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Monitoring of Dangerous Exogenous Geological Processes in the Water Protection Zone of Tsimlyansk Reservoir

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***Abstract*—Remotely-piloted aerial vehicle can significantly increase the effectiveness of monitoring the condition and compliance with regulations for using the water protection zones of large water bodies. These vehicles collected the information for examining the water protection zone of the Tsimlyansk Reservoir providing the morphological and morphometric data of the shores of various types, as well as the evaluation of erosion forms and the intensity of coastal processes.**

Keywords—water protection zones, Tsimlyansk Reservoir, remotely-piloted aerial vehicle, erosion processes, morphological and morphometric data, coastal processes

I. INTRODUCTION

The preliminary detection of dangerous erosion processes in water protection zones, which can lead to their deterioration, is of great importance for and needs the adequate measures to block and minimize all possible negative consequences. Taking into account the length and peculiarities of the natural conditions of the coast of the Tsimlyansk Reservoir, it is extremely difficult to carry out regular observations and monitorin) of the state and compliance with the procedures of its use in water protection zones by traditional methods of ground surveys.

The application of remotely-piloted aerial vehicle can considerably expand the capabilities of organizations the monitoring of the state and the appropriateness of use of water protection zones of large water bodies as they effectively collect, systematize and analyse the information by means of GIS technologies. Tsimlyansk Reservoir is characterized by a wide spread of loessial rocks and alluvial-fluvioglacial sands, low forest cover, which contributes to the active development of erosion processes.

The main exogenous processes in this area of the shore are abrasion, landslide and wide development of gully network. Dangerous exogenous processes have become widespread in the water protection zone of the Tsimlyansk Reservoir, as evidenced by a number of works [1-4].

The East Don denudation-tectonic ridge is the southern end of the Dono-Medveditsky shaft of the Central Russian - Upland. The alternation of stable and weak to weathering rocks led to the formation of stepped slopes of river valleys. The planar erosion has exposed on many slopes of the Don river and the Tsimlyansk Reservoir to the source rock. The segmentation of the territory of the region by the ravine-braced network is very high, reaching 2 km per 1 km^2 and more [5].

The intensity of the processes of erosion segmentation of soils, and, as a result, the siltation of the Tsimlyansk Reservoir depend on the type of landform presentation of adjacent watersheds, so it is extremely important to conduct monitoring studies of morphological and morphometric characteristics of water protection zones of coastal areas. The intensity of erosion processes increases with growing fragmentation of the territory of the river hydrographic network and intensification of economic use of land. The increase in erosion-hazardous

areas of ravine-braced origin on the arable land, as a rule, has an area twice as large.

The purpose of the study is to develop and test a methodology for monitoring erosion processes of water protection zone of water bodies on the basis of software and hardware systems of unmanned aerial vehicles.

II. Methods and materials

In 2017, the staff of The Federal Water Resources Agency presented the research and developed an original method of examination and determination of morphological and morphometric characteristics of the shores using photographic materials obtained from an remotely-piloted aerial vehicle (Phantom 4pro), taking into account the techniques discussed in a number of works [6-9].

Based on this model, an unmanned aviation complex (UAV) was formed. It is designed to conduct remote monitoring of coastal areas from heights from 1 to 300 m from the ground (water) surface level, at a distance of up to 3.5 km from the remote control (in practice, in line of sight, the maximum UAV distance from the take-off point was about 6 km). The flight lasts 30 minutes; the total length of the route is up to 15 km. The unmanned aerial vehicle is equipped with support for GPS/GLONASS satellite positioning systems.

The processing of the photographic materials collected by using UAV, is by means of the program Agisoftphotoscan. Photoscan, which allows the experts to create maps of heights, as well as to measure the coordinates of points, distances, areas and volumes, to display profiles of sections on a user-defined track. The orthophoto was created based on the data of original images and reconstructed models, and it produces the resulting image is of high resolution.

Various modes of operation of UAV were used to test the methods of coast monitoring. For shore photography, the camera lens is oriented perpendicular or at an angle, usually 450, to the horizontal plane, and when photographing the shore ledge – it is placed subhorizontally (perpendicular to the breakage plane). The shooting of the territory of temporary drainage and accumulative bodies was carried out with an inclined position of the lens. The shooting of the shore was carried out depending on its structure and the ability to maintain a stable connection with the UAV operator from a height of 4 to 50 meters relative to the take-off point (TOP). At the same time, the UAV was above the water area of the reservoir at a distance of 20-50 meters from the shore.

