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ИЗУЧЕНИЕ ГИДРОГЕОЛОГИЧЕСКИХ УСЛОВИЙ ГЕГАМСКОГО ХРЕБТА МЕТОДОМ ВЕРТИКАЛЬНОГО ЭЛЕКТРИЧЕСКОГО ЗОНДИРОВАНИЯ

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Аннотация: Территория Гегамского горного хребта характеризуется густыми неровностями гидрографической сети. Более 70% поверхности Гегамского хребта покрыто трещинами андезитового, андезито-базальтового, андезито-дацитового состава. В результате гидрогеологических и геофизических исследований выявлено несоответствие между данными водного баланса на территории Гегамского хребта и новыми, и старыми (погребенными) водоразделами. В результате геофизических и гидрогеологических исследований водных ресурсов в водосборном бассейне озера Севан выявлена и уточнена взаимосвязь между новейшим и старым водоразделами горного хребта, оценено наличие отклонений между старым и новым водоразделами. При проведении геофизических исследований на территории Гегамского хребта была применена четырехэлектродно-симметричная модификация метода вертикального электрического зондирования (ВЭЗ). В результате проведенных исследований была составлена карта палеорельефного слоя всей территории Гегамского хребта. В соответствии с составленной картой выделены отклонения регионального водного слоя от водораздела к озеру Севан, к западу и юго-западу. В северной части высокогорья происходит смещение современных и погребенных водоразделов. В результате комплексных исследований были определены (в некоторых случаях оценены) значения подземного (глубинного) стока речных бассейнов рек Веди и Азат. Выделены основные направления движения подземных водотоков, а также распределение новейших и старых (погребенных) водоразделов по отношению друг к другу. Исходя из закономерности формирования подземного потока, необходимости локализации и поиска дополнительных источников водоснабжения, актуально уточнение границ заглубленных водоразделов, требующих дополнительных исследований.

Ключевые слова: горный хребет, подземный водоток, подземный бассейн, водораздел, геоэлектрический разрез, палеорельеф, скважина, измерительные пункты электроразведки.

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Study of hydrogeological conditions of the Geghama range by the method of vertical electric sounding

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Abstract: The territory of the Geghama mountain range is characterized by dense irregularities of the hydrographic network. More than 70% of the surface of the Geghama ridge is covered with cracks of andesite, andesite-basalt, andesite-dacite composition. As a result of hydrogeological and geophysical studies, a discrepancy was revealed between the data of the water balance on the territory of the Geghama Ridge and the new and old (buried) watersheds. As a result of geophysical and hydrogeological studies of water resources in the drainage basin of Lake Sevan, the relationship between the newest and old watersheds of the mountain range was identified and clarified, the presence of deviations between the old and new watersheds was estimated. A four-electrode symmetric modification of the vertical electric sounding (VES) method was applied during geophysical studies on the territory of the Geghama Ridge. As a result of the conducted research, a map of the paleo relief layer of the entire territory of the Geghama ridge was compiled. In accordance with the compiled map, deviations of the regional water layer from the watershed to Lake Sevan, to the west and southwest are highlighted. In the northern part of the highlands, there is a mixture of modern and buried watersheds. As a result of complex studies, the values of the underground (deep) flow of the river basins of the Vedi and Azat rivers were determined (in some cases estimated). The main directions of movement of underground watercourses are highlighted, as well as the distribution of the newest and old (buried) watersheds in relation to each other. Based on the regularity of the formation of an underground stream, the need to localize and search for additional sources of water supply, it is important to clarify the boundaries of buried watersheds that require additional research.

Key words: mountain range, underground watercourse, underground basin, watershed, geoelectric section, paleorelief, borehole, measuring points of electro-sounding.

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Introduction

Groundwater is the best alternative water resources to supply the water needed for agriculture, industrial and domestic purpose [1]. Though surface water is claimed to be the principal supply of freshwater, groundwater is relied upon globally to meet human needs and agricultural purposes [2]. Geophysics survey especially geo-electrical survey is widely used in order to locate the groundwater resources [3—7]. Strong correlation between estimated and pumped aquifer parameters suggest that, in case of sparse well data, geophysical technique is useful to estimate the hydraulic potential of the aquifer with varying lithology [8]. As an alternative, geoelectric measurements from the soil surface by DC (direct current) electric geophysical method, applied especially through the vertical electrical sounding (VES) technique, enable a non-invasive and relatively inexpensive hydrogeological characterization [9—11].

