Preliminary patterns of the formation abrasion-accumulative jumpers in the bays entrance gates of the lake area of the Volgograd Reservoir

M S Baranova, A I Kochetkova, E S Bryzgalina, O A Ob'edkova and D A Leont'ev

The Volzhskiy branch of the federal state autonomous educational institution of higher education Volgograd State University, 11, 40 Let Pobedy str., 404133, Volzhskiy, Volgograd region, Russian Federation

unlesi@mail.ru, maria_baranova2902@rambler.ru*, aikochetkova@mail.ru, bryzgalina_elena@mail.ru, obedkova.olga@yandex.ru, denis.leontev92@yandex.ru

Abstract. The article contents preliminary process patterns. They were obtained as a result of a researching of some representative bays of the Volgograd reservoir in 2019-2020, as well as an analysis of archival materials, maps and satellite images. The bays separation process depends on the primary volume, morphological features, lithological composition of the coasts, the speed and direction of wave, the frequency and repeatability of storms, and the anthropogenic factor. There are some differences in the formation of the abrasion-accumulative jumpers on the right and left coasts of the reservoir. It was previously established that current's speeds formative jumpers are 0.48-0.62, 0.63-0.78, 2.83-2.89, 3.60-3.64 m/s. The spatiotemporal dynamics of the formation and development of bays estuarine abrasion-accumulative jumpers of the Volgograd reservoir was revealed by our researching.

1. Introduction

Alongshore transport of sediments, resulting from the destruction of the coasts, caused a derivative process in the Volgograd reservoir. This process is the complete or partial separation of its bays from the main water area of the reservoir by abrasion-accumulative jumpers (AAJ). The process most actively develops at the lake area of the reservoir (from dam of Volzhskaja hydroelectric power station to Rovnoe village).

Articles of R. Bagnold (1947) [1], I.O. Leont'ev (2014) [2], J. Pegan et al. (2018) [3], S. Ouillon (2018) [4], A.O. Gorbunov et al. (2019) [5], E. Grottoli et al. (2019) [6], M. Hemmingsena et al. (2019) [7] and etc. are devoted to researching of alongshore sediment transport. The problem of formation of estuarine abrasion-accumulative jumpers was not investigated by these scientists. However, foreign and Russian experience was used by us when studying the processes of alongshore transport and sedimentation of sediments.

The process of bays separation from the main area of the reservoir by abrasion-accumulative jumpers is poorly understood now. The exception is some researching on Cimljanskoe [8, 9], Kujbyshevskoe [9], Kamskoe and Votkinskoe reservoirs [10, 11] and etc.

The first information about the formation of abrasion-accumulative jumpers in the entrance gates of bays within Volgograd reservoir we found in the articles of 1964 [8] and 1976 [12]. Work on the study
of alongshore transport of sediments and process of formation abrasion-accumulative jumpers was continued in 2008-2009 by collective of ecologists of Volzhskiy Humanities Institute (branch of Volgograd State University). Now it is the Volzhskiy branch of Volgograd State University. Head of work was candidate of geographical sciences O.V. Filippov [11, 13]. However, the formation of abrasion-accumulative jumpers, spatiotemporal dynamics, and the granulometric composition of the forming material has not been investigated, and the general ecological state of bays has not been studied at that time. This was done by us when conducting of this researching.

The process of overlapping entrance gates of bays by abrasion-accumulative jumpers is one of the regional ecological problems and it leads to the loss of a number of the Volgograd reservoir bays as a part of the feed base, spawning areas, feeding of juvenile aquatic organisms and their ecological habitat.

A complex approach when researching of bays and AAJ was used by us for a study of formation and development of estuarine abrasion-accumulative jumpers.

2. Materials and methods
Materials of this article were data from expedition researching of some representative bays of lake area of the Volgograd reservoir in 2019-2020; archival materials of expeditions on the project “Volga floating university” of Volzhskiy branch of Volgograd State University from 2008, 2010-2016; satellite imagery Landsat 1986-2016 [14] and Google Earth 2002-2018 [15]; maps from album of plans [16] and atlas [17].

