RESEARCH PAPER

ANALYSIS OF THE BOTTOM TOPOGRAPHY OF THE RESERVOIR DUE TO SEDIMENT TRAPPING (ACCORDING TO THE KRASNODAR RESERVOIR, RUSSIA)

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ABSTRACT. Morphometric descriptions of reservoirs are usually limited to the type, shape, altitude position, bed size and volume of water in them. The article presents the results of the analysis of the bottom topography of the Krasnodar reservoir and the transformations of this for 2005-2021. The analysis was carried out based on the materials of bathymetric surveys for the usable volume of the reservoir on an area of 224 km^2 with the creation of digital elevation models. The topography of the reservoir bottom is represented by flat sections of flooded accumulative plain with prevailing slopes of about 0.2–0.4°, dissected by riverbeds of lower-order tributaries. The transformation of the topography is caused by gradual silting. The total volume of sediments for this area in 2005-2021 amounted to 127 million m^3 with an average siltation layer of 0.4 m. To describe the morphological properties of the bottom topography, we used geomorphometry techniques with the calculation of the BPI index (Bathymetric Position Index) and the classification of mesoscale topography forms based on it. For the riverbed, there are topography forms related to three types of surfaces: flat (Lower Bank Shelves), concave (Depressions, Deep Depressions) and convex (Reef Crests, Back Reefs, Mid-Slope Ridges). The constructed maps reflect the differentiated morphology of the bed surface, the evolution of topography forms and the change in roughness under conditions of continuous transformation of the basin and allow judging the prevailing morphogenetic processes. Morphologically, the coastal zone and the shallow part of the riverbed are the most difficult to construct. Here, along with long-shore reef crests of different genesis, deep depressions and simple depressions in the form of underwater channels on the deltas of extension can form on the accumulative shoal.

KEYWORDS: valley reservoir, sediment trapping, transformation, bottom topography, morphometric analysis, topography forms, Bathymetric Position Index (BPI), GIS, Krasnodar Reservoir

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INTRODUCTION

The Krasnodar Reservoir on Kuban River (Russia) was put into operation in 1973, and according to the classification is a large reservoir (Avakyan et al., 1987). The reservoir located in the south of Russia near Krasnodar on the border of two regions – Krasnodar Territory and the Republic of Adygea, has two key functions – flood control and irrigation. When filled to the design level in 1975, the area of the reservoir reached 400 km^2, and the total volume was about 3 km^3. The reservoir belongs to the valley type, has an elongated shape. It had a length of 46 km, a maximum width of 11 km with an average depth of 5.9 m and a maximum depth of 24.7 m at the initial stage of operation (Lurie et al., 2005).

The reservoir serves as a reference object of the entire irrigation system of Krasnodar Territory and the main source of water for rice crops in the lower reaches of Kuban River with an annual intake of water in about 3.3 km^3 for irrigation. In this sense, an important characteristic is the useful volume of the reservoir – 2.2 km^3 according to the design parameters. The peculiarity of the water regime is seasonal volume regulation with relatively large intra–annual amplitudes of the water level reaching 7 m in some years. This amplitude acts as a factor in the formation of the bed surface, contributes to the formation of significant areas of variable flooding, constant movement of the contact zone "water – land", and also affects the circulation of water masses.

Among the rivers of Russia, on which large reservoirs have been created, Kuban River has the highest turbidity – 0.68 kg/m^3. According to (Rules..., 2008; Alekseevsky et al., 2012), up to 95-98% of sediments brought by the river are deposited in the reservoir. According to our calculations, during 1973-2021, as a result of sediment trapping, the useful volume of the reservoir decreased from 2,160 to 1,270 million m^3, and the mirror area – from 400 to 224 km^2 (Pogorelov et al., 2022). Sediment trapping is accompanied by a continuous restructuring of the underwater topography due to interrelated geomorphological and hydrological processes – sediment deposition, changes in the local structure of currents, etc. (Litovka et al., 2019; Pogorelov, Laguta, 2020; Pogorelov et al., 2021, 2022). Note that the above processes are typical for a number of similar hydraulic structures (Zhang Wei et al., 2015; Andjelkovic et al., 2017; Honek et al., 2020; Shiferaw, Abebe, 2021; Li Xin et al., 2023). Of particular interest are studies related to the use of remote sensing (Dalu et al., 2013; Abaev et al., 2022) and having a long follow-up period (Peng, Chen, 2010; Liu, Lv, Li, 2021).

In the formation of the topography of the reservoir bed and its transformation, the leading role belongs to fluvial processes, of which delta formation processes are the most active. During the period of the reservoir's existence, the evolution of Kuban and Belaya river deltas significantly affected its morphometric characteristics (Laguta, Pogorelov, 2019; Pogorelov et al., 2021). Immediately after the filling of the Krasnodar Reservoir, the alienation of its north-eastern part – the former Tshchik Reservoir - started (Kurbatova, 2014), which was facilitated by the development of the delta of Belaya River, the preservation of the old dam and the collapse of the Tshchik Reservoir. At certain elevations, the section of the former Tshchik Reservoir lying above did not become riverbed, which is usually characteristic of valley reservoirs. At present, the estranged Tshchik Reservoir has its own circulation conditions and sediment deposits.

According to our calculations for the period 2005-2021 (Fig. 1) the volume of sediment accumulation in the main reservoir without taking into account the separated Tshchik Reservoir and deltaic sediments of the dividing bridge amounted to 127 million m^3 (Pogorelov et al., 2022). The maximum volumes of sediments and sedimentation rates during the removal of suspensions were recorded in the deltas of Kuban and Belaya, the smallest – in the dead volume area, i.e. in the western (deepest) part of the basin. As we can see (Fig. 1), the underwater topography near the shore is most susceptible to transformations, where in the process of active long-shore and transverse sediment transport, the continuous formation and transformation of accumulative and abrasive forms occurs. The activity of topography formation in valley reservoirs in the zone of long-range transport with the formation of mesoscale forms is confirmed (Finarov, 1986; Nazarov et al., 2011; 2013). The presence of local negative landforms (pits) is the result of limited technogenic removal of bottom sediments in 2005-2021. The total area of such forms is 13 km^2.

