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Chemical-Bacteriological Composition and Assessment of Ecological Condition of Two Natural Lagoon-Type Lakes in Batumi (Adjara AR)

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Abstract Seasonal research of two relict lagoon-type lakes of Batumi (Adjara Autonomous Republic, Georgia) – Nuri-Gel and Ardagan waters has been carried out to assess their modern ecological condition. To assess the eco-situation of the lake waters, some physical, organoleptic, biochemical, chemical microbiological qualitative parameters have been experimentally determined. The topicality of the research is due to the fact that people often have an irreversible negative impact on the current sanitary-bacteriological condition of the waters of Lake Nuri-Gel and Ardagan. Based on the research, it has been revealed that in many cases the environmental quality mitigation parameters of the above-mentioned lakes are not within the maximum permissible concentration (MPC), which is caused by the negative impact of anthropogenic factors (such as draining faecal water fecal waters and various waste in lakes, caused, in many cases, by negative human activities). Due to the strategic importance of the research lakes, it is necessary to systematically research the ecological condition of their waters in order to assess the degree of cleanliness of these important ecosystems and to take timely preventive measures. At the same time, it should be noted that both lakes have recreational value and they are used for fishing, water sports and active relaxation, which further exacerbates the problem. To solve the ecological problems of Nuri-Geli and Ardagan lakes, we consider it necessary to carry out systematic cleaning works on them and to carry out periodic sanitary-bacteriological and hydrochemical control over their waters. It is necessary to work in a complex way to successfully overcome the tasks of rational use of their resources.

Keywords Lake, Water, Quality Parameters, Multi-Element Analysis, Coliform Bacteria

1. Introduction

There are 859 lakes on the territory of Georgia, with a total area of 170 km^2 and they differ from each other in geographical location, genesis, configuration, chemical composition. Lakes are found everywhere in Georgia and

they contain about 1 billion cubic meters of water. This mass of water is of strategic importance to the country from a strategic point of view (hydropower, irrigation, fishing, fish farming, peat extraction, healing mud, tourism, etc.). Most of Georgia's lakes are fresh-water, as the mineralization of water often does not exceed 0,1-0,2g/l and their chemical composition is of the hydro-carbonate, chloride or sulfate type [1]. Ardagani Lake has a natural formation and it is a relict remnant of a series of small narrow and scarce lakes on the shores of Batumi at one time, which ran along a narrow strip to the south-west of the Black Sea coast. The length of the lake is 520m, width - 70-80m. The lake used to be fed only at the expense of groundwater, but later it was connected to the city's central drainage collector and it was assigned the function of a kind of reservoir. Lake Nuri-Gel is the largest relict lake on the Adjara coastline. It is located in Batumi, on the territory of 6 May Park, at an altitude of 0,2m above sea level. The volume of water in the lake is 0,24 million cubic meters. It is mostly fed by groundwater and is of lagoon origin. The lake is separated from the Black Sea by a narrow strip of land with a width of 140-150 meters. Its total area is 5 hectares, the coastline is straight, the greatest depth is 5-6 meters, the lake is of marine origin, but it became fresh in later periods, as a result of the abundant rainfall characteristic of Batumi [2].

The chemical composition of lake water is often irreversibly negatively influenced by factors of anthropogenic origin, which cause the limiting parameters of their ecological purity to deviate from the maximum permissible concentrations (MPC) [3, 4]. Among such factors are: increasing pollution every year with industrial and domestic wastewater, fecal masses, oil, which leads to the accumulation of toxic substances and deterioration of water quality [5].

The actuality of the problem was determined by the fact that anthropogenic impacts pose a serious threat to the normal functioning of the ecosystems of Nuri-Gel and Ardagani lakes in the territory of Adjara. However, both lakes are recreational, fishing, water sports, and active recreation areas, which further highlights the seriousness of the issue. Therefore, the above lakes are high risk objects, that require daily attention in terms of systematic control over their ecological parameters, in order to make it possible to determine the terms and pace of periodic cleaning works on them.

Considering the great importance of the lakes in the development of the national economy of the country, the aim of our research was to study some qualitative and sanitary-bacteriological indicators of the two natural lagoon-type lakes on the territory of Batumi, in order to assess the degree of their pollution at the modern stage.

