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Assessment of the dynamics of the surface area of the Shatsk Lakes over a long-term period based on remote sensing data in connection with fluctuations in their level (1985–2023)

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Abstract. The purpose of the article was to assess the long-term dynamics of the area of the Shatsk Lakes (Volyn region, Ukraine) and the spread of water blooms on their surface using remote sensing data in connection with fluctuations in the level of these water bodies for the period 1985-2023. Satellite images from the American Landsat-5,7,8 mission and the European Sentinel-2 L2A mission were used. Long-term data from state monitoring were also used to monitor: a) water level at the hydrological station of Svitiaz Lake; b) the amount of precipitation at the Svitiaz weather station. It was established that the area of the Shatsk Lakes (Svitiaz, Liutsymer, Chorne Velyke) over the long study period, obtained using satellite images using the NDWI (Normalized Difference Water Index), ranged as follows as a percentage of the average annual values of the lake's surface: Svitiaz – 85–101 %; Liutsymer – 85–100 %; Chorne Velyke – 79–100 %. The area of water bloom in these lakes over the long study period, obtained using satellite images using the NDTI (Normalized Difference Turbidity Index), ranged as follows as a percentage of the average annual values of lake's surface: Svitiaz – 0.04–4.43 %; Liutsymer – 0.2–7.9 %; Chorne Velyke – 0.1–11.9 %. Among the studied lakes, minimal water bloom was observed in the largest among them, Svitiaz, which indicates its better ecological condition. The maximum bloom of water was typical for the small Chorne Velyke Lake. Variations in the area of lakes, water levels and the amount of precipitation are interconnected, which was confirmed by the example of Svitiaz Lake. The resulting pair correlation coefficients (r) between these characteristics are 0.6–0.7. In 2023, the area of Svitiaz Lake was the largest in the last 10 years, as the water level in the lake was also the highest in a decade, which is mainly due to good winter snow reserves. The use of remote sensing techniques to study the morphometric parameters of lakes can provide valuable results for identifying environmental problems. An in-depth study of these problems can take place in nature using instrumental methods, water sampling and analysis.

Keywords: Shatsk lakes, Svityaz lake, lake area, water bloom, water level, remote sensing of the Earth, Volyn region, Ukraine

Оцінка динаміки площі Шацьких озер за багаторічний період за даними дистанційного зондування у зв'язку з коливаннями їхнього рівня (1985–2023 рр.)

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Анотація. Метою статті була оцінка багаторічної динаміки площі водного дзеркала Шацьких озер (Волинська область, Україна) та поширення цвітіння води на їх поверхні у зв'язку з коливаннями рівня цих водойм за період 1985-2023 років. У дослідженні використано супутникові знімки американської місії Landsat-5,7,8 та європейської місії Sentinel-2 L2A. Також використано багаторічні дані державного моніторингу: а) за рівнем води на гідрологічному посту озера Світязь; б) за кількістю атмосферних опадів на метеостанції Світязь. Встановлено, що площа Шацьких озер (Світязь, Люцимер, Велике Чорне) за багаторічний період, досліджена за допомогою супутникових знімків з використанням індексу NDWI (Normalized Difference Water Index), становила від середньорічної величини: Світязь – 85–101 %; Люцимер – 85–100 %; Велике Чорне 79–100 %. Площа цвітіння води в цих озерах за багаторічний період, досліджена за допомогою супутникових знімків з використанням індексу NDTI (Normalized Difference Turbidity Index), становила від середньорічної величини: Світязь – 0,04–4,43 %; Люцимер –

0,2–7,9 %; Велике Чорне – 0,1–11,9 %. Серед досліджених озер мінімальне цвітіння води проявляється в найбільшому серед них – Світязі, що свідчить про його кращий екологічний стан. Максимальне цвітіння води характерне для невеликого озера Чорне Велике. Коливання площі водного дзеркала озер, рівня води та кількості атмосферних опадів пов'язані між собою, що було виявлено на прикладі озера Світязь. Отримані коефіцієнти парної кореляції (r) між цими характеристиками становлять 0,6–0,7. В 2023 р. площа озера Світязь була найбільшою за останні 10 років, оскільки рівень води в озері також був найвищим за десятиліття, що в основному пов'язано з значними запасами снігу взимку. Застосування методів дистанційного зондування для дослідження морфометричних параметрів озер дає можливість попереднього виявлення екологічних проблем. Поглиблене вивчення цих проблем необхідно проводити на натурі із застосуванням інструментальних методів, відбором проб води та їхнім хімічним та гідробіологічним аналізом.

