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Study of the Anthropogenic Impact on the Change of Geoecological Conditions of the Khojahasan Lake, Azerbaijan

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The paper considers the results of geoecological and geophysical studies conducted in the Khojahasan Lake basin in the Western part of Baku. The main purpose of the work was to study the anthropogenic impact on geoecological conditions of the lake. To assess the development of exogenous geological processes in the coastal zone of the lake and their impact on the environment, geophysical studies were carried out by the vertical electric sounding (VES). From 1990 to 2014, the physical and chemical characteristics of water and sediments were studied in a representative section of the lake. Metal concentrations, including such toxic elements as Cu, Zn, Cd, Sr, Ba, Pb, Cr, and Ni, were determined in the trace element composition of bottom sediments. It was revealed that since the mid-XIX century and especially since the second half of the XX century the high rate of population growth and urbanization in the territory of the Absheron Peninsula (in the Republic of Azerbaijan the name Apsheron was changed to Absheron) led to intensive use of natural resources and increased anthropogenic load on the environment. Technogenesis actively violates the natural cycle of matter and energy in lakes (limnogenesis), along with other natural media, as lake basins are located in lowlands and often accumulate industrial, municipal, agricultural, and other discharges. Pollutants accumulated in the lake basin affect hydrobiochemical conditions, transform quantitative and qualitative indicators of the aquatic environment and bottom sediments. Factors affecting the lake landscape are genetically different, unequal in the degree and nature of the impact, as well as in duration.

Key words: anthropogenic factors; the Khojahasan Lake; geoecology; wastewater; sediments; vertical electrical sounding (VES)

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Introduction. Intensive development of industrial enterprises and transport infrastructure has caused severe environmental problems. Large amounts of emissions into the environment have caused global problems such as climate change, the greenhouse effect, acid rain and the formation of ozone holes, the solution of which has become the main task of the world community. Over the past decades, much scientific research has focused on the impact of anthropogenic factors on the natural environment [6, 9, 11, 12, 15, 17, 19]. It is known that the emission of hydrocarbon, heavy metals, radioisotopes and other toxic substances into the environment leads to their accumulation in soils, reservoirs and other components of the ecosystem, therefore, the protection and restoration of natural resources is the main goal of researches all over the world [13, 14, 22].

Urban areas within industrial regions are experiencing the greatest load. Along with other industrial countries, anthropogenic load on the environment as a whole, including lakes, is increasing in Azerbaijan [3, 8]. Lake systems are fundamentally important for the environment, biosphere and population. They are more vulnerable to the anthropogenic impact [10, 20, 21].

One of these lakes in Azerbaijan is Khojahasan. The lake is located in the northern part of the Yasamal valley at an altitude of about 14 m (Fig. 1). The lake is elongated in the meridional direction. Since the Yasamal valley in the Khvalyn and Khazar periods was the bay of the Caspian Sea, marine sediments predominate in the structure of the lake basin. The hills near the western shores are composed of clay-slate of the Akchagyl period, and the northwestern shores consist of sandy clay layers of the productive stratum [7].

The area of the Khojahasan Lake is more than 1 km^2, the length is about 3 km, the greatest width is 0.6 km, and the maximum depth is about 5 m [18] The catchment basin of the lake is about

Fig.1. View of the Khojahasan Lake from the West Bank

20 km^2 and partially covers Shabandag and Zigilpirinsky uplifts, as well as the Balajar plateau. With the building development in this territory, the surface runoff to the lake is insignificant.

The area surrounding the lake is arid, with a dominant climate of moderately warm semi-deserts and dry steppes with dry summers. The annual amount of total solar radiation is about 132 kcal/cm^2, the average annual air temperature is 14.5 °C, the average temperature in January is about 3.5 °C, in summer on some days air temperature rises up to 41 °C. The average frost-free season lasts for 295-300 days. The average annual soil surface temperature is 17 °C. Annually there are about 250 mm of rainfalls in the lake area; the maximum falls on the cold half-year period. Annual rainfall trend shows two maximums: in autumn (November) and spring (April). Of the total annual rainfall, 6 % are solid, 86 % are liquid and 86 % are mixed precipitations. There are 7-10 days with snow cover per season on average. In some severe winters, occurring due to significant surge of cold air masses, snow can fall and remain for a longer time, in warm winters there is no snow at all. An insignificant amount of solid precipitations determines a low snow cover depth, most often reaching 1-5 cm. Possible evaporation is more than 3 times higher than the annual amount of precipitation.

