Paleoreconstruction of natural conditions as the basis for the rational use of natural resource management on the territory of the Neva Lowland

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Abstract. Modeling the evolution and dynamics of hydrological conditions of the Neva Lowland is of great theoretical and practical importance. The lowland is located in the Neva River basin, through which water from Europe's largest Lake Ladoga flows. From the Mesolithic to the present day, the river has been a source of drinking water and biological resources and an important transportation route. The location of the river at a major crossroads of transcontinental routes connecting West and East, North and South Eurasia, determined the metropolitan functions of the territory and the development of the multi-million city of St. Petersburg. The city's location on the Neva Lowland caused floods and gave rise to a number of environmental and geo-environmental problems. To optimize the use of natural resources, the cartographic models of the terrain are in great demand, on their basis it is possible to improve quantitative assessment and trends of waterlogging processes, submergence, risks of floods and disturbances in the water balance, exceeding the concentration of pollutants in water and bottom sediments. Reconstructions of hydrological conditions of the Neva Lowland in the Holocene are of interest for clarifying the evolution of natural and climatic conditions of the North-West Russian Plain. The aim of the article is to discuss the possibility of using GIS methods to study changes in hydrological conditions on the basis of actual data obtained so far in geography and archeology (geo-position and dating of objects of nature and material culture). The result of the work are maps that allow solving the problems of rational zoning of the territory, taking into account geological and environmental risks.

1 Introduction

Under conditions of global warming significant changes may occur north of 56ºN, in ancient times this latitude was considered as the border of the Arctic [1]. This region is the most sensitive to global climate changes due to the lack of solar energy. Moreover, tectonic movements are significant here. Paleogeographic studies carried out in Northern Europe and North America have revealed traces of paleo-tsunamis and large-scale changes in hydrological conditions (water level fluctuations, slow and catastrophic floods). Such processes require detailed research and should be taken into account in the long-term planning of the development of the northern territories. catastrophic floods).

Possibilities of modern geographic methods and software for spatial analysis of potential environmental claims can be considered using the example of the Neva Lowland (Prinevskaya Lowland). The lowland is located at 60º latitude at the junction of the Baltic crystalline shield and the ancient Russian platform. The centerpiece of this territory is the Neva River, which carries water from Lake Ladoga, Europe's largest lake, to the Gulf of Finland in the Baltic Sea. The Neva River is used by the population as a source of drinking water, biological resources, as well as a water transport route. At the mouth of the Neva there is the northernmost city with a population of over five million, and the banks of the river are being actively built up. Building a dynamic GIS model and 3D model of the Neva Lowland will improve the assessment of waterlogging processes, submergence, as well as the risks of floods and excess concentration of pollutants in water and bottom sediments. This information is necessary for the optimization of modern nature management and long-term territorial planning.

The aim of the article is to discuss the possibility of using GIS methods and studying changes in hydrological

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conditions based on the facts accumulated to date in history, archeology and earth sciences. To achieve this goal, the authors have analyzed the main sources of information – archives of natural and archaeological data, existing experience in the reconstruction of natural environments of territories using GIS. The authors' models of the hydrological situation of the Neva Lowland in Holocene (the boundaries of the Baltic and Ladoga transgression) are presented and their correlation with the elements of modern territorial and production structure of this territory is analyzed.

2 Methods of Research

The geographic database (DB) includes characteristics of natural and anthropogenic objects that preserve information about the past. The main source of information is the published paleogeographic data on the litho-, bio- and chronostratigraphy of bottom sediments of lakes and peat deposits of bogs in the region under study. Additional information may be obtained during expeditionary work on sampling in poorly studied areas of the territory (at different hypsometric levels). Comprehensive laboratory processing of samples includes radiocarbon dating, lithological, diatom, palynological, chironomid analyzes, as well as determination of the content of organic matter in the samples by the method of weight loss on ignition. To include new data in the database, the correlation of new data with paleogeographic information obtained from scientific publications is carried out. The results of the reconstruction of changes in the natural environment of the territory are presented in the form of paleogeographic maps showing the dynamics of hydrological conditions, changes in the types of lake sedimentation, changes in the main dominants of the vegetation cover and climatic characteristics.

ERS and GIS methods are used for the spatial analysis of paleogeographic data. To create a series of maps characterizing the main stages of the evolution of the hydrological conditions of the territory, the QGIS program is used. The program allows to work with the map layer by layer and analyze the spatial combinations of information presented on different layers, as well as to group the marking objects by their dates and qualitative differences.

