Monitoring of the hydrological regime of the Saratov reservoir using the MNDWI index

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Abstract. The article analyzes the possibilities of using Earth remote sensing (ERS) indices for monitoring the state of the environment. The possibility of using remote sensing indices for monitoring and forecasting the state of water bodies and watercourses, their hydrological characteristics was assessed. Within Samara region, the possibility of using the Modified Normalized Difference Water Index (MNDWI) to assess the water saturation of the Saratov reservoir in the Vasilievsky Islands area was considered. This territory was chosen due to the fact that it is sufficiently indicative for assessing changes in the hydrological regime of the reservoir. The processing of multispectral images taken by the Sentinel-2 satellite was carried out on the basis of green and short-wavelength spectral channels. The area of the water surface was calculated based on the number of binary pixels of the processed images. In accordance with the calculations, it was revealed that the area of the Saratov reservoir in the Vasilievsky Islands area has increased. At the same time, it was noted that the area of the water surface of small water bodies that have no connection with the reservoir has increased. The results obtained showed a high efficiency of monitoring changes in the hydrological regime of the reservoir when using the MNDWI.

1. Introduction
Remote sensing of the Earth (hereinafter ERS) is the acquisition of a certain set of data on the earth's surface using multispectral images of space satellites without direct contact with the earth's surface. Remote sensing is used for monitoring the state of the environment, assessing anthropogenic impact, as well as for solving meteorological problems.

Currently, the field of remote sensing is developing rapidly. To calculate certain characteristics on the basis of multispectral images, various indices have been created and are being developed. At the moment, there are at least 160 variants of remote sensing indices. The main advantage is the ease of obtaining them and a wide range of tasks solved with their help [1]. The calculation of these indices mainly depends on the two most stable parts of the spectral curve, which are practically independent of other factors. It should be noted that initially the ERS indices were used in agriculture to assess the development of plants and their vegetative capacity. Vegetation indices include the following: RVI, NDVI, IPVI, SAVI, MSAVI1, MSAVI2, etc. With the development of the scientific field of remote sensing, the indices began to be used to control water resources, their hydrological regimes, the level of pollution and anomalous phenomena.

To assess the characteristics of water bodies and watercourses, indices such as NDWI, MNDWI, NDII and many others are used.
Normalized Difference Water Index (NDWI) is an index that determines the amount of water in the vegetation cover based on the reflection of solar radiation. The NDWI is sensitive to changes in plant water content. It is less sensitive to weathering than the Normalized Difference Vegetation Index (NDVI). The NDWI index is calculated by the formula:

$$NDWI = \frac{NIR - SWIR}{NIR + SWIR},$$

where NIR is the near infrared region of the spectrum, SWIR is the near shortwave infrared region of the spectrum.

This index is mainly used for monitoring swampy areas, the range of values varies from -0.1 to 0.4 [2].

Second Normalized Difference Water Index (NDWI2). The index was developed by McFeathers (1996). This index is necessary in order to determine the water flooding and moisture content of wetlands, as well as to delineate the surface area of water bodies. The NDWI2 index is calculated using the formula:

$$NDWI2 = \frac{green - NIR}{green + NIR},$$

where NIR is the near infrared region of the spectrum, green is the green region of the spectrum.

The main disadvantage of this index is the large number of noise effects.

Modified Normalized Difference Water Index (MNDWI). The algorithm was developed by Xu (2006) and can effectively suppress and even remove noise effects from the water surface, as well as noise from soil and vegetation. Improving the resulting MNDWI image results in more accurate data extraction from images with built-up land, soil and vegetation. The MNDWI index is calculated using the formula:

$$MNDWI = \frac{green - SWIR}{green + SWIR},$$

where green is the green region of the spectrum, SWIR is the near shortwave infrared region of the spectrum.

To calculate vegetation indices, multispectral images from space satellites (Landsat 8, Terra Modis, Sentinel-2, etc.) are used, containing various ranges, the main of which for calculating NDWI indices are red (Red), green (Green), infrared channels (near (NIR) and near shortwave (SWIR)). In this article, we used multispectral images from the Sentinel-2 satellite with a resolution of 10 and 20 meters, respectively.