The prevailing wind directions are northern (38 %) and southern (19 %), with an average annual wind speed of 6.0 m/s. Winds of the northern direction (the local name is «Khazri») with a speed of 20-25 m/s are observed quite often. In cold weather, Khazri leads to a sharp decrease in air temperature, and in summer it reduces the heat [2].

Exogenous geological processes (EGP) on the territory of settlements and near the lake shores cause enormous damage to the state of the earth's crust, economy, and also creates multifactorial environmental problems for the region. Assessment and prediction of the EGP hazard, based on the geological and lithological structure, as well as the physical characteristics of soils in the selected area, allow us to conduct geophysical studies performed by the method of vertical electric sounding (VES) [5].

The aim of this work is to assess the current geoecological state of the Khojahasan Lake and the development of exogenous geological processes in the coastal zone through geophysical studies.

Materials and methods. Water and bottom sediment samples from the Khojahasan Lake served as research materials. In order to assess the environmental impact of the lake, the following tasks were solved using the VES method:

1) a detailed layering of the geological section to a 40 m depth;

2) determination of some expected physical parameters of the geological environment and the thickness of individual layers;

3) the identification and tracking of inferred faults in the study area.

Geophysical study was carried out by a symmetrical array AMNB, spacing with AB/2 = 1; 2; 3; 4; 5; 6; 7; 8; 9; 10; 10; 12; 12; 14; 16; 18; 20; 22; 24; 24; 26; 26; 28; 30; 32; 34; 36; 36; 38; 38; 40, as well as MN/2 = 0.3; 0.3; 0.3; 0.3; 0.3; 0.3; 0.3; 0.3; 0.3; 0.3; 1; 0.3; 1; 1; 1; 1; 1; 1; 1; 2; 1; 2; 2; 2; 2; 2; 2; 3; 2; 3; 3 ERA-MAX electrical exploration equipment with a frequency of 4.88 Hz along one profile (I-IC-U) in a scale of 1:5000.

The measuring setup was oriented in the profile direction, with the length of 4219 linear meters and 15 physical points. The coordinates of the observation sites were determined using the GPS.

In order to assess the physical and chemical state of water and bottom sediments, studies were carried out on a representative area of the lake during 1990-2014. The following trace elements were found in bottom sediments: Cu, Zn, Cd, Sr, Ba, Sn, Fe, Ti, Pb, V, Cr, Mo, Mn, Co, Ni (Fig.2). To assess the contribution of each heavy metal to the lake's pollution, their bulk earth values were determined in bottom sediments samples. Particle size distribution and mineralogical compositions of bottom sediments were also studied.

The analyzes were carried out according to the generally accepted method in the corresponding laboratories of the Institute of Geology and Geophysics of the National Academy of Sciences of Azerbaijan. Hydrochemical classification of waters was performed according to O.A.Alekin [1]. In order to fulfil the task, there were two research priorities:

1) the geophysical method was used to study the state of the geological environment surrounding the lake (layers and rocks were studied to a depth of 40 m);

2) the chemical composition of water and bottom sediments was studied by geochemical methods in order to identify its changes as a result of anthropogenic impact, potential pollution sources, etc.

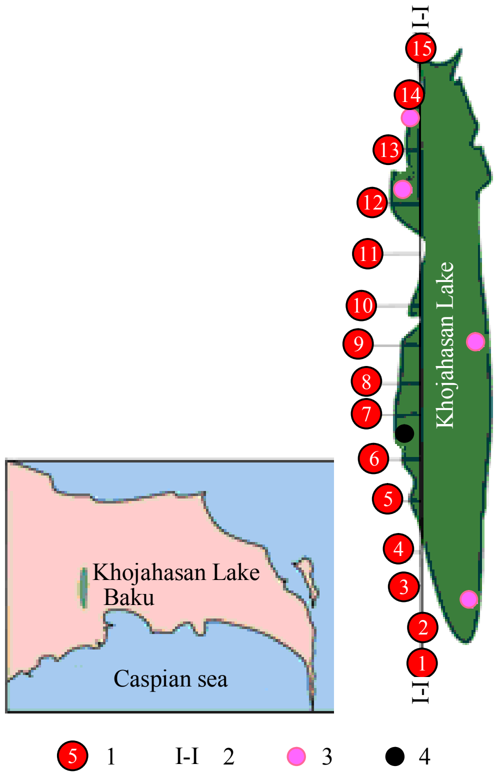

Fig.2. Geophysical profile location scheme near Khojahasan Lake and sites of water and bottom sediments sampling

1 – VES points and their numbers; 2 – the geophysical profile line; 3 – water sampling points; 4 – bottom sampling point

Results and discussion. The current state of the Khojahasan Lake was formed in two stages: the period of natural development and the period of anthropogenic impact.