Ключові слова: Шацькі озера, озеро Світязь, площа водного дзеркала озера, «цвітіння» води, рівень води, дистанційне зондування Землі, Волинська область, Україна

Introduction

It is known that lakes are natural depressions filled with fresh or salt water. This leads to the differentiation of lakes according to their origin, chemical composition (fresh, mineral), feeding method and characteristics of water exchange (wastewater, drainless).

Currently, lakes as natural reservoirs are not only sources of water, but also areas of biodiversity and a significant recreational resource. But human activity leads to the deterioration of their ecological condition. As a result, anthropogenic activity accelerates processes in the life cycle of lakes, such as shallowing (increased heating of a lake, development of aquatic vegetation, its death and deposition of residues), swamping (activated by filling the lake with sediment – products of destruction of the shores and organic substances). This accelerates the transformation of the lake into a swamp (Pasichnik et al., 2021).

The ecosystems of the Shatsk Lakes (Volyn region, Ukraine) are among the best preserved among the lowland landscapes of Eastern Europe, as noted by many researchers (Ilyin, 2007; Khomik, 2013; Fesyuk et al., 2021; Khilchevskyi et al., 2020; 2021; 2022a; Ilyin, Ilyina, 2022). The Shatsk lakes are of great importance because they contain significant water, biological, mineral and recreational resources. The reservoirs are under the protective regime of the Shatsk National Natural Park, founded in 1983.

In these lakes, a significant amount of sapropel of the Volyn region is concentrated – centuries-old bottom deposits formed from dead aquatic vegetation, the remains of living organisms, plankton, as well as particles of soil humus, which is a valuable resource for the agricultural sector and cosmetic production (Pasichnyk et al., 2021).

Since 2019, the discussion on the shallowing of Lake Svitiaz and other lakes of the Shatsk group has become more urgent, with scientists associating this process with both climate change (Fedoniuk et al., 2020) and the work of the Khotyslavskyi quarry for the extraction of chalk and sand (Yatsiuk et al., 2021; 2022).

However, it should be noted that in the year 2023 the lakes of the Shatsk group turned out to have unusually high water levels. Thus, according to the Svitiaz weather station, in the spring the water level in Lake Svitiaz rose to the control level of 171 cm, which is one of the highest levels in a decade. The reasons for the lake being full in 2023: a) in winter there were significant snow reserves; b) the lock in the canal through which Svitiaz is connected to Lake Luky-Peremut was repaired and blocked. (Shepela, 2023; Khilchevskyi, Plichko, 2023).

Therefore, studying the long-term dynamics of the area of the water surface of the water bodies and the spread of water blooms on their surface is one of the important tasks of the rational use, protection and reproduction of water resources of the Shatsk lakes. For this purpose, remote sensing methods of the Earth can be used – the authors have experience in using (Zatserkovnyi, Plichko, 2018; Plichko et al., 2021; Khilchevskyi, et al., 2022b). Remote sensing methods allow us to identify features and key problems in determining the directions for the rational use of lakes and planning preventive measures for protection from anthropogenic impact.

The purpose of this study is to assess the long-term dynamics of the area of water surfaces of the Shatsk lakes and the distribution of water blooms on their surface using remote sensing data in connection with variations in the level of these water bodies for the period 1985–2023.

Material and methods

For assessment of the dynamics of the area of the Shatsk lakes, three lakes were studied: Svitiaz, Liutsymer and Chorne Velyke. These lakes were studied using remote sensing data, namely archive satellite images of the U.S. Geological Survey Landsat-5,7,8 (USGS) and archive satellite images of the European mission Copernicus Sentinel-2 L2A (Copernicus Data Space) for the period 1985-2023, cloud cover 0%, angle 46-51°, with a resolution of 30 m. Satellite images of the spring period were used to assess the total water area of the lakes, since this period is optimal for studying changes in surface water areas. Satellite images of the summer period were used to study the long-term dynamics of lake bloom.

Long-term state monitoring data were also used: a) on the water level at the hydrological station of Svitiaz Lake; b) on the amount of precipitation at the Svitiaz weather station. Data were taken from the archive of the Boris Sresnevsky Central Geophysical Observatory of the State Emergency Service of Ukraine (State water cadaster, 2014; 2022).

