

Assessment of the Ecological State of Volga–Akhtuba Floodplain Water Bodies Using Remote Sensing Methods

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Abstract — Ecological condition of the Volga-Akhtuba floodplain strongly depends on the set of hydraulic structures (the hydroelectric power station and the reservoirs located on the Volga river) that is an important problem today. The effects of a serious anthropogenic intervention into natural river regime manifest as a decrease in the river's average flow rate and in balance violation of its water bodies' occupancy during the spring flood on the Volga-Akhtuba floodplain territory. This fact indicates the need for multilateral research on a par with continual monitoring of this biosphere reserve and the search for adjustment options of water discharge volumes and terms during the spring flood. We have studied the degree of flooding and the intensity of water bodies' overgrowth with higher plants. Also, the general ecological state of the floodplain was rated. In this article we used cartographic research methods based on remote sensing methods (RS) and geographic information systems (GIS). As a result, we established that floods of the last decade are characterized by insufficient water content of the river. The maximum volume of water discharges and the floods' duration in general trend is decreasing. Class of the “Medium overgrown lakes” (43,4 %) prevails among the studied remaining lakes.

Keywords: *Volga-Akhtuba floodplain, flooding, water bodies' overgrowth, higher aquatic vegetation, geographic information systems (GIS), remote sensing (RS)*

I. INTRODUCTION

Volga-Akhtuba floodplain's (VAF) landscape ecological complex is vulnerable to critical changes because of flooding conditions' deterioration which is caused by global reconstruction of Volga river streambed and its hydrological regime. Building of the Volga Hydroelectric Station, the Volgograd Reservoir and the other reservoirs located

upstream resulted in changing of Volga hydrologic features and forming of the massive geotechnical system. This system involves the upper route of the Volga-Akhtuba floodplain.

Controlling the river stream, the hydroelectric power station causes day and week cycles of changing the water depth and the flow rate in both upper and lower calan pounds. However, this factor is not the only one that violates the hydrological regime of specially guarded natural park's "Volga-Akhtuba floodplain" territory. Changes in the floodplain's hydrologic features are significantly caused by anthropogenic impact on its area. These activities transfigure hydrographic network's natural landforms such as river sleeves, anabranches, lakes, estuaries and others. Thus, all the aspects mentioned above lead to various problems in the Floodplain's ecological condition. As a result, VAF is undergoing vegetation overgrowth that causes loss of the water capacity [1], [2], [3], [4]. The natural topography change, meadow and water bodies basins' overgrowing in its turn damages the biodiversity of this geobiocenosis, the rich ornithological fund. Thereby, the above destructive factors directly or indirectly lead to various problems of the VAF ecological condition. The issue of VAF's watering monitoring and correction of the Volga-Kama cascade's operation is relevant and needs immediate interposition.

The study is to estimate the ecological state of different Volga-Akhtuba water bodies by remote space sensing and cartographic methods.

In order to do that, the following tasks were set and performed:

- to analyze the prevailing hydrological conditions at this moment of VAF water bodies` flooding conditions` assessment;
- to estimate the level of VAF territory`s flooding on the example of 99 water bodies located in its different parts;
- to determine the degree of water bodies` overgrowth in different VAF areas.

II. MATERIALS AND METHODS (MODEL)

In this paper we used cartographic research method based on Google Earth Web-cartographic source and Quantum GIS and ArcGIS geographic information systems [5]. To make a remote analysis of objects' state we have digitized 99 VAF's water bodies and have calculated lake basins', water mirrors` and its higher aquatic vegetation overgrowing squares [6].

The full list of researched VAF water objects and of shooting dates is presented below.