The article presents the results of hydrogeological and geophysical studies along the western slope of the drainage basin of Lake Sevan and the Geghama mountain range. The purpose of the research was to identify the discrepancy between the water balance data on the territory of the Geghama range and new and old (buried) watersheds. In the course of the research, about 1100 field curves were measured and processed by the method of VES produced earlier, as a result of which a map of the generalized paleorelief layer of the regional mountain range was compiled, underground watercourses and buried (old) regional watersheds were identified. The power of the watersheds of the mountain range has also been studied, and the central watercourses have been identified.

Geological characteristics of the region

Sevan basin, which is located between the Lesser Caucasus and the Armenian volcanic highlands, has a complex geological structure, different relief forms with variegated reworked forms. By features geological structure, the lake basin is divided into two parts: the northern and eastern (which belong to the folded-clumpy regions of Armenia) and southern and western (which form part of the Armenian volcanic highlands). In the southwestern part, they are widespread strongly porous and permeable rocks with cracks, and in high mountain areas — chingils, which act as a regulator to feed rivers. Unlike from the southwestern part, the northeastern part of the basin stands out the absence of more or less large sources, the presence of many small tributaries, mudflows are characteristic. Almost all dropped here precipitation flows down the slope into streams or directly into the lake. Many of the rivers in the period of low water does not reach the lake. Basin rivers Lake Sevan are mainly fed with mixed water: melt water, rainfall and underground. The feeding of the rivers originating from the Geghama and Vardenis mountains, which are of volcanic origin, predominantly underground (60—80%). Mainly underground power have the rivers Gavaraget, exclusively underground — Lichk [12—13]. At work [14] discussed some issues of regulation and management of river runoff associated with the feature of the geological and hydrogeological structure of the river basin and the composition of soil.

The geological structure of the Geghamarange mainly involves Miocene volcanic formations, as well as Pliocene-Fourth lavas, and in the gorges, there are exits from Eocene tuffs and andesite-basalt lavas. Clay deposits are located in the center, and their carbonate composition is higher along the length of the eastern coast, where there are microliths of the late Senon and Paleogene and organogenic-detritus limestone.

From a tectonic point of view, the Sevanhorstantiklinal of Cretaceous-Paleozene growth, which is part of the Ophiolithic zone of Sevan-Amasia, is considered the oldest in the studied territory of the Geghama mountain range. Wells were dug in the foothills of the Geghama mountain range, where the remains of Santon were found.

This mass is disturbed by a displacement of 150 m, observed when placing impression horizons of slag tuffs. Eocene and Late Cretaceous sediments extend beneath Neogene sediments.

Larger than the southeastern corrugated structures of the Gegham Ridge is the syncline of the enamel stone, consisting of Neogene (Sarmatian) deposits. The next asymmetric Horst-anticline rise extends between the valley of the Gegharkunik River and the Western shore of Lake Sevan, known as the Dashkend rise [15].

The Geghama Mountain Range is a huge thyroid ridge with an area of 2800 km^2. The watershed part is located at an altitude of about 2800—3600 m and is a plateau with a separate cover and lava flows, on which separate volcanic peaks and extrusion domes rise.

The territory of the Geghama mountain range is characterized by dense irregularities in the hydrographic network. If the northern part of the mountain range is devoid of surface flow and from a hydrographic point of view is a deserted territory, then the southern part is separated by numerous river valleys — Azat, Vedi, Gavar, etc.

A large role in the formation and distribution of groundwater belongs to the lithological composition of water-saving and water-repellent layers. More than 70% of the surface of the Geghamarange is covered with cracks of andesite, andesite-basalt, andesite-dacite composition. Here, in the lava section, there is a change of several floods, which are divided into removed residual species or mixtures of slag and slag. These mixtures act in the form of waterproof. All lava on the ridge is characterized by high water permeability and water catchment. Lava formations of high power (according to geophysical data more than 700—800 m) are distributed among volcanic, metaform and intrusive types of decomposed surfaces. Under the buried lava, the old relief is almost everywhere widespread and is a regional waterproofing layer.

Hydrogeological and geophysical research of the region. Within the Lake Sevan basin, large-scale water, geophysical, and exploration works were carried out at the Scientific Research Institute of Water Problems and Hydraulic Engineering of Armenia and by the Armenian Studies Department.

V.K. Davydov first studied the medium-long-term water balance of the lake in natural conditions in 1927—1934. The results of the study were used in the development of a preliminary scheme for the use of lake water resources. Then B.D. Zaikov (1925—1945) and the Academy of Sciences of the Republic of Armenia (1947) as a result of their research in 1961—1962, a three-volume work entitled "Results of complex studies of the Sevan problem" was published.

Table 1 below shows a comparative table of the values of the components of the lake's water balance.

