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# GEOGRAPHY ENVIRONMENT SUSTAINABILITY

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# SPATIAL AND TEMPORAL DYNAMICS OF THE BAIKAL COASTAL LINE CAUSED BY CONTROL OF THE LAKE LEVEL REGIME

ABSTRACT. The paper presents the results of a study on changes in the coastal line of the Yarki islands (North Baikal) using remote sensing data of the Earth. Vector shape files were generated from the automated classification of the multi-temporal Landsat data. The analysis suggests a systematic decrease in the Yarki's sandbar area.

KEY WORDS: remote sensing, multispectral image, interpretation, automated classification, vector layer

## INTRODUCTION

After commissioning of the Irkutsk hydroelectric power station in 1957 and of the subsequent cascade of the Angara hydroelectric power stations (the Bratsk and the Ust-Ilim), by 1959, the average level of Lake Baikal rose by more than 1,2 m in relation to its natural level (455,61 m; here and further, measured in the Pacific Ocean system), which has led to the formation of a new hydrological regime of the lake [Galaziy, 1988]. Thus, at present, the level of Lake Baikal for the most part does not depend on natural factors but is heavily influenced by the Angara hydroelectric system [Monitoring ..., 1991]. The intra-annual fluctuations in the lake level increased from of 82 cm (under its natural regime) to 94 cm (after the control implementation) [Atlas..., 1993]. The rise of the lake level had a negative impact on the productivity of the aquatic flora and fauna, biodiversity, water birds and animals, and has led to the erosion of the coastline. The end-result of the construction of the Irkutsk hydroelectric station is the transformation of Lake Baikal into an artificial reservoir with all the ensuing consequences.

During high-water years of the mid-1990s, there were level marks well above 457 m. As a consequence, there was a mass destruction and erosion of the coastline of the low eastern coast (coastal forests, recreation areas, beaches, and coastal structures), water logging, and flooding of agricultural land and settlements. There has been a widespread environmental damage to the natural biological complex of the lake system. There are estimates of the economic damage to the economy of Buryatia; there is also a negative experience with the litigation of JSC "Irkutskenergo" [Hydropower..., 1999]. In order to prevent such processes, the Government of the Republic of Buryatia in agreement with the Irkutsk Oblast Administration initiated the adoption of the 2001 Resolution of the Government of the Russian Federation № 234 "On the limits of the water level in Lake Baikal under

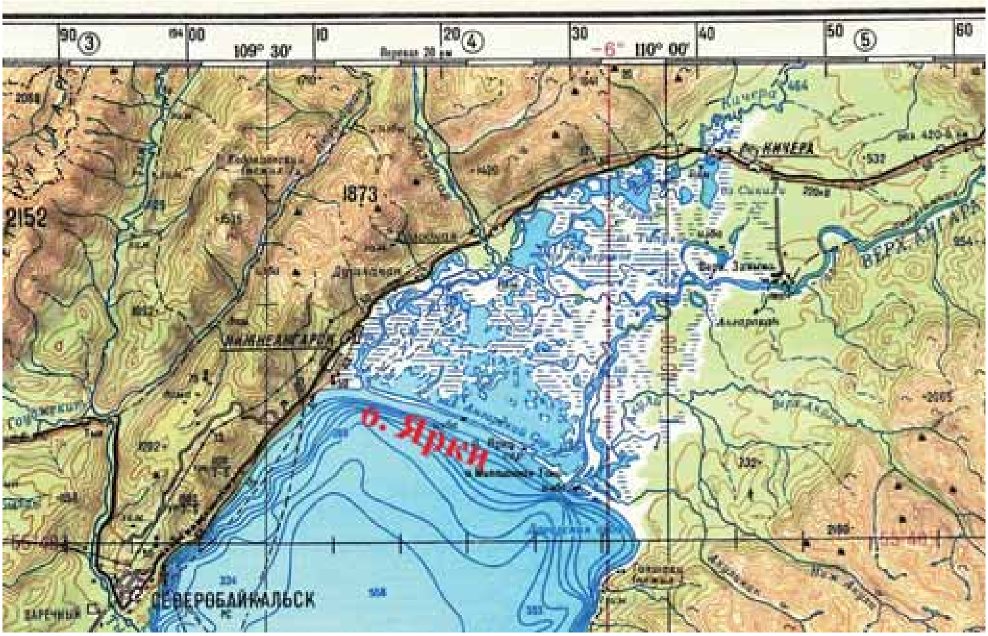


**Fig. 1. A fragment of a topographic map 1:500 000 scale (the North Baikal region). (The name of the Yarki islands is shown in red.)**

economic and other activities". This by-law of the Federal Law "On Protection of Lake Baikal" regulates the lake level fluctuations in the range of 456 to 457 m.