The UAV shooting of abrasion shores (ledges) was performed in the three modes: the lens is directed vertically downwards (UAV flight height above the take-off point from 50 to 100 meters); the lens is inclined to the horizontal surface at an angle of 450, the flight height up to 100 meters; the lens is oriented horizontally, the UAV flight passes below the take-off point, mainly at the height of the central part of the coastal ledge.

In the first two cases, the front view of the coastal ledge can be obtained by processing series of consecutive images with overlap of at least 60% by means of the Agisoft program. In the horizontal position of the lens, you can analyse both the image of individual shots and the materials obtained during the processing of a series of shots.

In the first phase, we determined the length of the coast and made orthophoto of the selected sector investigated from UAV, we marked the coordinates of the coastline and the inspection points of the coast.

Fig.1. Inspection points of different coast types of Dubovsky Site: 1 – landslides; 2 – accumulation; 3 – ravine; 4 – abrasion; 5 – low flooding coast

Using the tools of the program “polyline → possible to measured → planned characteristics” you can get the coordinates of the profile, and using the tool “profile → built” – the profile of the coastal ledge (Fig. 4).

Fig.2. Panoramic photo.

Fig.3. The orthophoto on the side.

Fig.4. Profile of the coastal ledge of the landslide coast of Dubovsky Site.

Morphometric parameters of the coast were taken directly on the profile: the height of the cliff is 15 m; we calculated the slope (the ratio of the excess to the application) is 0.52; the width of the beach – 2.5 m, we defined the coordinates, the perimeter and area of landslide body - 2026.73 m^2 (Table.1.)

TABLE 1. MORPHOMETRIC PARAMETERS OF DIFFERENT COAST TYPES OF DUBOVSKY SITE

Type of coast	The height above the edge, m	Slope	Turfness/ Projective cover, %	The width of the beach, m	Area, m^2
Landslide	15	0.52	10	2.5	2026.7
Abrasion	7.0	0.7	0	0	
Low coast	0.8	0.01	80	1.3	
Accumulative	0.9	0.03	70	10	10652.9

These indicators can be used for repeated surveys of the shore area, to determine the intensity of landslide processes. The accumulative coast type situated in the flight section is represented by a sandy cape. The following data were determined for this form based on the use of the AgisoftPhotoScan software tools: perimeter, area, hypsometric profile, which recorded the width of the active part of the beach, the area of the projective cover with vegetation.

With the increase of the scale of the orthophoto it is possible to determine the composition of vegetative cover (tree, shrub, herbaceous). These data are necessary to assess the activity of coastal processes and to monitor the state of the water protection zone of the reservoir.

Based on the materials of photography performed by unmanned aerial vehicle (UAV) processed in GIS ArcMap10.2.2, Agisoft PhotoScan Professional (on the example of Dubovsky district of Rostov region) we calculated the density of the erosion network of the water protection zone of the Tsimlyansk Reservoir. The density of erosion segmentation (K) was determined by the formula:

$$K=L/P, \quad (1)$$

where L – the length of the erosion network in the area P.

According to the formula given above, the average density of erosion segmentation of the territory was calculated. This was determined by the sum of the lengths of the thalwegs of all erosion forms present in the survey site and the sum was divided by the area of this site measured in km2. Thanks to the photographic materials obtained by UAV, the calculation of the density of the erosion network can be performed remotely in the GIS ArcMap10.2.2, Agisoft PhotoScan Professional, which greatly simplifies the monitoring of the water protection zone. The tasks of assessing the density of erosion segmentation of the water protection zone included:

- visual interpretation of erosion of landforms of the study area by the photographic materials collected by means of UAV;

- marking all of the thalwegs for further calculations and to create a separate layer for the GIS project named “The condition of the water protection zones and the coasts of the Tsimlyansk Reservoir”;

- creation of layer areas of the territories for the calculation of the erosion density network;

- calculation of the density of the erosion network in the GIS ArcMap10.2.2.