The stage of natural development continued until the middle of the twentieth century. Water collection in the lake occurred only during the rainy period, and its depth did not exceed 0.5 m. During the hot season, evaporation of snow and rainwater collected in the lake occurred. Since the flow of surface spring water in the northwestern part of the lake was small, it moistened the sediments only partially, and its role in the lake supplement was insignificant. Thus, it can be noted that during the natural regime, the Khojahasan Lake was a small reservoir, mainly filled up with precipitations. The central parts of the lake basin were salty mud, with a slightly salty, usually ephemeral, environment.

The period of anthropogenic load, which began in the middle of the twentieth century, is still continuing. Industrial wastewater generated during the oil and gas fields exploitation, wastewater from neighboring industrial and processing enterprises, as well as domestic and agricultural emissions from the villages of Khojahasan and, in part, Yeni Sulutepe, increased the volume, square and depth of the lake several times, causing a number of environmental challenges. According to our data, more than 9 million m^3 of wastewater is discharged into the lake from the above facilities, 80 % of which is domestic water. A large amount of wastewater is discharged into the lake through three output lines, including 6220 m^3/day along the first, 173 m^3/day along the second and 260 m^3/day along the third line [4].

The northwest coast is the most polluted part of the lake. Along the east coast runs the Baku-Tbilisi railway. High water levels are dangerous for the road. From time to time, roadsides from the side of the lake are compacted with large stones so that the railway track does not collapse during fluctuations.

During the anthropogenic impact, the water level in the lake rose by 5-6 m, which required a decrease in the level of accumulated water to prevent possible accidents. For this purpose, in 1971, an overflow diversion dam was installed in the southern part of the lake. When the volume of water in the lake reaches a certain level, the water flows from here to Gu Lake, located east of Red Lake. A stream of water flows through the earthen bed and, spreading along the entire railway, forms numerous ponds and wetlands, causing new environmental problems. In its natural state, the lake was undrained. After 1971, variable runoffs were observed.

Currently, the main sources for the lake are rainfalls, domestic, agricultural and industrial wastewater, and possibly a small amount of groundwater. Losses of lake water are associated with evaporation, runoff to the Krasnoe Lake at certain times of the year and infiltration.

The water level in the lake over the past 50-60 years, generally increases, and the levels of seasonal fluctuations do not exceed 0.5 m. In the hot season, the water temperature on the coast increases to 30 °C. On cold winter days, ice formation is observed in the coastal zone of the lake.

Since among the supply sources of the Khojahasan Lake domestic water is dominated, the level of mineralization of lake water is low and averages up to 3000 mg/dm^3 (Table). According to the chemical composition, the lake's water belongs to the sodium group of the chloride class. Usually in the water mass a slightly alkaline medium is formed. The concentration of dissolved oxygen in winter is close to normal (8-10 mg/dm^3), and sharply decreases in summer (5-7 mg/dm^3).

The chemical composition of the waters of the Khojahasan Lake in different years, mg/dm^3

Sampling date	pH	Anions			Cations			Mineralization
		HCO_3^-	SO_4^{2-}	Cl^-	Ca^{2+}	Mg^{2+}	$Na^+ + K^+$	
05.1990	8.5	336	384	500	90	52	433	1670
11.1994	7.7	30	452	960	100	66	724	2500
06.1998	8.2	330	522	376	83	75	380	1790
12.2014	7.9	10.1	179.3	584.3	131.1	184.8	528.6	1833

If we consider the features of changes in the degree of mineralization of the water of the Khojahasan Lake in recent decades, we will see that the mineralization of water varies between 1700-2500 mg/dm^3 and has stabilized in general in recent years. The degree of water mineralization decreased by 8-10 times compared to natural conditions, while the degree of pollution increased several times.

The main role in the change of water chemical composition is played by elements of the typomorphic group (Fe, Pb, Zn, Cd, Mo, Co, Mn). The accumulation of heavy metals in lake systems is diverse and, in general terms, corresponds to the sedimentation mechanism of shallow-water basins. The order of accumulation of elements is associated with geochemical barriers, especially with the physico-chemical regime, which often had an individual, often complex-group character for each element, which determines the geochemical mechanism of matter telescoping.

