clayey interlayers.

water rock density, natural moisture content, and filtration coefficient of rocks of the study area were compiled.

In the compiled probable lithological-geophysical sections, 8 to 10 layers can be traced consisting of clays and boulder-pebble deposits with sand filler, with a specific electrical resistivity of 1—1.5 and 40—180 Ohm·m, respectively.

The proposed lithological-geophysical sections clearly demonstrate the process of sediment accumulation. That is, each boulder-pebble layer alternates with thin clay layers that act as water-resistant barriers — aquicludes. This means the geological section is potentially promising for the exploration of fresh groundwater.

Thus, the geological section has been thoroughly dissected. The identified layers are plicatively dislocated, and no clearly defined faults were detected.

In all lithological-geophysical sections with increasing depth of layers, a decrease of $\rho_{s.e.r.}$ is observed, which is normal.

The compiled map shows an increase in the average value of $\rho_{a.e.r.}$ at the northeastern edge of the survey area.

In some parts of the territory, $\rho_{a.e.r.}$ varies between 60—76 Ohm·m, while in the central and southwestern parts, it ranges from 40 to 60 Ohm·m (Fig. 3, *a*). This is presumably related to the presence of fine-grained rocks in the section and an increase in their natural moisture content.

A map compiled using the average $\rho_{a.e.r.}$ shows a similar situation (Fig. 3, *b*).

As noted above, the compiled maps based on the estimated rock density and the density of rocks under water will most reliably locate fresh groundwater (Fig. 3, *c*, *d*).

The survey area is relatively flat. On the southwestern edge, the absolute elevation ranges from 213 to 215 m, increasing to 223—225 m to the northeast.

One of the objectives of the geophysical survey was to determine the thickness of the

