EVALUATION OF ECOLOGICAL STATUS OF BOYUKSHOR LAKE ON THE BASIS OF LABORATORY ANALYSES, REMOTE SENSING DATA AND GEOGRAPHIC INFORMATION SYSTEMS

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In order to define the measures required for restoration of ecological system of Boyukshor Lake and surrounding areas, the current state of the area should be evaluated. Evaluation should be based on a complex study. For this purpose, chemical and physical-biological analyzes of the surface of Boyukshor Lake and chemical analysis of bottom sediments were carried out. Pollution sources were identified. Moreover, using the Remote Sensing (RS) data and Geographic Information Systems (GIS) technologies, the reservoir area of Boyukshor Lake, the dynamics of the water surface, and the spectral properties were determined and analyzed.

Keywords: *Boyukshor Lake, Absheron, spectral description, remote sensing, geographic information systems.*

The Absheron peninsula located in the east part of the Republic of Azerbaijan and is surrounded by the Caspian Sea from the north, south, and east. The capital city Baku and the largest industrial city Sumgayit are both located there [1]. Forty percent of the Azerbaijan country population and 70% of industrial potential belong to the Absheron peninsula. Oil extraction started in the region more than 150 years ago. High density of population, rapid industrialization, and oil production led to changes in the ecological conditions of the peninsula [2]. These anthropogenic effects also caused ecosystem degradation of the peninsula's lakes. Boyukshor Lake is one of Absheron lakes, which is characterized by very high level of antipogenic influence [5; 15].

There are about 200 lakes in Absheron, most of them are small, their total area is near 50 km^2. Absheron lakes are located at the range of heights from 20 to 120 m. In the summer time, most of these lakes are drying. All of them are salty, they have salinity of 5-300 g/l and contain chlorine (Cl^-) and sodium (Na^+) ions. In natural conditions, the main source of nutrition for lakes during the cold season is atmospheric precipitation. In the warm season of the year, their water diminishes or dries out. This natural water regulation of the lakes continued until 1960 and gradually began to change as a result of anthropogenic impacts. Rapid increase in the volumes of industrial, and domestic wastewater, which flowed into the lake during the last 50 years due to the intensive development of the industry (especially oil production) and agriculture, led to their severe contamination, the growth of their areas, and the emergence of new lakes [3]. Thus, the high level of urbanization in the Absheron peninsula, the rapid development of large-scale urbanization and agro-industry led to sharp changes in the hydrogeological regime of the area, including sharp increase of both lake and underground water levels and degradation and pollution of all the components of the environment: atmosphere, soil, surface and underground waters. The expulsion of industrial areas, settlements and villages, roads and infrastructure, resulted in ecological degradation spreading for thousands of hectares [7].

Boyukshor Lake located in the central part of the Absheron peninsula is one of the largest lakes in the rergion. Total area of its surface is 1160.33 hectares. Boyukshor lake is divided into two parts with artificial weir: an eastern (738.47 ha) and western (421.86 ha). The weir separating lake into two parts prevented the exchange of water in the lake and thereby created a variety in physical, chemical, and biological properties of both water masses and bottom sediments. The western part is relatively small and slightly shallow, but its coastal level is 112 cm higher than the eastern part. The creation of the weir facilitated the management of water levels in the eastern part, thus simplified lowering. The measurements carried out at the same date showed that difference among water level of the parts was about 125 cm. There is practically no connection between these lakes. The water balance of the lake is formed by precipitation, industrial and household water fell directly on the basin and on the surface. It is known that pumps operating in the lake to prevent water rise transmits at least 3 million m^3 water to the Caspian Sea in a year. The water balance should lead to the drying of the lake, but it does not happen. It is assumed that the water of the underground watershed horizons in water balance flows into the lake, on the other hand, the pollution of the lake water and the creation of a thin molecular layer in the evaporation process reduce the intensity of evaporation [4]. According to scientific literature, the amount of steam has been reduced at these years by 50%. Both of the considered factors play an important role in the water balance of Boyukor lake.

The gray-brown soil type is spread in the lake basin and in the surrondings. The land-forming rocks are different and their structure consist mostly of limestone or gypsum. One of the characteristic features

of these lands is the predominance of small sand and large dust fractions, as well as sanding of upper horizons. Generally, gray-brown soils are young soils and they are formed on proluic-alluvial sediments.

Transition to genetic layers is clear and gradual. According to the results of laboratory analysis, the granulometric composition of gray-brown soils is light-clayey. Thus, the amount of physical clay varies between 23.06–28.48% in the upper layers (*tab.* 1a).