Standard morphometric characteristics of reservoirs adopted in hydrometry reflect the type, shape, altitude position, size of the bed of reservoirs and the volume of water in them. However, little attention is paid to the study of bottom morphology, despite its role in the formation of integral morphometric parameters. The reason is the difficulty of obtaining the source data. In this regard, we note a number of works (Van Maren et al., 2013; Su Teng et al., 2015; Mahfouz, Dekhkanova, 2019; Liu et al., 2020; Wang Yanjun et al., 2020). At the same time, the geomorphological features of the reservoir bottom topography, as well as the dynamics of the topography, are key ones to understanding the processes of reservoir transformation and forecasting its morphometric characteristics (area, depth, volume of water at different levels, bathygraphic and volumetric curves of the reservoir, etc.). With the development of spatial analysis tools using DEM (Zemlyanov et al., 2011; Kalinin et al., 2018; Akylbekov et al., 2022), including geomorphometry tools (Geomorphometry..., 2009; Florinsky, 2021), the analysis of the bottom topography of reservoirs has reached a new technical level. Studies have appeared related to the modeling of sediment trapping of reservoirs based on channel, erosion and related processes (Suresh Babu et al., 2000; Yutsis et al., 2014; Zhou Yongqiang et al., 2015; Alahiane et al., 2016; Rakhuba and Shmakova, 2022).

The morphological properties of the bottom topography of the Krasnodar reservoir have not been studied and are of particular interest from the perspective of its long-term evolutionary transformations. The article reveals the main tasks:

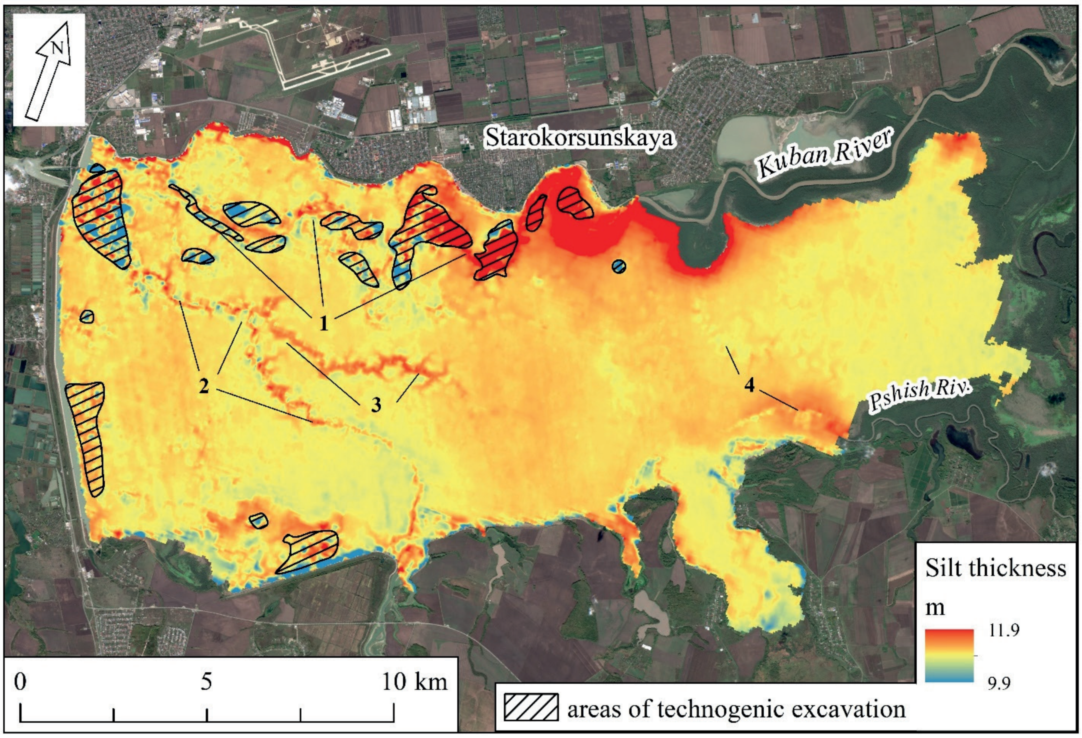

Fig. 1. Increment of the sediment trapping layer of the Krasnodar Reservoir over the period 2005–2021. Flooded riverbeds of Kuban (1), Psekups (2), Tuapcha (3) and Pshish (4) river

1) to describe the morphological properties of the underwater topography of the Krasnodar reservoir using geomorphometry techniques, to determine the main topography forms of the reservoir basin and build appropriate maps;

2) to establish long-term morphometric changes caused by the restructuring of underwater and surface (shallow water, shore) topography, to assess the intensity of deformations of the reservoir bottom.

3) to identify the dominant morphogenetic processes to establish the regularities of sedimentation, the nature of its manifestation in the topography of the bed and the coastal zone.

MATERIALS AND METHODS

The analysis was carried out according to bathymetric surveys of the Krasnodar Reservoir made with the participation of the authors in 2005 and 2021. Bathymetric surveys were carried out in accordance with (Guidance Document ..., 2012); the methodology of field research and processing of raw materials is described (Laguta, Pogorelov, 2018). Bathymetric surveys 2005 and 2021 are of the same type in terms of technical support, tacking and density of sounding points. The surveying conditions of different years did not affect the final DEM and the correctness of the comparative analysis. Morphometric analysis and calculations were performed using pre-constructed digital models of the reservoir bottom topography with a spatial resolution of 50 m (Fig. 2). The features of the operation of the reservoir in the period 2005–2021 generally should be considered ordinary: the fully supply level was reached annually with significant seasonal level variability. During this period, the reservoir provided anti-flood and irrigation functions against the background of a permanent decrease in its useful capacity. Since in the process of transformation of the reservoir, its north-eastern part (the former Tshchik Reservoir) separated from the main basin of the reservoir, the main calculations were performed for the regulated section of the Krasnodar Reservoir with an area of 224 km^2 (Fig. 1).

