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ASSESSMENT OF THE IVANO-ARAKHLEY LAKES WATER AREA CHANGES ACCORDING TO REMOTE SENSING DATA

ОЦЕНКА ИЗМЕНЕНИЯ ПЛОЩАДЕЙ ВОДНОЙ ПОВЕРХНОСТИ ИВАНО-АРАХЛЕЙСКИХ ОЗЕР ЗАБАЙКАЛЬЯ ПО ДАННЫМ ДИСТАНЦИОННОГО ЗОНДИРОВАНИЯ

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The article describes the experience of using remote sensing data to study the changes in the water areas of the Ivano-Arakhley lakes of Transbaikalia from the series of Landsat images. The method of water surface interpretation based on the multichannel spectral water index MNDWI is considered. The change in the area of 24 lakes of the Ivano-Arakhley group with an area of more than 0.1 km^2 over the period 1989–2013 was determined. The analysis, based on the correlation, was carried out by the authors; a statistically significant consistency of the water area oscillations has been shown in 13 of the 24 lakes. It has been revealed that all lakes, subjected to analysis, have a downward trend line of the area values for the period under the study

Key words: *Ivano-Arakhley lakes; Landsat; area of water mirror; MNDWI; remote sensing; correlation analysis; satellite monitoring; area of water surface; precipitation; cluster analysis*

Описан опыт использования данных дистанционного зондирования для изучения изменения площадей водного зеркала Ивано-Арахлейских озер Забайкалья по космическим снимкам серии Landsat. Рассмотрен метод дешифрирования водных поверхностей по многоканальному спектральному водному индексу MNDWI. Определено изменение площадей 24 озер Ивано-Арахлейской группы площадью более 0,1 км2 за период 1989–2013 гг. На основании проведенного корреляционного анализа показана статистически значимая согласованность колебаний площадей водного зеркала у 13 из 24 исследованных озер в многолетнем разрезе. При этом выявлено, что у всех озер, подвергнутых анализу, имеется нисходящая линия тренда значений площадей за исследуемый период

Ключевые слова: *Ивано-Арахлейские озера; Landsat; площадь водного зеркала; MNDWI; дистанционное зондирование; корреляционный анализ; спутниковый мониторинг; площадь водной поверхности; атмосферные осадки; кластерный анализ*

Introduction. Climatic changes that occurred in recent decades on a global scale are manifested in variations of surface air temperature. This entails major shifts in precipitation and evaporation conditions [6]. Lakes may be one of the indicators of such changes at the regional scale. Their complete appearance or disappearance, their reduction or increase are indirect confirmation of water and heat balance elements response to the climatic changes. The variation in morphometric characteristics of lakes has significant consequences for water and terrestrial ecosystems [14] and it affects the use of water bodies in economic activities.

Ivano-Arakhley lakes are located in Central Transbaikalia, in the south of the Vitim plateau within the Beklemishevsky tectonic depression between the Yablonov and Osinov ranges in the northeast direction [16]. Lakes have recreational value for the Chita City inhabitants, they are used for fishing and fish farming. At the same time, they are subjected to high recreational impact, and the vegetation cover of their catchment area undergoes significant changes due to fires [3, 8].

The group of Ivano-Arakhley lakes includes Shakshinskoe and Arakhley lakes with an area of more than 50 km2, seven lakes with an area between 1.0 km2 to 50 km2 and fifteen lakes with an area between 0.1 km2 to 1.0 km2. The studies of the hydrological regime of the Ivano-Arakhley lakes are usually based only on the data from regime observations of the two largest lakes, Arakhley and Shakshinskoe. However, due to their greater water area, depth and water mass volume, they may have differences in the conditions of the hydrological regime formation from the other smaller ones. At the same time, most of the lakes remain uncovered by ground-based observations and therefore it is important to use remote sensing methods for their study.

At present, satellite monitoring allows to obtain various morphometric characteristics of water bodies, such as length and width of the stream-flow, the meander radius of curvature [1], lake water level and its surface area [4; 5; 9; 13]. The information on the water surface areas, obtained from the remote sensing data, may also be useful for hydrochemical and hydrobiological research [2; 7].

