Methodological aspects of operational cartographic and space environmental monitoring of the impact zone of the Angara river reservoir cascade

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Abstract. The necessity of organizing environmental monitoring of the zone of influence of the cascade of Angarsk reservoirs is substantiated. The goals, objectives and stages of its practical implementation on a systematic methodological basis using the operational data of remote sensing of the Earth and the capabilities of geographic information mapping.

1. Introduction

Since the middle of the last century, a cascade of large hydropower plants has been built on the Angara River. This is a powerful impetus for the development of the regional economy. At the same time, the construction of hydroelectric reservoirs caused radical changes in the lithosphere, hydrosphere, atmosphere, and biosphere, and serious environmental problems. Therefore, the integrated operational environmental monitoring of the impact zone of the Angara river reservoir cascade based on the cartographic method and Earth remote sensing materials is required.

The Angara river cascade includes Irkutsk, Bratsk, Ust-Ilimsk and Boguchany reservoirs. The flooding area is 9823 square km, the water mass volume is 230.3 cubic km, the coastline is 12 thousand km, the length of the territory from south to north is 1302 km, the depth of flooding is up to 100 m, the area of influence is more than 50 thousand square km.

The main environmental and social problems are due to the violation of the natural hydrological regime of Baikal lake, the Angara River in the lower part of the Yenisei River [1], as well as the exploitation of forest and mineral resources of the region [2, 3].

The violation of the hydrological regime changed quality and bio-productivity of water, deteriorated land quality, land management conditions. Settlements and enterprises were moved to other locations due to flooding of coastal areas.

Three areas with a disturbed hydrological regime can be distinguished.

Firstly, it is the reservoirs where terrestrial ecosystems were replaced by water (flooded) ones. Currently, water quality is unsatisfactory due to a decrease in the rate of water exchange, pollution by effluents, rotting of flooded and floating wood.

Secondly, it is the coastal zone which is an arena for groundwater abatement and soil waterlogging [4, 5].

Thirdly, it is the zone adjacent to the coastal line, where climatic, hydrogeological, landscape and other geographical conditions have changed.
Since the middle of the last century, intensive exploitation of forest resources and industrial logging have been carried out in the Angara River basin. As a result, coastal forests are depleted. In the Angara region, about half of the trees have already been cut down. The situation is exacerbated by fires, droughts, diseases, pests, windfalls and industrial emissions.

As a result of irrational logging and fires, vast territories are often flooded. Floods affect settlements and soil.

The third environmental problem is negative changes in the natural environment of the coastal areas where there are open-pit mines (e.g., coal mines or mines where the drag-and-hydraulic method is applied). Technogenic activities change natural hydrogeological conditions, increase the infiltration of loose sediments, transform the hydrological regime of watercourses, cause an imbalance in natural relations, deteriorate soil and vegetation, pollute rivers.

2. Monitoring

To solve the above mentioned problems, it is necessary to implement the operational environmental monitoring as an information system of regular long-term observations that provide information on the state of the environment in order to assess and predict its changes, study the anthropogenic component against the background of natural processes, identify destabilizing factors and causal relationships in the geographical systems [6, 7].

The main task is to assess and predict the dynamics of natural-anthropogenic systems using the remote-cartographic method in combination with field observations at representative test sites. To solve this problem, it is necessary:

- to specify the landscape structure of the territory;
- to adapt monitoring methods to regional conditions;
- to identify the degree and nature of environmental damages;
- to develop methods for environmental mapping;
- to identify ways of nature management rationalization.

3. Methods

It is evident that the regional environmental monitoring requires relevant scientific methods. In modern conditions, it is necessary to combine ground, remote and cartographic methods into a single integrated research method. An important advantage of this method is speed, objectivity and diversity of the results obtained with a sharp reduction in labor-intensive field works which is of great importance when studying large, inaccessible and underdeveloped regions.