Morphometric analysis included the recognition of surface elements and assessment of the roughness of the bottom of the Krasnodar Reservoir by DEM. The classification of morphometric surface elements by DEM is based on the method of calculating the BPI (Bathymetric Position Index) and classification of morphological elements based on it (Guisan et al., 1999; Weiss, 2001). This index, being a modification of the TPI index (Topographical Positions Index) (Jenness, 2006), is focused on working with bathymetric survey materials. Until now, it has been used mainly to study the topography of the seabed (Wilson et al., 2007). The BPI index is multiscale and involves the construction of "rough" (Broad-BPI) and detailed (Fine-BPI) bitmaps. The calculation of the BPI was preceded by the conversion of the original DEM into a bathymetric model; at the same time, we selected the forced level of 35.23 m as zero, and assigned negative values to the heights.

BPI is the difference between the absolute height of a given point (in the raster layer – cells) and the average height of points in a given buffer around the source point. Positive index values correspond to surface bulges; negative values correspond to concave shapes; values near 0 indicate that the surface is close to flat. To reduce the effect of autocorrelation of the initial data on the results of morphometric classification, we use the normalized index value (Weiss, 2001). Normalization is carried out according to the formula:

$$BPI = int\left(\left(\left(\frac{BPI - mean_{BPI}}{\sigma_{BPI}}\right)\times 100\right)+0.5\right) \quad (1)$$

where BPI_{sd} – normalized value of *BPI*, int – conversion to an integer, meanBPI – average value of the *BPI* index (across the entire dataset), – the mean square deviation of the BPI index values (across the entire dataset).

In addition to the raster layers of the Fine-BRIL and Broad-*BPI* indexes, a slope map and a bathymetric map are needed to recognize (classify) elementary landforms. The number of classes, their name and morphometric parameters are set by the user in CSV format. The procedure for isolating morphometric elements of the

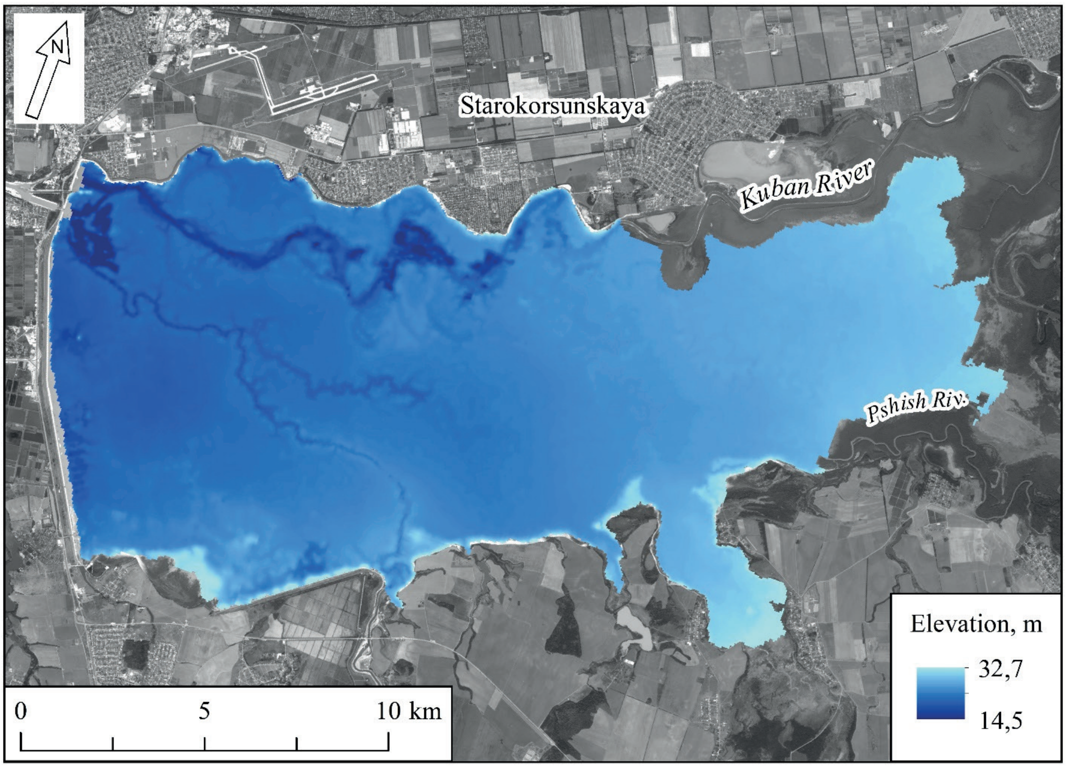

Fig. 2. Digital elevation model of the bottom of the Krasnodar Reservoir, built according to the 2005 survey data

bottom surface is described (Verfaillie et al., 2007). We have experimentally established the parameters for calculating the BPI index, which provide an optimal level of detail of the bottom topography forms in relation to the spatial resolution of DEM. A search box in the form of a ring with specified internal and external radii was used (Table 1). When choosing the parameters, we were guided by the sizes of recognized positive and negative forms of the bottom topography of the reservoir under study, which we refer to mesoscale, namely, long-bank shafts with their ridges and slopes, depressions and deep depressions.

The reconstruction of the bottom topography under the influence of silting was analyzed using roughness parameters. From the point of view of morphology, the ruggedness index can be interpreted as a measure of the complexity (heterogeneity, variability) of the topography. There is no generally accepted method for calculating ruggedness: we have applied the index of Terrain Ruggedness Index (TRI) (Riley, 1999) and Vector Measure of Ruggedness (VRM) (Sappington, 2007; Hobson (1972). Ruggedness parameters were calculated according to DEM data in a sliding window of 3×3 cells.