Gavaraget river starts from the southern slopes of the Geghama mountain shield at an altitude of 3130 m (it is the source of the Gegharkunik tributary). Gavaraget flows into Lake Sevan at the border between Small and Big Sevan at an altitude of 1900.6 m, the average slope is 24.6 ‰. Several tributaries, many of which have a temporary flow, flow into Gavaraget, originating from the top zone of the Geghama mountain range. The length of Gavaraget along with the Gegharkunik tributary is about 50 km, the catchment area is 480 km^2 (that is, the second in the Sevan Lake basin) [16].

The table shows that the values of the components of the lake's water balance (according to different authors) differ little from each other and do not exceed 5%, so we can admit that the water balance of

Table 1

Average long-term water balance of Lake Sevan in natural conditions
Средний многолетний водный баланс озера Севан в естественных условиях

Authors	Unit of measurement	Inflow						
		tributary	precipitation	all	evaporation	the flow of the Hrazdan river	underground stream	all
V.K. Davidov	mln m^3 mm	770 540	550 388	1933	1210 855	50 35	60 42	1320 932
B.D. Zaikov	mln m^3 mm	765 540	552 390	1317 930	1203 850	43 30	71 50	1317 930
A.M. Mkhitaryan and others	mln m^3 mm	730 516	524 370	1254 886	1117 790	52 36	85 60	1254 886

Table 2

Average monthly values of atmospheric precipitation (mm) and water flow m^3/s
Среднемесячные значения атмосферных осадков (мм) и расхода воды, $м^3/с$

Atmospheric precipitations, mm													
Meteorological stations	**Observation period**	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**	**X**	**XI**	**XII**
Gavar	1891–1915, 1923–2021	17.4	19.4	32.7	44.3	67.0	70.3	59.4	43.1	36.1	37.0	26.9	17.1
Urtsadzor	1949–2021	27.0	29.5	41.9	52.1	53.6	29.7	16.3	10.7	12.7	30.1	31.6	24.2
The flow of water, m^3/s													
River – observation point	**Observation period**	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**	**X**	**XI**	**XII**
Gavaraget – Noratus	1926–1945, 1946, 1948–1950, 1952–1992, 1997–2021	2.97	2.95	3.31	5.01	6.55	4.42	2.91	2.39	2.68	2.93	3.00	2.97
Azat – Garni	1936–1994, 2000–2021	3.01	3.07	3.51	7.67	12.3	8.96	3.17	2.55	2.61	2.91	3.04	3.01
Vedi – Urtsadzor	2001–2021	0.83	0.94	1.49	4.11	5.65	1.19	0.41	0.29	0.28	0.45	0.61	0.75

Lake Sevan is given with great accuracy. Table 2 presents the average monthly values of atmospheric precipitation (mm) and water flow.

The relationship between the newest and old watersheds of the mountain range was identified and clarified as a result of geophysical and hydrogeological studies of water resources in the catchment basin of Lake Sevan. The presence of deviations between the old and new watersheds was assessed, which has a certain impact on the catchment balance of the catchment basin, to the detriment of Lake Sevan [17].

Methodology

VES method is one of many methods in geophysics [18]. Electrical resistivity method and RS & GIS techniques are very much useful in identification of potential aquifer zones for exploitation, management and recharge of groundwater [19]. VES as a geoelectrical method has proven its effectiveness throughout the history of groundwater geophysical investigation [20]. In study, the results showed that geo-electrical resistivity was proven as a successful method as it is widely applied in finding the potential groundwater zone [21], besides the rapid sampling and low cost of performing vertical electrical sounding (VES), may justify the use of this geophysical technique for preliminary porous aquifer characterization, especially in regions absent of or with insufficient monitoring wells [22]. Discovering of groundwater aquifer, adds to determine the main lithology, shaly sandstone, sandstone and sandstone to limestone, of the aquifer and the complicated structural setting at form of inferred faults by using VESs [23].

From the various kinds geophysical studies of conducted on the territory of the Geghama ridge, the article presents the method of VES. A four-electrode-symmetric modification of the VES method was applied, and the largest hole size of the electrodes feedin. A and B was chosen

