Assessment of ecological state of the Chogray reservoir using remote sensing of the Earth (Stavropol Territory, Russia)

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Abstract. The article presents the assessment of the quality of the waters of the Chogray reservoir. The authors describe the hydrochemistry, the dynamics of changes in the salinity of the water and the water regime of the reservoir. The main sources of water pollution are identified. The quality of the waters of the Chogray reservoir is assessed.

1. Introduction
The Chogray reservoir was founded on the Vostochny Manych River on the border of the Stavropol Territory and Kalmykia (Russia) in 1969. This reservoir is a public water body, as well as of multipurpose. The reservoir area is 193 km², the total volume is 720 million m³, the useful area is 670 million m³, the minimum area is 10 thousand hectares, the maximum is 19.3 thousand hectares, the length is 48.8 km, the maximum width is 9 km, in the tail parts – 800 m. The average depth of the reservoir is 3.8 m, the maximum in the dam zone is 8.0–10.8 m. Shallow waters with depths of up to 2 m during the growing season occupy from 30 to 80 % of the total area. Water in the Chogray reservoir along the coastline flows is unevenly drawn. Water flows into the dam near the southern part of the Kumo-Manych Canal and the waters of the local runoff of the Golub, Chograi and Raguli beams on the southern side of the reservoir.

2. Methods and materials
In order to identify the state of the Chogray reservoir, the following methods were used: (methodologies for determined indicators):
• the method for measuring the mass concentration of phosphate ions in drinking, surface and wastewater by the photometric method with ammonium molybdate. Federal environmental regulation 14.1: 2: 4.112-97 (2011);
• the method of measuring the mass concentration of chloride ions in drinking, surface and wastewater by the mercury method. Federal environmental regulation 14.1: 2: 4.111-97 (2011);
• the method of measuring the mass concentration of sulfate ion in samples of natural and waste water by the turbidimetric method. Federal environmental regulation 14.1: 2.159-2000 (2005);
• the method for measuring the mass concentration of nitrite ions in drinking, surface and wastewater by the photometric method with Griss reagent. Federal environmental regulation 14.1: 2: 4.3-95 (2011);
• the method for measuring the mass concentration of nitrate ions in drinking, surface and wastewater by the photometric method with salicylic acid. Federal environmental regulation 14.1: 2: 4.4-95 (2011);

The studies were conducted during the period from 2015 to 2017.

3. Results
The studies of the ecological state of the Chogray reservoir took place in two stages: 1) the study of changes in the coastline of the reservoir using remote sensing data; 2) the geochemical studies of individual sections of the reservoir.

In order to identify the chemical composition of the reservoir waters, we selected 6 water samples. The samples were taken in accordance with GOST 31861-2012 “Water. General requirements for sampling”, which establishes general requirements for sampling, transportation, preparation for storage of samples, designed to determine indicators of its composition and properties [1, 12]. The samples were studied in the research laboratory “Ecoanalytical Laboratory” of the North Caucasus Federal University using a Thermo Genesys 10S UV-Vis dual-beam spectrophotometer. The determination of the hydrogen index of water samples was carried out on a pH METR pH-150MI ionometer. We selected three sampling points: 1) in the water area of the Chogray reservoir on the territory of the Chogray reserve; 2) the mouth of the river Dove; 3) the mouth of the Chograi river.

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Today the ecological situation at the reservoir has worsened, which is confirmed by the scientific work of the neighboring region [8]. The main polluted waters come from the Kuma River. The mineralization of water increased to 1.6–1.7 g/l with sulfate-chloride-hydrocarbonate type of salinization. The concentration of toxic sulfate ions SO2- reaches 0.7 g/l, and chlorine ions – up to 0.3 g/l. The water of this reservoir is not suitable for drinking and is partially suitable for irrigation and watering of livestock.

The long-term accumulation of the flood waters of Terek, bringing a large amount of sand, gravel, silt and clay, led to siltation of the bottom of the reservoir. Consequently, its volume decreased to 280 million m$^3$, and the water surface area decreased to 130.4 km$^2$ [3].

During the analysis of the changes in the borders of the Chogray reservoir using data from remote sensing of the Earth, we found that the area of the water body decreases over time [7]. The largest reservoir was in 1985, when its area was 193 km$^2$. Over the 20 years of operation, the reservoir area has decreased by almost a third – to 130.4 km$^2$. Today, its area is about 115–120 km$^2$.

The analysis of changes in the coastline of the Chogray reservoir was carried out using data from remote sensing of the Earth [11]. When analyzing the changes in the shoreline of the reservoir, we used satellite images from Landsat 5 and 8. In our study, we used 3 images from Landsat satellites: 2 Landsat 5 images from 1985 and 2000 and one Landsat image 8 – 2016. As a result of overlapping the images, a map with a scale of 1: 150 000 was obtained (Figure 1).
Figure 1. Change in the borders of the Chogray reservoir.

The map shows a tendency towards a decrease in the area of the reservoir over time. The largest scales the reservoir has in 1985, when it was filled to the design level. Its area then amounted to 193 km$^2$ [4]. In subsequent years, there was a gradual decrease in area. Over the 20-year period of operation, the reservoir area decreased by almost a third – to 130.4 km$^2$. The lowest area indicators until 2000 were noted in the low-water year of 1999 – 113.4 km$^2$, lower by 3.2 m and, therefore, this led to a change in the position of the coastline. The water level depends mainly on the water supply and water intake from it [7]. According to the results of geographic information monitoring, the area of the studied object was:
in 2009 – 93.2 km$^2$, in 2010 – 123.8 km$^2$, in 2011 – 125.9 km$^2$ and in 2012. – 112.1 km$^2$ [6].