The practical result of operational monitoring is environmental forecasting whose general principles are as follows:

- minimization of negative anthropogenic impacts;
- consideration of primary and long-term consequences of hydraulic engineering construction;
- development of preventive and compensatory measures.

In addition, environmental forecasting is based on consistency, objectivity, scientific validity, coincidence of theoretical models with practical manifestations, variability of solutions and expected consequences.

Environmental forecasting is system-integrated, since it covers various aspects: hydrological, chemical, biological, sanitary and hygienic, economic development, etc.

For the environmental forecasting of natural processes, various methods are used: analogues, extrapolations, expert estimates, mathematical, spatial and temporal, cartographic methods, geographic information systems, etc [8].

The systematic operational environmental remote-cartographic monitoring of the cascade of the Angara River reservoirs includes a number of related stages aimed at achieving the following goals:

- development of technical and economic documents;
- development of working documents;
- construction of water facilities;
- operation of water facilities.

At the planning and development stages, the following works are performed:
- problem statement, identification of generalized goals, boundaries and criteria of the ecological systems (analysis of natural and anthropogenic factors and conditions for creating reservoirs and influence zones);
- creation of the system, identification of its priorities, primary structuring, approximate division of the system into subsystems and elements (studies of the processes of reforming the banks of reservoirs, identification of pollution sources);
- construction and study of a model, analysis of development of the system based on parameters used for verification moments (assessment of coastal destruction and changes in the coastal zone, assessment of the conditions for improving water quality, forecasting of changes in the reservoir influence zone);
- development of recommendations for the operation of the model system, comprehensive analysis of the forecasting results, checking their compliance with the goals, development of recommendations for improving the model and the state of the system (recommendations for rational use of natural resources and minimization of coastal destruction and changes in the coastal zone, changes in water quality, suggestions for its improvement).

If a hydroelectric power station has already been built and the reservoir is full, the monitoring can be divided into several stages:
- identification of the general research strategy on the basis of a thorough study of source materials for the analysis of natural and technological conditions, identification of territorial boundaries of research, statement of generalized goals, tasks and ways to achieve them;
- modeling of the system based on its priorities, analysis, primary structuring and approximate division into subsystems and elements;
- forecasting of the development of the system based on the results obtained at the previous stage and parameters for verifying the forecast based on model options for various effects;
- development of recommendations for the optimal operation of the system based on a comprehensive analysis of forecasting results; development of recommendations for improving the real state of the system.

The operational remote monitoring of the impact zone is based on the integrated use of various data and materials from aerospace surveys, field ground and aerial visual observations, various maps, etc. Topographic and geodetic data are used at all stages as the basis for planning and organizing operational remote-cartographic environmental monitoring of the reservoir impact zone.

Topographic maps are used for studying the situation, linking objects. They are used as an accurate basis for creating intermediate and final cartographic materials at all stages.

Geodetic materials are used to obtain accurate quantitative data on the most dynamic monitoring objects (rapidly eroded banks, growing ravines, etc.) [9].

Remote sensing materials - aerial photographs and satellite images (analog, scanner, radar, etc.) - are also used at all stages as a source of efficient, visible and easy-to-use primary information [10-15].

Hydrometeorological and hydrochemical data are used at the second and subsequent stages. They include:
- operational information on the hydrological and meteorological status of the reservoir basin;
- regime hydrometeorological generalizations (cadastral publications);
- short-term hydrographic and meteorological forecasts;
- comprehensive studies of the hydrological situation of water systems.
- data on the volume and number of limiting and representative pollutants.

Data on natural resources and economic potential are used at the first stage. They cover all types of environmental management (industrial, agricultural, forestry, recreational, etc.), which are accompanied by environmental negative consequences.

When assessing natural resources and the water management system, special attention is paid to the degree of development of the anthropogenic component:
- areas of new economic development, where extensive forms should be minimized;
- areas of early economic development with the prevailing interaction of economic activities and natural components, where both resources and environmental reproduction abilities of geosystems are endangered;
- urban areas where problems are related to quality of the environment.