Processing and interpretation of satellite images was carried out using the free QGIS software. In this case, preliminary image processing was performed, which consisted of three stages: geometric correction and georeferencing, radiometric calibration and atmospheric correction. As most of the satellite data were already georeferenced and geometric aberrations were corrected, radiometric calibration, selection of the area of interest, image cropping and atmospheric correction were performed in the QGIS program.

Interpretation of satellite images is based on the use of automatic image classification procedures. In this study, two indices were selected – NDWI (Normalized Difference Water Index) to assess the long-term dynamics of the total area of lakes and NDTI (Normalized Difference Turbidity Index) to assess the long-term dynamics of the area of lake water bloom.

NDWI calculation is based on the difference and sum of the green and near-infrared spectral band (Gao, 1995):

$$NDWI = (R_{GREEN} - R_{NIR}) / (R_{GREEN} + R_{NIR}), \quad (1)$$

where R_{GREEN} – green band of the electromagnetic spectrum of image, R_{NIR} – near-infra-red band of the electromagnetic spectrum of image.

In addition, we took into account that NDWI increases the contrast between water surfaces and areas not covered by water. It is known that water bodies conform to positive values of this index, and the others – negative values, and often the optimal limit is different from zero.

The study of long-term dynamics of water bloom on the surface of lakes was carried out using the NDTI (Normalized Difference Turbidity Index). The NDTI algorithm (Lacaux, 2007) is determined by the formula:

$$NDTI = (R_{RED} - R_{GREEN}) / (R_{RED} + R_{GREEN}), \quad (2)$$

where R_{RED} – red band of the electromagnetic spectrum of image, R_{GREEN} – green band of the electromagnetic spectrum of image.

The transmission coefficient in the visible part of the spectrum for water decreases with an increase in the amount of aquatic vegetation within the lake and thus affects the value of the NDTI. The higher the index, the greater the spread of algal bloom in the lake. Meanwhile, the wavelength ranges from 600 to 800 nm. The graph below illustrates the spectral imaging patterns of water, soil and vegetation from approximately 0.3 to 6.0 µm. (Fig. 1). The causes of water bloom in the lake can be both natural factors and anthropogenic human activity in the catchment area and the entry of pollutants.

Fig. 1 shows that vegetation, for example, reflects relatively little energy in the visible spectrum and absorbs visible energy, in particular in the blue and red ranges for the use of photosynthesis. However,

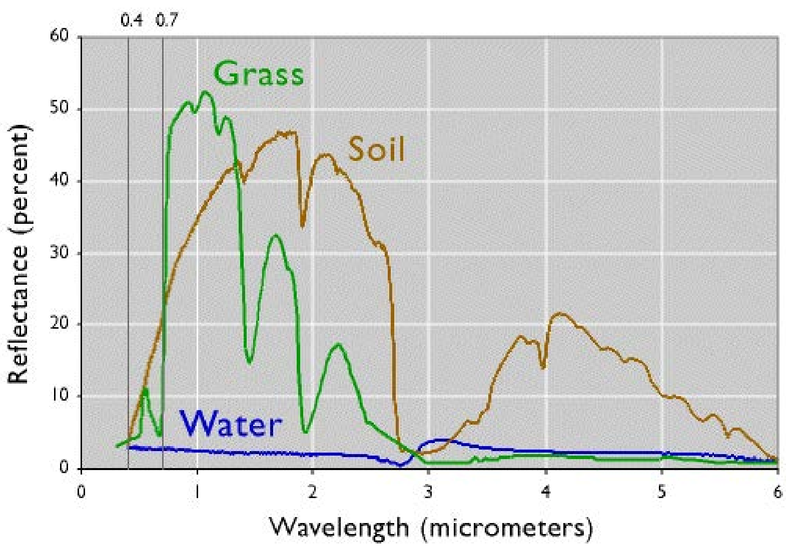

Fig. 1. The spectral response patterns of soil, grass, and water (The Nature of Geographic, 2023)

about half of the incoming near-infrared radiation is reflected, which is typical for healthy vegetation. Soil reflects more energy at longer wavelengths than vegetation. Water absorbs most of the incoming radiation across the entire wavelength range. Therefore, being aware of their typical spectral radiation characteristics, it is possible to identify natural bodies of water in remote sensing images and assess their condition in summer images (The Nature of Geographic Information, 2023).

Thus, as a result of the application of remote sensing data processing methods, maps and graphic materials were created on which we can trace and assess the long-term dynamics of changes in the area of the Shatsk lakes and water blooms on their surface.