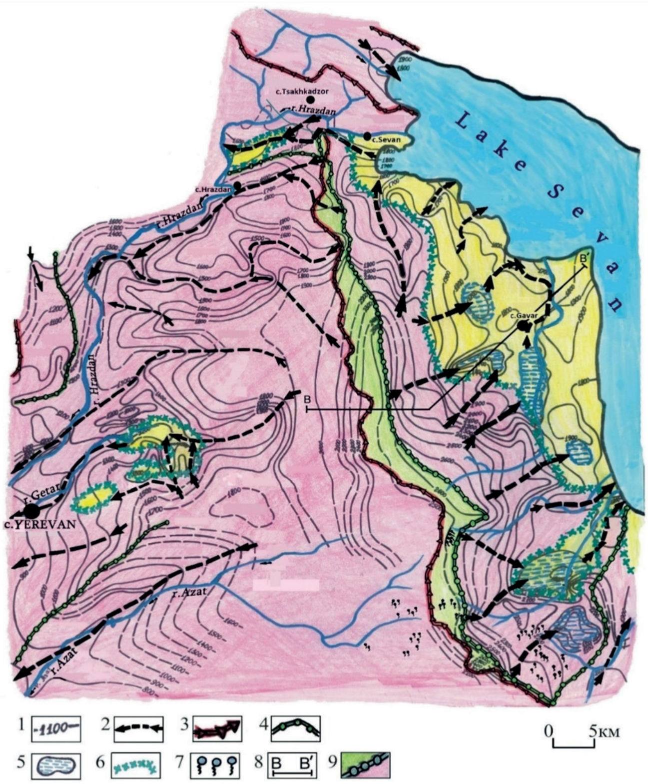
1500 m, based on the depth of the study (up to 500 m). Measurements were carried out at wells dug mainly or at previously measured VES points.

The application of VES in prospecting for groundwater within the fractured terrain is relatively inefficient. Therefore, at work [6] this research aimed at using integrated resistivity methods (azimuthal resistivity survey (ARS) and VES) to defined the structures and porosity parameters in the area to overcome the lapses experienced in applying VES method alone. Integrated geoelectrical and hydrochemical surveys were used to investigate and delineate different types of groundwater in the Kuala Selangor alluvial aquifer [24].

VES is a method to generate one dimensional of resistivity distribution in vertical section. The vertical electrical sounding (VES) method was employed to study and map the subsurface variation of resistivity in the numerous area [25 – 27]. The MRS together with VES has been shown to be a useful and important tool for identifying and distinguishing freshwater from possible salt-affected water [28].

Research results

New measurements were made to determine the spatial position of the watershed buried in the mountain range and the absolute elevation of the relief of the regional watershed. More than 1100 new and previously constructed electrical-sounding graphs were developed and interpreted, and sections of about 30 wells were studied. Because of the research, a map of the paleorelief layer of the entire territory of the Geghama Ridge was compiled (Figure 1).



1 – regional waterproof relief curves with absolute figures, meters
2 – main ways of development of central watercourses (paleohivites)
3 – newest surface watershed
4 – regional buried watershed
5 – the drainage basin is buried
6 – extended contact of submerged water
7 – outlets from natural sources
8 – direction of the geophysical and hydrogeological section
9 – inversion zone of the newest and buried reliefs

Fig. 1. Map of the regional waterproof relief of the Geghama mountain range
Рис. 1. Карта регионального водонепроницаемого рельефа Гегамского горного хребта

The deviation of the general watershed from the watershed to Lake Sevan is highlighted on the compiled map. In our opinion, as a result, the northern water flows are directed towards the Hrazdan River basin, and the central and southern water flows of the eastern slopes of the mountain range are unloaded in underground reservoirs on the territory of Sarukhan-Gavar.

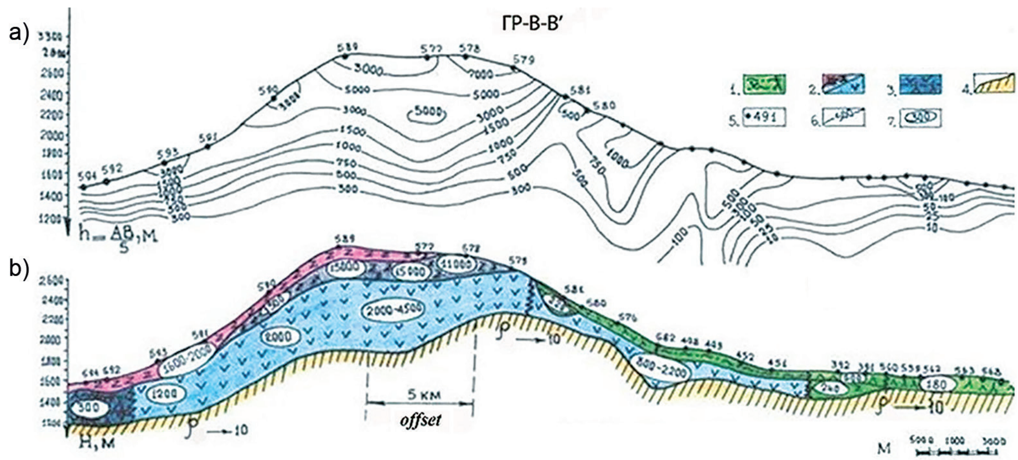
Studying the map of the presented paleorelief shows that there is a deviation from the newest and buried watersheds along the entire perimeter of the mountain range, because of which part of the groundwater formed on the deflected southern slopes of the intake reliefs participates in the formation of groundwater on the western slopes.