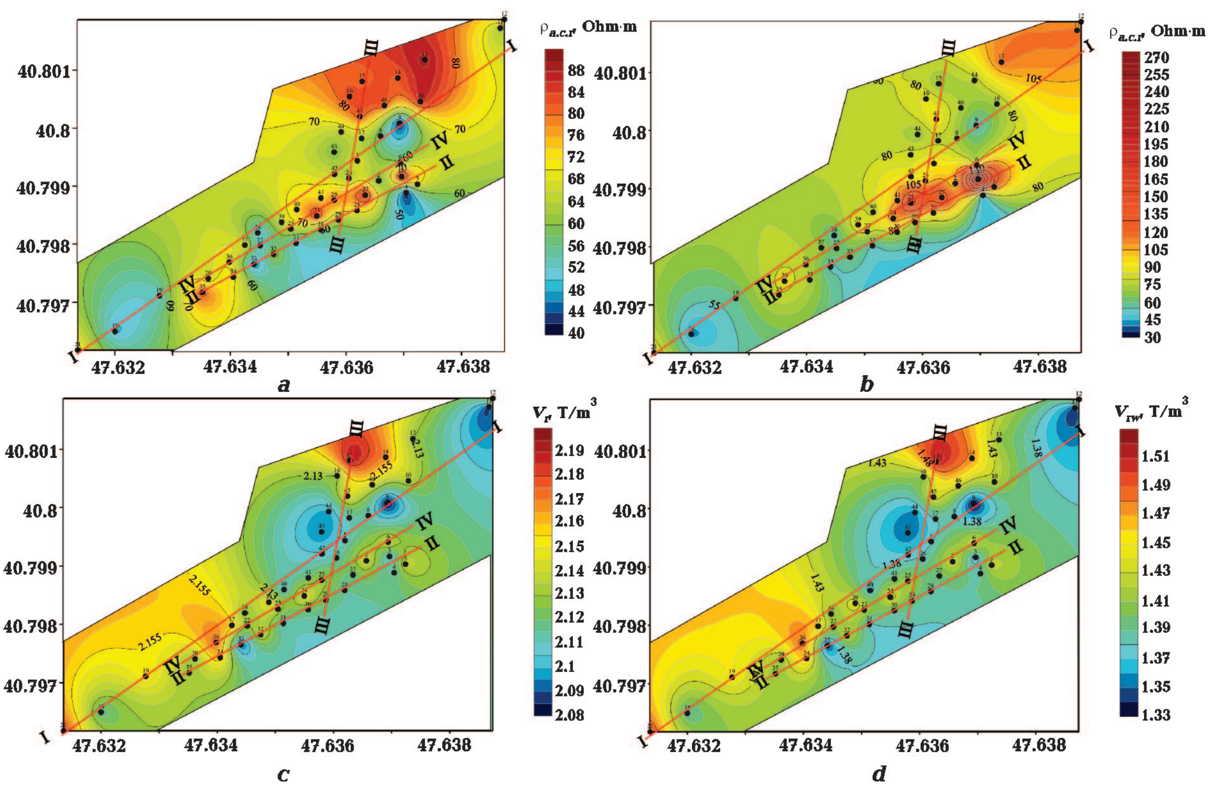

Fig. 3. Maps of the average apparent (*a*) and specific (*b*) rock resistivity, predicted rock density (*c*) and underwater rock density (*d*) of the study area.

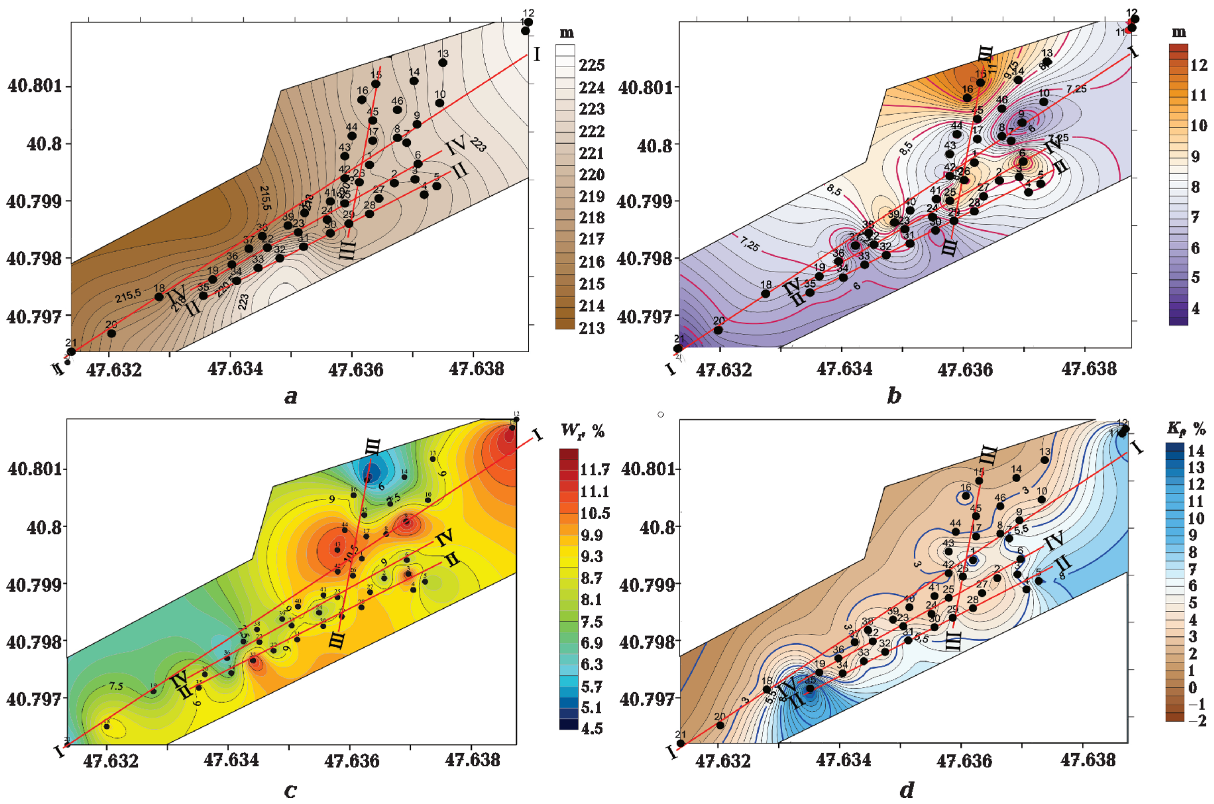

Fig. 4. Maps of relief in meters (*a*), thickness of alluvial deposits in meters (*b*), natural moisture in % (*c*), filtration coefficient (*d*).

alluvial deposits. The resulting map of alluvial deposit thickness across the area shows an increase from the northwest to the southeast.