Results and analysis

1. Brief description of the Shatsk Lakes region (Volyn region, Ukraine)

The Shatsk lakes are located in the Western Bug Basin, are of karst origin and are a unique natural complex of the Volyn Polissia region of Ukraine. The bedrock is dominated by chalk and marl of Upper Cretaceous period, which leads to intensive development of karst. According to the geomorphological structure, the territory is an alluvial-moraine or accumulative lowland, which is located on the watershed of the Baltic and Black Sea basins.

There are several levels in the geological structure of the area, namely: the crystalline base, the Shatsk lakes trough of the Jurassic and Cretaceous periods and the Mesozoic deposits. The most widespread throughout the territory are the Upper Cretaceous deposits, which have the ability to form karst. This is also facilitated by precipitation and groundwater circulating through cracks and forming numerous rising springs in the lakes. On the territory of the Shatsk Poozeria there are 28 lakes with a total area of about 61.31 km^2 and a water mass of 312.8 million m^3. The area of the lakes ranges from 0.01 km^2 to 26.21 km^2. The water level in the lakes depends on the amount of precipitation and groundwater. (Khilchevskyi et al., 2022a) – Fig. 2.

Important morphometric characteristics of the group of Shatsk lakes that were selected for the study are the area of the water surface and the average depth (Khilchevskyi, Zabokrytska, 2020) – Table 1.

As can be seen from Table 1, according to morphometric indicators (water surface area and maximum depth of lake basins), the largest and deepest lake is Svitiaz (area 26.21 km^2, maximum depth 58.4 m), the second largest is Liutsymer Lake (area 4.43 km^2, maximum depth 11.2 m) and the smallest in area is Chorne Velyke Lake (area 0.84 km^2, maximum depth 4.8 m).

Svitiaz Lake has hollows with narrow fissures, which reach the 20-50 meters in depth. There is an island on the lake with an area of 7 hectares.

It is important to note that the bottom of the lakes is sandy, and in deep places is silty. The shores of the

Fig. 2. Map of the location of the Shatsk lakes in Volyn region, Ukraine

Table 1. Main morphometric characteristics of the studied lakes of the Shatsk group in Volyn region, Ukraine

Name of the lake	Area, km²	Water volume, thous m³	Length, km	Width, km	Depth, m	
					Average depth, m	Maximum depth, m
Svitiaz	26.21	19070.0	7.81	3.36	6.90	58.4
Liutsymer	4.43	1949.2	3.10	1.43	3.40	11.2
Chorne Velyke	0.84	169.7	1.36	0.62	1.77	4.8

lakes are mostly low, swampy, and overgrown with vegetation. The water level in the lakes depends on the amount of precipitation and groundwater. In addition, human activity has a certain influence on the regime of water levels in the Shatsk Lakes. In particular, the increase in the area of drainage reclamation in the region in the second half of the 20th century to a certain extent influenced the water level regime in the lakes and thus the water-regulating role of the lakes.

2. Assessment of long-term dynamics of lake area using the NDWI

For Lake Svitiaz, a comparative assessment of the long-term dynamics of the water surface area was performed using the NDWI index (March 1985–2023). Fig. 3 shows for illustration purposes a processed version of a satellite image for 2007, the year of maximum water level.

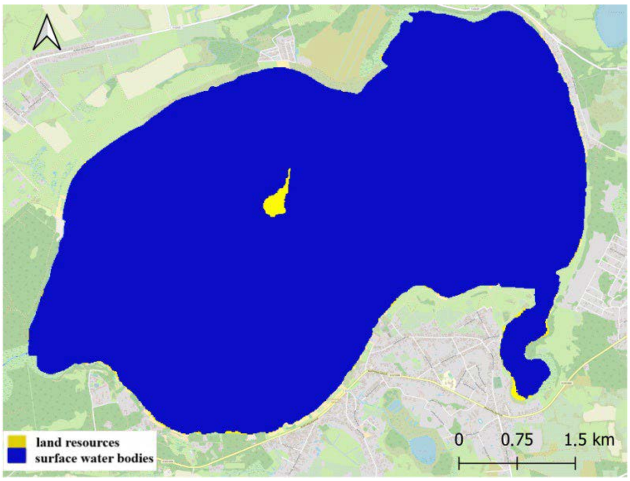

Fig. 3. Illustration of the process of determining the area of the lake's water surface using the NDWI: satellite image of Lake Svitiaz for 2007 – the year of maximum water level