This is seen in the geological and geophysical section in Figure 2. This explains the cost of a relatively high module of underground sources of the western slopes. According to the project presented by us, the widest part of the deviation of the newest and old watersheds reaches up to 5 km, and the area of the entire rejected watershed is 150 km^2.

According to the data of vertical electric sounding curves, within the depression under high-resistance lavas with ρ = = 500 — 2000 ohms m, their relatively low-resistance aquifers with ρ = 250 — 450 ohms m lie everywhere. Of particular interest is the geoelectric contact established here under the lava rocks. The contact in question plays a controlling role in the distribution of the underground runoff of the area. Analysis of the paleorelief map shows that in the northern part of the highlands, there is a displacement of modern and buried watersheds, as a result of which part of the surface waters of the eastern slopes takes part in the formation of groundwater of the western slopes of the highlands (basins of the Hrazdan, Azat, Vedi rivers).

Taking into account the results of complex studies, the values of the underground (deep) runoff of the river basins of the Vedi and Azat rivers were determined (in some cases estimated).

The amount of underground runoff formed within the modern basin of the Azat River increases due to underground runoff coming from the western slopes of the Gegham Highlands. The mixing of modern and underground watersheds has been



1 – volcanic formations; 2 – Pliocene-Quaternary lavas; 3 – andesite basalts; 4 – cover;
5 – VES points; 6 – iso-ohmer lines; 7 – values of the electrical resistivity of rocks

Fig. 2. An example of the deviation of the newest and buried watersheds of the Geghama mountain range
Рис. 2. Образец отклонения новейших и погребенных водоразделов Гегамского горного хребта

established. This area is about 50 km^2. With an underground flow modulus of 8 l/s·km^2, a flow of 0.4 m^3/s (0.013 million m^3/year) is formed here. Taking into account this additional flow coming from the Geghama Highlands, the total underground flow within the catchment basin of the Azat River is about 1 m^3/s.

To the west of the modern bed of the Vedi River, its ancient bed has been determined. Here, according to hydrodynamic calculations (according to the Darcy formula using the results of geophysical studies), the underground flow in the paleorusl of R. The lead is estimated at ~1 m^3/s. According to water balance calculations, an underground runoff of about 1.9 m^3/s is formed within the catchment basin of the Vedi River [29].

On the map of the regional waterproof relief presented by us, one of the main streams located on the eastern slopes of the Geghama mountain range is the Central Water Stream. It is formed at 2500—2300 m and has a direction from south to North, which flows into Lake Sevan near the village of Chkalovka. In the West, it is bounded by the main watershed of the mountain range, and in the east by a local watershed with a south-west-northeast orientation. Both deeply penetrating atmospheric media and infiltration waters participate in the formation of central water flows. To estimate the flow rate of water flows, we used the hydrodynamic method, using the Darcy formula. For the paleo hot of the Central Watercourse, according to our data, the following picture was obtained: the width of the antiquity of the water flow is over 750 m, at the bottom is 250 m, the thickness of the water horizon is 100 m, the filtration coefficient is KF = 25 m/day, the hydraulic slope-according to the paleorelief — 0.080. The flow rate of water flows is expected to be 1.15 m^3/s [30].

Conclusion

In the western part of the drainage basin of Lake Sevan, throughout the Gegham ridge, taking into account the pace and volume of population growth and further development of the national economy, a significant water shortage is expected. There is a great need for drinking and irrigation water, especially in settlements located at higher elevations. Based on the regularity of the formation of an underground stream, and the need to locate and search for additional sources of water supply, it became urgent to clarify the boundaries of buried watersheds that require additional research. Because of the research, we came to the following conclusions:

- To identify local and regional watersheds of the distribution of underground flows, in volcanic structures, the method of VES is effectively used.
- The dispersion of the newest and old (buried) watersheds in relation to each other was highlighted on the presented map.
- The main directions of movement of underground watercourses are highlighted.
- To obtain new water intakes based on the research data, a drilling site of water wells will be proposed.
- It was necessary to build a final relief map of the regional waterproofing of the studied area on a scale of 1:100,000, where the distribution of the underground flow for the eastern and western slopes of the Geghama Range will be allocated.

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