The area for which the density of the erosion network is calculated is the territory of the water protection zone, enclosed between the boundary line of the water protection zone of Tsimlyansky Reservoir and its officially adopted coastline.

The work used the shots obtained by means of UAV collected on the territory of the water protection zone (WPZ) of Tsimlyansky Reservoir of Dubovsky Municipal District during the period from 25.06.2017 to 09.11.2017 from a height of 100 m. These shots cover almost the entire territory of the WPZ of Tsimlyansky Reservoir of Dubovsky Municipal District. The data processing and the preparation of images for interpretation was performed in Agisoft PhotoScan Professional.

With the visual decoding, the studied and digitized objects are identified primarily by direct features that are directly displayed in the pictures. These include shape, size, tone, colour. Therefore, for the accuracy of decoding it is necessary to apply the concept of the main erosion forms occurring in the study area.

The morphology and morphometry, the the internal structure, the conditions and time of occurrence, the subsequent transformations of linear erosion forms vary considerably. The forms of different age appeared in different conditions, so they differ in their morphology, morphometry, and the internal structure. Their classifications based on different principles have been proposed by many researchers (V. V. Dokuchaev, A. S. Kozmenko, D. L. Armand, S. S. Sobolev, G. V. Zanin, A. I. Spiridonov, and many others). In recent works the majority of researchers include the following items into the forms of fresh erosion are: potholes, furrows, gullies, ravines and braces [10, 11]:

- Erosion furrow is the initial stage of the formation of the ravine, it results from the trickle erosion of the surface of the slopes. Its width does not exceed 0.5 m, depth 0.1-0.4 m, with the length up to tens of meters.

- Potholes (pot holes) annually present linear erosive forms with a depth of 0.5 m, width 0.5-1.0 m, usually destroyed by plowing.

- Gully – a valley with steep and bare slopes with a pronounced brow. Its depth to 1.0-2.5 m, width – to 4-5 m, length-1.0-1.5 km. It is the rudimentary form of the ravine.

The ravines are steep slopes of the potholes, developing under the influence of channel temporary watercourses. The depth of ravines can reach 40-50 m, width 150-300 m, length 3-5 km.

- Brace/beam (dry land, wooded ravine, small ravine, cut bank) – is a dry or with a temporary watercourse valley having

turfed slopes. In the steppe regions, the beams form dried river beds. Beams are hollow-concave bottom, often without the visible channel, the slopes are convex, gradually passing into the watershed space. A distinct vertex is usually missing. The length of beams is usually from hundreds of meters to 20-30 kilometers, depth from several meters to tens of meters, width to hundreds of meters. The slopes and the bottoms are covered with turf and often covered with bushes or woods, the destruction of which accelerates beams erosion. Because of the temporary streams or small streams, bottom erosion is common in the beams, so although they are the most stable of all erosion forms, they should be in the focus of the analysis of erosion segmentation of the study area. The braces are usually clearly seen and In the pictures, so we can recognized them easily. Their bottom always has more moisture than the slopes and watershed surfaces, and from early spring they are covered with dense grassy vegetation. Ravine-braced system can reach a considerable length, a distinctive feature of such a system presented in the images is a tree pattern.

One of the indicators of erosion landforms is the origin of the passage contour, therefore, to clarify the location of the thalwegs of the images in the program Agisoft PhotoScan Professional we built “contours” and “polygons” of heights with the intervals of 1 m.

In addition to the direct indication, the indirect signs of visual interpretation of erosion forms are also relevant. Reliable indirect signs or indicators of the presence of washed soils are morphometric features of the landforms. They are the predominant forms of land, the total dismemberment of the territory, the steepness and exposition of the slopes. For example, the steepness of the slopes does not let the beams be plowed, which serves as an indirect sign of interpretation, as an indirect sign is the presence of bypass field roads. The state of vegetation also acts as a reliable indicator of the presence or absence of erosion processes and the intensity of their development. In the fields with developed crops, the outwash of the soil may be the indicator of the blindness in seedlings

With the visual interpretation, the studied and digitized objects are identified primarily by direct features that are directly displayed in the pictures. These include shape, size, tone, colour. The interpretation of such erosion forms as furrows, potholes, gullies, ravines was carried out. Following the digitization of all the survey area 2148 polylines appeared. Each polyline is the thalweg of a particular erosion forms or systems. The sum of all the lengths of the erosion network on the site was 132.6 km.