Soil profiles are less variable and the horizontal differences are weak. Light color indicates that there are fewer substances in the soil. Among the basic ingredients, hicroscopic moisture content is 2.4–3.0% throughout the profile. The total amount of humus is 0.65–1.32% un upper layers. The total amount of nitrogen is 0.08–0.12%. Amount of carbon dioxide is 14.15–17.14% along the profile. The pH level of the water suspension is 7.8–8.3 units, indicating that the soil has alkaline environment (*tab.* 1b).

Total of absorbed grounds in this lands is 4.20–8.42 Eq. Ca cation is the most prevalent among the cations, its content is 56.43–60.81% of the total amount. The amount of Mg cations that holds the second place is 35.63–38.81%. The Na cation, which holds the last place, is 3.56–4.76% of the total of *absrobed grounds (tab. 1c).*

Tab.1a

Granulometric composition of Boyukshor Lake basin lands (absolute in dry land with, %)

Cut off, №	Depth, cm	The size of the particles in mm and the amount in %						Physical clay in % <0.01mm
		1–0.25	0.25–0.05	0.05–0.01	0.01–0.005	0.005–0.001	<0.001	
				Light clay gray-brown				
1	0–23	1.94	54.86	14.72	12.06	9.28	7.14	28.48
	23–49	2.18	57.78	13.66	10.60	8.92	6.86	26.38
	49–69	2.46	59.22	12.84	11.36	7.72	6.40	25.48
	69–104	2.30	49.06	15.58	13.46	8.52	5.34	27.32
	104–179	2.96	60.14	13.84	9.32	7.20	6.54	23.06

Tab. 1b.

Main composition of Boyukshor Lake basin lands (absolute in dry land with %)

Cut off №	Depth, cm	Hysteroscopic moisture	General		CO_2	For CO_2– $CaCO_3$	In the pH-suspense
			Humus	Nitrogen			
				Light clay gray-brown			
1	0–23	3.0	1.32	0.12	7.17	16.25	7.8
	23–49	2.7	1.05	0.10	6.98	15.86	8.1
	49–69	2.6	0.65	0.08	7.54	17.14	8.3
	69–104	2.9	–	–	6.60	15.00	8.2
	104–179	2.4	–	–	6.22	14.15	8.0

Tab.1c.

The amount of bases absorbed in the territory of Boyukshor Lake basin lands (absolute in dry land with)

Cut off №-si	Depth, cm	Absorbed bases with nat. Equ.			Total of absorbed bases with nat. Equ.	From the total of absorbed bases, in %		
		Ca	Mg	Na		Ca	Mg	Na
					Light clay gray-brown			
1	0–23	5.12	3.00	0.30	8.42	60.81	35.63	3.56
	23–49	2.37	1.63	0.20	4.20	56.43	38.81	4.76

Fig. 1. Oil mine waters flowing into the lake.

During the observations of the coast of Boyukshor lake and during the field study, different sources of waste water poured into the lake were determined. Most of the waters coming from the north and south-west coast are pouring from oil fields (*Fig.* 1). The waters flowing from the south-eastern side is household water. Water pouring from the southern part is mainly the waters of stone processing workshops [6].

At present, the amount of oil transported by the wind is very small due to the barriers that were created to isolate oil contaminated water in western and northern parts of the lake. This measure was very productive for purification of eastern part of the lake and gradual ecological improvement.

Large-scale ecologically-restoration work carried out in recent years has critical importance for ecological situation of Boyukshor Lake and surrounding areas. Future pollution is prevented by isolating the waters and bottom of the eastern part covering approximately 1/3 of the lake from all types of pollutants. Residential homes, which are currently experiencing a strong negative impact from the lake, and also diverse small businesses are being transported from this area. Oil-contaminated sediments of the lake are mechanically collected and removed from the area.

In accordance with the Decree of the President of the Republic of Azerbaijan dated December 26, 2013 "On Additional Measures in the Field of Improving, Conserving and Using the Ecological Situation of Boyukshor Lake", significant work was done at the initial stage of improving the ecosystem of Boyukshor lake and surrounding areas and successful results were achieved [5].

Laboratory analyses of the samples taken from the waters of Boyukshor lake show that despite significant differences in the level of contamination, both eastern and western parts of the lake are influenced by the same anthropogenic impact.

The lake is artificially divided in two parts and since practically no water exchange occurred, the differences in all the chemical indications are apparent. Taking into account that the water samples were taken at the time, when evaporation indicators were minimal and atmospheric precipitation indicators were maximal, then there is no doubt that the difference between these figures in the dry season are even greater. Nethertheles, waters of both parts are similar in organoleptic properties, they are odorless, but differ in transparency and visual color.

