

The development of an interactive database for assessing the ecological and geomorphic state of aquatic ecosystems

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Abstract. The paper discusses the basic principles of using geoinformation technologies to study relief-forming processes and the ecological state of aquatic ecosystems. The object of the study is the territory of the city of Sevastopol within the valleys of the Chernaya, Kacha and Belbek rivers. To conduct environmental monitoring, it is proposed to use field and chemical-analytical methods. According to the data obtained, information and analytical maps with a geodatabase are produced. Creation of an information and analytical map with a database using GIS toolkit makes it possible to identify factors influencing the deformation of the river bed and changes in the ecological state of aquatic ecosystems. The proposed technology for monitoring the study area allows saving data, using them in projects, and supplementing these data as new information becomes available.

1 Introduction

The study of the characteristics of the physical and geographical conditions of the region is carried out in order to make fuller use of natural resources and to identify the patterns of their distribution. Thus, one of the significant problems of geomorphology is the study of modern processes of relief formation [1]. Many of the relief-forming processes create conditions for the manifestation of dangerous geomorphological processes. Among them, modern exogenous processes are the main. These include: fluvial, glacial, aeolian, permafrost and other processes. Nowadays, the knowledge of modern exogenous geomorphological processes is possible on the basis of the study of the spatial and temporal structure of exogenous relief formation [2].

The identification of relief-forming processes, as well as factors affecting the ecological state of aquatic ecosystems, and the development of an information database using GIS technologies at reference sites will make it possible to take timely action in the territories used in economic activities. The objective of the study is to analyze the use of geoinformation technologies for studying relief-forming processes and the ecological state of aquatic ecosystems (using the territory of the city of Sevastopol as an example).

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In the physical and geographical conditions of the city of Sevastopol, modern exogenous processes of relief formation are of great importance. To study natural processes and determine the state of aquatic ecosystems, studies are carried out annually as part of environmental monitoring. Based on the results obtained from monitoring, conditions for determining corrective action are created. It is made in cases where the target indicators of environmental conditions are not achieved.

The studies were carried out in 2016-2020 within the three main waterways of the city of Sevastopol – the Chernaya River (35 km long), the lower courses of the Kacha (5.4 km long) and Belbek rivers (17 km long). The main task of field research is to obtain data that substantiate the calculation of the average long-term rate of river banks erosion, as well as the ecological state of water bodies. The calculation results are further used for forecasting dynamics of structural changes in the studied rivers.

The field study was carried out in two stages. The first one is theoretical. It involves the identification of the processes developed in the study area, according to literary and other sources. The second stage is practical, field. During this stage the variation was created and the measurements were carried out.

2 Overview of breached regions to explore

The study is based on the organization of systematic observations at stationary hydrological stations and hydrochemical observation sites within the rivers of the city of Sevastopol. These are landfills or key areas for the study of exogenous processes and control of the aquatic ecosystems ecological state. The observation results are presented in the form of cartographic material. The creation of a map clearly illustrates an important information model of the development of natural and natural and technology induced processes, the state of the territory and conditions necessary for the management of the national economy (stability, vulnerability of this territory) [3-5].

During the study, a visual examination is also used, i.e. walking in the study area with a certain frequency. This method is applicable both for previously unexplored territories and for static observation sites. During the survey of the coastal slopes, the height of the ledge above the water level, the steepness of the slopes, the shape of the coastal slope, the presence of vegetation, the presence of deformations (cracks, landslide steps, erosion grooves and gullies) were studied. The natural and artificial conditions of the formation process were also compared. All changes that have occurred since the last survey were necessarily recorded. If the intensification of the process was observed, the possible reason was found out. For this purpose, sketching or photographing was carried out with capturing the dimensions characterizing a particular process. Moreover, schematic profiles of landslide and landslide-talus slopes were constructed. Within the coastal protection zone and water protection zone, sustainable land use, presence of unauthorized dumping grounds, and wastewater discharge were assessed.

In order to control the pollution of water bodies in the study area in 2020, observations were carried out on the basis of geochemical indicators in six sites located:

- on the Belbek River in the Frontovoye village (background site, border with the Republic of Crimea), Lyubimovka village (control site, organized wastewater discharge);
- on the Kacha River in the Vishnevoe village (background site, border with the Republic of Crimea), Orlovka village (control site, river mouth);
- on the Chernaya River to the village of Rodnikovoye (background site, unpolluted section of the river, protected area), in the village of Oktyabrsky (control site, organized wastewater discharge; the closing section of the river).