The cartographic basis for modeling the hydrological conditions of the Neva Lowland territory was created on the basis of a series of 1:100000 scale maps. The boundaries of the maximum flooding of the Neva Lowland territory in the Holocene were drawn in accordance with the data of different authors: Litorina transgression of the Baltic Sea 10 m above the current world ocean level 7.6-7.2 kyr BP [2]; Ladoga transgression raising the level of Lake Ladoga to 20 m above sea level 3.5 kyr BP [3]. However, the dating of these events remains a matter of debate. There is a possibility that the rise in water levels in the region occurred at the same time.

3 Results and Discussion

3.1 Sources of information for creating a geographic database and reconstruction of the stages of evolution of the natural environment of the Neva Lowland in the Holocene

Archaeological materials on the Neva Lowland are very limited, due to the fact that ancient people chose for permanent settlements dry elevated places of the Karelian Isthmus and the Izhora plateau. Excavations at the promontory settlement at the mouth of the Okhta river (in the center of St. Petersburg) testify to the economic development of the river and the broad contacts of the population of these lands with the Baltic regions and the north of the Russian Plain about 5,000 years ago [4].

The position at the crossroads of transcontinental routes connecting West and East, North and South of Eurasia explains the metropolitan function and high development potential of this territory [5]. Today the territory is actively developing under the influence of the largest industrial and cultural center in Russia, sea and river port - the city of St. Petersburg [6, 7]. However, the development of a multi-million city is associated with a number of environmental problems (drinking water supply, pollution, flooding, pressure on the earth's surface), which require reliable models of the relief and hydrological conditions of the territory (taking into account their modern dynamics and evolution). The most suitable tool for solving such problems is GIS modeling, which is widely used in scientific research, in the dissemination of reference information and in management [8-10].

The works of A.V. Amantov, V.M. Anokhin, D.Yu. Bolshiyanov, N.N. Verzilin, D.A. Subetto, M.V. Shitov and other researchers [11-14] are devoted to the issue of the evolution of the nature of Lake Ladoga and its territory, the Karelian Isthmus and the Neva Lowland. However, the published data poorly correlate with each other, and their interpretation varies significantly. The main differences are related to the question of the history of the Neva River formation. The time and reasons for the formation of the Neva - whether it was the result of a revolutionary restructuring of the river network or a gradual transformation of a narrow sea channel into a river - are debated. It should be noted that macro-regional characteristics obtained in different parts of the Baltic Sea and similar conditions in North America [15-23], as well as the methods of general physical geography and geomorphology developed in recent decades [24], are still poorly involved in this discussion. The doctrine of rhythms in nature by A.V. Shnitnikov - E.V. Maksimov [25], which makes it possible to determine and predict the changes in humidification conditions of the global climate and a separate territory, has also not found application.

3.2 Capabilities of software tools for spatial analysis for solving theoretical issues and applied problems.

The paleogeographic database (DB) was created to reconstruct the stages of the development of the hydrological situation and to create prognostic models of the development of the territory. The elements of the database are the following information: 1) object name; 2) geographical coordinates of the object (latitude and longitude); 3) altitude above sea level; 4) altitude marks of lower and upper surfaces of bogs (or cores of lake bottom sediments); 5) dating and characteristics of the studied quaternary deposits; 6) archaeological data: names and location of sites, nature and age of finds. Placing the data on the map made it possible to highlight the areas where it is necessary to collect additional information. The augmented spatial model will be able to provide the zoning of the territory in accordance with the proposed hypothesis or search question.

Spatial analysis of these materials contributes to solving theoretical problems and practical problems of modern nature management, for example: 1) the problem of the origin of the Neva River and its name, 2) modern environmental zoning of the territory, and 3) drawing up long-term perspective plans for economic development. A few examples are considered further in the study.