The lake is salty and concentration of salts is higher in the western part. (*Tab*. 2). In the summer season the difference gets greater due to the fact that the western part is more shallow and its waters become warmer under the sun rays resulting in more intensive evaporation. The increased steaming increases the concentration of salts in water [8].

On the other hand, high salinity in both parts of the lake differs from the less salty lakes exposed to other anthropogenic pressure. Saltness of Boyukshor lake is related to layer waters as Puta, Zigh, Zabrat and some others. This can be explained by the discharge of these lakes into a reservoir formed in the mines located in the surrounding area and by the interference of the saline horizons of the saline layer on the bottom of the lake.

Though the western and eastern parts are different in terms of the amount of dissolved ions in water, the proportion of cations and anions in both parts corresponds to total salt quantitative changes. The main anion is chlorine (Cl^-), the main cations are sodium (Na^+) and potassium (K^+). Lake alkalinity in the western part is 8.8 and in the eastern part is 8.4 (*tab*. 2). The amount of oxygen dissolved in Boyukshor Lake varies between 4.9 and 5.2 mg/l. The biological and chemical demand for oxygen is 12.7–13.5 and 37.3–39.7 mgO/l respectively. Indicators show that lake water is supplied with enough oxygen. The analyses also show that concentration of water-soluble substances using in agriculture is also very high. Thus, the amount of soluble nitrites, nitrates, and ammonium in the water exceeds the permissible concentration rate (*tab*. 3).

Tab. 2

The results of the chemical analysis of water samples of Boyukshor Lake

Ions	Western part			Eastern part		
	mg/l	mg-ekv/l	mg-eqv,%	mg/l	mg-eqv/l	mg-eqv, %
HCO_3^-	341	5.59	1.30	363	5.95	1.13
SO_4^{2-}	11485	324.0	75.42	14066	397.0	75.78
Cl^-	9125	396.0	91.69	11531	500.0	92.44
Na^++K^+	9125	396.0	91.69	11531	500.0	92.44
Ca^{2+}	157	7.85	1.82	135	6.75	1.25
Mg^{2+}	341	28.03	6.49	415	34.11	6.31
			Rigidity			
		mg-mg/l			mg-mg/l	
General		35.88			40.86	
Temporary		0.00			0.00	
Carbonated		8.8			8.4	
			Residues			
		mq/l			mq/l	
Dry residue		26264			32326	
Amount of salts		26086			32124	
			Acidity			
pH		8.8			8.4	

Tab. 3

The results of the physical-biological analysis of water samples of Boyukshor Lake

№	Designated components	Unit of measurement	YVQH	Amount	
				West	East
1	Electric conductivity	10^{-3} Sm/cm	–	74.350	60.400
2	Color, visual	–	–	Colorless	Yellowy
3	Transparency	cm	–	41	33
4	Odor , with organoleptic method	–	–	odorless	odorless
5	Dissolved oxygen	mg/l	≥4	4.9	5.2
6	OBS5	mgO/l	6.0	12.7	13.5
7	OKS	mgO/l	30.0	37.3	39.7
8	Nitrite ion, NO2	mg-equ /l	0.02	0.6	0.7
9	Nitrate ion, N03	mg/l	9.0	11.0	13.2
10	Ammonium ion , NH_4^+	mg/l	0.39	2.1	2.4
11	General phosphorus (PO_4^{3-})	mg/l	3.5	0.67	0.89
12	Phenol	mg/l	0.001	0.005	0.006
13	SSAM	mg/l	0.1	0.01	0.08
14	Oil and oil products	mg/l	0.05	0.15	0.1

The results of the chemical analysis of the samples taken from the bottom sediments of Boyukshor Lake indicate that there is a high degree of pollution by all major parameters. The main pollutants are oil and oil products; their amount in bottom sediments is 1453–1475 mg/kg.

There are sharp differences in distribution of the pollutants on the bottom between eastern and western parts of the lake (*tab.* 4). Increase of oil contamination is observed from the center to the coast in both parts, reaching maximum in northern and southern areas.

The residues of oil and other organic waste flowing in the lake merged with water-soluble mechanical substances and formed a layer having thickness up to 50–60 cm. Despite high oil pollution, lake water are polluted with heavy metals arising from deep layers with oil. It is observed that the concentration of copper and nickel exceeds the permissible norm by 2–3 times. Although the concentration of other heavy metals is lower than the permissible limit, the quantity of lead, zinc, and cadmium is very high (*tab*. 4).