The assessment of water quality was carried out by comparing the values of concentrations of the determined components with the water body quality standards for

water bodies of value to fisheries. It includes the standards for maximum permissible concentrations of harmful substances effects in water of water bodies of fishery value (MPC).

The mathematical calculations of the results of the quantitative chemical analysis were performed. Thus, the background level of pollution of the surface water of each watercourse was established. For a comprehensive assessment of the water body pollution, the specific combined water pollution index (CWPI) and the coefficient of water pollution complexity (K_n) [3] were used.

An electronic map does not make it possible to accurately display the deformations of the river bed over the observation period and to reveal the dynamics of changes in the state of water resources. The most accurate is the field research method and the creation of an information and analytical map based on the data obtained. According to the data it is possible to monitor the ecological and geomorphological state of aquatic ecosystems for a certain period of time.

The creation of an interactive database of exogenous relief-forming processes in the form of information and analytical maps of key observation sites of the study area will allow monitoring coastal deformations and identifying areas with the most intensive changes in valleys in general.

This approach makes it possible to carry out geomodeling, geoinformation and spatial analysis using a database.

The interactive database ensures the following tasks: data aggregation; geocoding; cartometric measurements; interaction with databases of spatial and attribute data; surface zoning (including the construction of buffer zones); implementation of imposition operations; network and specialized analysis.

Such a database can become an important basis for creating an automated system for recording and monitoring the state of inland waterways of the Russian Federation [4]. It will be a key component of the automated interaction of participants in the process of vessel traffic along the inland waterways, including interaction with automated vessel traffic control systems and in the project of creating a unified multiservice network of basin authorities of the inland waterways and with other systems [5-9].

Let's consider the key tasks that need to be solved when creating an interactive database. These include defining the interactive structure as a set of links and classification of the data structure, a list of managed forms, etc .; definition of roles and user identification systems; determination of the nature of distribution and cross-platform (a web-oriented database seems to be correct, provided that the appropriate level of protection is ensured); ensuring information security of the database creation and operation based on the requirements for modern automated control systems and intelligent transport systems, and others.

3 Development of a mathematical model for assessing regional distance

The database can be understood as a multi-level system with many hierarchically separate levels interconnected with other levels. Taking into account the distribution of the future control system and the heterogeneity of the transmitted traffic (streaming and elastic), it is possible to introduce the system necessary in the future to monitor the state and maintenance of inland waterway from the point of the user's view in a triad: database, automated control system with a set of services and multi-service data transmission network.

Let's consider the issue of user identification.

User identification model is created in three main stages:

1. It is necessary to roughly divide the entire system being created into service classes.
2. For each class it is necessary to define a set of services included in it.
3. Conduct the process of user identification for the triad system as a whole and as a class sequence of steps to identify the user in each service of a specific class. Based on the mandatory access control model, the process dynamically changes over time under the influence of external factors, as a result the system increases its potential.

Let us introduce the following symbols:

1. C_i is the i class of services.
2. S_{ij} is the j service in the i class.
3. a_{kij} is the k user identification attribute, defined in the j service of the i class.
4. $A_{ij} = \{a_{1ij}, a_{2ij}, \dots, a_{kij}\}$ is a set of user identification attributes, defined in the j service of the i class.

To transfer the attributes of user identification, the following can be used: keyboard (login, password); e-token (transfer of electronic digital signature); contact memory (touch memory); current switch; plastic contactless keychain; smart card; transponder (for transmitting wireless codes (squawk code, etc.)), biometric identification, and other devices [6].

For each attribute $V_a \in A_a V_a$ a domain is identified (discrete values are allowed for domains).

The plurality 2^{V_a} is the super domain of the $V = \bigcup_{a \in A} V_a$ attribute. Thus, the user identification model can be represented as a pair (A, V) .