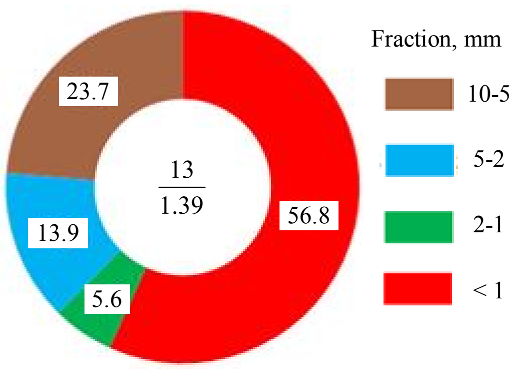

Fig.3. Particle size distribution of bottom sediments of the Khojahasan Lake, %

Particle fall time, s in the numerator; particle density, g/cm^3 in the denominator

Compared to bottom sediments, the content of major elements in the aquatic environment is tens to hundreds of times lower. Issues of sources, migration and deposition of trace elements in the aquatic environment and bottom sediments in connection with the metal accumulation heterogeneity are not fully clarified [16].

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Along with natural factors, anthropogenic emissions are also involved in the formation of bottom sediments. Fractions with a diameter of 5-10 mm and less than 1 mm represent 23.7 % and 56.8 % of sediments, respectively. The number of other fractions is insignificant (Fig.3).

The sediment is composed of eight minerals with a predominance of quartz and calcite (Fig.4).

The variety and number of components that form the bottom sediments rocks are as follows, %:

Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	K_2O	CaO	TiO_2	MnO	Fe_2O_3	Cl	VC*
1.06	2.00	9.26	47.7	0.025	2.44	1.88	14.26	0.548	0.043	5.25	–	15.6

*VC – the number of components that volatile at 950 °C.

Analysis of the presented data shows that silicon, calcium and aluminium oxides (71.2 %) dominate among the components of the bottom sediments. The concentration of organic carbon in sediment is 1.50-1.70 %. Since the most populated and industrially developed zone is located on the northwest coast of the Khojahasan Lake, the pollution is also active in this area.

A certain part of pollutants entering the lake with various discharges accumulates in bottom sediments. The trace element content in sediments, sampled from the northwestern part of the lake in 2015 is shown in Fig.5.

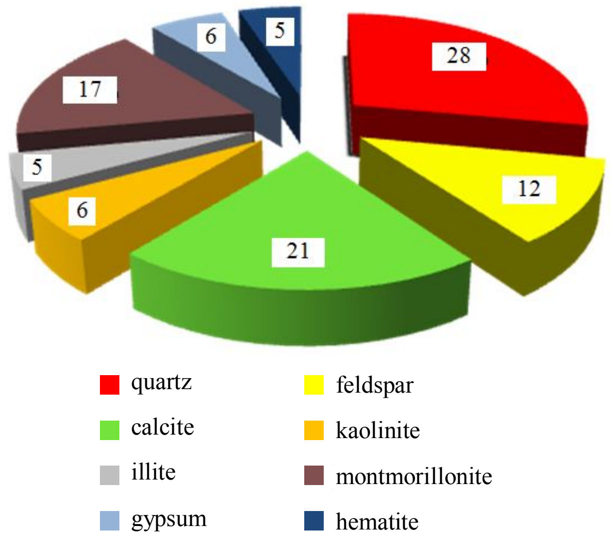

Fig.4. Mineral composition of bottom sediments of the Khojahasan Lake, %

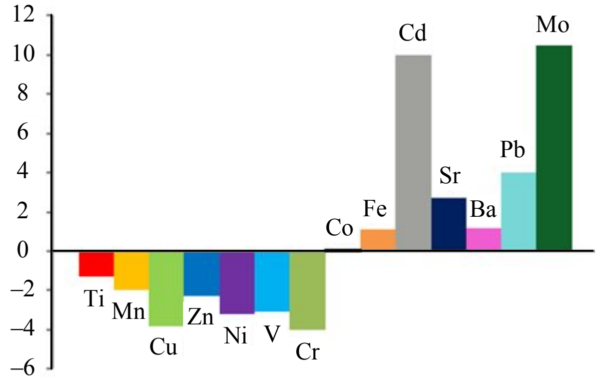

Fig.5. Diagram of the enrichment factor of trace elements in bottom sediments of the Khojahasan Lake as compared to the global abundances