The microbiological state of the lake waters also shows pollution. Thus, in the eastern part of the lake, the total number of bacteria in the lake varies from 700 to 1500 specimens per ml, and the number of wastewater bacteria ranges from 10 to 20 specimens per ml. In the western part these figures are almost twice lower.

The high salinity of the lake waters does not create conditions for the strong development of water plants. For this reason, the lake's flora is represented by some simple diatoms and cyanobacteria. Pollution of the lake's coastline with solid domestic waste and oil, as well as high alkalinity of water, almost prevents growing of green plants on shallow parts and coast of the lake [6].

In the study, along with laboratory analysis and field studies of Boyukshor lake, the research continued through the RS data with applying of GIS technologies. First of all, the Digital Elevation Model (DEM) of the lake and surrounding areas were obtained based on Shuttle Radar Topography Mission (SRTM) data provided by NASA. The model was designed in 2014 with precision of 1*1 arcsecond (approx. 30 m) [6]. On the basis of the designed model, the boundaries of the lake's water collecting area were determined (*Fig.* 2). The reservoir area of the lake is 3684.9 ha. The DEM data was used for planning of sewerage and rainwater management.

The dynamics of the lake area have been analyzed on the basis on photos taken by Landsat satellites in different years. Significant changes in the area of the lake were revealed by comparison of photos taken by the Landsat-5 satellite in 1984 and 1994, by the Landsat-7 satellite in 2005, and Landsat-8 satellite in 2015 [7]. The area of the lake in 1984 increased to 1516.8 ha, in 1994 it increased to 1700.3 ha. In the next 11 years, the area of the lake was decreasing by 417 ha to 1283.3 ha, and the area of the lake continued to decline. In 2015, it was 1053.15 ha. In recent years, the dynamics of the lake area stabilized.

Tab. 4

The results of the chemical analysis of bottom sediments of Boyukshor Lake

Designated components		Norm	West	East
Humidity of samples, %		-	26.57	26.89
	Hydrogen indicator, pH	6.2–8.5	8.0	8.2
	Phenol, mg / kg	Not restricted	0.021	0.03
	The amount of oil and oil products, mg/kg		4375	1453
	SSAS, mg/kg	Not restricted	0.12	0.2
Heavy metals, mg/kg	Zinc (Zn)	70	37.13	42.39
	Lead (Pb)	32.0	16.54	22.32
	Nickel (Ni)	4.0	11.43	13.54
	Chromium (Cr)	6.0	5.45	5.45
	Copper (Cu)	3.0	7. 90	8.60
	Cadmium (Cd)	3.0	0.667	0.569
	Manganese (Mn)	1500	743.0	945.0
	Iron (Fe)	Not restricted	9886	10434
	Aluminum (Al)	Not restricted	9667	8796

Fig. 2. Watershed of the Boyukshor lake.

NDWI (Normalized Difference Water Index) was determined on the basis of the Landsat-8 satellite imagery in 2015. NDWI based on RS data was used for monitoring of water content variability. NDWI was calculated on the basis bands of green (0.561 mkm), near-infrared (0.865 mkm), and shortwave infrared (1.603 mkm) by two different mathematical formulae [8–9].

$$NDWI_1 = \frac{0.561\text{mkm} - 0.865\text{mkm}}{0.561\text{mkm} + 0.865\text{mkm}} \quad (1)$$

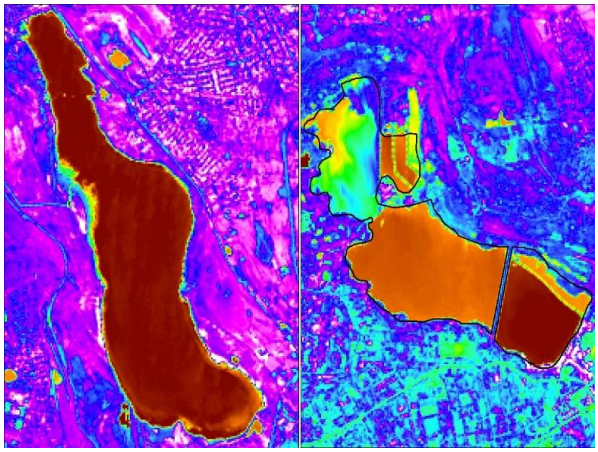
$$NDWI_2 = \frac{0.865\text{mkm} - 1.603\text{mkm}}{0.865\text{mkm} + 1.603\text{mkm}} \quad (2)$$

In the present study, the formula (1) is used. In order to make comparative analysis of NDWI of Boyukshor lake, NDWI was also constructed for Jeyranbatan water reservoir located on the Absheron peninsula as well. Jeyranbatan water reservoir is considered to be ecologically clean and it provides part of Baku with drinking water [10]. For this reason, the Jeyranbatan water reservoir was selected for NDWI comparison (*fig.* 3).