2. Materials and Methods

Two water objects were selected for the research in Batumi (Adjara Autonomous Republic, Georgia): Lake Nuri-Gel; Lake Ardagani. When sampling water intended for chemical analysis, two containers with a volume of 1.5 liter, made of a polymeric material, we rinsed with water at least three times, and then filled the containers to the top. When sampling water at the same point for different purposes, first of all we took samples for microbiological analysis. We used a sterile vessel (with a volume of 0.5 l), which was opened immediately before sampling the water. During sampling, they must be protected from dust and splashes. After filling, the vessel was immediately closed with a sterile cork. When filling the vessel, we left a space between the cork and the surface of the poured water, so that the cork does not get wet during transportation. During transportation, vessels were protected from contamination. Microbiological analysis of water samples was started on the same working day on which samples were taken. The maximum storage time for samples was 6 h, at the temperature 4-5 ℃ [6, 7]. Water samples were taken from the lakes from several points for 2 seasons (autumn-winter), and a medium sample was obtained by mixing them. Additionally, another sample was taken from Lake Ardagan, for which its most polluted location was selected.

The ecological status of the water of these lakes was assessed based on the following limiting parameters: Physical and organoleptic parameters- temperature, color, smell, transparency, floating particles, which were determined visually and using a thermometer [8]; pH- using potentiometric method – by laboratory pH-meter (Mettler Toledo); Chlorides, dissolved oxygen and biochemical oxygen demand (BOD_5) were determined by titrimetric methods [9, 10, 11]; Using complexometric method were determined - Ca^{2+}, Mg^{2+} ions and water hardness [12, 13]; Multi-element analysis of water was performed on a plasma atomic emission spectroscopy by ICPE-9820 [14]; Sulfate content and concentration of NH^{4+} ions was happening by photometric method [15, 16]; The number of total coliform bacteria was determined by the method of microbial cultivation [147]. We analyzed the results statistically and compared the maximum permissible concentrations (MPC).

3. Results and Discussion

3.1. Organoleptic Indicators of Waters

We rated the smell of water at the most polluted location on Lake Ardagani in the autumn over 5 points. The water here was very muddy, with an uncharacteristically foreign intense yellow color. Floating particles were observed to a depth of about 0-50cm, indicating a high degree of turbidity in the water and an abundance of suspended particles (Table 1). According to the average sample taken from another location of Ardagani Lake, the smell was 4-5 points, the water was muddy, colored - greenish-yellowish,

floating particles were observed from the surface up to 0-30cm. According to the average sample taken from Lake Nuri-Gel, the smell was 3-4 points, the water was weakly turbid, colored - greenish-yellowish, the floating particles were observed in the layer up to 0-10cm. A similar regularity was observed in the waters of the lakes during the winter season.

3.2. Physico-Chemical Parameters of Lake Waters

The maximum temperature in the waters of the lakes was observed at the heavily polluted location -22 ℃, the minimum at the Lake Nuri-Gel-8 ℃. The temperature regime of these lakes is mainly determined by the proximity of the Black Sea, so even in winter the water temperature is above the absolute minimum (+5 ℃) [18]. The maximum pH of the lakes water was observed in winter, the minimum-in autumn, which is caused by the accumulation of organic substances, with the increase of temperature in autumn, which causes water acidification (Table 2). Nuri-Gel water pH ranged from 7,74 to 7,90. In samples taken from Lake Ardagani, pH values for both seasons were below maximum permissible concentrations (7,28-7,32).

The maximum chloride content was observed in Ardagan Lake in both seasons and it exceeded the MPC of 1,05-1,7 times, which is evidence of serious pollution of Ardagan Lake water. The content of NaCl (salinity) is in a regular relationship with the concentration of Cl^- ion. Seasonal salinity decreased in winter, which was caused by heavy rainfall (Table 3). The water dissolved oxygen content was higher in winter (4,5-5,5mg/l), compared to the autumn season (4,20-4,47mg/l). This is due to the circumstance that the solubility of gases in water increases with decreasing temperature in winter. The minimum content of dissolved O_2 was observed in the water taken in the polluted section of Lake Ardagani in autumn (4,20mg/l).