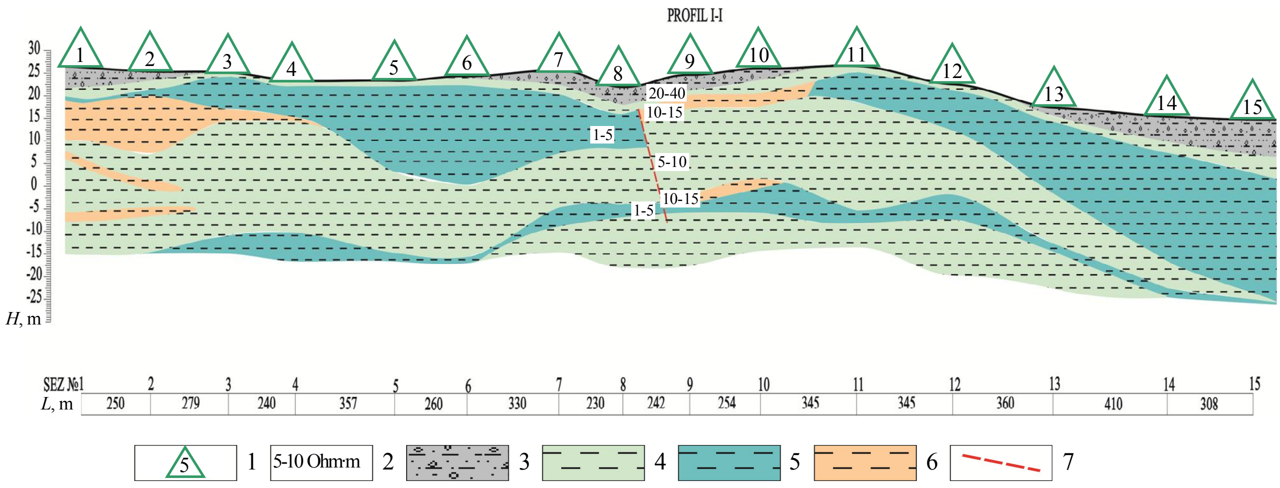

Fig.6. Estimated lithological and geophysical section along the I-I profile

1 – numbers of VES points; 2 – electrical resistivity of rocks; 3 – deluvial deposits; 4 – clays; 5 – highly moist clayey rocks; 6 – clay with thin sand layers; 7 – inferred faults identified by the VES

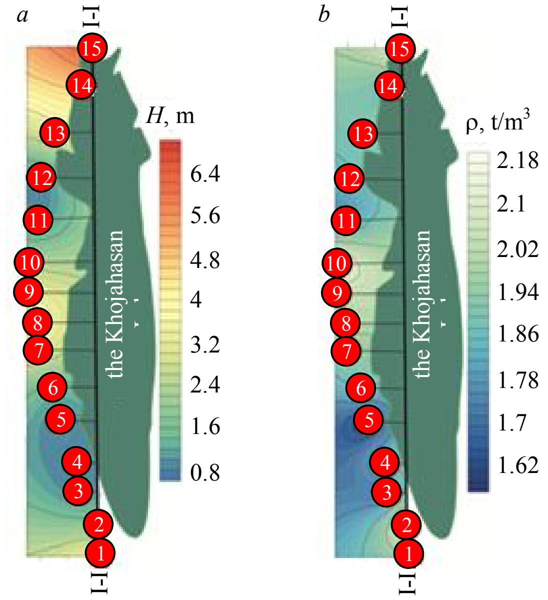

Fig.7. Schematic map of sediments along the coastal zone of the Khojahasan Lake and the development of EGP: *a* – iso-thickness; *b* – densities in the natural state

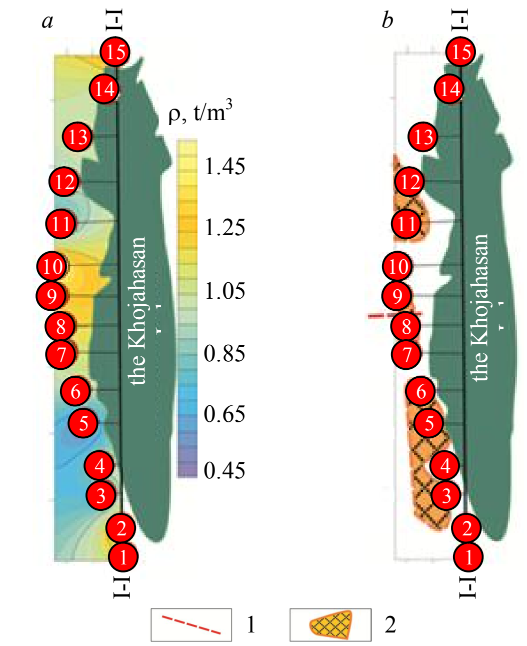

Fig.8. Schematic map of sediments along the coastal zone of the Khojahasan Lake according to the results of geophysical research: *a*– density under water; *b* – areas of EGP development