On the right bank of the Garachay river the thickness of alluvial deposits varies in the range of 1—5 m, and on the left bank of the river, it is 7—12 m, and $\rho_{s.e.r.}$ 50—450 Ohm·m.

To locate fresh groundwater as accurately as possible, a map of the probable natural moisture content (W_r, %) was compiled (Fig. 4, *c*).

In the southwestern part of the study area, the natural moisture content of the sediments varies within the range of 1—6 %, and in the northeastern part, 10—12 %, which is a regularity, since boulder-pebble deposits are widely developed in the left-bank part.

In the right-bank part of the study area, the sediment filtration coefficient (K_f) varies between 1 to 3 m/day, while in the left-bank part, it ranges from 6 to 12 m/day.

This situation is explained by the fact that the floodplain on the left bank is dominated by gravel and pebble deposits with boulders. However, in the right-bank part of the area, clay deposits are predominantly formed with occasional gravel inclusions.

Based on the apparent electrical resistivity values of the rocks in the study area, 3D models were constructed along the *X*, *Y*, and *Z* axes.

The models clearly demonstrate how the electrical resistivity of the rocks that make up the geological section decreases from the surface down. We believe this is primarily due to the lithological composition of the rocks and the underlying waters.

Given the above, it can be assumed that the study area is promising for the search for fresh groundwater.

Conclusion. The main results of the geophysical survey using the VES method are as follows:

– the geological section of the study area was detailed, and six to eight layers of varying thickness and specific electrical resistivity were identified;

