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Assessment of spatial and temporal dynamics of the Selenga River channel deformation

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Abstract. The identification of spatio-temporal patterns of transformation of the Selenga river channel is an important task, which has both theoretical and practical importance. Dynamic seasonal and long-term changes in the levels and flow rates of water in the Selenga river, as well as significant kinetic energy of the flow cause a high intensity of channel processes, which must be taken into account in the construction and operation of hydrotechnical and shore protection, as well as other protective structures. A retrospective comparative analysis of the dynamics of channel deformation based on the thematic automated interpretation of Landsat satellite multi-temporal data is carried out. This, together with engineering hydrological calculations, allowed us to perform a qualitative and quantitative assessment of the results of the long-term manifestation of natural processes in a vast area occupying part of the Selenga valley from the state border to its delta. In the course of work, for the first time a map of the Selenga river channel dynamics. Areas with different types of channel stability have been identified, the channel classification has been carried out into meandering, straight and braided sections.

1. Introduction

The relevance of studying the processes of the Selenga channel deformation is connected with a high degree of agricultural, industrial and urban development on its coastal areas. Selenga is the largest river flowing into Lake Baikal. The Russian part of the Selenga river basin lies within the southern and central regions of the Republic of Buryatia and the western regions of the Zabaykalskiy krai. There are large populated settlements on its banks, including the city of Ulan-Ude (430 000 people). The Federal highway "Baikal" R-258 and the section of the Trans-Siberian railway run along the river at several extended sections in close proximity to the channel. One of the negative impacts of water is the deformation of the channel network: erosion and destruction of banks, changes in flow rate, redistribution of runoff, etc. [1].

The waters of the Selenga River are intensively used not only for household needs, but also for agricultural and industrial supply. Dynamic seasonal and long-term changes in the levels and flow rates of water in the river, as well as significant kinetic energy of the flow in the Selenga channel cause a high intensity of channel processes, which must be taken into account in the construction and operation of hydrotechnical and shore protection, as well as other protective structures. In this regard, the identification of spatio-temporal patterns of transformation of the Selenga channel is an important task, which has both theoretical and practical importance.

In the work, the main purpose of which is to establish patterns of transformation of the Selenga channel, a retrospective comparative analysis of the dynamics with the identification of areas of different manifestations of channel processes based on the thematic interpretation of Landsat satellite date is carried out. This, together with engineering hydrological calculations, allowed us to perform a qualitative and quantitative assessment of the results of the long-term manifestation of natural processes in a vast area occupying part of the Selenga valley from the state border to its delta.

The methodological basis of the study is formed by the works of R S Chalov (2004, 2007), N N Nazarov (2007) and other well-known geomorphologists and hydrologists. The practical part is based on the application of remote sensing research methods. At present, modern tools for obtaining information, such as remote sensing methods, are used to obtain reliable information about the terrain and to assess its natural and anthropogenic changes [Schovengerdt].

An urgent task is to identify the sections of the river that are most susceptible to channel deformations, with the aim of predicting them using the data of remote sensing of the Earth.

The purpose of the work is to assess the dynamics of the coastline of the Selenga River.

Objectives: processing and analysis of multi-temporal imagery of the Selenga channel, assessment of the stability of the channel, typification of the Selenga channel by the type of deformation.

2. Materials and methods

From the geo-portal of the US Geological Survey by means of GloVis search system (http://glovis.usgs.gov/) 2 "autumn" scenes of Landsat 1989, 1997, 2006, 2010 and 2015 were downloaded. The spatial resolution of the downloaded images is 30 m/pixel. A prerequisite when downloading images was a complete lack of clouds (0 %), high quality (Qlty = 9) and high level of preparation of images (L1T level – orthotransformation, radiometric and atmospheric corrections).

For the purposes of hydrological interpretation, images obtained in the range of the electromagnetic spectrum of 0.6-0.8 μm were highly informative. In this case, the water surface is sharply separated from the images of other natural formations. There is a wide possibility of automated recognition of objects through the mathematical formalization of the interpretation process and the use of modern digital image processing systems [1, 3]. Synthesis with staining of the image obtained in the near-infrared zone of the spectrum is applied, in red, in the first middle infrared - green, and in the red visible zone - blue, i.e. pseudo-color RGB composites with a combination of 4:5:3 channels were created.

Height radar data of the Digital Elevation Model SRTM (Shuttle Radar Topography Mission) were downloaded from the FTP-server of the U.S. Geological Survey. To conduct relief morphometric analysis, a number of the corresponding morphometric maps were established and analyzed (along with the data of field observations): hypsometry, slopes, and aspects. In addition, topographic modeling of three-dimensional images was conducted.

