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Morphodynamics of Irkutsk water storage basin influence zone and principles of its geoinformation mapping

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Abstract. Principles, procedure and results of the subject mapping and morphodynamic analysis of the influence zone of Irkutsk water storage basin are described based on the morphosystem concept, remote sensing data and geoinformation mapping technologies.

1. Introduction

Irkutsk water storage basin is the first one in the Angara river series. It was formed as a result of Irkutsk hydroelectric power station (IHPS) construction that started in 1950 and was finished in 1958, with the basin replenishment to the design reference mark (DRM) of 456.59 reached .in 1962. Correspondingly, the level of Lake Baikal rose by 1.46 m, and the lake practically became part of the water storage basin. The net volume of the basin river part of the basin is 0.07 km³, while that of the lake part, 23 615.39 km³. The river part is used for daily discharge control, and the lake one containing over 99 % of the total volume is used for long-term and yearly discharge control and provides balanced IHPS work. The surcharged headwater level (SHL) mark in case of high water throughput with the probability of 0.01 % (once in 10,000 years), is 458.2 m, while a dead water level (DWL) mark is 456 m, the level fluctuations being 1 m.

In spite of the fact that IHPS is a low-pressure channel-type station, a vast area (1,386 km$^{2)}$ underwent submersion and ground flooding, including agricultural zones (323 km^2), over 200 settlements, a segment of the Irkutsk-Listvyanka highway and a part of Round-Baikal railway (Irkutsk-Mikhaljovo-Podorvikha-Baikal section). Nearly 3,000 homesteads and 17, 000 people were moved out of the flood zone.

The length of the artificial reservoir following a straight line from the Angara river outlet to the IHPS dam is 55 km, with the average width of 2.8 km (maximum being 7 km). However, due to the indented riverbank line resulting from the submerged feeders' mouths, the shoreline is significantly longer, being 143 km for the left riverbank, and 132 km, for the right one. The DRM water table area exceeds 154 km^2. The average reservoir depth is 13.2 м, with the maximum depth (35 m) being at the headwater wall of IHPS. The water catchment area (excluding the lake part) is 542 km^2.

IHPS is the first big hydroelectric station in Siberia. It has generated over 200 billion kWh of renewable electric power, which has allowed the lowest (in Russia) power rates in the region and catalyzed industrial development, including power-consuming plants such as Irkutsk aluminum plant. There is a motor road built over the dam serving as bridge over the Angara river. IHPS maintains the navigable water depth all the way to Bratsk water storage basin and provides stable work of both the dam and downstream intakes. Having a big water storage and diverse means for the discharge control, IHPS allows effective control of the winter floods characteristic of Irkutsk and caused by hanging dams. Discharge flow at the tail-water wall can reach 6,000 m^3/s, while due to the large-scale development of the flood-plain areas, flooding starts with the discharge flow of 3,000 m^3/s.

On the other hand, the construction of the hydroelectric stations series on the Angara river has aggravated the environmental situation as it was followed by an abrupt disturbance of the existing landscape as well by intensification and diversification of the hazardous exogenous geological processes [1].

As DRM is reached, the submerged slopes and the shallow water areas become the main arena of the geological processes intensification. First of all, it is direct transformation of the shore relief under the influence of the waves and currents, followed by intensive processes forming the new shoreline: abrasion, accumulation and sediments transfer. As a result of the erosion and water roiling, the clay component of the sediments is carried away by the water as suspension, while the sand component stays.

On the overlying slopes of the recently formed banks, geological and hydrogeological processes that had a latent character before get activated: ravine erosion, karst, suffusion, subsidence, landslide, land slip, etc. In the shallow water zones, above-water accumulative reliefs are formed (beaches, over-wash flats, swells), and on the shore edges adjacent to deep water, underwater accumulative prisms are formed. The above processes intensity is not declining, the other way round, it is often increasing, which indicates that the water storage basins banks are far from being in a stable state.

The basin’s influence is not limited by the change of the shoreline and the adjacent slopes. There is a risk of underflooding, waterlogging, forest extinction, etc. for the whole shore area. The scale of the influence zone depends on the size of the water storage basin, DRM position and its fluctuation amplitude, varying from a few meters to a few kilometers.

In the underflooding zone including the riverside of the reservoir, there is an increase in the ground water level and its fluctuation synchronous with the reservoir water level fluctuation, resulting in ravine erosion, suffusion and karst.

In the bank transformation zone including the subzones of direct wave influence (cliffs, beaches and underwater terraces), the main geological processes include weathering and abrasion with the related landslides, flow slides and land slips, as well as sediments transfer and accumulation.

In the permanent flood zone connected with the subaqueous reservoir part, sedimentation takes place, mostly of an abrasion origin, as well as sod, turf and sinker flotation.

The reservoir influence is also observed in the tail-water part and further down the stream, as well as in the upstream part of the backwater influence zone. In parallel, the hydrogeological and atmospheric conditions are changing: flow velocity, flowage, ice mode, temperature, humidity, wind and fog, etc.