As it can be seen from *fig.* 3, ecological state of the western part of Boyukshor lake is better in comparison with its other parts. Central part is chracterized by medium pollution, and vast contamination is observed in the eastern part.

A comparative analysis of spectral characteristics of Jeyranbatan water reservoir and Boyukshor lake was also conducted in the study (*fig.* 4). As it can be seen from the fig. 4, starting from the red region of Boyukshor lake, spectral reflection in the NIR region is also rising. Spectral reflection of clean water areas in the NIR region is minimial and absorption is maximal. When water objects are polluted with oil products and industrial waste, reflection in the NIR object icreases

[11; 16]. From the above mentioned facts and graphs (fig. 4), it is possible to determine that Boyukshor lake is extremely polluted.



a) b)

Fig. 3. Comparison of NDWI of Jeyranbatan water reservoir (a) and Boyukshor lake (b).

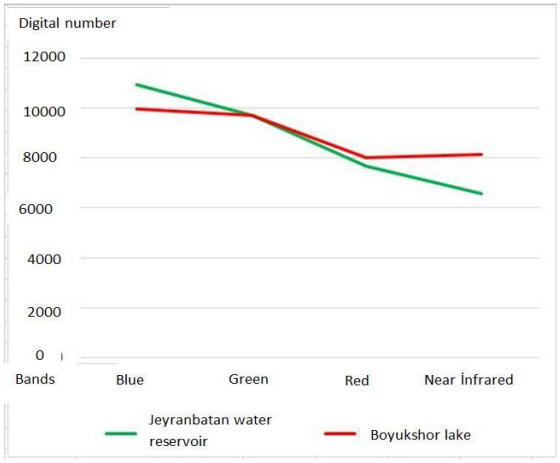


Fig. 4. Spectral reflection of Jeyranbatan water reservoir and Boyukshor lake

Conclusion

Laboratory analyses of chemical, physical, and biological sediments of Boyukshor lake water and the results of the field studies of the surrounding areas by the use of GIS technologies of RS data indicates that the level of pollution of lakes, as well as sediments and polluted waters, solid domestic waste, oil, petroleum products, and heavy metals should be regarded as a source of danger to human health. For the ecological improvement of the Boyukshor lake and surrounding areas, complex large-scale measures are required. These activities should cover the treatment of lake water and bottom sediments and the ecological improvement of surrounding areas. They must complement one another and ultimately provide a healthy water, soil, and air environment.

To improve the water environment, the configuration, depth, area and usage capabilities of the coast line, the relevant protection zone should be established. All kinds of waste and wastewater flowing into the lake should be processed, oil and oil products, solid domestic and construction waste should be removed. The oxygen regime of the lake water should be improved to assist the restoration of the environment. Moreover, the measures aimed at improvement of the ecological health of the surrounding areas should be taken, solid wastes should be recycled, water formed in the area should be removed by sewerage and pumping, oil contaminated areas should be rehabilitated, and green areas should be created from native plant species in accordance with agrotechnical requirements.

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Received 21.05.2018.
Revised 02.09.2018.

ОЦЕНКА ЭКОЛОГИЧЕСКОГО СТАТУСА ОЗЕРА БОЮК ШОР НА ОСНОВЕ ЛАБОРАТОРНОГО АНАЛИЗА, ДАННЫХ ДИСТАНЦИОННОГО ЗОНДИРОВАНИЯ И ГЕОГРАФИЧЕСКИХ ИНФОРМАЦИОННЫХ СИСТЕМ

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Для представления объем работы, проводящийся и которая будет проводиться по улучшению экологического здоровья озера Боюк Шор и округляющий территории, следует оценить настоящий положению указанной территории. Оценка должна основываться на комплексных исследованиях. С этой целью в этой статье были проведены химический и физико-биологический анализ поверхности озера Бойкшхор и химический анализ донных осадок. Были идентифицированы источники загрязнения. Кроме того, с использованием технологий дистанционного зондирования (ДЗ) и технологий географических информационных систем (ГИС) была определена и проанализирована площадь водохранилища озера Боюкшор, динамика поверхности воды и спектральные свойства.

Ключевые слова: озеро Боюкшор, Абшерон, Пейзаж, спектральное описание, Дистанционное зондирование, ГИС.

Поступила в редакцию 21.05.2018 г.
После доработки – 02.19.2018 г.