TABLE 1. SPACE SHOTS INFORMATION

Samp.	Water body`s naming (lake)	Shooting date
1	Nareznoye	06-06-2002
2-8	Davydkino; Deminskoe; Lopushistoye; Pet`kino; Shelkovaya Muala; Zolotoe; Zubovskiy Il`men`	10-05-2009
9	Degryatnoye	08-10-2009
10	Milekhino	01-06-2011
11-12	Chubatoye; Lebedinoye	06-06-2012
13	Zhestkovo	14-06-2012
14	Vitushka	09-08-2012
15-17	Karshikha; Semenovoye; Shnurovatoye	01-06-2014
19-21	Bolshaya Nevidimka; Malaya Nevidimka; Spomoye	25-06-2014
22-28	Bolshoi Il`men`; Danilino; Kustistyy Sadok; Raskatnoe; Sukhodol; Utinoye; Zumora	05-08-2014
29	Glukhoye	16-08-2014
30-92	Bakanovskoye; Baklanchik; Beketovskoye; Beschastnyy Liman; Bolshoi Pokrovskiy Liman; the Bolshyye Kuderminy lakes; Borunovskoye; Boyarskiy Liman; Chichyora; Chikamazy; Goreloye; Gusinyy Liman; Dvoinichnoye; Dvoinyashki; Dolgin`koye; Dubok; Kazachka; Kozel; Kochkamyy Liman; Kochkin Liman; Kosoye (Northern); Kosoye (Southern); Krinichka; Kunak; Kust; Kustik; Lesnoye; Marchenko; Mityaevoye; Muruzhnyy Liman; Nizhnyaya Shinkarka; Orlovskoe; Perereznoye (1); Perereznoye (2); Peschanka; Rach`ye; Razreznoye; Sadok; Savinki; Sazan`ye (1); Sazan`ye (2); Selyagino; Solyonye Plyosy; Solovyeyvo; Svetloye (1); Svetloye (2); the Svetlyye Limany lakes; Svetlyy Liman; Svinoy Liman; Talovoye (1); Talovoye (2); Topkiy Liman; Topolevoye; Uglovatoye; Utinoye; Shchuch`ye (1); Shchuch`ye (2); Shinkarka; Shirokogorloye; Shtany; Shuvaevskoye; Zhupirka	24-08-2014

Samp.	Water body`s naming (lake)	Shooting date
93-99	Bolshoye Vasino; Bolshaya Kulyazhka; Chaika (Eastern); Chaika (Western); Kochkovatoye; Kochkovatoye (Eastern); Kochkovatoye (Western)	04-09-2014

a. Several lakes have similar or same naming. To distinguish them from each other we noted the lakes with the same name by extra numbering or we added a geographical side of the world indication regarding a key object.

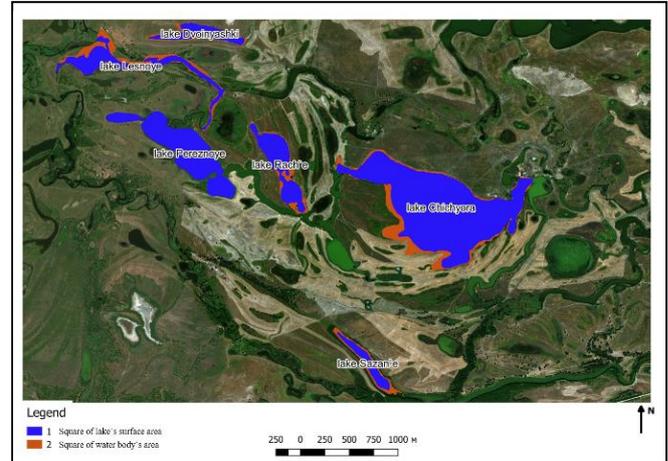


Fig. 1. Demonstration of the snapshot digitization (as example) with 6 lakes of the Volga-Akhtuba floodplain in Quantum GIS software

An example illustrating the results of VAF lakes' basin and water surface digitization during summer baseflow period is given in the article (Fig. 1). The geographic location of all selected for research water bodies is presented in Fig. 2. The information about each reservoir's shooting dates is displayed in Table 1.