The analysis of these materials allows us to distinguish between the following territories:
- conflict (possible irreversible negative processes);
- crisis (possible irreversible negative consequences);
- catastrophic (possible irreversible changes).

Geological and geomorphological data are used at the first two stages. They include:
- geomorphological maps - to assess terrain and forecast coastal changes;
- geological maps - to clarify the lithology of the coast in terms of its resistance to erosion;
- hydrological maps - to assess areas of existing and future swamps, a capacity of peat islands, volumes and areas of flooded forest;

Forest taxation data are used at all stages to conduct research on various environmental conditions of the reservoir:
- taxation indicators of the wood mass after logging;
- quarterly taxation indicators of woody vegetation of the coastal zone.

Thus, the schematic diagram of the integrated remote monitoring system of the zone of influence of the Angara river cascade reservoirs includes four interconnected blocks, each of which has different tasks:
- observation;
- assessment;
- forecasting;
- development of recommendations aimed at preventing harmful effects.

4. Results and discussion

Geoinformation and remote sensing data should be a technological component of the environmental cartographic and space monitoring of vast territories and territories of the Baikal region. The component consists of four subsystems: obtaining initial information, obtaining additional information, collecting and storing information, processing information. It is a monitoring GIS that accumulates, organizes, analyzes, and updates spatial and other information about the state of the natural environment.

The GIS has powerful tools for constructing any models of territories and situations within them, as well as tools for spatial and non-spatial data analysis, with the help of which patterns inherent in the monitoring object are revealed. The GIS tools characterize the dynamics of changes. The combination of dynamic characteristics in the GIS environment and interpretation based on the identified patterns allow us to predict the development of a monitoring object with a greater or lesser degree of probability.

The technological scheme for creating the GIS space monitoring of the zone of influence of the Angara river reservoirs contains standard stages: preparation, production and adjustment.

At the preparation stage, the GIS content component and requirements for the technological and software monitoring are developed.

The production stage involves organization of the monitoring network and GIS information support, creation and constant updating of the database, development of criteria and assessment of the monitoring object, development of modeling and forecasting algorithms for the monitoring and visualization (presentation) of monitoring results for consumers.

At the adjustment stage, the efficiency, quality of intermediate materials, and reliability of the forecasts are evaluated, the system for receiving and transmitting information is improved, the database structure is improved, and the modeling and forecasting algorithms are updated.
The central element of the GIS space monitoring system is the information system whose most important subsystem is the database.

The base of cartographic, aerial survey, satellite imagery, literature and reference data and their attributes reflecting the internal structure and complex hierarchical relationships of all these data must meet a number of functionality criteria, ensure quick access and visual display of the working area, perform general orientation and data georeferencing functions, show the geographic coverage for each type of data.

The system should sort, search for, and display both the same type and the same type of metric and semantic data, show materials available in the database at a specific point by its geographical coordinates or data on the route, frame, date of shooting, type of sensors, spectral channels, image projection, DEM grids, etc.

The attributive database of field work materials should respond to requests containing the numbers of field routes and observation points, types and subtypes of objects to be observed, the date and type of surveys available in the database of field and aerial imaging images.

Finally, the geographic information system should ensure easy creation and modification of the database, be user-friendly.

At the second stage, the technological scheme involves preparatory and basic works. The result of the organizational monitoring program was the map of environmental assessment of the state and dynamics, as well as environmental forecasting of the state of the environment in the impact zone.

The preparation works for the implementation of the reservoir monitoring program includes the following steps:

1. Collection of source materials (maps, aerospace images, literature, department materials, statistics and field data).
   - Topographic maps at 1: 200 000-1: 500 000, industry maps and plans at 1: 10 000-1: 50 000, maps of various thematic areas (geological, forestry, etc.) were collected.
   - Scanner satellite images were prepared on the territory of the Angarsk reservoirs using the satellite systems Landsat (1973-2009 survey) and Resource (1993 survey), as well as using data of Internet portals of the ScanEx engineering and technological center, Google Maps, etc.
   - Various literature and department materials, field and statistical data were collected.