RESULTS AND DISCUSSION

Features of the bottom topography

Among the morphometric features of the Krasnodar valley reservoir that determine the restructuring of the topography, we highlight the following: the topography of the reservoir bottom inherited both elements of river valleys with cut-in channels (Kuban, Pshish, Psekups) and extensive fragments of a flat plain that existed before flooding in 1973-1976. The Kuban riverbed, flooded near the right bank, is particularly well traced (Fig.. 2). The Kuban valley on the reservoir site is characterized by transverse asymmetry, namely, a high steep right bank descending into the old Kuban riverbed, and a gentle sloping left bank with a weakly pronounced terrace. Between the banks there is a plateau-shaped slightly dissected surface. Currently, there is an increased accumulation of sediment in flooded riverbeds in comparison with the background (Fig. 1). In the flooded riverbed of Kuban, which has maximum depths, the turbid flow is localized. Hydrodynamic activity here manifests itself in a special way: the jet in the flooded channel of Kuban is pressed against the right bank, which contributes to intensive erosion of the shore until an accumulative body is formed in the form of a retractable delta.

The predominant process in the topography formation of the bed during the study period is the gradual leveling of its surface, leveling from above in the process of continuous sediment trapping. The average thickness of silt layer in the studied water area for 2005-2021 was 0.40 m; the variability of the sediment trapping layer thickness over an area of 224 km^2 is characterized by a standard deviation of 0.81 m. The average slope of the bed surface in 2005 was 0.20°, in 2021 – 0.18°. A decrease in the average slope is an obvious sign of gradual leveling of the bed during silting. Elevated slopes on the accumulative plain, as a rule, mark the flooded coastal slopes of river valleys.

Elementary forms of topography: selection and analysis

Against the background of these geomorphological features, it is of interest to reveal the elementary topography forms of the accepted methodology (Fig. 3), as well as the dynamics of the transformation of these forms for 2005-2021. (Fig. 3, Table 2). Examples of terrain profiles divided into morphological types of landform elements are shown in Fig. 4.

In the process of classifying the surface of the reservoir bed, six morphological elements were identified (Table 2, Fig. 3, 4), belonging to three categories of surfaces: flat (plateaus), concave (depressions) and convex (shafts and their slopes). Let us consider the origin and dynamics of each one and the selected elementary forms of the reservoir basin.

According to the survey data of 2021, 89.2% of the reservoir area is occupied by an accumulative plateau-type plain, which before flooding was the Kuban floodplain, dissected by riverbeds. The prevailing slopes within the plain are 0.1–0.4°. The concept of a plateau reflects to the greatest extent the basic properties of this form of topography – plane, flatness.

Negative forms – hollow-shaped depressions and more pronounced elongated depressions – occupy 2% and 4.1% of the area, respectively. Genetically, the depressions have different origins: some belong to flooded riverbeds, some to the concave foothills of long–bank accumulative form – ridges. At the same time, old channels in the process of silting and reduction of the inclined surface as a result of the action of denudation demolition evolve in the sequence "depression – deep depression – lower bank shelf", and newly formed channels (for example, in the delta of Pshish River) form depressions during embedding. The most difficult in the morphological sense is the coastal area and the shallow part of the bed (littoral), where, along with positive topography forms (long-shore shafts), negative forms (depressions) can form on the accumulative part on the abrasive part of the shoal.

The flooded valleys of Kuban, Psekups and Tuapcha rivers (the former right tributary of Psekups) are well expressed in topography. During the study period, the valleys of the last two were divided into separate sections and are currently evolving towards the plateau. In general, the share of depressions in the total area of the reservoir bed is decreasing, which cannot be said about the depressions (Table. 2), some of which are formed in the areas of newly formed banks of fluvial origin – deltas of extension.

The positive elements of the morphology of the bed are represented by a group of wave-like forms, within which we distinguish three elementary forms: reef crests, back reefs, mid-slope ridges, frontal (distal) slopes and rear (proximal) slopes. As in the case of the group of negative landforms, the origin of the ridges is different. And is genetically determined by the contribution of accumulative (alluvial) and abrasive processes (see below). The location of the characteristic genetically homogeneous elementary forms is illustrated in Figure 5. We reveal the following genetically homogeneous topography forms.

Table 1. Accepted parameters for calculating the BPI index

Index	Form of the search box	Inner radius		Outer radius	
		number of cells	m	number of cells	m
Fine-BPI	Ring	3	150	5	250
Broad-BPI	Ring	5	250	30	1500