We also used space images made in 2002, 2009, 2011, 2012 and 2014. Most shots are timed to the end of summer-fall baseflow. Water bodies` overgrowing areas were obtained as a result of digitization of images. The percentage of water bodies` overgrowing square was calculated relative to the total area of the basin.

We conducted an assessment of VAF lakes overgrowing by higher aquatic vegetation according to V.G. Papchenkov methodology dividing water objects into 8 classes depending on the percentage of overgrown territory of total area (Table 3) [7]. The data processing and its bar graph visualization were performed using GraphPad Prism 8 statistical analysis program.

III. RESULTS AND DISCUSSION

This research is divided into three separate logical parts in accordance with the tasks.

A. The prevailing hydrological situation during VAF overgrowing's assessment

We executed the Volga-Akhtuba floodplain hydrological situation's assessment relying on data of annual hydro-ecological monitoring since 2001 held by the ecological team of Volzhskiy branch of Volgograd State University

(Fig. 3). Further you can see brief hydrological characteristics of 2002, 2009, 2011, 2012 and 2014 Volga floods (Table 2) [8], [9].

- *The hydrological characteristic of 2002 Volga flood*

The 2002 flood may be characterized as "good" by total flow level. At the same time its hydrograph's ecological rating is "satisfactory" as the floodplain's middle tier had been watered up to only 19% [8], [9]. Maximum water costs were 26,100 m³ per second at the flood's peak. The flood was average in water level but long enough. The total duration was 65 days (from 20-04-2002 to 23-06-2002). The maximum water discharges period lasted 10 days, and the shallow fish spawning period took 25 days.

- *The hydrological characteristic of 2009 Volga flood*

The 2009 flood has been marked as "satisfactory" both by total flow level and by watering of floodplain's various tiers. The middle tier had been watered up to 28% [9] – that is slightly higher than in 2002. This is probably connected with bigger maximum water discharges at the flood's peak (27,040 m³ per second). However, this flood follows the same one of 2002 both by total flow level – as it was shorter (from 19-04-2009 to 09-06-2009) – and by maximum water discharges period – 3 days in total.

- *The hydrological characteristic of 2011 Volga flood*

The 2011 flood is unsatisfactory by total flow level and watering of floodplain's plant tiers. The middle tier had been watered up to 10%. The maximum water discharges were low – 24,990 m³ per second. The total duration is short – 44 days (from 21-04-2011 to 03-06-2011) as well as the maximum water discharges period – only 5 days.

- *The hydrological characteristic of 2012 Volga flood*

The 2012 flood's hydrograph is unique among all others of the last decades because it has two short-lived "peaks" and two shallow fish spawning periods. However, this experience was not long. To set the level corresponding to this consumption in floodplain's water bodies the spawning period should be continuous and last at least 8-9 days. The flood can be characterized as "satisfactory" by total flow level and by watering of floodplain's plant tiers. The middle tier had been watered up to 13% [9]. The maximum water discharges at flood's peak were 25,270 m³ per second. The total duration is short 53 days (from 23-04-2012 to 14-06-2012). The duration of the first "peak" is 6 days and the duration of the second one is 2 days.