2. Development of the program of ground-based ground and aero-visual monitoring of the coastal territories of the Angara reservoirs.
   - The program includes the development of a survey program for reference sites and polygons. Key sections of the survey are used as reference ones.
   - The field ground and aerial visual monitoring of the coastal territories.
     Information on ground objects, their properties and other statistical data obtained from space, cartographic, statistical and other materials are visually confirmed.
   - Interpretation of aerospace images (identification of forest vegetation, a microrelief, and water pollution).
     Ground objects, their spatial and attributive properties required for creating environmental maps are decrypted visually and automatically on the basis of satellite images (Landsat satellite systems).
     The implementation of the program for organizing the remote cartographic monitoring involves:
     - The choice of polygons as standards for the interpretation of aerospace images (areas with a high degree of reservoir impact)
       The choice of polygons aims at reflecting the most significant features of the landscape-ecological structure of the area. The reference areas that are decrypted from aerospace images and experience the greatest impact of the reservoir are selected.
       The following complementary forms of standards are applied - elementary standards and reference profiles.
       Elementary standards are clippings from pictures characterizing images of objects and phenomena. They are systematized in the form of thematic tables and can be arranged in an order that reflects the
classification of structural units of the natural environment. Elementary standards are presented as legends applied to the shooting materials.

The reference profile is a strip of the image on which a characteristic combination of conjugated natural complexes is displayed. It is accompanied by a detailed profile of landscape elements of the natural environment.

The standards are used to perform off-line decryption of remote images of new territories. The reliability of extrapolation is determined by control checks.

6. Creation of the monitoring system for reference polygons for decoding aerospace images.

An integrated system for monitoring the state of the environment in key reference areas is created. Space materials are being collected and decoded for assessing and forecasting changes in the state of the environment.

Aerospace images are decoded when recognizing objects from their aerospace images, determining qualitative and quantitative characteristics of these objects, studying the landscape-forming and environmental role of various factors.

The technological interpretation scheme involves collection of analytical data on the components of the natural environment, economic activities and their classification; identification and classification of natural-territorial complexes and natural-economic systems.

Decryption is carried out according to the generally accepted scheme: preliminary decryption - field studies - office decryption - control.

At the first stage, the main types of drawings are distinguished and contour bases are created. In field studies, a method for studying key areas (elementary standards) and landscape reference profiles is used.

7. Creation of a spatial database (aerospace images and electronic maps).

The database is created for spatial modeling of the impact area.

The database consists of a database of multi-temporal satellite images and maps, digital terrain models containing information on environmental changes.

8. Creation of an attribute database (input of attribute data into the database tables).

It is created simultaneously with the spatial database. Attribute databases are tables containing attribute information (data, indexes, keys, etc.). Attribute databases include metadata databases (shooting date, shooting time, cloud percentage, etc.).

9. The GIS analysis of spatial information using the databases (zoning, buffering).

The GIS analysis of spatial information allows you to get intermediate and final versions of thematic maps, graphs and tables. Maps can be either two-dimensional reflecting phenomena or different indicators, or three-dimensional representing the 3D-virtual model of the area; static or dynamic.

5. Conclusion

The methodological and technological developments designed for organizing the environmental monitoring based on geoinformation mapping and integration of remote sensing materials and GIS technologies were tested on the Angara river reservoir cascade characterized by a wide range of environmentally harmful, dangerous and undesirable geodynamic and other processes. The use of these developments made it possible to perform a qualitative analysis of the coastal soil erosion types, zoning and mapping, as well as to obtain quantitative characteristics of coastal processes [16].

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