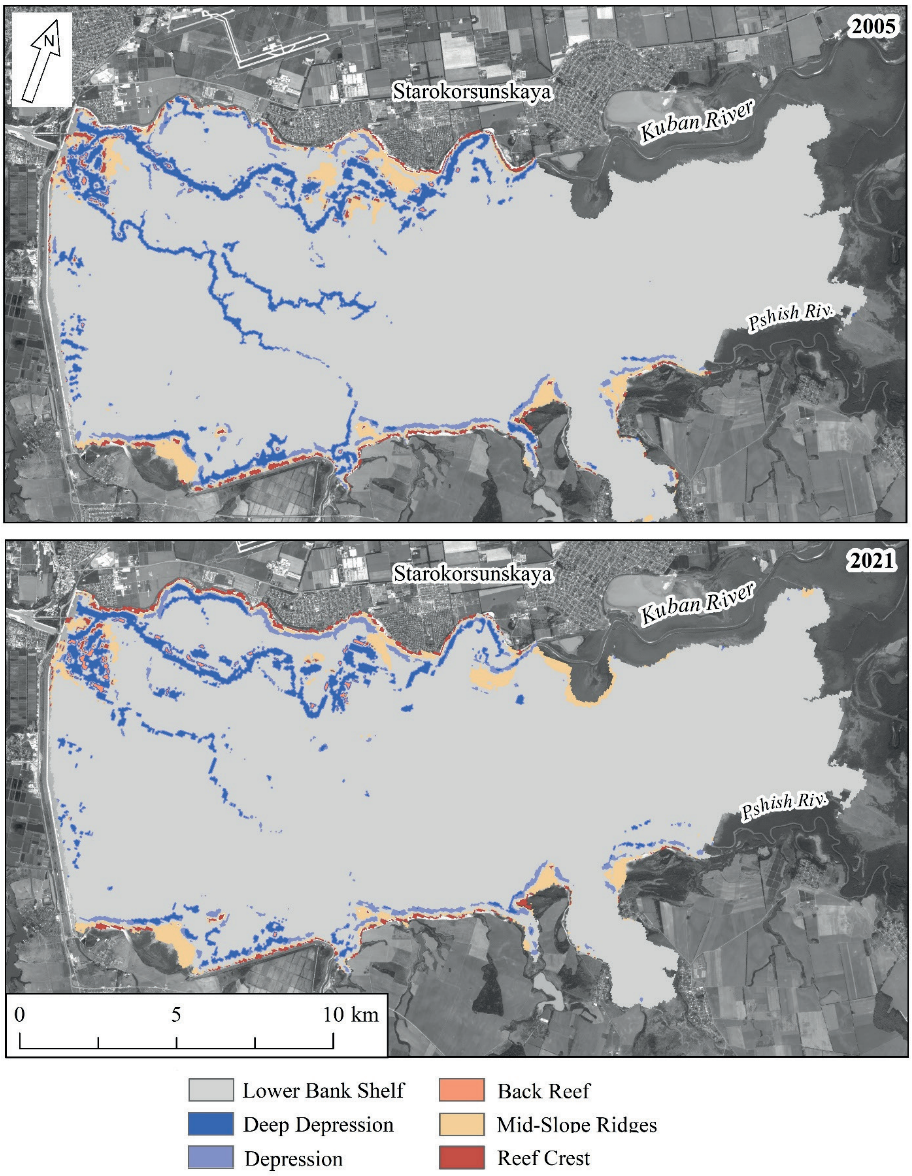

Fig. 3. Reservoir bed topography forms identified based on survey data from 2005 and 2021

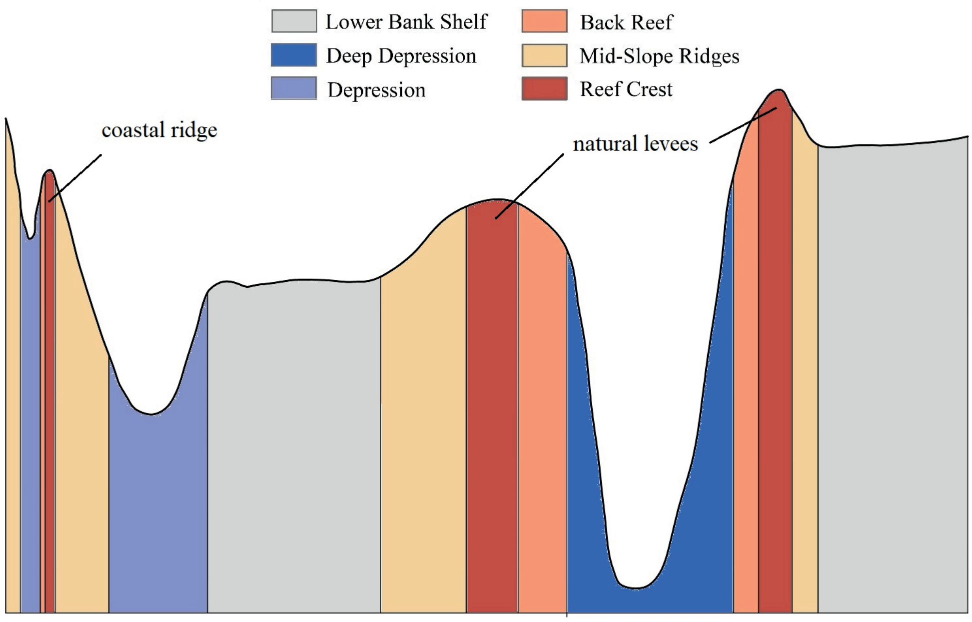

Fig. 4. Examples of terrain profiles divided into morphological types of landform elements

Table 2. Morphological elements of the bottom surface of the Krasnodar reservoir and their change in 2005–2021

Form of topography	2005			2021		
	Number of fragments	Area		Number of fragments	Area	
		ha	%		ha	%
Plateau (Lower Bank Shelf)	280	19787	88,3	222	19984	89,2
Depression	258	387	1,7	257	438	2,0
Deep Depression	172	1172	5,2	184	919	4,1
Mid-Slope Ridges	197	640	2,9	212	666	3,0
Reef Crest	208	317	1,4	166	295	1,3
Back Reef	144	98	0,4	92	98	0,4