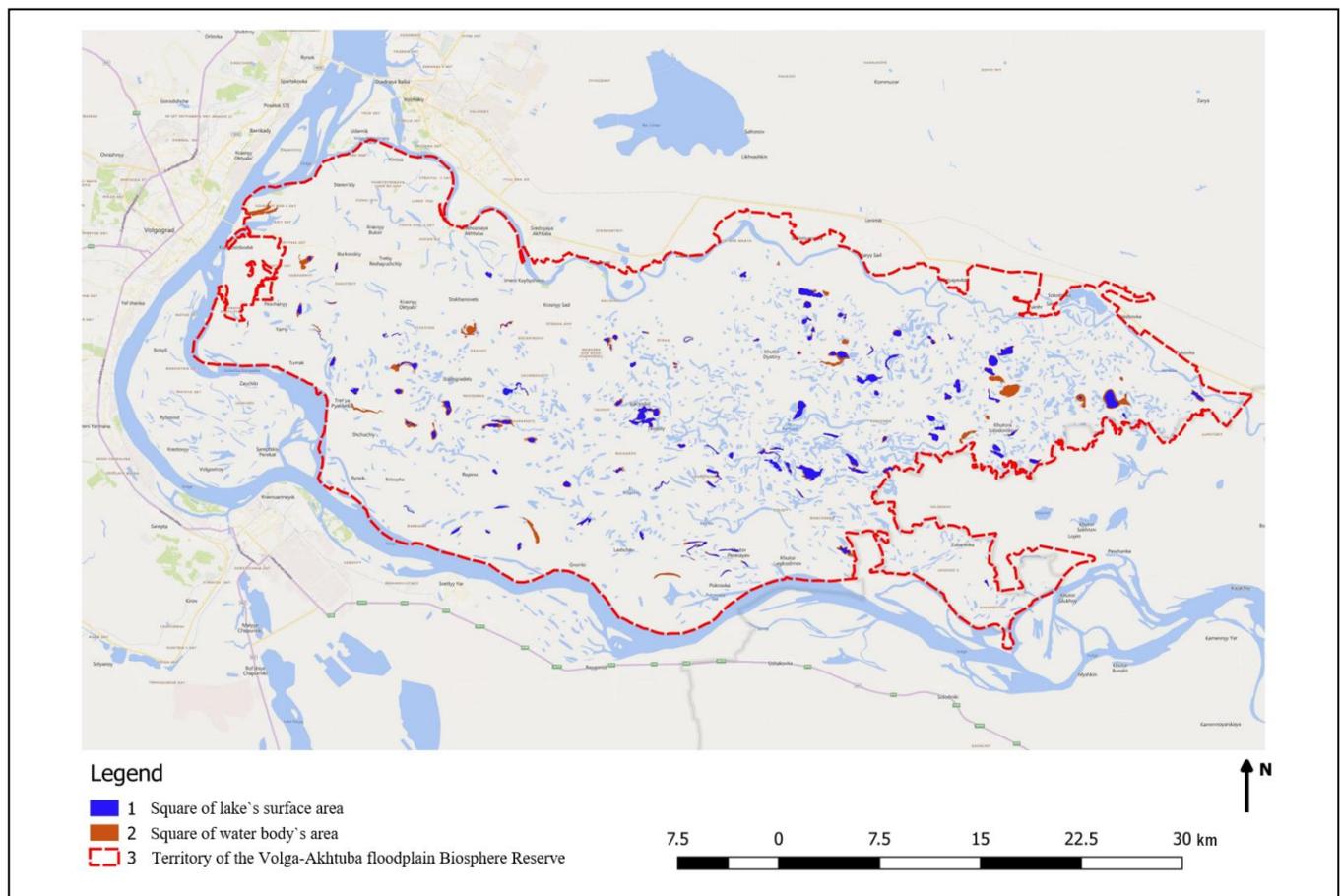


Fig. 2. The map of the studied water bodies` (lakes`) situated in Volga-Akhtuba floodplain biosphere reserve (Volgograd, Russia)

• The hydrological characteristic of 2014 Volga flood

The 2014 flood is unsatisfactory by total flow level and watering of floodplain's plant tiers. The middle tier had been watered up to 18%. The maximum water discharges were medium - 25,960 m³ per second. The very low watering was caused by the flood's brevity – only 41 days (from 23-04-2014 to 02-06-2014). The maximum water discharges period also lasted not so long – 5 days.