A real threat of a complete destruction of the Yarki islands requires individual consideration; these islands separate the open Baikal from the Verkhneangarsky shoal (Fig. 1). The Yarki is a sandy island system of 17 km in length and 200 m in width. The sandbar of the island is near the village Nizhneangarsk; the mainland is separated from the islands by the estuaries of the Kichera and the Upper Angara. Picturesque scenery, warm water (the lake warms up to 24°C), and long sandy beaches make Yarki one of the most attractive holiday destinations in the North Baikal area.

If the lake level approaches 457 m and under 3–5 day-straight specific wave conditions, the Yarki island system could just disappear and the cold Baikal water could destroy the entire unique ecosystem of the shallow area of the Upper Angara and the Kichera deltas, including the Upper Angara race of omul; the length of Lake Baikal could extend 40–40 km to the north. There will be changes to the entire lake basin and to its water level regime.

Wave activity within the entire extent of the shore from the village Nishzneangarsk to the Dagara with the estuarial part of the Upper Angara River, has been already incapable of supplying the inflow of suspended sandy particles with floodwater. Consequently, the volume of the incoming sedimentary material not only does not compensate the occurring destruction of the Yarki islands, but does not even maintain the conditions that had existed prior to the construction of the Irkutsk hydroelectric system before the rise of the lake level to the top of the flood-control capacity. [Potemkin, Suturyn, 2011]. According to the estimate of A.L. Rybak who has conducted lithodynamic research in this area, the long-term annual rate of erosion of the islands is 0,8–1,0 m/yr. Consequently, the complete destruction of the Yarki may occur in the nearest 30–40 years [Ymetkhenov, 1997].

## THEMATIC CLASSIFICATION OF THE NATURAL ENVIRONMENT

The paper analyzes changes in the coastline of the Yarki islands based on remote sending data. Regular space image collection is an objective and timely representation of the conditions of the Earth's surface and of its changes; modern geoinformation technologies of space imagery processing provide for precise georeferencing of multi-temporal data for studies of changes occurring on the Earth's surface. We have chosen the algorithm of the automated classification of satellite imagery for the optimal interpretation and automated zonal classification of the territory.

The procedure for satellite interpretation used in our work involved:

1) download of orthorectified Landsat imagery from the Internet;

2) image-processing – synthesis of the RGB-composites, coordinatewise isolation of necessary fragments;

3) objects' interpretation (thematic classification followed by generalization);

4) creation of thematic layers and editing;

5) compilation of the final map of the coastline changes of the sandbar.

Image processing was conducted using ENVI 4.7 + ENVI EX software application (www.ittvis.com/ENVI) that includes the most complete set of functions for remote sensing data interpretation and GIS processing. The thematic vector layers created were processed using ArcView3.3.

Mapping of the Yarki island system was based on the multi-temporal and multi-spectral imagery. The data were downloaded from the geoportal of the US Geological Survey (USGS) through the GloVis search system; four "summer" scenes of the Landsat platform were downloaded because the summer period is characterized by stability, duration, and the best quality of light conditions:

1) July 3, 1994 (spectroradiometer TM, cloudiness – 0%, image quality – 9);

2) August 12, 2000 (spectroradiometer ETM+, cloudiness – 17%, however, no clouds in the study area. therefore, image quality – 9);

3) September 22, 2006 (spectroradiometer TM, cloudiness – 0%, image quality – 7);

4) August 29, 2009 (spectroradiometer TM, cloudiness – 0%, image quality – 7).

Due to the nature of the Landsat satellite paths, it was not possible to download scenes for the same time-period. Even if the scenes were close in date, other factors interfered: cloudiness and poor image quality; in any case, we tried to obtain the scenes close in dates.