The main difficulty in interpretation of erosion forms near settlements are minor differences in altitude. Drawing contours is complicated by the presence of buildings and, as always, woody vegetation, but you can still find other indicators of the presence of soil erosion: more bright dense grass vegetation, formed the mouth of the temporary watercourse, the location of field roads relative to erosion forms.

An integral part of the dangerous erosion processes of the water protection zone of the Tsimlyansk Reservoir are ravines, characterized by a variety of morphometric and morphological properties.

In the study area, the ravine belongs to the coastal type, has a clublike shape and stretched from the North-East to the South-West.

Fig. 5. Ravine on Dubovsky Site (point 3, Fig.1)

The monitoring of erosion processes (ravine-brace net) in the water protection zone of the Tsimlyansk Reservoir was carried out using the program AgisoftPhotoScan; the orthophoto (from the top) also includes the definition of area and perimeter, length of the ravine in the riverbed, and a number of morphometric characteristics of the transverse profile of the ravine in the upper reaches and at its mouth: the steepness of the slopes of the ravine, the length of the ravine in the riverbed, m; the slope of the riverbed, the area of the ravine, the perimeter of the ravine, the depth of the ravine in the upper reaches and the mouth, the width of the bottoms in the upper reaches and the estuary.These parameters can be used for further monitoring of this erosion form.

III. Results

The main exogenous processes in the studied area are abrasion, landslide and wide development of ravine-braced network. Tsimlyansk Reservoir is characterized by a wide spread of loessial rocks and alluvial-fluvioglacial sands, low forest cover, which contributes to the active development of erosion processes.

Also, the bays of the left coast are characterized by the accumulative type, where the height of the shore above the water edge does not exceed 2.0 m. The coast formed from the interlayer sands and loams are characterized by weak abrasion-accumulative processes.

The coast of abrasion-landslide type on the site near Zhukovskaya station is a watershed slope of the hill Ergeni, with height from 10 to 24 m. The coasts are characterized by steep slopes or steep cliffs. It should be noted that abrasion-landslide costal area is characterized by the presence of two and sometimes three shoulders, as well as a variety of forms of processing (landslides, wave niches, washout niches, etc.). The developed coastal shallow has a width from 100 to 200 m. The width of its naked part together with the beach (folded loam and sandy-loamy material) can be 10-22 m.

Currently, this coast is characterized by medium and weak abrasion, the average rate of retreat of the coast (for the period from 2011 to 2016) does not exceed 0.1-0.3 m/year. However, according to the observations from UAV, the local sites

showed an activation of EGP, expressed in the separation of fractures and vertical displacement of large blocks of rocks.

The comparison of abrasion rates of the reservoir coasts (for the periods I-from 1953 to 1994, II-from 1995 to 2010. – 1.64 m / year, and III- from 2011to 2016) showed a gradual attenuation of this process in almost all types of coasts, due to the stabilization of coastal transformations of the reservoir and a prolonged (more than 10 years) low-water period of the Don river.

The relatively stable coastlines include accumulative areas of the coasts in the mouths of flooded braces and ravines in the bays of the reservoir. The main process of formation of such coasts is the appearance of beaches and accumulation of sediment along the entire width of the coastal shallows. Zhukovsky Bay has also the characteristics of this type.

On the left coast of Tsimlyansk Reservoir (from Zhukovsky refuge to Krivsky farm), the abrasion-landslide coasts take place. The landslides extend in a continuous band having a stepped shape. These steps in some places are very steep. The landslide scarps are directed back to the slope and are divided by a system of fissures. The landslide phenomena associated with the area of Tsimlyansk Reservoir also take place on the slopes of the beams flowing into the reservoir. The quaternary deposits contribute to the shift. The landslides are shallow, they occur separately having the length of 50-60 m, the width of 15-20 m and the height of the vertical offset of 5-6 m. Sometimes they have clustered occurance.

Erosion forms of the water protection zone (WPZ) of the Tsimlyansk Reservoir in this area are very diverse. In addition to ravines, erosion furrows (potholes) and gullies are widely developed, which in the evolutionary scheme of formation of gullies are usually considered as an intermediate form, but they are an integral part of erosion processes.