In order to narrow the study area directly to the water surface of the Selenga River, a coast mask was created using vector layers of the Roscartography digital map. Subsequently, identical fragments to the study area were cut out by coordinates of multitemporal RGB-composites according to the created mask. Deciphering of the Selenga channel was carried out using the ISODATA uncontrolled classification method (Iterative Self-Organizing Data Analysis Technique - an iterative self-organizing data analysis technique) [4]. This algorithm is advisable to use in the absence of a priori information about the subject. The method allows you to select the contours with a non-contrast spectral brightness structure. The optimal input parameters were determined: the number of classes is 5 (but it was varied), the maximum number of iterations is 20, the convergence threshold (the number of pixels that change their class membership when moving to the next iteration) is 5 %, the maximum standard deviation from the average is 13, the minimum number of pixels for class selection is 3, the maximum standard deviation inside the class is 5, the minimum spectral distance is 5 pixels.

The resulting intermediate images required further integration or division of classes, since the same objects fell into different clusters (due to lighting conditions), and different objects appeared in the same cluster (due to the same brightness). In the first case, the clusters were combined into one class, and in the second case, additional decoding features were used to distinguish between objects.

The next step in the deciphering of the obtained sites is postclassification processing, which was carried out by the "Majority Analysis" method. The purpose of the method is to enhance the reproduction of recognized objects, suppress noise and other random noise, in other words - generalization of the image. In the process of processing, the size of each pixel of the image was changed depending on the values of neighboring pixels in the sliding window with the size of 3:3 pixels. After postclassification processing the obtained raster images were converted to vector form.

So, the following sequence of satellite images processing is accepted during the research: 1) downloading orthotransformed Landsat images from the Internet; 2) image transformation - synthesis of RGB-composites; 3) generation of required fragments; 4) automated classification of water bodies; 5) creation of vector layers, their editing; 6) obtaining the final map of the Selenga river coastline change.

3. Results and discussion

During the work, an analysis of the results of the automated classification of Landsat multi-temporal images of the Selenga River at different times in Russia was conducted (Figure 1).

When analyzing the received multi-temporal vectors of the Selenga channel, 4 sites with different characteristics of the channel stability manifestation were identified (Table 1, Figure 2).

Stability of a channel is understood as the degree of its resistance to erosion. The stability is higher, when flow rate is lower and, accordingly, the lower the erosive ability of the flow. In addition, increased stability contributes to such a factor as a large resistance of the channel to erosion, which is determined by the size of the sediments forming the bottom, the cohesiveness of sediments composing the banks and fixed by the influence of vegetation, etc. The Lokhtin coefficient was used as an indicator of the degree of stability of the channel: $L = d / \Delta H$, where d is the average particle diameter of the soil composing the channel; ΔH is the fall of the river (m / km) [5].

For the starting point of 0 km, a bridge in the village of Treskovo was chosen, because this is where the river delta begins.