One of the main directions of the use of multiband images is the synthesis of color

**Table 1. Spectral bands (channels) of the radiometer Landsat TM and ETM+**

| Channel number | Resolution, m | Band | From, nm | To, nm |
|---|---|---|---|---|
| 1 | 30 | Blue | 450 | 515 |
| 2 | 30 | Green | 525 | 605 |
| 3 | 30 | Red | 630 | 690 |
| 4 | 30 | Near-infrared | 760 | 900 |
| 5 | 30 | Middle infrared – 1 | 1550 | 1750 |
| 6 | 60 | Far infrared | 10400 | 12500 |
| 7 | 30 | Middle infrared – 2 | 2080 | 2350 |
| 8 | 15 | Panchromatic | 520 | 900 |

images for visual interpretation with the subsequent automated classification. It is feasible to conduct object definition and delineation using images with intentional false color rendering. We used synthesis of: the near infrared spectral band – red color, the first middle infrared band – green color, and the red visible band – blue color, i.e., we created a pseudo-colored RGB-composite with a combination of channels 4:4:3 (Table 1). This combination of channels allows distinct differentiation of the land-water boundary and accentuation of hidden details poorly visible with the channels in the visible band only. As water gets deeper, it looks darker (including black color), which is associated with its absorption of the infrared light.

The fragments (21,5 × 11,7 km) that completely encompass the Yarki were cut from the obtained RGB-composites.

The next phase involved obtaining the Regions of Interest (ROIs). Because the task was to differentiate between land and water and water is relatively uniform in terms of spectral brightness and has the lowest values of the reflective coefficient in comparison with other natural objects (i.e., it almost never overlaps them in terms of brightness), we selected polygonal objects on water and land, which were later used as the training sets for the classification with training.

We used the supervised (i.e., with training) classification with rectangular method to isolate coastline. This method is used in cases when values of spectral brightness of different objects practically do not overlap and there are only few classes present. As it follows from the name, in the classification of spectral parameters, rectangular areas are isolated and these areas delineate the brightness values for the objects of this class. Then, the values of the spectral parameters in each pixel are compared with the limit values (minimal and maximal) in each class. If a pixel brightness parameters fit within one of the isolated ranges, it is included in this class. If the brightness parameters of a pixel do not fit in any range, it is included in the unclassified objects. If the brightness values fit within several ranges, several options of object classification are possible.

Two types of the standard sites were selected as the training sets: water surface and land. For each type of the standard sites, we have calculated the average value of pixel brightness and the standard deviation of brightness. The maximal standard deviation from the brightness mean in the "water" class did not exceed 2, which is associated with a relatively uniform characteristics of this object class. The downside of this isolation method is a partial overlap of the brightness parameters of the sandbar shoal and land; these overlaps were eliminated in subsequent processing [Tulokhonov, 2010].

In addition, in order to differentiate between the land and water surfaces, we used the algorithm of the unsupervised classification (the ISODATA method – the Iterative Self-Organizing Data Analysis Technique). It is feasible to use this algorithm in the absence of prior information on a survey object. The method allows delineating contours with a non-contrast (in terms of spectral brightness) structure. We have selected the optimal (in our opinion) parameters: number of classes – 2, maximal number of iterations – 20, convergence limit (a number of pixels that change their class with the next iteration) – 5%, maximal standard deviation from the mean – 13, minimal number of pixels for class isolation – 3, maximal standard deviation inside a class – 5, and minimal spectral distance – 5 pixels.

After the unsupervised classification, a classification map was obtained; the map reflects more objectively the groups of objects with close in values interpreted parameters compared with the supervised classification, because the clusters are identified automatically. However, the obtained map of the classification required further merging and splitting of classes because the same objects may be in different clusters (for example, due to light

**Table 2. The area of the vector layers of the sandbar Yarki**

| № | Name | Year | Area, $km^2$ |
|---|---|---|---|
| 1 | 1994-4-5-3_isle.shp | 1994 | 2.524 |
| 2 | 2000-4-5-3_isle.shp | 2000 | 2.052 |
| 3 | 2009-4-5-3_isle.shp | 2009 | 1.855 |

conditions) and different object can be present in the same cluster (due to similar brightness). In the first case, the clusters were merged within the same class, while in the second case, in order to separate the objects, additional interpretation parameters were used.

The land areals on the images obtained through the unsupervised and supervised classification appeared to be similar. This is due to the fact that land on the images is relatively uniform in spectral brightness and the water-land boundary is defined clearly because of the reflective properties of the water surface in the utilized combination of the Landsat channels.