Table 1. Organoleptic Indicators of Lake Waters

Location	Smell, Points		Transparency		Color		Suspended Particles	
	Autumn	Winter	Autumn	Winter	Autumn	Winter	Autumn	Winter
Lake Nuri-Gel	3-4	2	slightly turbid	slightly turbid	greenish-yellowish	weakly greenish-yellowish	observed from the surface 0-10 cm	observed from the surface 0-10 cm
Lake Ardagani	4-5	2-3	turbid	slightly turbid	greenish-yellowish	greenish-yellowish	observed from the surface 0-30 cm	observed from the surface 0-20 cm
Lake Ardagani (heavily polluted location)	>5	3	very turbid	turbid	intense yellow	weakly yellow	observed from the surface 0-50 cm	observed from the surface 0-30 cm
MPC [3,4]	2 points		it should be transparent at the level of 0-30cm		foreign color is not allowed at a depth of 0-10 cm		the presence of non-characteristic suspended particles in the surface layer of water is not allowed.	

Table 2. Water temperature, pH, Cl^- ions and salinity

Location	Autumn		Winter		Autumn		Winter	
	T, ℃	pH	T, ℃	pH	Cl^- mg/l	NaCl mg/l	Cl^- mg/l	NaCl mg/l
Lake Nuri-Gel	18	7,74	8	7,90	140,0	231,0	113,1	186,6
Lake Ardagani	21	7,32	11	7,51	567,1	935,7	369,0	608,85
Lake Ardagani (heavily polluted location).	22	7,28	12	7,45	605,3	998,7	392,3	647,3
MPC		7,70-8,5		7,70-8,5	not more than 350		not more than 350	

Table 3. Concentration of dissolved O_2, BOD_5, NH^{4+} and SO_4^{2-} ions in lake waters

Location	Autumn				Winter			
	O_2 mg/l	BOD_5 mg/l	NH_4^+ mg/l	SO_4^{2-} mg/l	O_2 mg/l	BOD_5 mg/l	NH_4^+ mg/l	SO_4^{2-} mg/l
Lake Nuri-Gel	4,47	5,5	0,70	14,5	3,85	3,6	0,45	8,2
Lake Ardagani	4,31	4,5	1,63	38,5	4,08	3,9	1,26	26,8
Lake Ardagani (heavily polluted location)	4,20	4,5	1,80	47,1	4,1	4,0	1,40	33,14
MPC	not less than 5 mg/l	not more than 3mg/l	0,39	100,0	not less than 5 mg/l	not more than 3mg/l	0,39	100,0

Table 4. Concentration of Ca^{2+} and Mg^{2+} ions and total hardness

Location	Autumn			Winter		
	Ca^{+2}	Mg^{+2}	hardness	Ca^{+2}	Mg^{+2}	hardness
Lake Nuri-Gel	45,8	10,2	56,0	31,1	9,7	40,8
Lake Ardagani	62,0	37,7	99,7	52,2	35,6	87,8
Lake Ardagani (heavily polluted location)	67,4	42,9	110,3	54,1	38,3	92,3

It should be noted that in both seasons at all locations the concentration of water- dissolved O_2 was less than the MPC. The surface water index, which determines the degree of their contamination with organic compounds, is called the biochemical oxygen demand within 5 days (BOD_5), the maximum permissible concentration (MPC) of which should not exceed 3mg/l. The fact of oxygen depletion of the study waters was confirmed at all locations and was: in autumn - 3,85-4,1mg/l, in winter - 3,6-4,0mg/l. This parameter decreased regularly in winter and increased in autumn, which was associated with seasonal changes in temperature and, consequently, a slowdown in the activity of microorganisms during the cold winter.