The most noticeable changes occurred at the narrowing point in the northwestern part of the reservoir. By 2016, large islands were formed here, which previously were not there. Large islands (more than 2.0 hectares) comprise over 80 % of the total area of the reservoir islands (about 0.4 thousand hectares). Small islands (less than 1 ha) are low and covered with vegetation. There are also islands that emerge from under water as a result of a decrease in its level. In the central part of the reservoir, the changes are not so significant.

While in its northeastern part a significant decrease in the size of the water mirror occurred. The border of the southern shore of the reservoir has shifted. At the mouth of the Chograi River, a narrowing of the water surface occurred. The degree of overgrowing of the reservoir, compared to 1975, increased, vegetation covered more than 50 % of the reservoir. Larger massifs of coastal-aquatic vegetation are concentrated in the western region, submerged plants are in the center of the lake-shaped part of the reservoir, whose biomass reaches 1.2–1.5 kg/m$^2$.

The content of nitrite ions in water in samples 2 and 3 (the mouth of the Golub and Chograi rivers) significantly exceeds the MPC. The highest values are observed in 2015 in sample 3 (Figure 2).

The presence of nitrates without nitrites and ammonium in water indicates long-term pollution. Natural and anthropogenic sources of their entry into the aquatic environment on the catchment area of the reservoir are mainly associated with fertilizers and animal waste.

The content of nitrate ions in the water of the Chogray reservoir is insignificant. Their greatest value was noted in 2015 in the second sample – 7.53 mg/l., and the smallest – in the first sample of 2017 (Figure 3).
The phosphate content in water significantly exceeds the maximum permissible concentration. The smallest indicators were found in the first sample (the water area of the Chogray reservoir on the territory of the Chograi reserve), and the highest in the third sample (the mouth of the Chograi River) (Figure 4).

The presence of phosphates indicates possible pollution from industrial effluents or effluents from agricultural fields. The high level of these phosphate substances affects the intensive development of blue-green algae, which release toxins into the water during dying.

The maximum permissible concentration (MPC) of sulfate ions in water is 100 mg/l. The indicators in samples are many times higher than MPC. The smallest values were noted in the first sample in 2015 and 2017, and the highest – in the second sample in 2015. Sulfate ion is an indicator of anthropogenic pollution introduced by rivers, groundwaters and direct discharge of poorly treated industrial, agricultural and domestic wastewater into the Chogray reservoir (Figure 5).
There is no excess of MPC of chloride ions in the first sample. In the second sample there was an excess in 2015. The highest value was noted in the third sample of 2015 – 375 mg/l. Chlorides exhibit high migration ability due to good solubility. High concentrations of chlorides enter the reservoir from poorly treated industrial and domestic wastewater (Figure 6).

![Figure 6. Content of chloride ions in the water of the Chogray reservoir](image)

In all the samples, water has an alkaline reaction. The highest pH was found in the third sample of 2015 (fig. 7).

![Figure 7. pH of the water of the Chogray reservoir](image)

According to the classification of O.A. Alekin [2], the water of the Chogray reservoir belongs to the category of sulfate-chloride class waters. The sulfate content in the water ranged from 325 to 547 mg/dm$^3$, chlorides from 216 to 375 mg/dm$^3$, which indicates the entry into the water of the reservoir of insufficiently treated industrial and domestic wastewater, as well as agricultural effluents. The mineralization indices are determined on the basis of studies conducted earlier by other researchers [9]. The mineralization of the water of the Chogray reservoir changes seasonally: it increases from spring to autumn and in the reservoir itself as it moves away from the dam to its western part. The maximum mineralization indices (1.5–2.2 g/dm$^3$) were noted in the western part of the reservoir. The eastern near-dam area (1.1–1.6 g/dm$^3$), which receives fresh water from the Terek and Kuma, is more desalinated. Both these phenomena are associated with high volatility and the nature of the supply of water to the reservoir and alkaline soils that have gone under water.

An indirect indicator of the presence of organic substances in the reservoir is oxidizability, which in the spring ranged from 9.4 to 12.1 mg O/l and reached its highest values in the summer period (18.0–18.8 mg O/l) in the western part of the reservoir. This site is characterized by shallow water, intense warming of water, significant siltation and overgrowing. The gas regime in the reservoir is favorable for aquatic organisms.

The oxygen content in the surface layers during the growing season is usually close to saturation, sometimes significantly exceeding it (up to 120–140 % saturation). In the near-dam horizons, this indicator can decrease to 50–60 % of saturation. The deterioration of the oxygen regime was observed in summer in some overgrown and silted parts of the reservoir. The oxygen concentration in the water was within the average of previous years and amounted to 4.5–8.6 mg O/l [5].

**4. Conclusion**

Nowadays, the reservoir is experiencing a pronounced anthropogenic load. Water, according to sanitary and epidemiological standards, does not meet the standards of drinking and public water
supply. A prolonged decrease in water level leads not only to a change in the mineral composition of water, but also to salinization of the soil and a decrease in biodiversity. The violation of the hydrological regime of rivers caused by hydraulic engineering construction leads to salinization and eutrophication of reservoirs. The decrease in the flow rate causes sedimentation and siltation of the reservoir. Washing out of the banks by currents occurs.

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