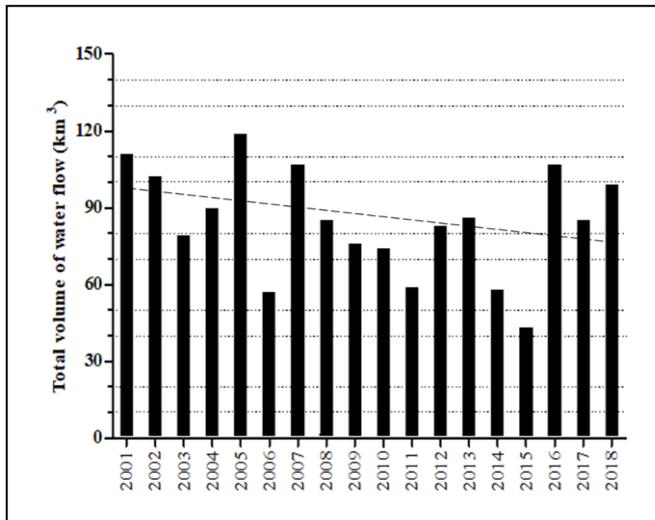


Fig. 3. The total volume of Volga's water flow change dynamics at flood periods from 2001 to 2018.

As you can see from the graphic (Fig. 3), we can generally characterize the floods of the last years as low water with its decrease tendency. The same trends we can see in maximum water discharges at floods' peak, their total duration and maximum water discharge period analysis. These factors hurt the Volga-Akhtuba floodplain water bodies' ecological state because such indicators show the Volga's flow rate insufficient for river sleeve and lake basins' irrigation; this decreases their water capacity [10]. Besides, with such low watering level the water cannot flood the upper tiers of the floodplain that leads to degradation of various species, including endemic, plant populations.

B. The Volga-Akhtuba floodplain territory watering level assessment

You can see the basin and water mirror area ratio of VAF lakes in the Fig. 4 and 5. From the presented diagrams we found the average lakes' occupancy is 76%. This situation is connected with unsatisfactory hydrological state during the last decades. We can watch easily the critical situation in a number of lakes watered on less than 30%, such as Pet`kino, Shtany, Deminskoye, Kosoye (Southern), Shelkovaya Muala, Sadok, Kochkovatoye. They are typical central floodplain's tier saucer-shaped and loped lakes with

small depth and area (almost all of the named lakes are less than 20 ha).

TABLE 2. FLOOD PARAMETERS FOR THE RESEARCH YEARS

Year	2002	2009	2011	2012	2014
Maximum water discharge volumes, (m ³ /sec)	26,010	65	10	25	102.07
Total flood duration (days)	27,040	52	3	24	74.22
Duration of maximum water discharges during spring flood (days)	24,990	44	5	11	56.82
Duration favorable for fish spawning period (days)	25,270	53	8	13	78.57
Total volume of spillway (km ³)	25,960	41	5	12	55.96

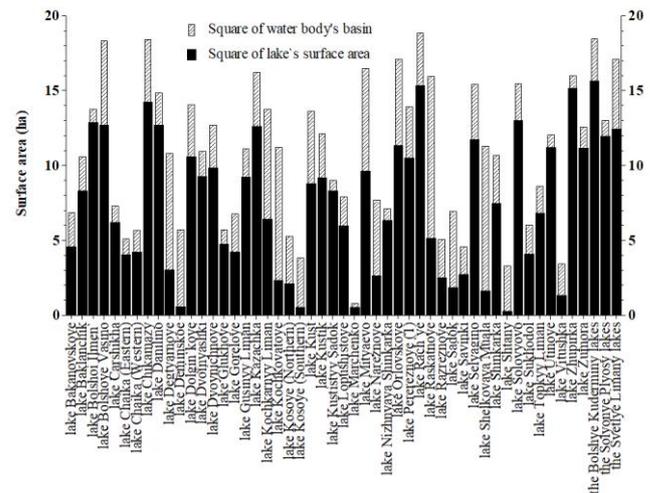


Fig. 4. Basin and water mirror area ratio of VAF lakes of less than 20 ha.