Field and analytical research methods were applied in this work. Field methods include hydrostatic leveling, geometric leveling, sediment sampling, technical photography of work areas. Analytical methods contain cartographic method using GIS technologies, graphical method, mathematical methods, including the method of mathematical statistics. Separately, it should be noted granulometric analysis of sediment's samples using sieve method and linear particle measurement.

3. Results and discussions
This article contents results of processing and analysis of field expedition materials for 2019-2020, archival data for 2008, 2010-2016, maps [16, 17] and satellite images [14, 15]. We carried out this work in 2019-2020. Field researching of bays and analysis work of the received materials will be continued in 2021; therefore, the revealed patterns are still preliminary.

According to the results of the work 2019-2020, the following patterns of formation abrasion-accumulative jumpers in bay's entrance gates of the lake section of the Volgograd reservoir were revealed:

3.1. The primary volume of bay (bay's volume in 1958 [16, 17], when the Volgograd reservoir has been created)
The primary volume of bay is determinant, but not the only factor contributing to bay's separation. Small bays (with a primary volume of less than 300 thousand m$^3$) separates most actively, medium bays (300-1000 thousand m$^3$) separates a lesser degree.

Large bays (with a primary volume more 1000 thousand m$^3$) have not yet been closed by abrasion-accumulative jumpers. Two- and three-horned bays of the left coast are an exception. Thus gradually lost its branches and divided into two or three separate water areas, due to intensive destruction of the coasts near the entrance gate (the bays Ternovyj, Sharova Balka and etc.).

3.2. Morphological features
During the existence of the Volgograd reservoir, abrasion-accumulative shallows considerable in length (width 100-300 m and more) have formed near the both coasts of the Volgograd reservoir. This shallows proceeds in AAJ in entrance gates of bays.

Formation process of abrasion-accumulative jumpers in entrance gates are begun from the southern spit, which is formed and begun to increase earlier than the northern one on the most part of bays
(Rubezhnyj (figure 1), Shirokij, Vodjanoj bays and etc.). As a rule, forming southern spit is curved inward of the bay. The last peculiarity was noted as a classification feature of coastal accumulative forms by [18].

![Figure 1. Right-coast (southern) spit is actively formed in entrance gate of the Rubezhnyj bay (photo by authors, 24 July 2019).](image)

The entrance gates of bays located below (to the south) of the protruding coastal capes close more slowly (the bays Guseva, Rubezhnyj and etc.) because such capes limit the sector of the dispersal of wind waves.

Hole-like “pockets” or rynoks, formed under the influence of “frictional runoff currents” often shapes near bays entrance gates from the side of the reservoir (Boľshoj, Rostovýj, Drugalka bays and etc.). “Frictional runoff currents” contribute to the deposition of suspended sediments on abrasion-accumulative jumpers and spits.

The process of coastal destruction is less common on the lake area of reservoir to the north of the Butkovskij rynok (located in 201 km to north of the Volzhskaja hydroelectric power station). Here coastal deformations occur mainly due to river erosion. Bays to the north of the Butkovskij rynok also close more slowly (the bays Suhaja Osina, Bajdakov Ovrag and etc.). This is because of a shortage of building material due to a decrease in the energy of wind waves.