During the past 50 years, the average annual air temperatures have increased in the study area by 1.9°C. Total annual precipitation for the period of 1959–2009 has decreased by an average of 30 mm on the territory [10]. In this case, the level regime of the Arakhley and Shakshinskoe lakes is cyclical and depends on the regime of atmospheric precipitation [10].

Data and methods. In this study, we used a time series of 18 spatially aligned images including Landsat Level-1 standard data products Landsat 5 TM, Landsat 7 ETM+ and Landsat 8 OLI collections. The images were obtained for the period of 1989–2013 by USGS Earth Explorer service [12]. The spatial resolution of space images was 30 m, the time interval was 16 days. Clouds and cloud shadows, covering the Earth's surface, were major limitations in acquiring useful satellite imagery [4], so we have analyzed images with cloud cover not exceeding 20 %.

The most suitable technique for the lake surface area determining is the image interpretation by multichannel spectral water indices calculation [9]. Water indices were also used in the study of the Transbaikal steppe zone lakes and floodplain lakes of the Argun River basin [9]. The modified normalized difference water index (MNDWI) [15] has the best water surface interpretation properties due to a clearly defined detection threshold. This index is determined by the formula (1) [15]

$$MNDWI = \frac{\rho_{band2} - \rho_{band5}}{\rho_{band2} + \rho_{band5}}, \qquad (1)$$

where P_{band} *2,5* – denotes the intensity of radiation in 2 and 5 Landsat TM, ETM+ spectral channels

MNDWI is determined by using 2 and 5 spectral channels of Landsat 5 TM and Landsat 7 ETM + or 3 and 6 channels of Landsat 8 OLI. In this case, the boundary of water surfaces determination passes through zero and the values of the MNDWI greater than zero correspond to water surfaces. The initial images were subjected to radiometric calibration using Spatial Analyst module of ArcGIS 10 Desktop. As a result, the top of atmosphere (ToA) reflectance values were obtained [11], and they were used to calculate the MNDWI indices.

The basis of this study also was water level, data obtained at hydrological gauging stations located in the villages Beklemishevo (Shakshinskoe Lake) and Preobrazhenka (Arakhley Lake). These stations are included in the regime network of hydrometeorological observations of the Federal Service for Hydrometeorology and Environmental Monitoring of Russia (Roshydromet). Correlation, regression and cluster analyses were applied in this study. The Student criterion was used for assessing the significance of trends.

Results and discussion. The interpretation of remote sensing data allowed us to calculate water surface areas for 24 lakes with an area of more than 0.1 km^2 for 1989, 1990, 1993, 1994, 1996, 1999-2003, 2005-2011, 2013 (Fig. 1). A correlation analysis was carried out to assess the relationship between changes in lake areas in 1989–2013. On the basis of the analysis, a significant consistency in the variation of water surface areas between 13 lakes has been revealed (The Pearson's correlation coefficient r > 0,4 is significant for time series of 18 numbers, fig.2, tab.1).