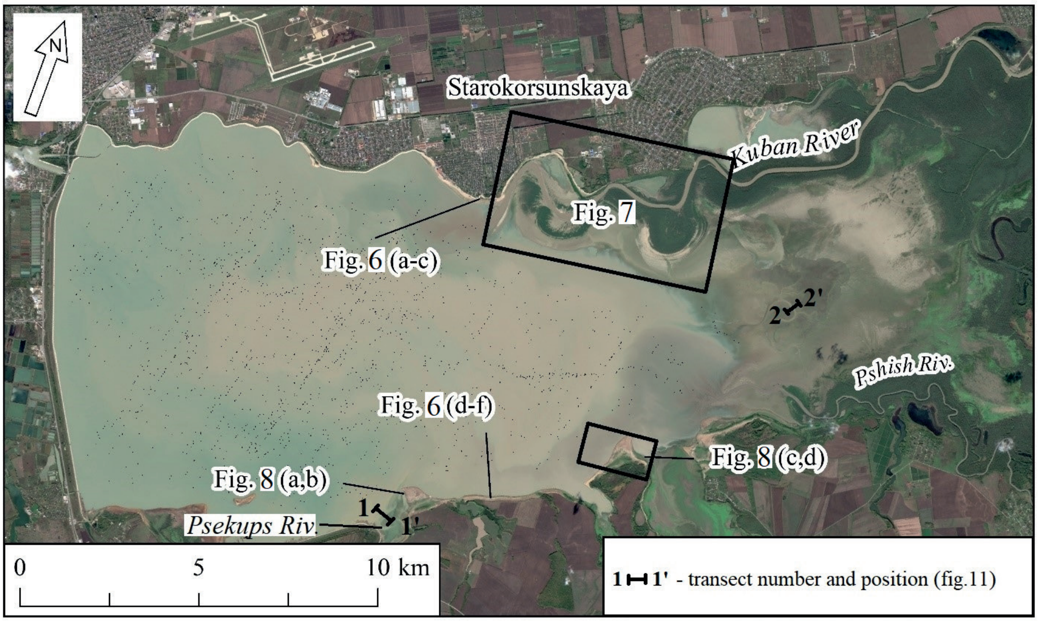

Fig. 5. Location of typical genetically homogeneous topography elements

1. In the littoral zone of the reservoir (coastal shoal) as a result of the transverse movement of sediments under the influence of the surf, accumulative forms – coastal ridges - have been formed both at abrasive and non-abrasive shores. Morphologically, the crests and mid-slopes of the ridges are expressed here, as well as the depressions separating the coastal ridge from the underlying lower bank shelf. The rear (shore-facing) slopes are not detected at the scale determined by the spatial resolution of the survey. The images (Fig. 6 a-e) accurately illustrate the series of coastal ridges, which has two main reasons – variable reservoir backwater and different intensity of waves. These two circumstances determine the limits of localization of the considered topography form. Long-shore ridges are also formed under the influence of the fluvial factor of morpholithogenesis - solid river runoff with a volume in the total material balance exceeding the contribution of the surf. The natural movement of the mouth as a source of sediment in the process of delta growth causes a constant change in the conditions of the formation of coastal ridges, giving rise to their new generations with the release of old ridges from wave surf effects (Fig. 7 a-b).

2. In the deep part of the reservoir bed, the natural levees of flooded riverbeds have been preserved. This form is found fragmentally along the flooded channel of Kuban River (Fig. 3). The presence of rudiments of the rear slopes of the ridges (here – facing inward to the channel), despite the loss of integrity as a result of long-term anthropogenic impact, indicates their former massiveness.

3. In addition to the above, reef-like forms are formed in the form of a naes or a tombolo connecting the uplands that existed before the flooding with the shore in the presence of a wave shadow (tombolo effect) (Fig. 8 a-d).

Consider the evolution of this topography. During the analyzed period, the coastal areas of the bottom, as well as flooded riverbeds (Fig. 9) and, accordingly, elementary landforms located in these areas were most subjected to morphological transformations. The transformations affected 34.1 km^2 or about 15% of the analyzed reservoir area. The differentiated nature of morphological transformations is reflected in Table 3.

When analyzing the transformation of convex forms, the following should be taken into account. Due to the almost complete overgrowing of the littoral of the reservoir in the zone of delta formation, most of the coastal ridges that have left and are leaving the zone of wave action by 2021 turned out to be inaccessible for bathymetric survey. Comparison of two different-temporal DEMs does not fully cover the boundary of the 2005 survey. Within the comparison boundaries, among the convex landforms (Reef Crests, Back Reefs and Mid-Slope Ridges) identified in the 2005 survey, there are still no coastal ridges formed with the participation of the fluvial process, although in the 2021 survey their participation in this category reaches up to 30%. With comparable areas of convex landforms in 2005 and 2021 (Table 2), their significant differences in genesis should be noted. The differences are due, on the one hand, to the appearance and development

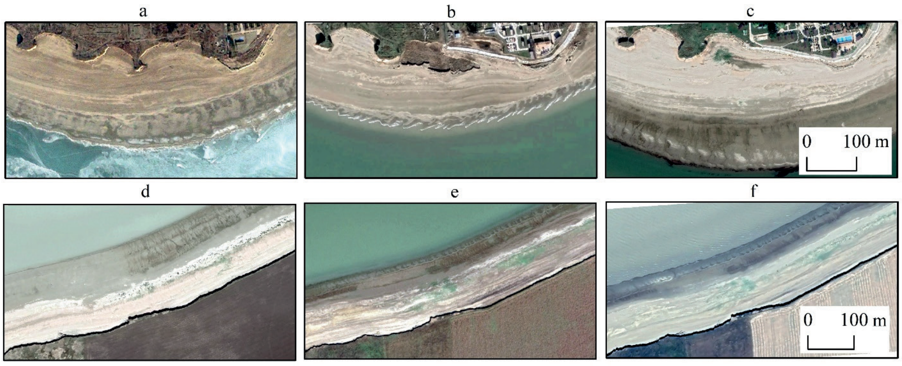

Fig. 6. Formation of characteristic convex topography forms – coastal ridges and their slopes. Imagery data: 30.12.2012 (a), 24.11.2016 (b), 18.10.2018 (c), 09.09.2014 (d), 24.09.2014 (e), 28.09.2017 (f). Maxar Technologies

Fig. 7. Generations of coastal ridges of the growing advanced delta of the Kuban River. Imagery data: 23.09.2014 (a), 18.10.2018 (b), 18.12.2022 (c). Maxar Technologies

Fig. 8. Formation of reef-like forms of topography in the form of a naes or a tombolo. Imagery data: 17.08.2005 (a), 28.09.2017 (b), 30.05.2013 (c), 30.12.2012 (d). Maxar Technologies – a, d; CNES / Airbus – b, c