### 3.3. Lithological composition of Volgograd reservoir coasts

The right coast of the reservoir, mainly folded by sandstones (including opoka-like and siliceous sandstones), opoka-like clays and opoka, supplies pebble and gravel of all fractions, large dusty fractions to the estuarial AAJ. Presence of sand on the jumpers is determined by loose ore weakly compacted sands and sandstones in the composition of the coast.
Table 1. Prevailing sediments fraction on abrasion-accumulative jumpers and spits of some bays of the Volgograd reservoir.

| Name of the bay | Bay's separation year | Sampling points | A middle of AAJ or spit | An edge of Volgograd reservoir |
|-----------------|-----------------------|----------------|------------------------|-------------------------------|
| Drugalka | 2018 | AAJ | Medium pebble (50-20) | Coarse pebble (100-50) |
| Bol'shoj | 2006 | AAJ | Medium pebble (50-20) | Coarse pebble (100-50) |
| Verhniy Urakov | - | Left-coast spit | Coarse pebble (100-50) | Coarse pebble (100-50) |
| Bahchennyyj | 1991 | AAJ | Medium sand (0.5-0.2) | Medium pebble (50-20) |
| Ovrag-1 | 1991 | AAJ | Medium sand (0.5-0.2) | Medium sand (0.5-0.2) |
| Ovrag-2 | Until 1986 | AAJ | Medium sand (0.5-0.2) | Medium sand (0.5-0.2) |
| Krestishhenskaja Balka | 1991 | AAJ | Medium sand (0.5-0.2) | Coarse sand (1-0.5) |
| Nameless bay-1 | 2016 | AAJ | Medium pebble (50-20) | Medium pebble (50-20) |
| Tretij | 2002 | AAJ | Medium sand (0.5-0.2) | Medium sand (0.5-0.2) |
| Rubezhnyj | - | Right-coast spit | Medium pebble (50-20) | Medium pebble (50-20) |
| Suvodskij Jar | Until 1986 | AAJ | Medium sand (0.5-0.2) | Medium sand (0.5-0.2) |

| | | | Percentage prevailing fraction in a sample | Percentage prevailing fraction in a sample |
|-----------------|----------------|----------------|----------------------------------------|----------------------------------------|
| Right-coast bays | | | 62.2 | 51.2 |
| | | | 62.3 | 50.1 |
| | | | 68.8 | 64.8 |
| | | | 84.0 | 43.4 |
| | | | 71.6 | 28.2 |
| | | | 79.8 | 52.4 |
| | | | 47.2 | 47.2 |
| | | | 46.4 | 64.4 |
| | | | 56.9 | 66.9 |
| | | | 63.1 | 59.1 |

| | | | Percentage prevailing fraction in a sample | Percentage prevailing fraction in a sample |
| Left-coast bays | | | 87.8 | 36.2 |
| | | | 51.1 | 34.4 |
| | | | 81.8 | 73.9 |
| | | | 76.1 | 25.6 |

a Nameless bay-1 is the bay located 3.5 km to northeast from Krestishhenskaja Balka bay.
b Nameless bay-2 is the bay located 0.7 km to north from Karagacheva Balka bay.

The granulometric analysis showed that coarse (100-50 mm) and medium (50-20 mm) pebble prevail in composition of sediments of abrasion-accumulative jumpers and spits of right-coast bays of the Volgograd reservoir composed predominantly of pebble and gravel of all fractions. Fractions with a size from 100-50 mm (coarse pebble) to 10-5 mm (coarse gravel) were noted in some samples; small fractions with a size from 5-2 mm (medium gravel) to 0.1-0.05 mm (large dusty particles) are found in some samples. Medium (0.5-0.2 mm) and small (0.2-0.1 mm) fractions of a sand prevail in composition of sediments of AAJ and spits of right-coast bays folded predominantly by sand fractions. It was revealed a small percent of fractions with a size less 0.05 mm (predominantly these are small dusty and limous particles). Medium and small pebble is occurred in separate samples.

The left coast of the reservoir is composed by sandy loams, different fractions of sand, and, it is composed by loams to a much lesser extent; outcrops of khvalynskie chocolate clays are registered on a considerable length of the left coast. The left coast supplies on the AAJ, basically, sand of all
fractions; it is dusty particles (with a prevalence of small fraction), in a less degree, sometimes it is clayey particles.

Medium sand (size 0.5-0.2 mm) prevails in sediment's composition of abrasion-accumulative jumpers and spits of left coast. Size of sediments is from 10-5 mm (coarse gravel) to less 0.05 mm (small dusty, limous and clayey particles).

