Estimation and forecasting method of water bodies overgrowth and siltation using geographic information systems on example of Kryukovskoye and Shapsugskoye reservoirs

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Abstract. The article presents research on the overgrowth degree of the Shapsugskoye and Kryukovskoye reservoirs. A new estimating and predicting method for water bodies overgrowth and siltation using remote sensing data (RSD) is proposed. As a result, the overgrowth degree of the considered reservoirs was determined from the beginning of their operation to 2019: 93.2% and 47.3% for the Shapsugskoye and Kryukovskoye reservoirs, respectively. A pattern of intensive growth periods of higher aquatic plants was found, according to which a forecast of further water bodies overgrowth was obtained.

1. Introduction
The overgrowth and siltation problems of water bodies are relevant today. The loss of useful water resources volume entails excessive reduction of fish populations, increasing the background concentrations of pollutants, a forced reduction of water withdrawal for domestic use and agriculture, reducing efficiency of energy generation by hydroelectric power plants and an increase in the rate of wear of hydraulic structures in the process of their operation [1].

The method proposed in this paper makes it possible to assess and predict the water bodies overgrowth and siltation in almost real time with a publicly available software product in order to make further management decisions on the reservoirs reconstruction (ponds, lakes, reservoirs).

2. Materials and methods
To determine the water bodies overgrowth boundaries for the period from 1984 to 2019, as well as to process the obtained data, we used: a public software product "GoogleEarthPro" with built-in tools, a compiler for writing program code "Python" and "Microsoft Word" for displaying a report on the state of water bodies. As examples to demonstrate the research, the following reservoirs were selected: Shapsugskoye and Kryukovskoye reservoirs, located in the Republic of Adygea and in the Krasnodar Territory, respectively.

To assess changes in the overgrowth boundaries of the Shapsugskoye and Kryukovskoye reservoirs, their satellite images, located in the open access of the GoogleEarthPro program, were used. The initial data for analytical calculation and water bodies overgrowth and siltation forecasting were obtained on the RusHydro website and on the NavionicsBoating program platform. Hydrological
characteristics (water level and volume, water surface area) in different time periods and maps of the reservoir bottom relief were used.

3. Results
Overgrowth assessment of ponds, lakes, reservoirs with higher aquatic plants is often made visually today, which is an inefficient method for large reservoirs, since there is a high probability of calculation error due to the considerable duration of territory exploration [2]. Aerial photography using unmanned aerial vehicles (UAVs) or remote sensing data (RSD) obtained from satellites allows you to get up-to-date data at a specific time, but such images have a relatively high cost, which makes it necessary to develop other assessing methods for water bodies overgrowth [3]. In this paper, we propose an assessing method using the publicly available software product "GoogleEarthPro". The tools of this software product contribute to the analysis of high-quality remote sensing data, since 1984.

Assessment of water bodies overgrowth using geographic information systems (GIS) can be performed using the following algorithm:

- Selection of satellite images for the considered observation period;
- Delineation of the water surface boundaries on each image for the entire period of research;
- Calculation of the reservoir overgrowth area relative to the water surface area at the initial stage of research;
- Data processing and forecasting.

During the research, by using built-in tools in GoogleEarthPro Kryukovskoye and Shapsugskoye reservoirs snapshots for the period from 1984 to 2019 (total of 72 images) were selected. The water bodies overgrowth assessment was made depending on the change visible in the images of the water surface. Using "RusHydro" data, the maps also marked the water surface boundaries at the time of the reservoirs operation start [4]. This is necessary to assess changes in the reservoirs overgrowth intensity.

The Shapsugskoye reservoir was put into operation in 1952 for a period of 50 years, and in 2002 the reservoir was emptied for the purpose of hydraulic structures reconstruction. By the end of its service life in 2002, the reservoir was overgrown by more than 50%, including on the dam site (figure 1).

![Figure 1. Changes in the water surface of the Shapsugskoye reservoir as a result of its overgrowth in the period from 1984 to 2019.](image-url)
The Kryukovskoye reservoir was put into operation in 1972 and according to the available data obtained during the research, from the moment of filling to 2019, this reservoir is overgrown by slightly less than 48% (figure 2).

Processing of data obtained from satellite images using the program code allowed us to identify a certain pattern of water bodies intensive overgrowth (table 1). The loss of water surface visibility at the dam site on both reservoirs accelerates the growth intensity and development of higher aquatic plants [5]. Perhaps this is due to the fact that vegetation, even in small volumes, has a significant impact on the water movement even during releases, forming "standing" waters that contribute to siltation and overgrowth.

| Year | Shapsugskoye reservoir | Kryukovskoye reservoir |
|------|------------------------|------------------------|
|      | Water surface area, ha | 72,1                   | 68,0 |
| 1984 | 3289                   | 2733                   |
| 1994 | 2405                   | 3465                   |
| 2000 | 2290                   | 3064                   |
| 2019 | 311                    | 2119                   |
| Plan | 4565                   | 4021                   |

So, on the example of the Shapsugskoye reservoir, you can see a sharp decrease in the area of the water surface between 1993 and 1994, due to reservoir overgrowth on the dam site. Further, its slow overgrowth continued until the end of its service life in 2002 (figure 3).
Almost the same situation has been observed at the Kryukovskoye reservoir since the partial overgrowth at the dam site in 1995 (figure 4).

According to the charts and trend lines, it can be concluded that overgrowth and, as a result, water bodies siltation will continue. Based on this, it is worth recommending a set of works on the reservoirs restoration, their cleaning and reconstruction.

**4. Discussion**

The method of assessment and forecasting of water bodies overgrowth and siltation considered in this paper can be used as monitoring for timely measures to face the excessive overgrowth [6]. It does not require serious time spent on the reservoirs exploration, and also allows you to analyze data that has not lost relevance [7].
Monitoring using this method will allow stable maintenance of 10-15% of vegetation over the water surface entire area, which will favorably affect such characteristics as:

- Conservation of the useful volume of water resources;
- Conservation of the fish population;
- Maintaining an environmentally friendly environment;
- Reducing the siltation intensity of reservoirs;
- Maintaining the volume of water withdrawal for municipal needs and agriculture;
- Improving the efficiency of hydroelectric power generation;
- Reducing the rate of wear of hydraulic structures during their operation [8].

5. Conclusion
In the course of the research work, a new method was proposed for assessing and predicting overgrowth and siltation of water bodies using geoinformation systems on the example of the Shapsugskoye and Kryukovskoye reservoirs. So, from the beginning of the reservoirs operation to 2019, higher aquatic plants covered 93.2 % and 47.3 % of the water surface of the Shapsugskoye and Kryukovskoye reservoirs, respectively. According to the forecast, in case of failure to take measures for reconstruction and cleaning, water bodies may become unsuitable for further use.

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