3.2.1The issue of the origin of the Neva River

The formation of the Neva River is one of the key issues in the geography of the North-West of Russia since this river receives the flow of three large lakes –Ladoga, Onega and Lake Ilmen, as well as many rivers, including the Volkhov. archaeological studies show, the Neva basin has been inhabited by mankind for a long time - during almost the entire Holocene. However, on the banks of the modern Neva, the sites of ancient people are practically absent. The exception is the lower course of the river at the confluence of the Okhta river, where cultural layers of the Stone Age have been investigated. In the descriptions, written by ancient authors, it was noted that the Ocean Bay (Gulf of Finland of the Baltic Sea) continues as a waterway to the Caspian Sea. This suggests the transit position of the river and its role in the economic development of the region. However, scientifically, the prevailing hypothesis is the recent formation of the river as a result of a break of the waters of Lake Ladoga, which is also confirmed by legends of the Flood and the testimonies of ancient authors about catastrophic floods that set in motion many European peoples. The discussion about the origin of the Neva and the history of Lake Ladoga has been going on for over 100 years. According to various sources, the time of the breakthrough of the Ladoga waters into the Baltic along the channels of small rivers, the predecessors of the Neva, is estimated for the period from 3 thousand years BC up to 7th century AD, some authors attribute this event to the late Ice Age [26-28].

The results of GIS modeling of the maximum transgression boundaries of the Baltic Sea and Lake Ladoga are presented in Figures 1 and 2. Analysis of the images shows that the hypothesis of a catastrophic flooding breakthrough does not fully correlate with the obvious facts: 1) the maximum level of the Baltic Sea does not affect the structure of the hydrographic network - its main directions remain (towards the Neva riverbed); 2) the maximum level of the Ladoga transgression of about 20 m could not lead to a breakthrough of water through the watershed, since the excess water is taken away by the Vuoksa, which, even in historical memory, reversed the direction of flow - this phenomenon often occurred during the spring floods. The watershed breakthrough version makes no sense at all if we accept the refined model of the lake development, in which the maximum rise of water is up to 12 m above the sea level. At the same time, it can be seen that the Neva River in each of the models is much shorter in length than today (74 km). When the two models are superimposed, its length is reduced to 15-20 km, which does not allow us to speak of it as a river, but only as a short channel.

3.2.2 Discussion about the origin of the name of the Neva River

The name of the river is interpreted in different ways today. It can mean “new” (in Sanskrit and in many other languages - nava [29, 30]), then this confirms the youth of the river and the preservation in the hydronym of the memory of its formation (the emergence of the New River). On the other hand, Lake Ladoga had for a long time the same name as Nevo, the bowl of which began to fill with water 14 thousand years ago (the whole system “lake - river” was denoted by one name). The age of the lake does not agree with the ideas about the youth (newness) of the objects and allows to consider their connection with the root navis “ship, vessel” (Latin nāvigātiō “navigation”, navigare “to sail a ship”, English navy “fleet”) [31]. Modern toponyms retain their navigational meaning: Lake Ladoga, the city of Lodeinoe Pole (Russian ladia – shallop, a boat of large displacement). Navigational conditions in Lake Ladoga are estimated as very difficult (over its surface, the wind is gathers strength, raising high waves). For this reason, a canal was built in the area of Southern Ladoga bypassing the shallow southern part of the water area in Southern Ladoga, by which the ships bypassed dangerous part of the way further to the south, north and east. Work on the creation of the water system, later called Mariinskaya, began under Peter I and lasted for over 100 years. During the laying of canals in the middle of the 19th century, cultural layers of the Stone Age settlements were uncovered (findings of A.A. Inostrantsev). All this confirms the transit function of the Neva as an important link in water communications.

3.2.3 Territory zoning for sustainable development

Due to global warming of the climate, flooding of territories caused by floods exceeding average multi-year levels has become more frequent. During floods, settlements located in river valleys are submerged [32]. It is possible to avoid such consequences by creating

new sites based on the selection of relief elements exposed to similar phenomena in the past. Zoning taking into account natural environmental risks is especially important for areas of new development. In the absence of information stored in the historical memory, the only basis for assessment is the reconstruction of the evolution of hydrological conditions of the territories. Overlaying the Holocene flood boundaries on the satellite image of the Neva Lowland allows to single out zones of natural environmental risk and zones of sustainable development (Figure 3). Elevated relief elements can be recommended for implementation of promising long-term projects requiring large investments. On low-lying territories, it is necessary to limit construction and organize monitoring of such phenomena as waterlogging of the soil and the release of radon, development of flooding and submergence processes. Taking into account such zoning, anthropogenic risks should also be analyzed – flooding during dam closure, pollution of surface water and soil, etc.