3.4. Some differences in formation of AAJ on right and left coasts

Large (with a volume of 1000-10000 thousand m$^3$) and very large bays (more than 10000 thousand m$^3$) of right coast have not yet been closed by abrasion-accumulative jumpers, as stated above. The final stage of AAJ separation of right coast is short in time (in some cases it is less than 3 years).

On the left coast the formation of abrasion-accumulative jumpers is slowed down because of the deficit of building material. Presumably, seiche currents prevents to formation of a bottom threshold in the entrance gates of this bays. The left coast for a long time exists in final stage of separation (up to 10-15 years).

Let’s dwell in more detail on differences in sediment's granulometric composition of estuarial abrasion-accumulative jumpers and spits of right- and left-coast bays of the Volgograd reservoir. Prevailing sediments fraction on abrasion-accumulative jumpers and spits of some bays presented in the table 1. It was noted that sediment samples were taken by us in the middle of the AAJ or spit and at the edge of the Volgograd reservoir.

According to the data in table 1, medium sand (size of particles is 0.5-0.2 mm) prevails on AAJ and spits of the left coast. Percentage of medium sand is higher in the middle of the AAJ or spit than on the edge from the Volgograd reservoir.

On the right coast medium sand fraction also prevails in the sediment's composition in the middle parts of bay's jumpers of Krestishhenskaja Balka, Tretij bay, Suvodskij Jar, Bahchennyj Ovrag-1, Bahchennyj Ovrag-2. Coatse sand (1-0.5 mm) forms more than 50 % sediments at the edge from the Krestishhenskaja Balka bay. Medium pebble (50-20 mm) prevails at the edge from the bay Bahchennyj Ovrag-1. Medium pebble also dominates in the middle parts of right-coast spit of Rubezhnyj bay and in the middle parts of AAJ of the bays Drugalka, Bol'shoj, Nameless-1. The main fraction at the left-coast spit of Verhnij Urakov bay is coarse pebble (100-50 mm). The sediment's granulometric composition is changed at the edges from the bays Drugalka and Bol'shoj, coarse pebble is also become the main fraction here.

The evaluitive calculation of current's speeds formative abrasion-accumulative jumpers and spits in this researching was done. We used the indirect method associated with granulometric analysis of sediment's samples. The calculation was carried out using the formulas of G.I. Shamov [19] and V.N. Goncharov [20], because these formulas provide the best convergence of results (table 2).

Table 2. The evaluative speeds of alongshore wind currents, formative abrasion-accumulative jumpers and spits (the calculation was done by [19] and [20]).

| Prevail sediments fraction in the granulometric composition of spit or AAJ (size of particles, mm) | Maximum current's speed, formative abrasion-accumulative jumpers and spits, m/s |
|-----------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------|
| Medium sand (0.5-0.2)                                                                         | 0.48 – 0.62                                                                    |
| Coatse sand (1-0.5)                                                                            | 0.63 – 0.78                                                                    |
| Medium pebble (50-20)                                                                          | 2.83 – 2.89                                                                    |
| Coarse pebble (100-50)                                                                         | 3.60 – 3.64                                                                    |

3.5. The spatiotemporal dynamics of the formation and development of bays estuarine abrasion-accumulative jumpers

The period of formation of the abrasion-accumulative jumper in the bays entrance gate, starting from the moment of its active growth, takes from 7 (Korotkij Lipovyj, Mostovoj bays and etc.) to 20 years (Bol'shoj, Birjuch'ja Balka bays and etc.) (it was determined by [14, 15]). The activation of the process
occurs during the formation of a jumper outside the coastal shallow, formed before the beginning of abrasion-accumulative processes in the Volgograd reservoir.

For example, active growth of the lower (right-coast) spit in the entrance gate of the Rubezhnyj bay has begun since about 2002 [14, 15]. Length of the spit has increased by about 20 meters. Expedition research of 2019-2020 confirmed that the bay is in the active stage of separation.