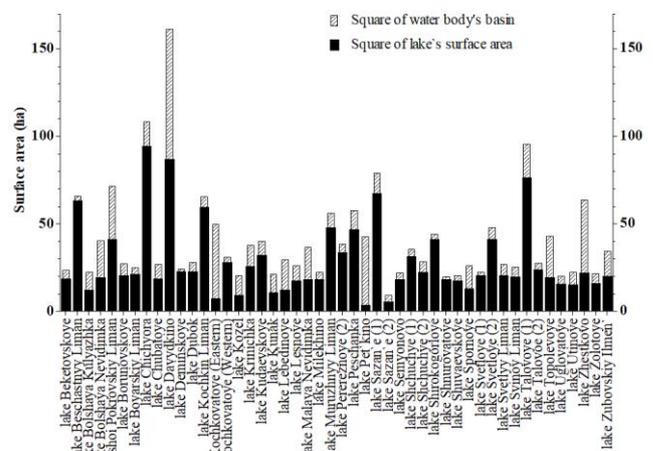


Fig. 5. Basin and water mirror area ratio of VAF lakes of equal to 20 ha or larger than 20 ha.

This causes their complete drying possibility in hot years. Such lakes' overgrowing threatens to the acceleration of silting process and to their water capacity decrease, which can cause freezing to the bottom and hydrobionts' death into these flood objects during winter low water.

C. Water bodies' overgrowing level assessment

You can see Papchenkov VAF water bodies' overgrowing level assessment procedure in Table 3. The analysis of 99 researched VAF water basin's overgrowing level result is showed in Fig. 6 and 7. All 99 lakes are divided into 2 groups: lakes of less than 20 hectares (Fig. 6) and lakes of equal to 20 ha or larger than 20 ha (Fig. 7).

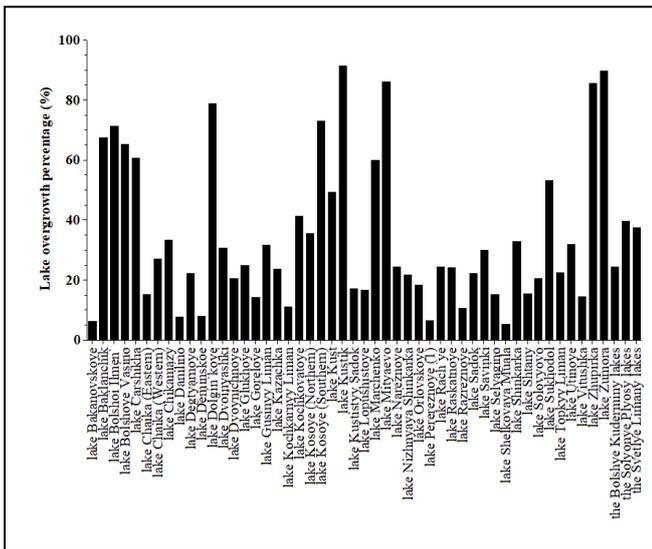


Fig. 6. Percentage of the basin's territory that has been overgrown with higher aquatic plants (%). Lakes with water mirror less than 20 ha

8	Completely overgrown	96-100	–
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The percentage of water bodies' cavity overgrown with higher aquatic vegetation zones, was estimated after digitizing the images. The whole territory of the lake's cavity was taken as 100%, the lake's overgrown parts of its area are calculated as a percentage.

As a result, all investigated 99 water bodies are divided into 8 classes in the following ratio: 2% – very weakly overgrown; 11,1% – weakly overgrown; 43,4% – middle significantly overgrown; 17,2% – overgrown; 10,1% – heavily overgrown. 0% – not overgrown or almost not overgrown, 0% – completely overgrown.