2. Materials and methods

One of the problems that can be observed using satellite images using the NDWI water index is monitoring the size of the area of water bodies [3, 4, 5, 6]. The NDWI as well as the MNDWI are used to monitor the hydrographic characteristics of water bodies. The purpose of the monitoring is to assess the long-term changes in the contours and area of the reservoir based on satellite imagery data. In this case, the MNDWI index has the advantage of using, which differs from NDWI in that it has a more accurate definition of the boundaries of water bodies [7].

Floods are an important problem at the present time, which pose a high risk, causing serious economic damage, as well as claiming a large number of lives every year. To determine the flood threat in advance, it is necessary to monitor water bodies prone to spills, where, in turn, the NDWI and MNDWI indices can be useful [8, 9, 10]. Observations were carried out to monitor the flood of the Diyala River in Iran, which proved the higher efficiency of the MNDWI index in comparison with the NDWI [11]. The NDWI and MNDWI indices are also used to monitor changes in the water area of lakes and river deltas [12, 13, 14].

The NDWI and MNDWI indices are used to monitor and monitor droughts in the southern hemisphere of the Earth. The NDWI index, together with the SDI index, can predict an increase in dry
days and rainfall [15]. The NDWI index can be used to assess the spatiotemporal dynamics of drought [16], as well as to assess the causes and consequences of river siltation [17].

The most important characteristic of the NDWI index is that it can be used to determine not only the level of plant development by measuring the amount of moisture, but also soil moisture [7]. The NDWI was used to assess the impact of changes in the Padma River Delta in Bangladesh on soil erosion and vegetation suppression [18]. The NDWI index, together with the NDVI index, allows monitoring the impact of dam construction on vegetation cover and changes in the coastline [19].

3. Results and Discussion
The object of the study is a section of the Saratov Reservoir and a lake in the area of the Vasilievsky Islands. The region where the research object is located is agricultural and the water bodies present on the map, such as the Volga River and small bodies of water, are sources of water consumption for agriculture. We have chosen the shooting period from May to September, when the most active agricultural work is being carried out. The analyzed images were taken in May, during the flood period, and in September, during the low-water level decrease.

Predicting changes in the area of a water body makes it possible to further assess the prospects for the development of irrigation systems in the adjacent territories.

In the work, water level changes were monitored using the MNDWI index, which proved to be effective in comparison with the NDWI indices due to the higher accuracy of data processing.

The analysis used images taken by the Sentinel-2 space satellite. To calculate the MNDWI index, images with a spectral range of 0.56 μm (green) and 1.61 μm (SWIR) with a resolution of 10 m and 20 m, respectively, were used (figure 1).
Figure 1. Space images from the Sentinel-2 satellite; (a) - snapshot date 05/27/2018, (b) - snapshot date 09/12/2018, (c) - snapshot date 05/25/2019; (d) - snapshot date 09/09/2019; (f) - snapshot date 05/04/2020; (e) - snapshot date 09/23/2020

Analysis of changes in the water regime of the reservoir based on satellite images is not informative enough. To estimate the size of the area of the Saratov reservoir for a three-year period (2018-2020), we proposed the relative value of the area of the water surface - $S_{ra}$. The calculation of this value is made on the basis of a multispectral image with the calculated values of the MNDWI index. The use of this index is due to the higher accuracy of determining the coastline of a water body [11]. The calculation of the relative size of the area of the water mirror was carried out by counting the pixels of multispectral images processed using the MNDWI index. To simplify the assessment, the option of converting the indexed image into a binary format was chosen, which made it possible to easily separate the pixels related to water bodies from others. The results of the calculations are shown in figure 2.

Figure 2. The relative area of the water table of the Saratov reservoir
4. Conclusion
Thus, the use of the NDWI index and its varieties is indeed in demand and useful for solving various problems. The normalized differential water index can be used to estimate flood flood areas, hydrographic characteristics of water bodies, etc.

The use of remote sensing data is important for monitoring due to a wide territorial coverage, efficiency, areas, all-weather radar survey, etc. These features are used in such spheres of economic activity as the oil and gas complex, agriculture, forestry and water management, in the assessment of anthropogenic and technogenic impact on the environment [8].

The application of the NDWI index is possible not only based on the use of remote sensing satellites, but also using aerial photography.

When observing for 3 years, a trend was found for an increase in the area of the mirror of water bodies. At the same time, it should be noted that the area of small-sized objects that do not have direct connections with the Volga River is mainly increasing.

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