The next step in the interpretation of the sites "water-land (non-water)" was the post-classification processing using "majority analysis." The purpose of this method is to enhance perceptance of the recognizable objects and to reduce noise and other random errors, in other words, to perform image generalization. In the course of processing, changes in the size of each pixel of the images occurred depending on the values of adjacent pixels in a sliding window of 3 × 3 pixels in size.

After the post-classification, the obtained raster images were converted into the vector format. Then, the interpreted contours of the water and land sites were edited in order to obtain only the vector layers of the sandbar.

The image for 2006 could not be post-classified correctly due to a poor quality of the image (the water surface in some places looks albescent and blends in with the sandbars). As a result, 3 multi-temporal vector layers have been obtained: for 1994, 2000, and 2009. There is a distinct systematic reduction in the area of the Yarki sandbar in 2009 compared with 2000 (by 0,2 $km^2$) and 1994 (by 0,7 $km^2$) (Table 2, Fig. 2–3).

It can be seen that the islands continue to deteriorate and that the coastline is primarily destructed on the lake's side. The main cause of the destruction of the Yarki is the rise in the water level and wave impact. The amplitude of the fluctuations of the water level at its 1 m rise and with controlled run-off has increased in the long-term. This has led to the activization of abrasion processes [Dynamics ..., 1976].

In order to measure the width of the sand-bar Yarki digitally using the GPS mapping


**Fig. 2. Comparison of the vector layers of 1994 and 2009: changes of the Yarki sandbar**

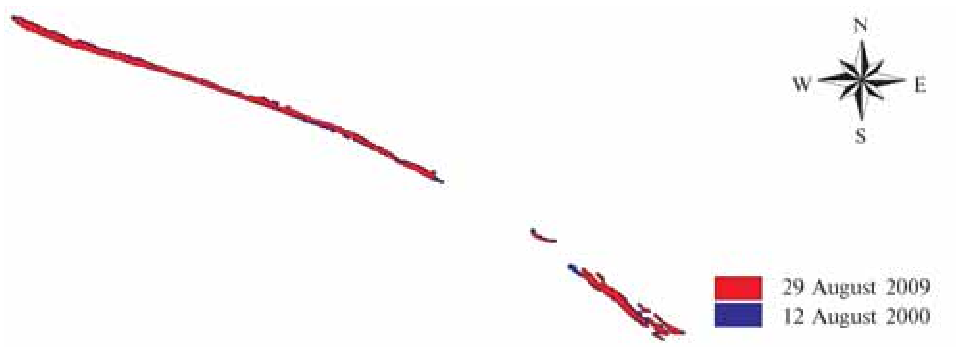


**Fig. 3. Comparison of the vector layers of 2000 and 2009: changes of the Yarki sandbar**

software OziExplorer, 2 way points in the widest site of the left part of the island were compared on the 1994 image. The coordinates of points 1 and 2 were saved in the wpt-file of the waypoints; the distance between these points was 243,7 m. Then, the 2009 image was loaded and it was overlaid with the waypoints from the wpt-file (Fig. 4). It can be seen, that the distance between the sandbar edges decreased. One more waypoint was added (№ 3) at the boundary of the sandbar in 2009. The distance between waypoints 1 and 3 was 158,6 m. Thus, the width of the island has decreased from 243,7 m in 1994 to 158,6 m in 2009; the difference is 85,1 m.

It is important to emphasize that the catastrophic activization of the coastal processes observed at present has been specifically caused by technogenic factors: the backwater effect of the hydrocomplex. The intense destruction of vegetation by recreating people in the Yarki has enhanced dune deflation and island flattening [Vicka et al, 2006].