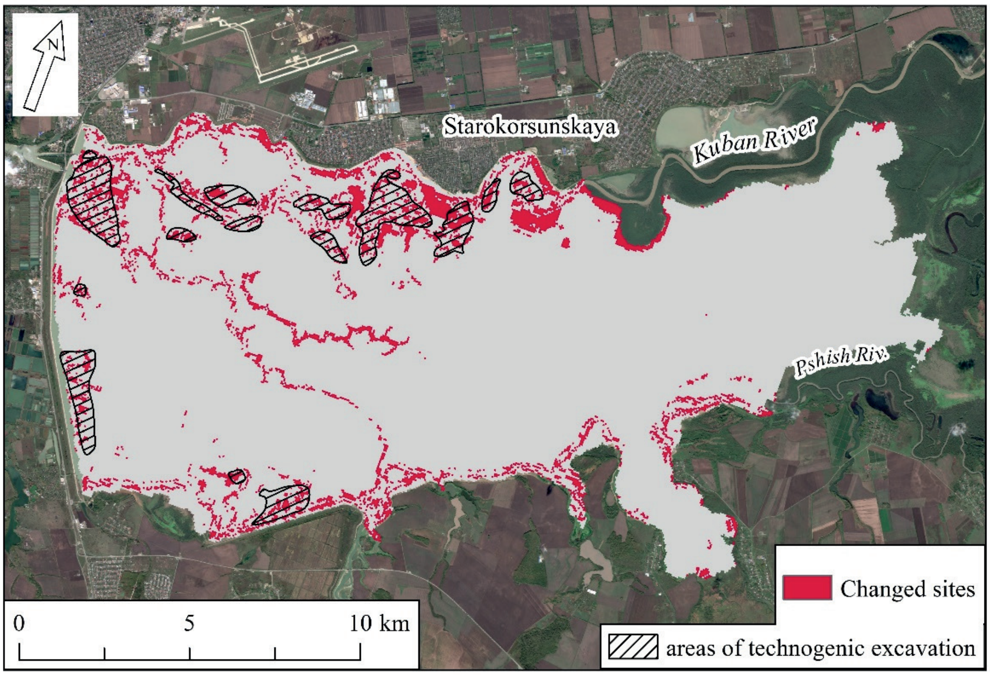

Fig. 9. Bottom areas subjected to morphological changes in 2005–2021

Table 3. Morphological transformation of the identified elementary landforms during 2005–2021

Topography forms		Area, ha
2005	2021	
Lower Bank Shelf	Back Reef	52
	Deep Depression	303
	Depression	179,25
	Mid-slope Ridges	232
	Reef Crest	31,5
Depression	Depression	29
	Lower Bank Shelf	165,75
	Mid-slope Ridges	11,75
	Reef Crest	0,75
	Back Reef	0
Deep depression	Reef Crest	6,5
	Deep depression	39,25
	Lower Bank Shelf	525
	Mid-slope Ridges	6,75
	Reef Crest	5,75
Mid-slope ridge	Back Reef	2
	Deep depression	5,75
	Depression	36
	Lower Bank Shelf	225,75
	Reef Crest	41,25
Back Reef	Depression	7,5
	Deep depression	0,75
	Plateau	53
	Mid-slope Ridges	0,5
	Reef Crest	9,5
Reef Crest	Back Reef	9,75
	Depression	3,75
	Deep Depression	4,75
	Lower Bank Shelf	78,75
	Mid-slope Ridges	76,75

of swells on potamogenic (deltaic) shores and, on the other hand, to the reduction in the area of ridges near the abrasion-type shores. A significant part of the Back Reefs and Mid-Slope Ridges are new forms formed on the former plateau, which reflects the intensity of the formation of new banks in the reservoir.

Negative surface shapes have also undergone transformations. The area of depressions tends to decrease, the area of hollows tend to increase (Tables 2, 3). At the same time, the number of detected depressions has increased slightly with a general reduction in their area, which indicates their fragmentation into separate fragments. A striking example of the "self-destruction" of depressions under the action of silting is the former channel of Tuapcha River, traces of which are practically not detected in 2021 (Fig. 3). The part of the depressions has been transformed into depressions. Along with this, as it turned out, new concave forms are formed within the former plateau (about 40% of their total area), which is caused by the embedding of the forming channels with the formation of depressions in the accumulative part of the shoal and underwater slopes of deltas. Thus, a section of a new underwater channel for 2005-2021 was formed near Pshish River in the form of a depression on the delta of the extension. The total area of concave forms during the study period as a whole decreased from 1559 ha to 1357 ha due mainly to their silting.

Let us single out the dominant geomorphological process of the evolution of the reservoir bed – the steady leveling of its surface, which was actually expressed in the growth of the plateau area by 2 km^2 over 16 years. The main "donors" of the process were Depressions and Mid-slope Ridges (Tables 2, 3).

Changing the ruggedness of the bottom topography

Similar trends were found in the changes in the ruggedness of the studied surface over the period 2005-2021, regardless of the parameters used (VRM, TRI). In general, in the process of silting up the reservoir, judging by the spatial statistical characteristics of VRM and TRI (Table 4), there is a decrease in the complexity, variability of the bottom topography. Thus, the CPI index for 16 years decreased from 0.32 to 0.29 m. In most of the plateau-type sections of the reservoir bed, the ruggedness parameters have not changed. Significant changes in ruggedness were noted in the areas of active topography transformation: in the places of emerging deltas of extension (Fig. 9), as well as in flooded channels due to leveling of the surface (Fig. 11) and fragmentation of channels (Fig. 3, 10).