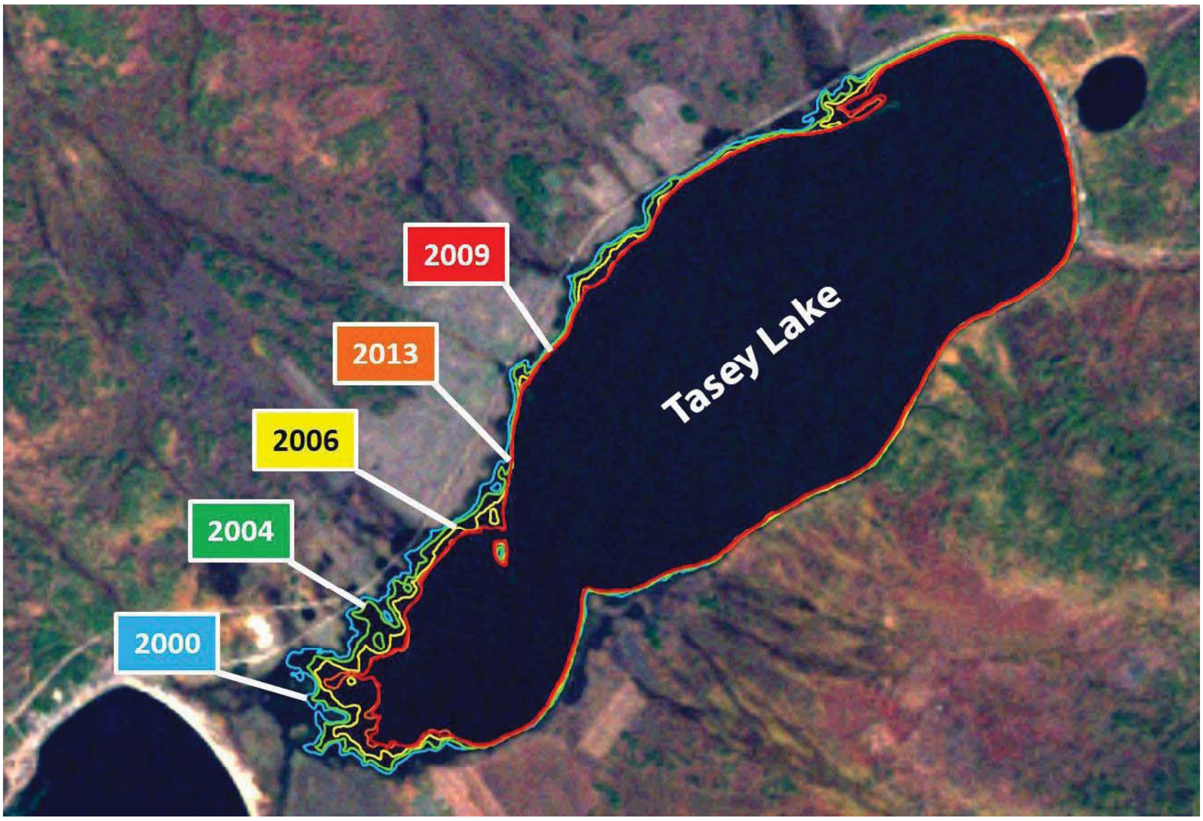

Fig. 1. Change in the area of the lake Tasey's water mirror for different years

Рис. 1. Изменение площади водного зеркала оз. Тасей за разные годы

As the analyzed images have gaps in some time periods, the missing morphometric characteristics for years with a lack of information have been restore, using the linear regression method, based on the available data. The missed water surface areas of the Arakhley and Shakshinskoe lakes were restored from the elevation data of these lakes, obtained at hydrological gauging stations, because the Pearson's correlation coefficients between the water elevation and areas for these lakes are 0.958 and 0,911, respectively. Due to the presence of a significant correlation between the morphometric characteristics of the investigated lakes (Table), the data of the remained 11 lakes were reconstructed from the time series of the Arakhley and Shakshinskoe water surface areas.