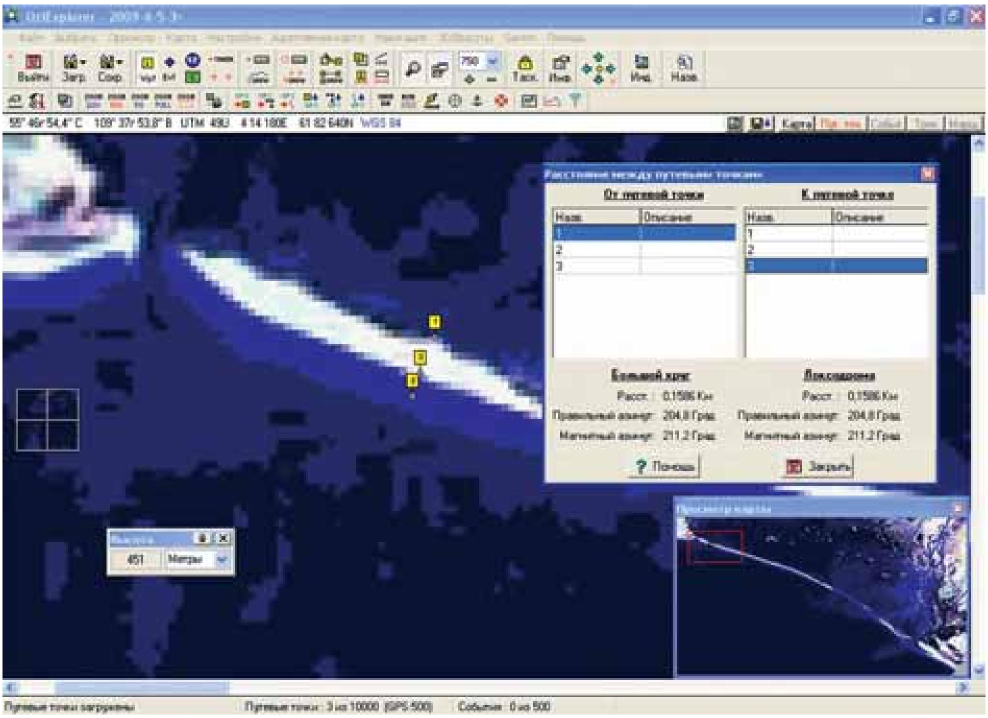

**Fig. 4. Changes in the width of the Yarki sandbar on the 2009 image. The sand shoals are in light blue. In the window (bottom right) the entire system of the Yarki islands is shown**

## CONCLUSION

Many islands of the Yarki system have been destructed by wave impact. In the fall storm period and at southern winds, surging associated with the nature of the spatial contours of the lake and the wind regime determine a substantial increase of the lake level in its northern part over the limit levels identified in the federal law. Specifically this situation causes the intense destruction of the Yarki island system – there are substantial changes in the sand islands and in bay-, beach-, and shoal-bars. Moreover, even at the existing water level regime, the destruction of the Yarki in the nearest future may cause the expansion of the cold Baikal water further north with the catastrophic consequences to the biota of the estuarial areas of the Kichera and the Upper Angara.

These circumstances give reason to preserve ecologically balanced system and to raise the question of the control of the water level regime within the average long-term fluctuations that existed before the construction of the Baikal Irkutsk hydropower complex, when fluctuations were in the range of 82 cm. Of course, this greatly complicates the task of hydropower electricity generation and requires its seasonal spread. However, this scenario is realistic, provided a sufficient number of hydrological stations exist and accurate weather forecasts are possible to allow storing in advance or releasing water of the Irkutsk reservoir.

With a lack of hydro-meteorological information, the need to increase the productivity of shallow waters of Baikal, and development of the tourism industry in the special economic zones, it is necessary to be more careful in respect to the coastal processes. This problem can only be solved with the mandatory legislative decrease of the amplitude of the minimal and maximal levels of the Lake Baikal water to the natural conditions prior to the construction of the hydropower system. In order to obtain timely information on the water level regime, to improve forecasting, and to avoid the influence of different natural phenomena on the water level of the lake within its entire area, it is necessary increase to the number of the gauging stations on the eastern and northern coasts of Lake Baikal. First, at the sites protected from the intense wind activity, for example, in Istomino, Lemasovo, Chyvyrkuysky and Barguzynsky bays, and north of the Yarki island system.

The conclusions of this paper are preliminary and at this time, it is difficult to speak with certainty about a consistent coastline retreat over a hydrological year based only on the analysis of the remote sensing data. It is difficult to quantitatively assess the rates of modern processes of coastal retreat, especially considering the fact that filling and drawdown of Baykal do not occur at a strictly uniform time (it depends on the water content in a particular year, the timing of the filling of the reservoir, the conditions of release of water through the locks of the Irkutsk dam, etc.). For ascertaining the rate of coastal erosion (in m/year) and the situation forecast, further monitoring work is required. ■

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