Beginning since 2006 the lower (right-coast) spit has been actively growing in the entrance gate of the Belen'kij bay, since 2014 there it has been a gradual increasing in the upper (left-coast) spit. Note that spits do not grow on one axis [15]. Researches of 2019-2020 confirmed that the bay is in the active stage of separation.

Activation of process of abrasion-accumulative spits formation is observed in entrance gate of Peschanij bay beginning since 2001 [14, 15]. The upper (right-coast) spit is formed more active. The bay was in final stage of separation in June 2019 (according to field data).

Our researching confirms the development (increase in width and length) of already formed abrasion-accumulative jumpers in time. For example, Bol'shoy bay was closed in 2006 [15]. An increase in the width of the AAJ of the Bol'shoy bay by about 15-20 m, according to Google Earth images, was happened from 2008 (first year of researching) to the present [15]. It was noted by field studies in 2019 that the emergence of new pebble ridges on the jumper near the reservoir edge.

3.6. Anthropogenic factor
Some forms of anthropogenic impact on the entrance gates of bays prevent to overlap of them. For example, entrance gates of some bays were cleared (the bays Suhoj, Kotlovyj, Tatarkina and etc.). In other cases, shore protection was carried out at the entrance gates of the bays (Kamyshinskij, Osadnyj bays and etc.) or near them (Belen'kij bay). This prevents the destruction of the coasts and the separation of the bay.

Other factors, contributing to the separation of the bay, are the speed and direction of waves, as well as the frequency and repeatability of storms in the Volgograd reservoir. These factors are actively worked out by the authors, because we do not present materials on thus here.

4. Conclusion
As a result of the study it was found that the separation process of the bays of Volgograd reservoir depends on the primary volume, morphological features, lithological composition of the coasts, the speed and direction of wave, the frequency and repeatability of storms, and the anthropogenic factor. There are some differences in the formation of the abrasion-accumulative jumpers on the right and left coasts of the reservoir. It was previously established that currents speeds formative jumpers are 0.48-0.62, 0.63-0.78, 2.83-2.89, 3.60-3.64 m/s. The spatiotemporal dynamics of the formation and development of bay's estuarine abrasion-accumulative jumpers of the Volgograd reservoir was revealed by our researching.

Acknowledgments
The reported study was funded by RFBR and Administration of the Volgograd region according to the research project № 19-45-343002 r_mol_a «The patterns of formation of abrasion-accumulative jumpers in the entrance gates of the bays of lake area of the Volgograd reservoir».

The authors thanks to candidate of geographical sciences O.V. Filippov, the head of the educational and scientific laboratory of ecological and social researches of the Volzhskiy branch of Volgograd State University, for invaluable advices in preparing this publication.

References
[1] Bagnold R A 1947 Sand movement by waves: some small-scale experiments with sand of very low density Journal of the Institution Civil Engineers 27 pp 447–469
[2] Leont'ev I O 2014 O raschete v dol'beregovogo transporta nanosov [About the calculation of alongshore sediment transport] Okeanologija 54 2 pp 226–232
[3] Pegan J, Lopez M, Lopez I, Tenza-Abril A and Aragones L 2018 Study of the evolution of gravel beaches nourished with sand Science of the Total Environment p 626

[4] Ouillon S. 2018. Why and How Do We Study Sediment Transport? Focus on Coastal Zones and Ongoing Methods Water 10(4) p 390

[5] Gorbunov A O, Kovalev D P and Kovalev P D 2019 Donnye nanosy, perenosimye techeniem v rajone razmyva berega zaliva Mordvinov (o. Sahalin) [Bottom sediments carried by the current in the area of destruction of the coast of Mordvinov bay (Sakhalin Island)] Geosistemy perehodnyh zon 3 2 pp 209–218