It was of interest to observe the process of accumulation of organic compounds at the above locations, as it is known that NH^{4+} is produced during the indirect regeneration of nitrogen in the surface layers of water, which is the result of destruction of complex organic compounds and is carried out by nitrogen bacteria (ammonifying bacteria, nitrifying bacteria).The ammonium nitrogen content in both seasons was much higher than the MPC: In autumn: 1,8 times - in Nuri-Gel Lake, 4,2-4,6 times - in Ardagani Lake; In winter: 1,2 times - in Nuri-Gel Lake, 3,2-3,6 times - in Ardagani Lake. The current situation indicates the fact of progressive eutrophication of lake waters. The sulfate content in Ardagani waters is higher than in Nuri-Gel Lake. However, the concentration of this parameter is within the MPC, which indicates that these lakes are not sulfate formation lakes.

Ca^{2+} and Mg^{2+} ions decrease seasonally from autumn to winter (Table 4). This circumstance may be related to the excessive amount of precipitation in winter, which causes abundant outflow of fresh water into the lakes and, consequently, a decrease in their hardness in the waters. The concentration of the above ions is in a regular relationship with the water hardness of the lakes. The minimum concentration of Mg^{2+} ions was observed in Nuri-Gel Lake – 9,7-10,2mg/l.

3.3. Sanitary-Bacteriological Analysis of Waters

Table 5. Total number of coliform bacteria (Escherichia coli bacteria) in 100 ml of water

№	*Location*	*Total number of coliform bacteria (cfu/100ml)*	
		Autumn	*Winter*
1	Lake Nuri-Gel	4600	1600
2	Lake Ardagani	>11000	2100
3	Lake Ardagani (heavily polluted location)	>11000	2900
MPC		*< 1000/100 ml - for agricultural and household purposes* *<500 /100 ml - in bathing areas* *<1000 /100 ml – for water sports and populated areas*	

Common coliform bacteria comprise up to 100 species

of microbes that make up the intestinal microflora of humans, animals and birds. Conventionally, they are also called pathogenic microbes. Determination of the total number of coliform bacteria revealed that the current sanitary-bacteriological condition of the lake waters has deteriorated in both seasons: In autumn, the total number of coliform bacteria (cfu/100ml) in Lake Nuri-Gel was 4600, which is 4,6 times higher than the MPC, and in winter-1600, or 1,6 times higher than the MPC (Table 5). As for Lake Ardagani, the total number of coliform bacteria (cfu/100ml), at this location in the autumn season exceeded 11000 in both samples, and in winter their number decreased to 2100-2900, however, this figure was 2,1-2,9 times higher than the maximum permissible concentration this season [17].