For $\forall A \subset S$ we define the following values:

$$V_S = \bigcup_{s \in S} V_s, \quad (1)$$

$$\bar{2}^{V_S} = \bigcup_{s \in S} 2^{V_s} \quad (2)$$

By a tuple of T-type we mean a function of the following form:

$$r : T \rightarrow \bar{2}^{V_T} \quad (3)$$

and $r(a) \subseteq V_a$ for all $a \in T$, then instead of $r(a)$ we use r_a , and for a tuple of T-type r_T , the set of all tuples of T-type will be denoted as $U(T)$ [7].

Note also that the values of the attributes of the user identification model can change during the operation of the network. It is determined by possible migration and changes in the composition of services, as well as by the type of identification. If such situations arise, a reclassification is needed [8, 9, 10].

To determine the probability of correct identification in the system, as a set of services divided into classes, we define the value:

$P_{kij}(a)$ – the probability of correct identification by the k user identification attribute, defined in the j service of the i class.

The total probability of correct identification will be determined by the expression:

$$P = \sum_{i=1}^{q_1} \left[\sum_{j_1=1}^{n_1} P_{kij_1}(a) + \prod_{j_2=1}^{m_1} P_{kij_2}(a) \right] + \sum_{j=1}^{q_2} \left[\sum_{j_3=1}^{n_2} P_{kij_3}(a) + \prod_{j_4=1}^{m_2} P_{kij_4}(a) \right] \quad (4)$$

where $n1$ is the number of pairwise independent services in the first class involved in identification, $m1$ is the number of pairwise incompatible services in the first class involved in identification, $n2$ is the number of pairwise independent services in the second class involved in identification, $m2$ is the number of pairwise incompatible services in the second set involved in identification [7-9].

The main information available to the user at the first stage of the development of an intelligent database, as part of the triad, is the information contained in electronic maps.

To build maps and create a database, the following information was needed:

- Satellite image of Landsat 7 ETM + (2020);
- Vector layer created by vectorizing space image.
- Field survey data: coastal edge displacement rates; channel bottom measurements; results of survey work using hardware and software systems; photographs.

According to the data obtained, graphs of coastal deformation of the studied rivers bed were built, information and analytical maps were created with a database of exogenous relief-forming processes for each control section (Figure 1).

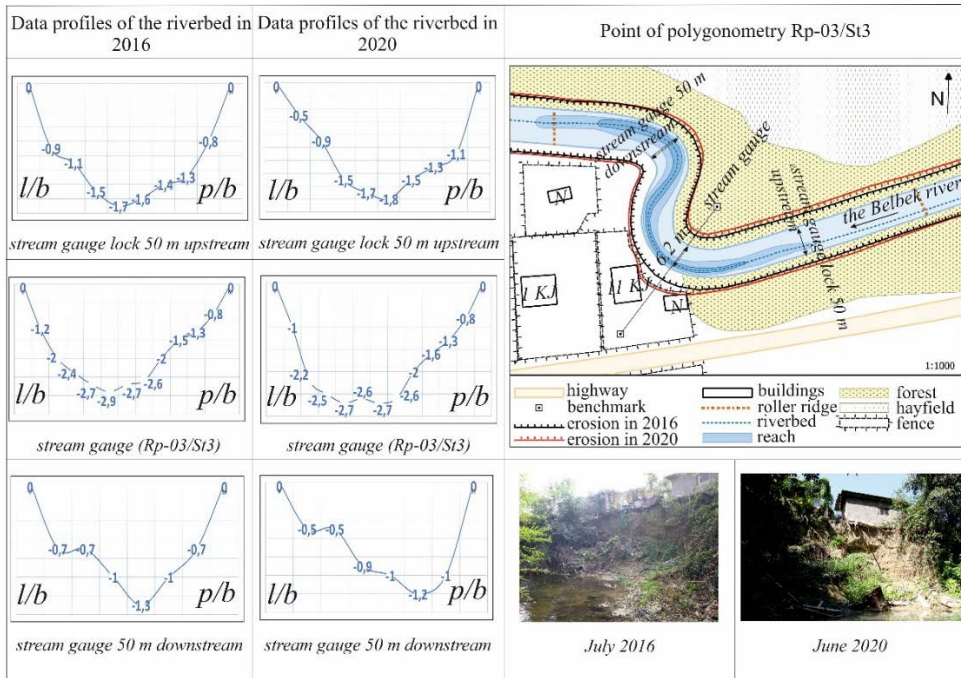


Fig. 1. Section 3 – the Belbek river – the village of Lyubimovka.