1 – inferred faults identified by the VES; 2 – areas of development of the proposed EGP

As can be seen from the diagram, the content level of six elements, including iron, cadmium, strontium, barium, lead and molybdenum, is 1.1-10 times higher than the bulk values in sedimentary rocks.

It should be noted that geophysical studies using electrical exploration methods in the surface area of the Khojahasan Lake were held for the first time. As a result of VES studies, based on a quantitative interpretation of the obtained data, the estimated lithological and geophysical sections were constructed along one of the profiles (Fig.6).

As a result of geophysical studies, rocks of different lithological composition were identified in the estimated lithological and geophysical section. The specific electric resistance $\rho_{s.e.r}$ and thickness of rocks vary respectively in the intervals of 1-35 Ohm·m and 0.5-25 m. These layers are presumably composed of deluvial deposits, clays, highly moist clays, and clays with layers of low-thickness sands.

The thickness and resistivity of the layers varies in the intervals, respectively: 0.5-3 m, 20-35 Ohm·m; 2-25 m, 5-10 Ohm·m; 1-18 m, 1-5 Ohm·m and 0.5-4.5 m, 10-15 Ohm·m. Based on the results of geophysical studies, it is assumed that the geological section around the Khojahasan Lake is mainly composed of clays and clay rocks. The thickness of individual layers in the section often varies, it is assumed that this is due to fluctuations in the level of the Caspian sea.

In the lithological-geophysical section of profile I-I, in the interval of VES N 8-9, a discontinuous steep-falling violation was revealed (Fig.7).

As a result of geophysical studies on the basis of determining the thickness and some physical parameters of deposits in the surface part of the section of the coastal zone of the Khojahasan Lake, the areas where presumably there is a development of exogenous geological processes and the development of these processes is intermittent and uneven, were allocated.

In the Western coastal zone of the lake, where EGP is developed, the thickness of the estimated mass is 0.8-4.8 m, and in the North-Eastern part, it increases to 6.4 m (Fig.8, *a*).

Across the study area, the density of sediments in which EGP is expected to develop varies from 1.62-2.18 t/m^3 (Central and North-Western parts of the coastal zone of the lake). In the South-Western part, there is an increase in the density of rocks from 1.62 to 1.84 t/m^3 (Fig.8, *b*).

In order to determine the development of the presumed EGP in the sediments on the coastal zone of the Khojahasan Lake, a map of the densities under water was drawn (Fig.8, *a*). It was found that the estimated densities of sediments under water in the coastal zone vary in the range of 0.45-1.45 t/m^3. In the South-Western and Central parts of the study area, the estimated density of sediments under water is 0.45-1.05 t/m^3, and in the North-Western part of the lake, it is 1.05-1.45 t/m^3.

The analysis of the geophysical survey predicts the development of EGP in the Western and South-Western parts of the coastal zone of the Khojahasan Lake and in the area where faults have been found. This is due to a decrease in the density of sediments in these areas and the presence of disjunctive dislocation in the range of VES N 8-9, resulting in the disturbed integrity of layers in this part of the coastal zone of the lake.

Conclusions. Analysis of obtained data allows us to draw the following conclusions:

– since the middle of the XX century, the undrained Khojahasan Lake was subjected to a multifactorial anthropogenic load; the volume of water increased due to the discharge of untreated wastewater; the levels of diverse pollutants in water and bottom sediments also increased; the degree of mineralization decreased;

– rock layers forming a geological section, according to the lithological composition, are mainly composed of: the top covering layer, interstratified layers of clays of different thicknesses and sands of lesser thickness, and sandy, highly moist and mineralized clays;

– favorable conditions for EGP were formed in the area of lake basin intersection with the east-western fault line; at the same time, there is the possibility of more rapid EGP development, most likely in the south-western and central areas;

– considering the horizontal arrangement of the layers forming the geological section of the shores of the Khojahasan Lake, it should be noted that there is a possibility of the formation of pseudokarst and sedimentation processes.

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