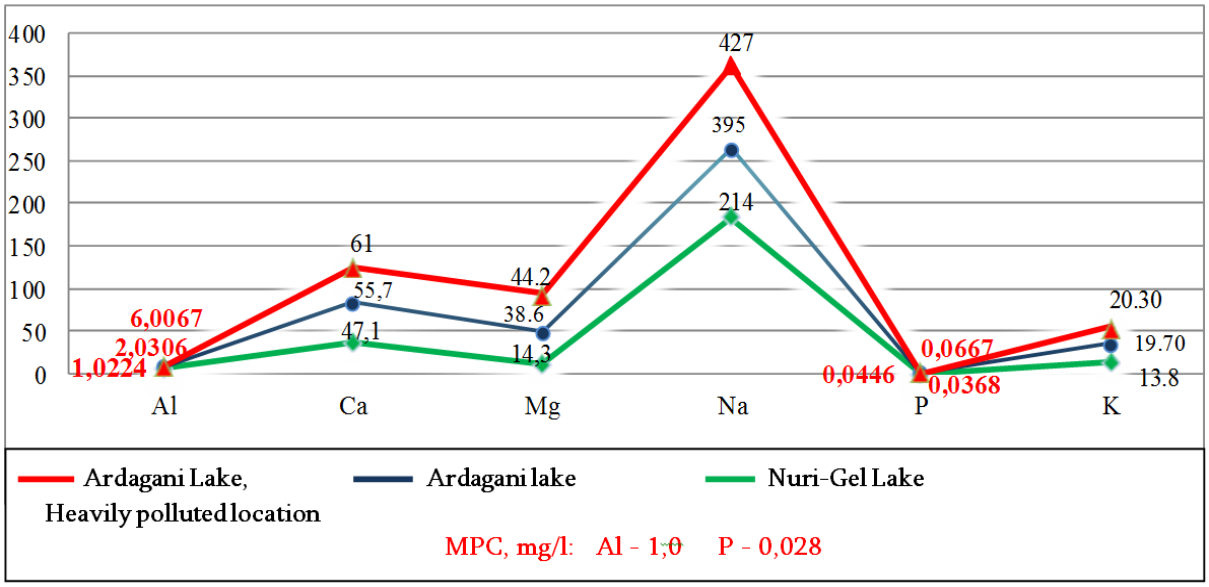

Chart 1. Multi-element analysis, macro-elements, mg/l

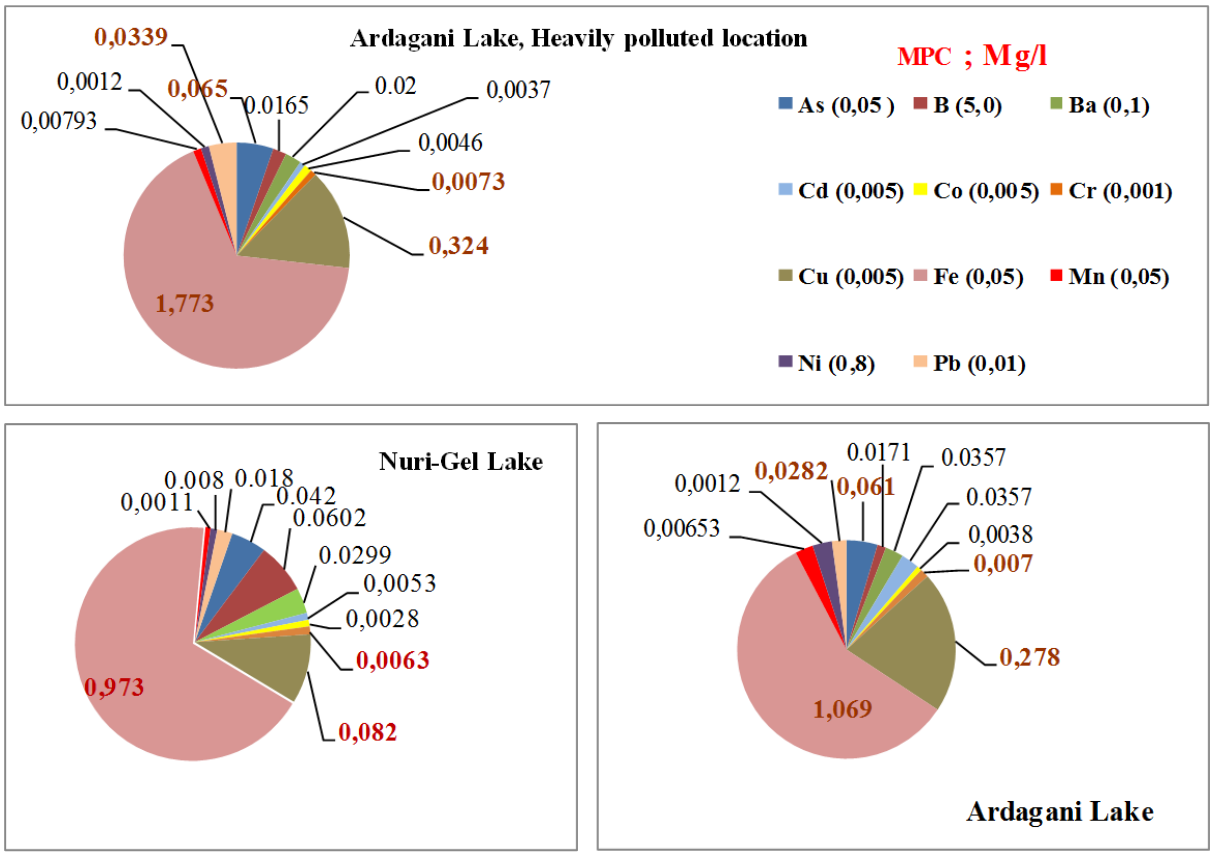

Chart 2. Multi-elemental analysis, micro-elements, mg/l

3.4. Multi-Elemental Analysis and Heavy Metals

Multi-elemental analysis of water samples taken at different locations in Nuri-Gel and Ardagani Lakes showed that the dominant role belongs to the following macro-elements: Na - 214-427mg/l; Ca - 47,1-61,0mg/l; Mg - 14,3-44,2mg/l, K–13,8-20,3 mg/l (chart 1). It should be noted that the concentration of phosphorus in all three samples was higher than the MPC, which indicates the accumulation of organic matter in the lakes. From micro-elements (including toxic elements) the amount of Boron, Barium, Cadmium, Cobalt, Nickel, Manganese in the water did not exceed the MPC. Multi-elemental analysis showed that the following concentrations were higher than the MPC in all three samples of highly toxic elements: Arsenic, Chromium, Copper, Iron and Lead (chart 2).

It should be noted that heavy metals are quite resistant to environmental factors. When they enter reservoirs and the soils, they become involved in metabolism and undergo various transformations. Their inorganic compounds are converted to weakly soluble hydroxides, carbonates, sulfides, phosphates, deposited on the bottom and accumulate in the humus horizon of soils [19, 20, 21]. They form organic complexes with metals. In addition, Hg, Zn, Pb, Cd, As, if entering the human body through food, cause serious poisoning, as their coefficient of material accumulation varies from hundreds to several thousand [22].

4. Conclusions and Suggestions

Identification of water resources is one of the most important issues of developing the national economy of the country. Comparative description of two lagoon-type lakes of Batumi are made, their present ecological conditions are identified and polluting factors are revealed. Organoleptic and physical-chemical parameters of lake's waters are determined experimentally, which in most cases do not meet the standards that installed by Resolutions of Georgian Government on Protection of Surface Waters of Georgia from Pollution.