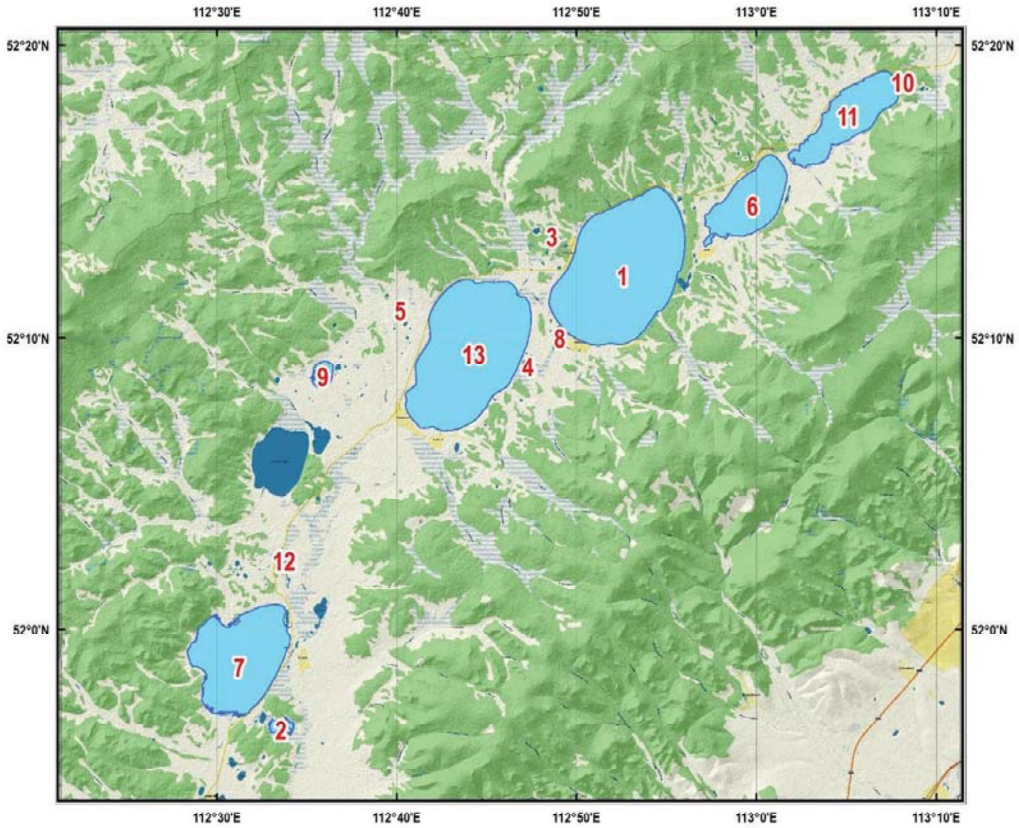

Fig. 2. Map-scheme of the investigated lakes: 1 – Arakhley; 2 – B. Guzhirnoye; 3 – Byloe; 4 – Gusinoye; 5 – Didulino; 6 – Ivan; 7 – Irgen; 8 – Karas; 9 – Kergendu; 10 – Sirotinka; 11 – Tasey; 12 – Uluztuy; 13 – Shakshinskoye

Рис. 2. Карта-схема исследуемых озер: 1 – Арахлей; 2 – Б. Гужирное; 3 – Былое; 4 – Гусиное; 5 – Дидулино; 6 – Иван; 7 – Иргень; 8 – Карась; 9 – Кергенду; 10 – Сиротинка; 11 – Тасей; 12 – Ульзутуй; 13 – Шакшинское

The Pearson's correlation coefficient matrix of the Ivano-Arakhley lakes water surface areas / Коэффициенты корреляции площадей водной поверхности Ивано-Арахлейских озер

Name/ Название	**Arakhley / Арахлей**	**Guzhirnoe / Гужирное**	**Byloe /Былое**	**Gusinoe / Гусиное**	**Didulino / Дидулино**	**Ivan /Иван**	**Irgen / Иргень**	**Karas / Карась**	**Kergendu / Кергенду**	**Sirotinka / Сиротинка**	**Tasey / Тасей**	**Ul'zutuy / Ульзутуй**	**Shakshinskoe / Шакшинское**
Arakhley/ Арахлей	1,00												
Guzhirnoe/ Гужирное	0,95	1,00											
Byloe/ Былое	0,91	0,94	1,00										
Gusinoe/ Гусиное	0,46	0,51	0,61	1,00									
Didulino/ Дидулино	0,96	0,95	0,93	0,42	1,00								
Ivan/ Иван	0,88	0,86	0,82	0,64	0,85	1,00							
Irgen/ Иргень	0,68	0,66	0,60	0,65	0,58	0,86	1,00						
Karas / Карась	0,94	0,95	0,93	0,52	0,91	0,87	0,69	1,00					