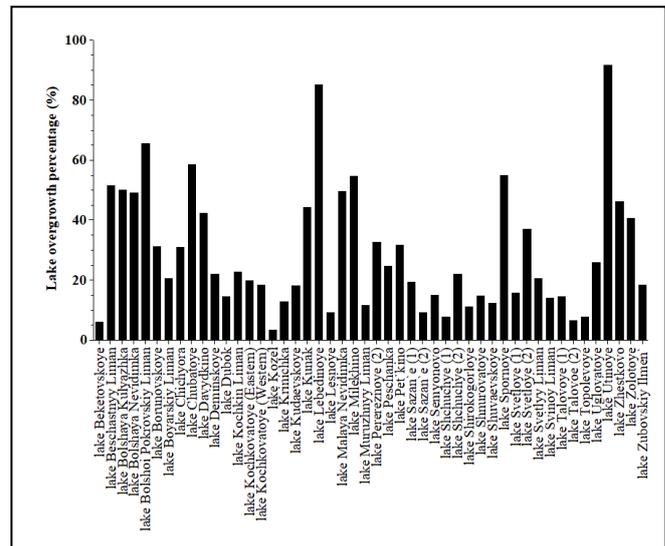


Fig. 7. Percentage of the basin's territory that has been overgrown with higher aquatic plants (%). Lakes with water mirror equal to 20 ha or larger than 20 ha

TABLE 3. THE DEGREE OF SOME SPECIAL SIGNIFICANT LAKES' OVERGROWTH BY THE HIGHER AQUATIC VEGETATION

№	Classification	The proportion of thickets area from the total area of the lake's pit (%)	Name of water bodies (lakes)
1	Not overgrown or almost not overgrown	<1	–
2	Very weakly overgrown	1-5	Beschastnyy Liman; Zhupirka
3	Weakly overgrown	6-10	Bolshoi Il'men'; Shirokogorloye; Utinoye
4	Middle overgrown	11-25	Baklanchik; Boyarskiy Liman; Chichyora; Dubok; Kudaevskoye; Kustik; Shchuch'ye (1); Svinoy Liman
5	Significantly overgrown	26-40	Chubatoye; Goreloye; Kust; Sazan'ye (2); Sukhodol
6	Overgrown	41-65	Bolshaya Nevidimka; Davydkiyo; Kozel; Mityaev; Malaya Nevidimka; Zhestkovo
7	Heavily overgrown	66-95	Degtyamoye; Raskatnoye; Sadok; Shtany

IV. CONCLUSION

The essential Volga-Akhtuba floodplain forming elements are its water bodies: lakes, shallow channels and anabranches which have an environment-forming function, they are concentrators of ecosystem's biodiversity. The hydrographic system of the northern part of the VAP is complicated and unique. Its state of which is determined by geomorphological features of the territory, volumes of water discharging during spring flood period and its duration. These are the most critical factors determining the vital changes in the floodplain's state – reduction of floodwater volumes [11], [12].

As a result of the studies, it was found that recent years are characterized by low flood water volumes. Maximum water discharge volumes and the total duration of floods have been declining over the last years. These circumstances have a destructive impact on the ecological status of the water bodies and the Volga-Akhtuba floodplain geobiocenosis in total. Lakes' basins do not fill up completely and water does not pour onto the floodplain territory in situations like this one. Among the studied lakes, "moderately overgrown" class is prevailing (43.4%). There is a lack of water bodies belonging to the categories "not

overgrown or almost not overgrown” and “completely overgrown” (0%).

Thus, a comparative analysis of the Volga-Akhtuba floodplain territory state by remote sensing methods showed that using these methods it is possible to evaluate the result of the territory watering after spring flood. These methods are useful for the rapid assessment of the current environmental situation, observations and can be used as primary source of information to make managerial decisions. Arranging a long-term practice of observation of the hydrological state of the Volga-Akhtuba floodplain using remote sensing methods will make it possible to predict the ecological problems and develop strategies to solve local and regional environmental issues.

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