Table 4. Statistical characteristics of ruggedness

Statistical characteristics	VRM		TRI	
	2005	2021	2005	2021
Average	$2{,}3\times10^{-5}$	2×10^{-5}	0,32 m	0,29 m
Median	$6{,}5\times10^{-7}$	6×10^{-5}	0,10 m	0,10 m
Standard deviation	7×10^{-5}	8×10^{-5}	0,51 m	0,51 m
Minimum	$1{,}7\times10^{-9}$	$2{,}7\times10^{-10}$	0 m	0 m
Maximum	0,0018	0,0017	7,40 m	7,90 m

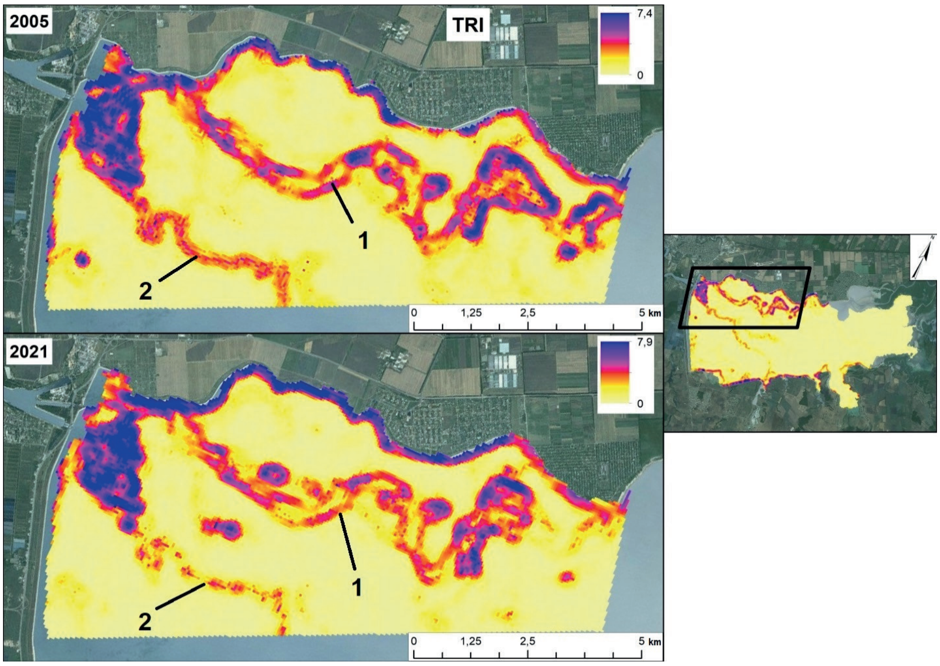

Fig. 10. Changes in the surface ruggedness index TRI for 2005-2021. Flooded riverbeds of the rivers Kuban (1) and Psekups (2)

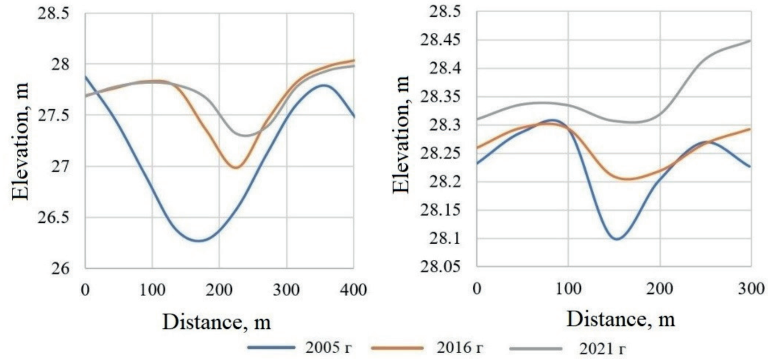

Fig. 11. Characteristic changes in the transverse profiles of flooded riverbeds of Psekups (left) and Pshish (right) rivers for 2005-2021

CONCLUSIONS

1. Standard morphometric characteristics of reservoirs adopted in hydrometry are limited by the type, shape, altitude position, bed size and volume of water in the reservoir, as well as bathygraphic curves. Morphometric analysis techniques using digital modeling bring the analysis of the bottom topography of reservoirs to a new level, contributing to the understanding of the processes of morphogenesis and the direction of transformation of reservoirs. One of the effective tools of geomorphometry is the multiscale BPI index (Bathymetric Position Index), followed by the allocation of elementary forms of bottom topography.

2. The key geomorphological process of the Krasnodar Reservoir is the accumulation of sediments, which generally leads to leveling of the bed surface. The average silt layer in the studied water area for 2005-2021 was 0.40 m, however, the thickness of the sediment trapping layer with average slopes of the bed surface of about 0.20 is very uneven. In the topography of the valley basin of the Krasnodar Reservoir, despite almost half a century of operation, the flooded valleys of Kuban, Psekups and Tuapcha rivers (the former right tributary of Psekups) have been well preserved.

3. As a result of morphometric analysis of the surface of the bed of the Krasnodar reservoir within a regulated volume on an area of 224 km^2, according to bathymetric surveys of 2005 and 2021, characteristic topography forms belonging to three categories of surfaces were determined by BPI: Lower Bank Shelf, Depression, Deep Depression, Reef Crest, Back Reef, Mid-Slope Ridges. In 2021, 89.2% of the reservoir bed area was occupied by Lower Bank Shelf, 4.1% – Depressions, 2% – Deep Depressions, 1.3% – coastal Reef Crests, 3% - Mid-Slope Ridges, 0.4% of the area – Back Reefs. The established topography forms, despite the morphological similarity, may have different genesis. Thus, some of the depressions are formed by flooded riverbeds, some by concave foothills of long–bank accumulative form – crests. The origin of the crests is also different and is determined by the synergy of fluvial (delta coast crests) and abrasive-accumulative processes (coastal crests).

4. In 2005-2021, morphological transformations affected 34.1 km^2 or 15% of the analyzed reservoir area. The coastal areas of the bottom, as well as flooded riverbeds, underwent the greatest restructuring. Some of the flooded valleys (Psekups, Tuapcha, etc.) turned out to be divided into separate fragments and in the process of sediment trapping evolve through the "depression – deep depression – lower bank shelf" stages. The evolution of the lower bank shelves, on the contrary, is characterized by defragmentation – a decrease in the number of fragments from 280 to 222 during the study period with an increase in the area of plateau-type surfaces by 2 km^2. The total area of deep depressions tends to decrease, and depressions – to increase. The formation of depressions, as topography forms, is noted on the accumulative shoal and underwater slopes of the emerging deltas of the extension (Kuban, Pshish). Positive topography forms are also subject to continuous transformation. A significant part of the Back Reefs and Mid-Slope Ridges are new formations formed on the former Lower Bank Shelf.

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