The nature, intensity and rate of erosional destruction largely depend on the composition and current state of rocks. The state of rocks is determined both by the degree of their lithification and the phase composition of the water in them. The most rapidly destroyed shores are composed of sands and sandy loams. The banks, composed of sandy loams of different dispersion, are eroded to a lesser extent. Thus, Holocene loamy formations are eroded more intensively in comparison with upper quaternary loamy rocks of the same genesis. The banks, composed of medium-quaternary loams, are eroded at a lower rate, especially in areas where the lower part of the slope is lined with coarse detrital material.

The deposition of the fluvial type of exogenous transformation depends on the development of depth, lateral erosion and flooding during the spring-summer flood. In all river valleys of the study area, there is an active accumulation of riverbed and floodplain facies of alluvium. The first of them is formed on all segments of valley complexes, but its most active formation occurs on meandering rivers sections.

The deposition of the floodplain facies during the observation period was recorded within the low levels of floodplain and on levees. The deposition was assessed by recording the morphometric characteristics of shallows composed of riverbed alluvium facies. Thus, it is possible to trace how the average conversion rate of the edge of the coastal slopes has

changed over three years. These indicators are directly related to heavy rainfall in this observation area in 2018. In 2020, minimal coastal deformations are recorded in all observation sites due to extremely dry summers and drying up of water bodies (Figure 2).

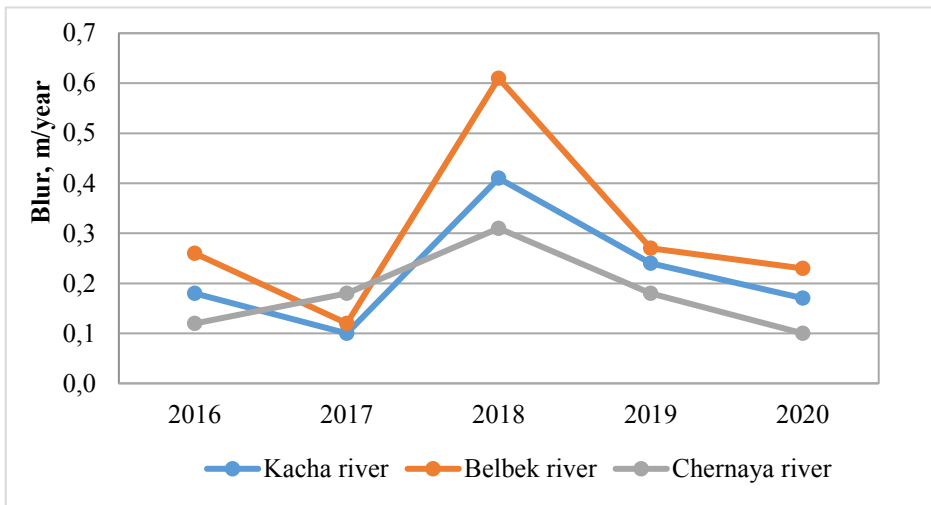


Fig. 2. Average annual coastal deformations of the river banks of the city of Sevastopol.

It should be noted that the territory of the Sevastopol region is involved in modern morpholithogenesis. Moreover, the formation and transformation of the near-surface geological space, including the shape of the earth's surface, is underway. The intensity of exogeodynamic processes directly depends on the lithological composition, the nature of the relief, climatic and hydrological factors.

The level of water bodies' pollution was assessed in accordance with the Method for Comprehensive Assessment of the Degree of Surface Water Pollution by hydrochemical indicators [3] and by the CWPI index (specific combined water pollution index). Based on the data obtained, graphs of the concentrations of pollutants were built for each observation site with reference to cartographic and photographic material (Figure 3).

4 Regional survey results

The reasons for exceeding the established standards in observation sites for phenols, copper, nitrites, sulfates and magnesium are the intake of pollutants from the catchment area and with wastewater for household purposes. All observation sites are located in areas of irrigated agriculture. Thus, with heavy rainfall, the likelihood of a diffuse runoff of pollutants from various anthropogenic objects increases. So, it will contribute to an increase in the concentration of pollutants in the aquatic ecosystems of the rivers of the city of Sevastopol.