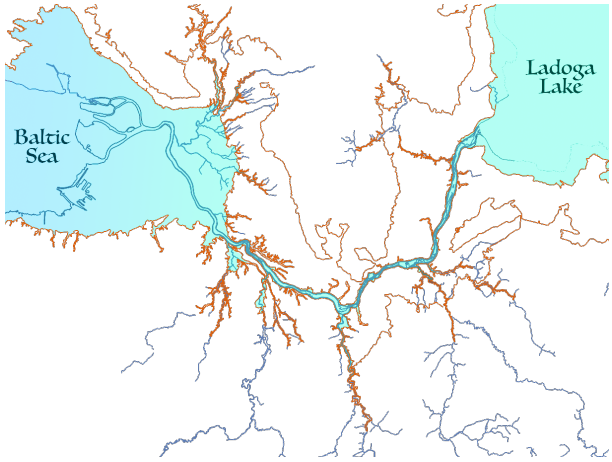

Fig. 1. Littorina transgression of the Baltic Sea (10 m above the current level)

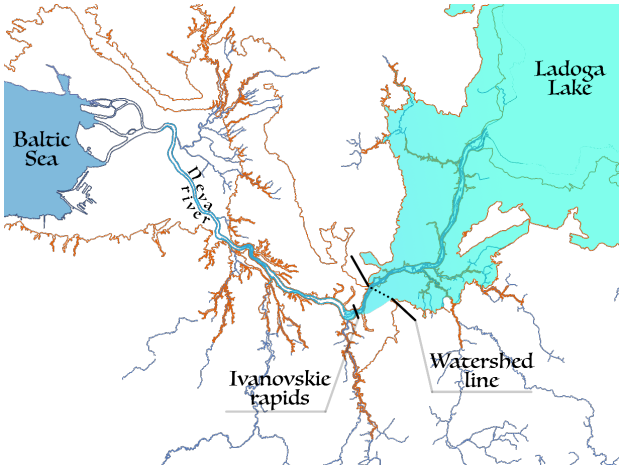

Fig. 2. Ladoga transgression (the boundary of flooding is shown when the water in the lake rises to 20 m above sea level, i.e., 16 m above the modern level).

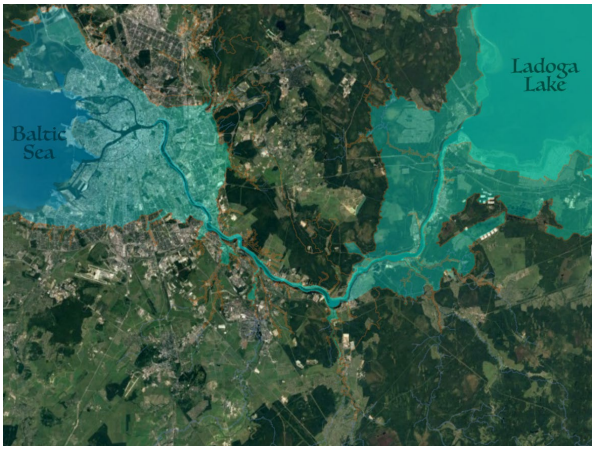

Fig. 3. Overlaying the Holocene flooding boundaries on the satellite image of the Neva Lowland, identifying zones of natural environmental risk and zones of sustainable development

4 Conclusions

The reliability of the forecast is determined by knowledge of the past, as well as the characteristics of the previous stages of development of the territorial system. It is especially important to assess the rate and direction of changes in natural processes in areas of prospective development, which include the Arctic. To reconstruct changes in the past, it is necessary to study archives of natural and anthropogenic data. Information about the development of the territory over hundreds and thousands of years is contained in such landscape characteristics as the height of river terraces, the composition and thickness of quaternary deposits, and the nature of organic inclusions.

At the present stage, sufficient data have been accumulated to start creating spatial paleogeographic reconstructions of the Neva Lowland. Such models will contribute to solving modern problems of nature management and can be taken into account in developing a strategy for sustainable development of the region in the context of global warming. Among the immediate scientific tasks of this area of research it is possible to allocate: 1. modeling the development of the Neva Lowland in the Holocene and creating a digital model of the region's relief at different stages of its existence, followed by calculations of surface levels in different historical periods using GIS methods; 2. clarification and obtaining new data on prehistoric settlements in the context of environmental changes; 3. establishing the time of formation of the Neva River based on the combined use of paleogeographic data of both natural and anthropogenic nature (archaeological data).
Fundamental studies of the spatiotemporal heterogeneity of the natural environment are useful for optimizing existing planning schemes for any territory.

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