During the analysis of the distribution of erosion forms of the water protection zone of Tsimlyansk Reservoir in the study area, we allocated five sites, characterized by the density of erosion segmentation. (Fig.6)

Fig.6. The analysis of the density of the erosion network of the additional layer POLYGON

The density of erosion segmentation of the water protection zone of the Tsimlyansk Reservoir in this area varied from 2 km/km2 to 15 km/km2 , with an average of 9 km / km2 in the area. For the analysis and visualization, "K" coefficient was ranked by linear interpolation into three degrees of erosion segmentation: 0-5 – low, from 5 to 10 - medium, from 10 to 15 – high. The most part of the analysed area is characterized by a high degree of erosion segmentation (55%), and this territory is not used for economic purposes, as a rule. The territory with a low degree of segmentation accounts for 12%, there is mainly a residential area or agricultural land.

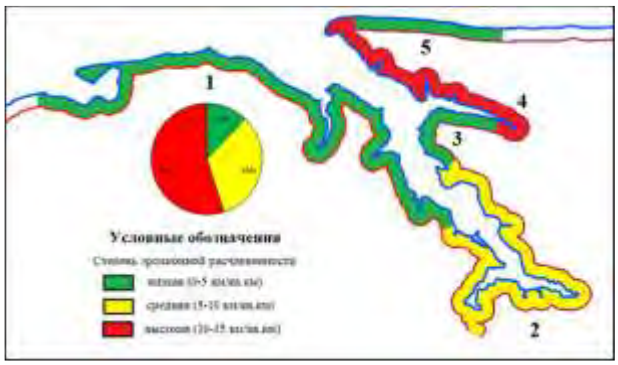

Fig. 7. The degree of erosion segmentation of the studied polygons

The coasts of abrasion-landslide type in the area of Zhukovskaya Station showed low levels of erosion of segmentation (from 0 to 5 km/km2); the accumulative coasts of Zhukovsky refuge (the bay area), typically have average values of density of erosive segmentation of WPZ from 5 to 10 km/km2, the highest degree of erosion segmentation of WPZ is demonstrated by abrasion and landslide coasts from Zhukovsky refuge to Krivsky farm.

In the context of stabilization of coastal processes in the modern period in some years, there may be a sharp increase in EGP, due to synoptic and hydrodynamic factors, this indicates the need to continue monitoring by means of traditional and modern techniques and methods (UAV).

Of course, the arrangement of additional observation to perform these tasks may require a significant increase in financial and material costs. In this case, the use of remote sensing methods, space images and survey of the coast with the use of UAV will significantly simplify the task of monitoring the coastal zone of the reservoir for changes in the position of the banks and will allow to accurately track the annual operational information about extreme situations.

IV. Conclusion

In accordance with the aim of the study, we carried out the visual interpretation of erosion landforms of the study area the using photographic materials obtained with the help of UAV; we marked of all thalwegs for further calculations and the creation of a separate layer for the GIS project "The State of WPZ and the coasts of Tsimlyansk Reservoir", we calculated the density of the erosion network of the WPZ of Tsimlyansk Reservoir (for example, Dubovsky district, Rostov region)

The use of unmanned aerial vehicles (UAV) made it possible to determine the density of the ravine-beam network in the study area and to characterize the morphology and morphometry of erosion landforms. In addition to ravines, erosion furrows (potholes) and gullies are widely developed, which in the evolutionary scheme of formation of ravines are usually considered as intermediate.

The studies have shown that the obtained UAV photographic materials can be used to monitor coastal processes and detail the types of the reservoir coasts.

The processed shots from UAV by the tools AgisoftPhotoScan allowus to complete a detailed morphometric study of coasts of all types, thereby replacing time-consuming field work, and also to monitor the coastal zone inaccessible areas.

In the context of stabilization of coastal processes in the modern period in some years there may be a sharp increase in dangerous exogenous processes due to synoptic and hydrodynamic factors, this indicates the need to continue monitoring with the application of traditional and modern means of control (UAV).

In this case, the use of remote sensing methods, space images and survey of the coast by means of UAV will significantly simplify the task of monitoring the coastal zone of the reservoir for changes in the position of the coastlines and will allow the experts to accurately track the annual operational information about extreme situations.

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