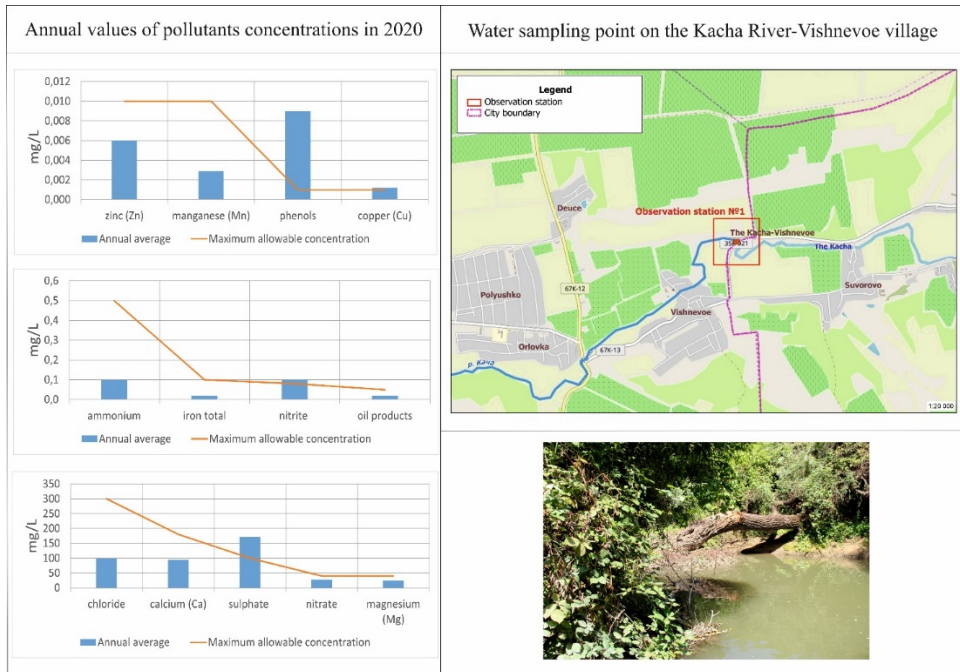


Fig. 3. Site 1 – the Belbek river in the village of Lyubimovka.

The creation of this kind of database makes it possible to analyze the factors influencing the coastal deformations of the river banks, to analyze and predict the dynamics of pollution of aquatic ecosystems. This solution provides the opportunity to store data, use it in projects, and supplement it by the user as new information becomes available.

Basic requirements for such an interactive database:

1. Graphic and attribute data must be stored in a relational database.
2. Three-tier architecture. Client, application server, and database server.
3. Integration bus.
4. Personal user workspace.
5. Using a flexible query system.

It is advisable to use the flexible and popular programming language Python, its libraries and frameworks, to introduce machine learning technologies into an interactive database. This will ensure high-quality and fast data classification and creation of datasets that facilitate efficient data processing and makes it possible to find dependencies and determine uncharacteristic (including abnormal) values.

The toolkit that allows you to analyze data using neural networks will significantly speed up operations and reduce the impact of the human factor without excluding from this process a specialist who makes a decision and evaluates the results obtained. The combination of organizational and technical measures for the transformation of exploring activities will give an undeniable competitive advantage in the study of the dynamics of riverbank processes and changes in the state of aquatic ecosystems.

5 Conclusion

The developed interactive map from the database makes it possible to analyze the factors influencing the coastal deformations of the riverbank, to analyze and predict the dynamics

of pollution of aquatic ecosystems. This solution provides the opportunity to store data, use it in projects, and supplement it by the user as new information becomes available.

Based on the results obtained, the following conclusion can be drawn:

1. When monitoring the modern transformation of ecosystems under the influence of anthropogenic factors, the most accurate is field and chemical-analytical methods, with the creation of an information-analytical map with a geodatabase based on the data obtained.

2. Creation of a GIS toolkit for an information and analytical map with a database makes it possible to identify the factors influencing the deformation of the river bed and changes in the ecological state of aquatic ecosystems. This technology for monitoring the study area allows saving data, using them in projects, and supplementing these data as new information becomes available.

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