The organoleptic parameters of Nuri-Gel and Ardagani lakes (smell, transparency, coloration, suspended particles) for two seasons (autumn-winter) don't meet the established norms. The pH of Nuri-Gel water is 7,74-7,90, which is within the MPC norm (7,7-8,5). In the samples taken from Lake Ardagani, the pH values for both seasons were below the MPC norm (7,28-7,32). The maximum chloride content was observed in Lake Ardagani in both seasons, they exceeded the maximum permissible concentration 1,05-1,7 times. Seasonal salinity decreased in winter. The minimum dissolved O_2 content was observed in the autumn at the heavily polluted location of Lake Ardagani (4,20mg/l). In both seasons, the concentration of dissolved O_2 was less than the maximum permissible concentration. Accordingly, BOD_5 exceeded the MPC norm (3,85-4,1mg/l- in autumn, 3,6-4,0mg/l- in winter). The concentration of Ca^{2+} and Mg^{2+} ions seasonally decreases from autumn to winter, which is caused by excessive precipitation in winter and, consequently, a decrease in water hardness. Sulfate content in Lake Ardagani is higher than in Lake Nuri-Gel.

The concentration of NH_4^+ in both seasons exceeds the maximum permissible concentration. Namely, during the autumn season: 1,8 times in Nuri-Gel Lake, 4,2-4,6 times-in Ardagani Lake; During the winter season: 1,2 times-in Nuri-Gel Lake; 3,2-,36 times-in Ardagani Lake. This condition indicates the fact of progressive eutrophication in the waters of the lakes. In both seasons, the sanitary-bacteriological condition of the lakes waters has deteriorated, which is confirmed by the increase in the total number of coliform bacteria, which seasonally exceeds the maximum permissible concentration in Lake Nuri-Gel by 1,6-4,6 times. On the Ardagani Lake - in the autumn season this indicator exceeds 11000, in the winter-2100-2900, but this season it is 2,1-2,9 times higher than the maximum permissible concentration.

Studies conducted on the waters of the Nuri-Gel and Ardagani lakes revealed that in many cases the qualitative parameters that are evaluating their ecological condition, are not within the maximum permissible concentrations (MPC), which is caused by the negative impact of factors of anthropogenic origin. Based on the strategic importance of the investigated lakes, we consider it necessary to carry out systematic treatment works on them and to carry out periodic sanitary-bacteriological and hydrochemical control over their waters. Systematic research of chemical composition of lake's waters and their periodic monitoring is necessary to evaluate their present conditions and to carry timely preventive measures to increase their quality.

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