In Irkutsk water storage basin, right-bank and left-bank parts are distinctly distiguished. The right bank in its lower part is formed by the Quaternary loessial-type sandy clay and sandy pebble sediments of the Angara terraces. The left bank is mostly formed by the Jurassic hard and semi-hard rocks, with the exception of the middle part (Bolshoi Kalei bay) where some sections are formed by sandy clay and sandy pebble sediments.

In the riverside zone that is 152 km long (55 % of the total length), most intensive and large-scale processes are those of an abrasion type, the maximum width of the wash-out area in some places exceeding 200 m. The disperse grounds forming the right bank on the section from the IHPS dam to Patrony settlement are mostly subject to erosion, which has already caused a large-scale irretrievable loss of lands, including the farm, plough and forest lands. The maximum heights of the abrasion terraces in the loose grounds in some points exceed 8 m, while in the hard and semi-hard rocks, they are up to 3 m. In 2000, the maximum wash-out area width was 180 m for the unstable grounds, and 25 m, for hard grounds [2], the indices being even higher at present.

Thus, the research of the Irkutsk water reservoir influence zone is of en evident scientific and practical interest on account of the intensive processes taking place in the area. It is also obvious that a complex on-line environmental monitoring system is needed for the research territory as a part of the

Angara series [3]. In this relation, Irkutsk water storage basin can be a reference object for the other water reservoirs monitoring because of its relatively small size and easy accessibility.

2. Methods, materials and technologies

The geoinformation mapping for the purpose of influence zone monitoring is based on the following components: methodology, information and technology.

The methodology component is a theoretical basis for the reservoir dynamics monitoring and GIS-mapping. It is represented by a morphosystem concept and morphodynamic analysis of the earth surface aimed at defining the relief natural divisibility and dynamic hierarchy, which allows further mapping on three generalization levels: morphostructure, basin, and slope [4, 5]. Mapping and zoning of the reservoir morphology and dynamics on the last two of the above levels (especially, the slope one) is one of the main principles for the reservoir morphosystems monitoring. It is in the basins that the melt water, rain water and ground water flows are separated, the bank slope systems being an arena for the most dynamic rearrangement of the morphodynamic conditions when filling and maintaining the reservoirs.

According to a basin concept, the basin systems' borders are marked by the watersheds, the thalwegs of the main water courses being effluent channels. The basin systems have only one outlet and rest directly on the reservoir shore line, i.e. the substance-and-energy flow lines form tree-like convergent systems. The basin systems normally include two or three levels of the lower order basins. The smallest taxonomy unit of the basin series, an elementary basin with a first order thalweg, is distinguished by the morphological character of the erosion network: the zero order thalwegs only make the bank slopes more complicate, with no basins forming.

The information component of the geoinformation system's mapping is a system of collecting, systematizing and on-line updating of the specific data bases. The information sources are: remote sensing on-line data updated on a non-stop basis (digital and analogue aerospace pictures obtained from various aircrafts and sensors); topographical, engineering-geological, landscape and other maps; digital models of the relief; data and material of the previous and recent research and surveys.

The technological component of the system's mapping is a geoinformation system (GIS) aimed at referencing, accumulating, storing, updating, processing and obtaining information on the reservoir dynamics. One of the main means of the data display and analysis is GIS-mapping that allows analysis and synthesis of the factors and conditions for the shoreline morphosystems formation and development on different scale and time levels.

3. Research results and analysis

The main result of the research is a reference small-scale map of Irkutsk water storage basin (Figure1). It represents morphodynamic types of the basin banks, as well as the ground types, morphological elements (the basin structure) and development areas within the basin influence zone.

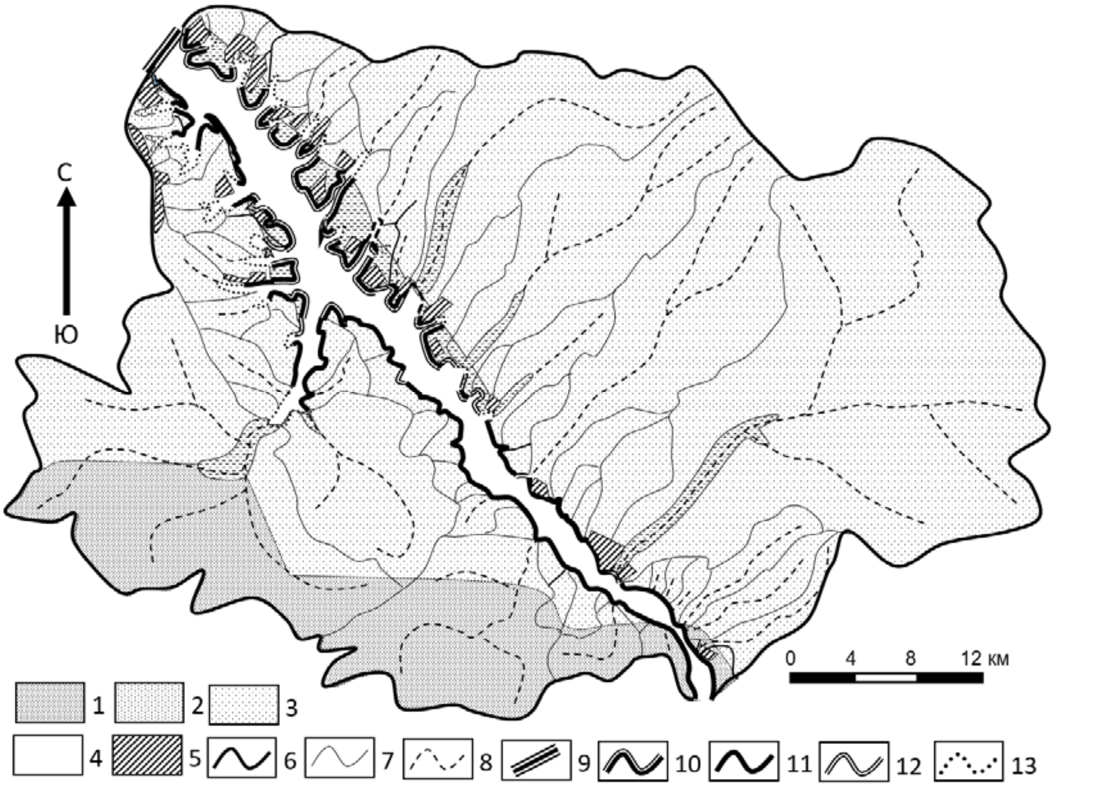
The bank types were defined on the remote sensing data, the basis for the definition being presence or absence of the morphodynamic elements: cliff, bench and beach.