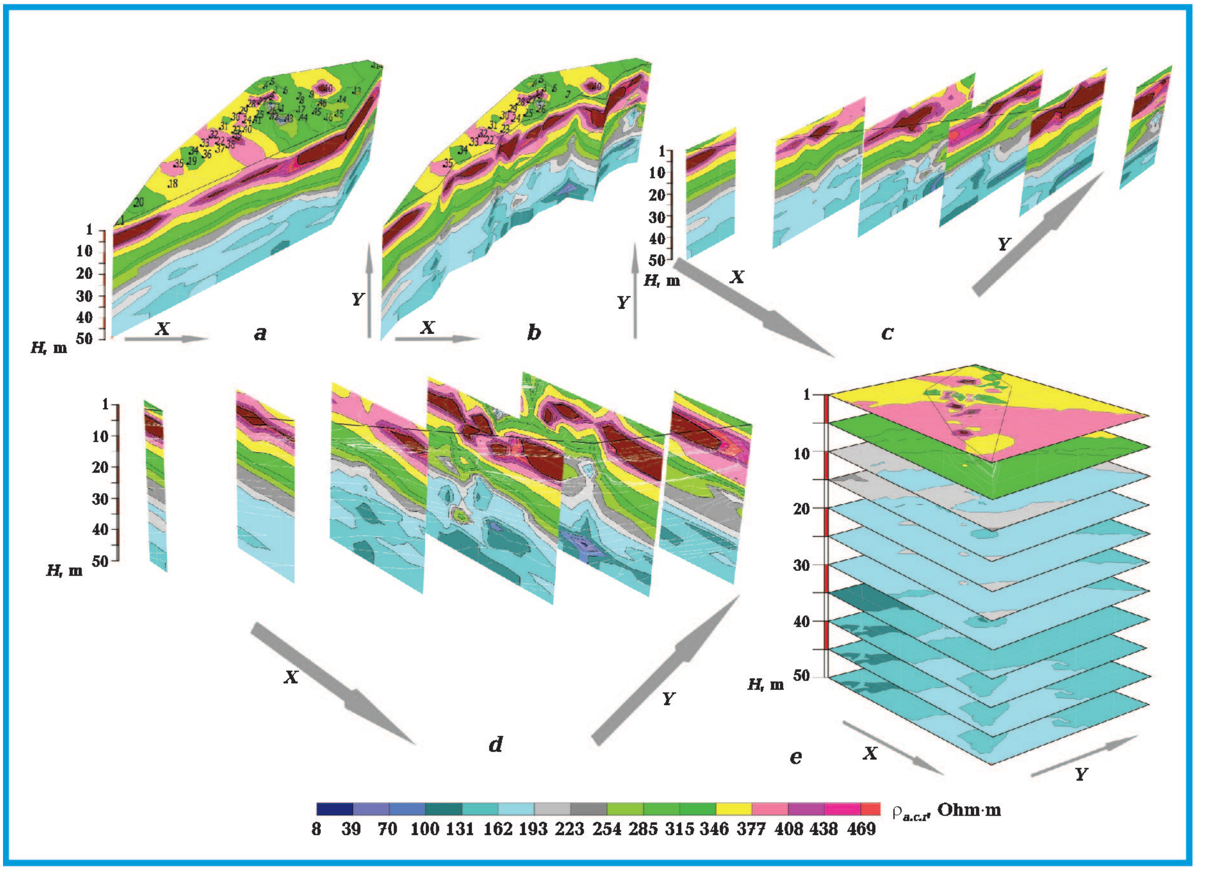

Fig. 5. 3D models of the study area: 3D model (*a*), randomly selected 3D model section (*b*), 3D model along the *Y* axis (*c*), 3D model along the *X* depth axis (*d*), and 3D model along the *Z* axis (*e*).

– the identified layers are plicatively dislocated;

– the identified layers are primarily composed of gravel and pebble deposits, including boulders and sand, alternating with thin clay interlayers;

– on the left-bank part of the river floodplain, the natural moisture content of the geological section increases, while in the right-bank part, it decreases. A similar pattern is observed with the filtration coefficient;

– the thickness of the alluvial deposits in the study area is uneven;

– each aquifer is underlain by an impermeable layer composed of clayey rocks.

From the perspective of freshwater prospecting, the Garachay river floodplain is of particular interest.

It should be noted that prior to the preliminary geophysical surveys, no geological surveys were conducted in the study area. Therefore, the availability of well drilling data, hydrogeological conditions, laboratory analysis, and their comparison with geophysical data would have contributed to obtaining even more reliable results.

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Дослідження підземних вод у басейні річки Гарачай методом вертикального електричного зондування

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Оскільки Азербайджан розташований переважно в напівпосушливій зоні, дефіцит води завжди був проблемою. Починаючи з другої половини XX ст., швидке зростання населення та економіки ще більше збільшило потребу у воді. Метою проведення геофізичних досліджень у басейні річки Гарачай методом вертикального електричного зондування було забезпечення прилеглих населених пунктів високоякісними прісними підземними водами. Геологічний розріз був детально вивчений. Він складається з 8—10 шарів валунно-галькових порід, що чергуються з тонкими глиняними прошарками. Геологічний розріз досліджуваної території плікативно диференційований. Кожен ідентифікований водоносний горизонт підстилається водонепроникним шаром, породи якого переважно складаються з глини. Товщина алювіальних відкладів коливається в межах 1—12 м, а їхній питомий електричний опір — в межах 50—450 Ом·м. Отримана карта товщини алювіальних відкладів по всій території показує збільшення товщини алювіальних відкладів з північного заходу на південний схід. Також були визначені основні фізичні параметри, такі як природна вологість, густина, густина порід під водою та коефіцієнт фільтрації. Слід зазначити, що на правому березі досліджуваної території коефіцієнт фільтрації осаду коливається в межах 1—3 м/день, тоді як на лівобережжі — в межах 6—12 м/день. Побудовані 3D моделі чітко демонструють, як питомий електричний опір порід, що складають геологічний розріз, зменшується від поверхні до глибини. Це, ймовірно, пов'язано зі збільшенням природної вологості порід з глибиною або збільшенням вмісту глинистих частинок у глибших шарах. Все це свідчить про те, що досліджувана територія є перспективною для видобування прісних підземних вод.

Ключові слова: електророзвідка, геофізичні дослідження, питомий електричний опір, щільність гірських порід, природна вологість.