End of table

Name / Название	Arakhley / Арахлей	Guzhirnoe/ Гужирное	Byloe/ Былое	Gusinoe / Гусиное	Didulino / Дидулино	Ivan /Иван	Irgen / Иргень	Karas / Карась	Kergendu / Кергенду	Sirotinka / Сиротинка	Tasey / Тасей	Ul'zutuy / Ульзутуй	Shakshinskoe / Шакшинское
Kergendu / Кергенду	0,64	0,63	0,65	0,65	0,53	0,69	0,81	0,66	1,00				
Sirotinka / Сиротинка	0,92	0,93	0,89	0,42	0,92	0,73	0,51	0,85	0,56	1,00			
Tasey / Тасей	0,91	0,94	0,84	0,57	0,85	0,87	0,69	0,90	0,60	0,88	1,00		
Ul'zutuy/ Ульзутуй	0,78	0,77	0,72	0,57	0,70	0,78	0,75	0,73	0,84	0,77	0,83	1,00	
Shakshinskoe/ Шакшинское	0,75	0,75	0,69	0,69	0,63	0,82	0,84	0,73	0,85	0,69	0,82	0,92	1,00

To identify the homogenous groups of lakes with similar oscillations during the study period, a cluster analysis with the Euclidean distance method, using the statistical software package Statistics (http://statsoft.ru/) was carried out. This made it possible to distinguish three groups of lakes (Fig. 3), large (area is more than 50 km^2), medium (area is more than one km^2) and small ones (area is more than 0,1 km^2).

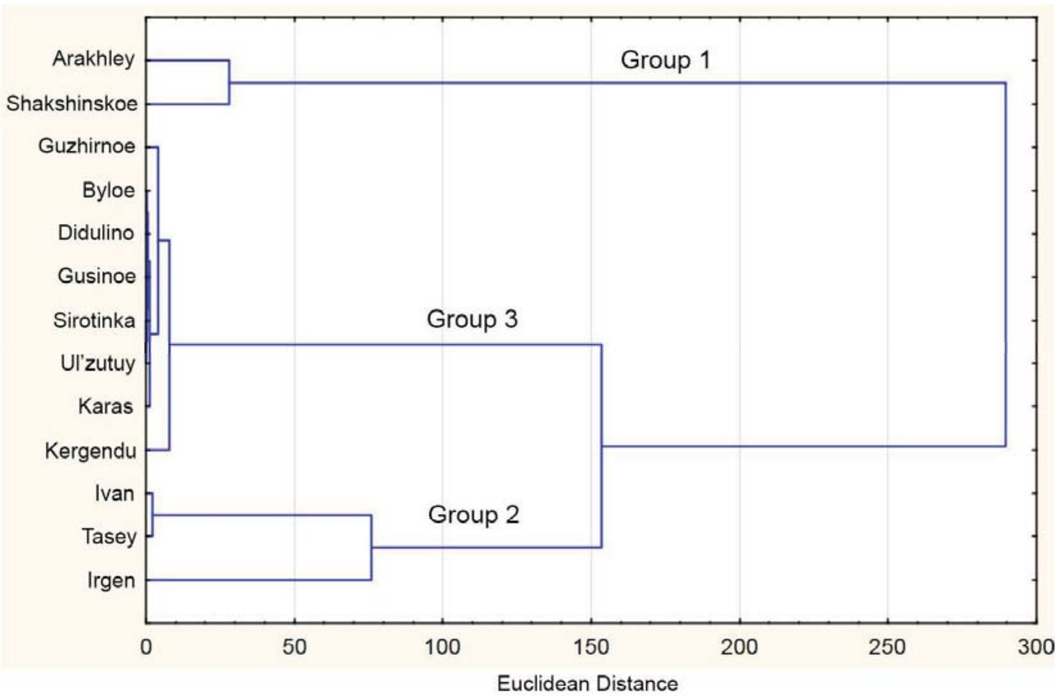

Fig. 3. Dendrogram of the lakes' similarity in the areas of water mirror according to the method of Euclidean distances (group 1 – large lakes, 2nd group – medium lakes, 3rd group – small lakes)