The abrasion speed of the abrasion banks is higher than the accumulation speed (typical of the banks adjacent to deep water on the unstable disperse grounds in the conditions of strong heaving and currents at the capes in the widest basin parts).

The abrasion and accumulation of the relatively stable banks are insignificant (typical of the straightened banks adjacent to deep water on the stable semi-hard rocks).

The abrasion speed of the accumulative banks exceeds the abrasion speed (typical of the banks adjacent to shallow water on the disperse grounds in the wind- and wave free conditions behind the capes and in small bays).

There is no abrasion of the waterlogged banks, the accumulation being insignificant (typical of the long shallow bays banks near the submerged feeder rivers mouths).



1-3 Ground: 1. – hard rocks: strong-metamorphic Archaean granitoids, gneiss, crystal shale, marble; 2 – semi-hard rocks: sandstone, siltstone, mudstone, conglomerates, coal; 3 – disperse: sandy clay, sand, pebble; 4. – the basin water area; 5. – developments areas; 6-8 – structure lines: 6 – main watershed divide of the water catchment area; 7 – watersheds of the second order; 8 – thalwegs; 9. – IHPS dam; 10-13 – morphodynamic bank types: 10. – abrasion; 11. – table; 12 – accumulative; 13. – waterlogged.

Figure 1. Morphodynamic map of Irkutsk water storage basin.

4. Discussion

Geoinformation mapping is the most effective monitoring tool. The usage of the GIS technologies and digital cartography allows research and analysis of the complex mechanism of big water storage basins formation and development based on their digital cartographic models implemented in a two-, three- and four- (time dynamics) dimensional representation. GIS-mapping modeling expands the means of information and data accumulation, updating, transfer, replication and control. It is an indispensable, effective and flexible tool for scientific, departmental, administrative and other organizations for identifying, connecting to the territory, studying and evaluating the abrasive, earth slides/land slips, gravitational, karst, biogenic and other negative processes taking place in the riverside area and beyond its borders, as well as for forecasting, planning and controlling the measures on dealing with the above processes and eliminating their consequences.

The principles used for classification of the mapped shoreline and for mapping of the water basins influence zone are specifically adjusted to a wide use of the remote sensing data. The classification should be cartographic that is, it should be a basis for further on-line mapping of the lengthy shore line and vast areas of the Angara series influence zones, in particular in the limited financing and time conditions. A morphotopological principle has been taken as a basis of the shoreline mapping classification, as it is morphotopology that presents the result of the past, the basis of the present and the background for the future relief development. At the same time, it is an indicator for identifying the natural and technogenic morphosystems characterized by the integrity and relative stability of their inner structure, energy and substance exchange, etc. The main factors defining the morphotopology, borders, type, view and intensity of the basin's morphosystems transformation are:

– geomorphological (relief morphology and morphometry);
– engineering-geological (ground stability in relation to weathering and denudation);
– hydrogeological (wind and wave conditions, water level fluctuations, outflow and wave currents, ice conditions);
– landscape (climate type, vegetation cover);
– anthropogenic (technogenic disturbance of the area).

The cascade bank slope systems are classified by the morphotopological and morphodynamic characteristics, the morphosystem types being defined by the aggregate of the relief morphology and morphometry, engineering-geological and landscape conditions and anthropogenic influence.

5. Conclusion

The considered GIS-mapping system has been designed as a basis for the studies and analysis of the shore dynamics of Irkutsk water storage basin as well as for the development of the population and technical objects protection in the shoreline zone. It can be also used by different administrative, scientific and industrial organizations for the purpose of on-line evaluation of the banks wash-out and urgent managerial decision-making.

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