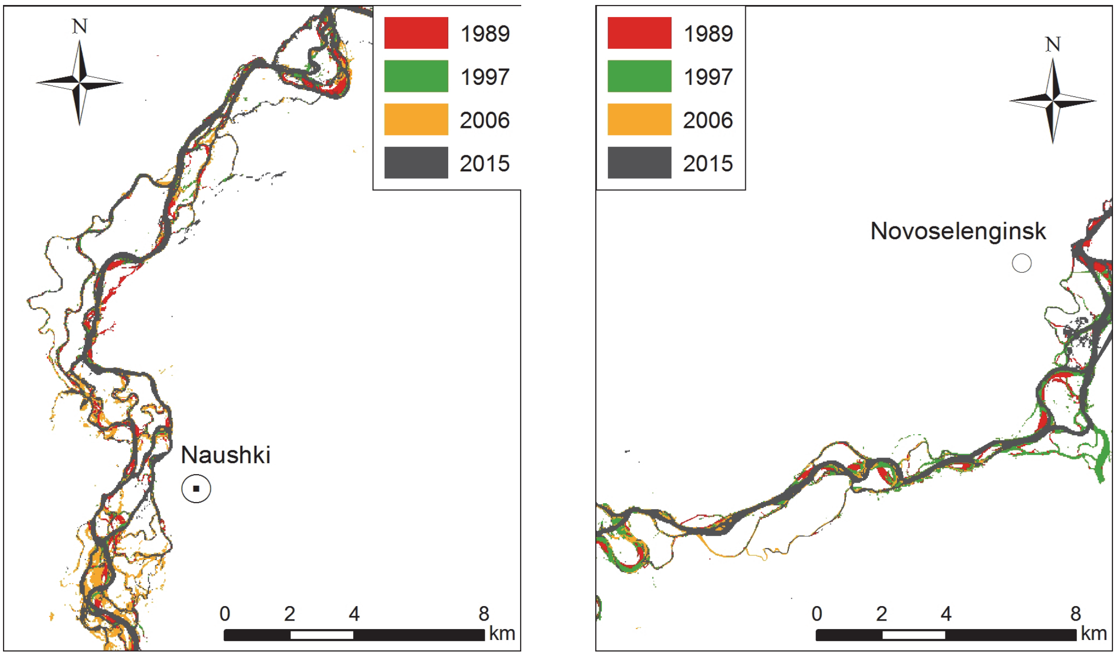

Figure 1. Example of implementation of Landsat multi-temporal image classification.

Table 1. Distribution of the Selenga River channel patterns.

Section	Distance from Treskovo settlement (km)	Channel pattern	Lokhtin coefficient
S1	51	relatively stable	3.12
S2	118	relatively stable	1.32
S3	190	stable	16.00
S4	313	unstable	0.70

The total length of the Selenga River from the border with Mongolia (Naushki village) to the bridge to Treskovo village is 322 km. Using the classification of R S Chalov [6], 3 channel patterns were identified in the considered areas: straight, meandering and braided (Table 2).

Table 2. Correlation of morphodynamic channel patterns on the Selenga river (%).

	Straight	Meandering	Braided
Total length (km)	104.8	152	65.5
From the entire length (on the territory of the Russian Federation), %	33	47	20
Section	S2a, S3	S2c, S4a	S1, S2b, S4b

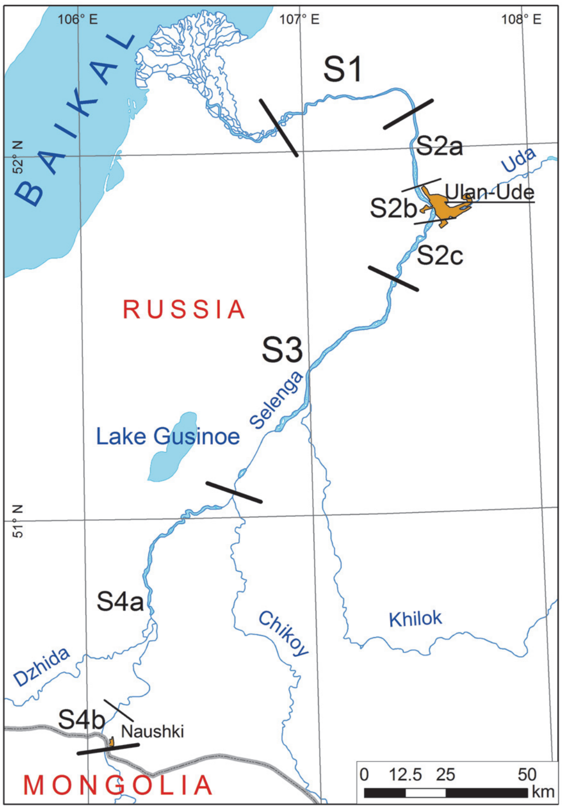

Figure 2. Distribution of Selenga River channel patterns.

It has been revealed that meandering pattern is typical for the most part of S4 section (section with unstable channel) and is 152 km from the total length. S2c section is with unstable channel. There is no meandering in S3 (stable channel) area. Straight pattern is typical for S2a and S3 sections and is 104.8 km from the entire length of the Russian part of the watercourse. The braided pattern has the shortest length of 65.5 km and is observed in sections S1 (section with relatively stable channel), S2b and S4b.

In the course of the work the map of the Selenga river channel dynamics was obtained for the first time. Sites with different types of channel stability were identified, and the channel was classified into meandering, straight and braided sections.

4. Conclusions

The results of the study allowed to identify areas of stability and patterns of the Selenga River channel, which will be used in future for detailed study of the impact of channel processes on economic activity in the Selenga River valley under climate change conditions. Special attention will be paid to the study of areas with unstable channel, as the study has shown that they coincide with areas of maximum population concentration and economic development.

It is planned to identify morphometric indicators such as: river width, meander neck length, axis length, radius of curvature, water flow length, and sinuosity of meander. The dynamics of these indicators will be linked to climate change and land use.

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