Рис. 3. Дендрограмма сходства озер по площадям водного зеркала по методу евклидовых расстояний (1 группа – крупные озера, 2 группа – средние озера, 3 группа – мелкие озера)

During the period from 1989 to 2013 synchronous fluctuations of water surface areas were observed in the studied lakes (Fig. 4). The greatest mutual consistency was noted on the lakes Arakhley, Didulino, Karas, Guzhirnoe, Byloe (the linear correlation coefficient was 0.91 … 0.94), the smallest coherence corresponds to the lakes Gusinoe and Kergendu. To assess the long-term trends in the morphometric characteristics of lakes, the regression analysis was performed. In general, the water surfaces of lakes have decreased. For the water areas the time series linear trends were calculated. It has been found, that the trend has a negative sign for all studied lakes during the study period (Fig. 5). At a 5 % significance level the trend was reliable for all lakes, except Lake Ulzutuy. The trend magnitude varied from minus 0,002 to minus 0,091, the average value was minus 0,027.

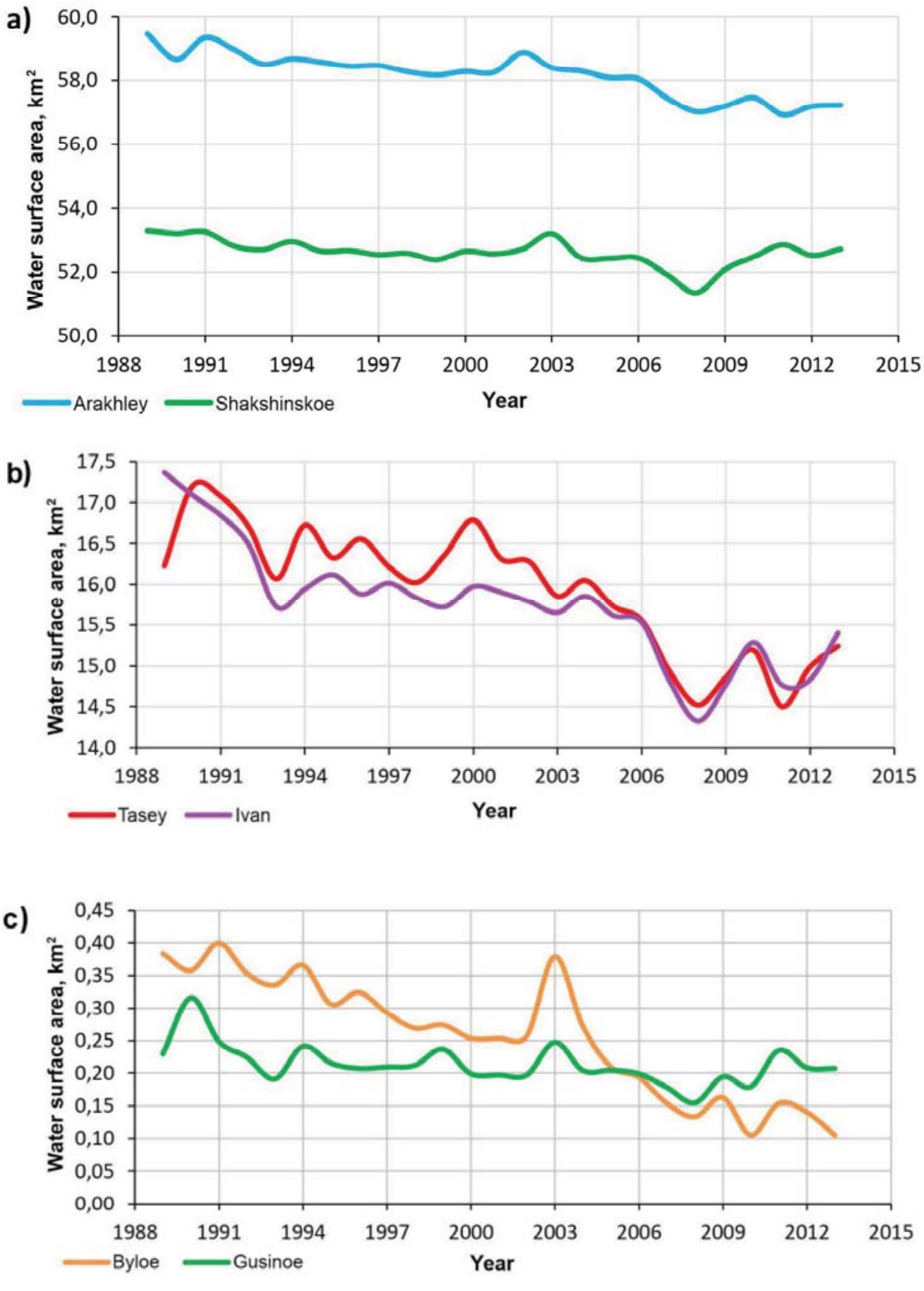

Fig. 4. Graphs of changing areas of the Ivano-Arakhley lakes for the period 1989-2013 for lakes: a) large; B) medium; C) small

Рис. 4. Графики изменения площадей Ивано-Арахлейских озер за период 1989–2013 гг. для озер: а) крупных; б) средних; в) мелких

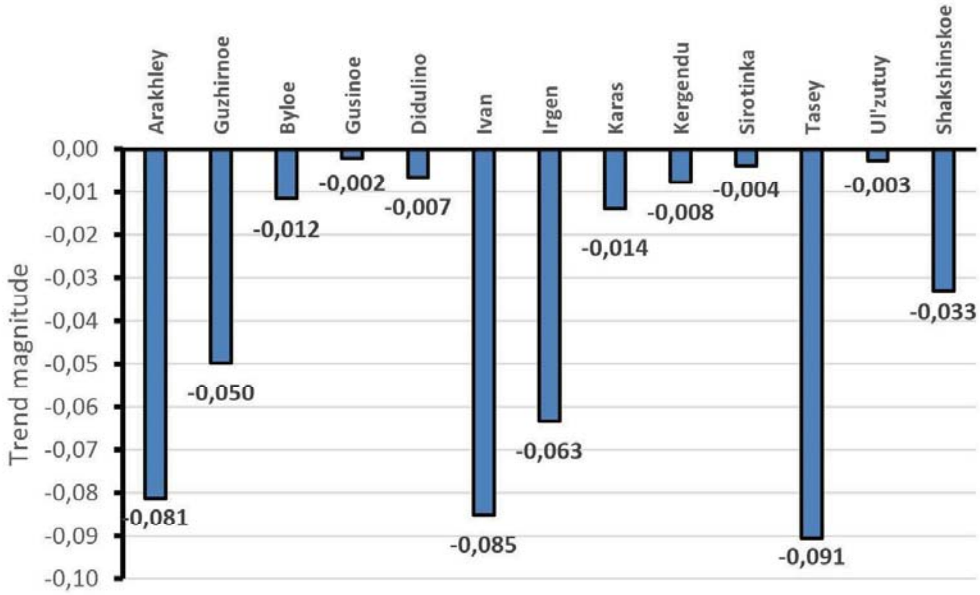

Fig. 5. The values of trends in the area change from 1989 to 2013

Рис. 5. Значения трендов изменения площадей за период с 1989 по 2013 гг.

Conclusions. Thus, as a result of the work, the following conclusions should be drawn. During the period from 1989 to 2013 synchronous fluctuations of water surface areas were observed in the studied lakes. The greatest mutual consistency was noted on the lakes Arakhley, Didulino, Karas, Guzhirnoe, Byloe (the linear correlation coefficient was 0,91 ... 0,94), the smallest coherence corresponds to the lakes Gusinoe and Kergendu. It has been found, that the trend has a negative sign for all studied lakes during the studied period.

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