[6] Grottolia E, Bertoni D, Pozzebonc A and Ciavola P 2019 Influence of particle shape on pebble transport in a mixed sand and gravel beach during low energy conditions: Implications for nourishment projects Ocean and Coastal Management p

[7] Hemmingsena M, Eikaas H and Marsdena D 2019 A GIS approach to sediment displacement in mixed sand and gravel beach environment Journal of Environmental Management p 249

[8] Zubenko F S 1964 Berega Volgogradskogo vodohranilishha [Coasts of the Volgograd reservoir] Materialy k izucheniju pereformirovanija beregov Volgogradskogo vodohranilishha pp 78–124

[9] Baranova A I, Zubenko F S, Kudrjavceva E T, Radchenko Je K and Semenova N N 1967 Izuchenie fiziko-geologicheskikh processov na poberezh'jah i beregah vodohranilishhh po ajeronsnimka [Study of physical and geological processes on the coasts of reservoirs from aerial photographs] (Leningrad: Nauka, Leningradskoe otdelenie) p 283

[10] Nazarov N N 2013 O dvizhenii i akkumuljacii nanosov v beregovoy zone Kamskih vodohranilishhh na sovremennom stadii ih razvitija Dvadcat' vos'moe plenarnoe mezhvuzovskoe koordinacionnoe soveshchanie po probleme jerozionnyh, ruslovyh i ust'evyh processov Perm' [About movement and accumulation of sediments in the coastal zone of Kama reservoirs at the modern stage of their development] pp 32–42

[11] Nazarov N N, Nikonorova I V, Filippov O V and Frolova I V 2015 Krupnye akkumljativnye obrazovaniya beregovyh zon vodohranilishh [Large accumulative formations of coastal zones of reservoirs] Erozionnye i ruslovye processy Sbornik trudov pp 199-207

[12] Znamenskij V A and Ushakov B I 1976 Gidrometeorologicheskij rezhim ozer i vodohranilishh SSSR. Volgograd reservoir (Leningrad: Gidrometeoizdat) p 84

[13] Filippov O V, Zolotarev D V and Solodovnikov D A 2009 Ekologicheskie problemy zalivov i ust'evyh pritokov Volgogradskogo vodohranilishha v uslovijah abrazii i v dol'beregovogo transporta nanosov [The ecological problems of bays and estuarial tributaries of the Volgograd reservoir in conditions of abrasion and alongshore sediment transport] Problems of a comprehensive study of the Volgograd reservoir: collection of scientific articles pp 119-142

[14] U.S. Geological Survey [Available online https://www.usgs.gov/]

[15] Google Earth [Available online https://www.google.ru/intl/ru/earth/]

[16] Stalingradskaja jelestrostancija na reke. Al'bum planov sudovogo hoda na uchatke ot plotiny do Balakovo Volge (The Stalingrad power station on the Volga River. Album of plans of ship passage from dam to Balakovo) 1958 (Leningrad: Gosudarstvennyj institut proektirovanija na rechnom transporte Lengiprorechtrans) pp 54

[17] Atlas edinoj glubokovodnoj sistemy evropejskoj chasti RSFSR. Reka Volga. Ot Saratovskogo gidrobiul' dorozha do Astrahani [Atlas of a single deep water system of the European part of the RSFSR. The Volga River. From Saratov waterworks to Astrahan'] 1988 ed. I M Primatova and E T Miroshnikova (Moscow: Ministry of river fleet of the RSFSR) p 52

[18] Zenkovich V P 1962 Osnovy uchenija o razvitii morskih beregov [The foundation of learning about evolution of sea coasts] (Moscow: USSR Academy of Sciences Publishing House) p 710

[19] Shamov G I 1959 Rechnye nanosy [River sediments] (Leningrad: Gidrometeoizdat) p 380

[20] Goncharov V N 1954 Osnovy dinamiki ruslovyh processov [Basics of the dynamics of watercourses processes] (Leningrad: Gidrometeoizdat) p 452