It should be noted that the characteristic years for Svitiaz Lake were 2007 (maximum level) and 2020 (minimum level). The water level in Svitiaz Lake in these years was 163.59 m and 163.06 m, respectively (amplitude 0.53 m). When the area of the lake's water surface decreased, the number of yellow pixels in the satellite image increased, indicating that the water was moving away from the shore and becoming shallower. It should be noted that in the spring of 2007, the area of the lake's water surface increased to 26.45 km², which exceeded the average annual area of the lake's water surface, instead in 2020 it decreased significantly and amounted to 22.40 km² (85% of the average annual area of the lake's water surface). It is important to note that in 2023, the water surface area of Svitiaz Lake was the largest in the last 10 years – 25.75 km² (98% of the average annual water surface area of the lake) since the water level was also the highest in a decade, which is mainly due to the significant snow reserves in the previous winter (Fig. 4).

Fig. 5 shows graphs of the dynamics of the area of the Shatsk lakes (Svitiaz, Liutsymer, Chorne Velyke) by 1985-2023.

In Liutsymer Lake, the water surface area varied during the long period of study from 4.43 km² in 2007 (100% of the average annual area of the lake) to 3.79 km² in 2020 (85% of the average annual area of the lake's water surface). At the beginning of the observation period in 1985, the area of the lake's water surface was 4.39 km² (99% of the average annual area of the lake's water surface), and in 2023 – 4.25 km² (96% of the average annual area of the lake).

In Chorne Velyke Lake, the water surface area has changed over many years from 0.84 km² in 2007 (100% of the average annual water surface area of the lake) to 0.667 km² in 2020 (79% of the average annual water surface area of the lake). At the beginning of the observation period in 1985, the water surface area of the lake was 0.81 km² (96% of the average annual area of the lake), and in 2023 – 0.80 km² (95% of the average annual area of the lake).

Thus, the analysis of satellite images showing variations in the area of the water surface of the studied Shatsk lakes for 1985–2023 allowed us to identify the following characteristic years: the maximum area of the water surface of the lakes (2007, 2010, 1999); minimum water surface area of lakes (2020, 2019, 2004) – Table 2.

3. Assessment of long-term dynamics of lake bloom using the NDTI

A lake's water bloom is a natural phenomenon caused by the massive development of phytoplankton (microscopic algae) which manifests itself due to a

Fig. 4. The water level in Svitiaz Lake in July 2023 was higher than in previous years: the southwestern part of the lake in the area of the Boarding House «Shatsk Lakes» (photo by Valentyn Khilchevskyi)

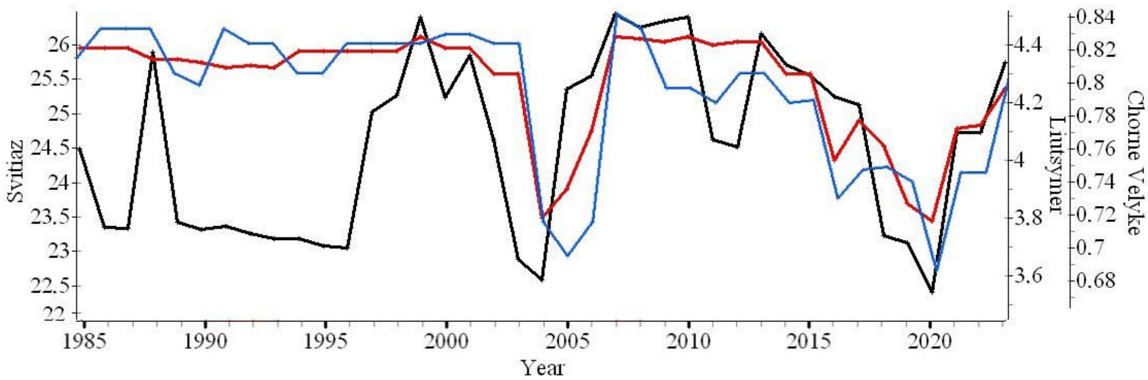

Fig. 5. Dynamics of the area of lakes Svitiaz (black on the graph), Liutsymer (red) and Chorne Velyke (blue), determined from satellite images using the NDWI (1985–2023), km^2

Table 2. The area of the water surface of the Shatsk lakes for characteristic years, determined from satellite images using the NDWI (1985–2023), % of the average annual area (see Table 1)

Name of the lake	Maximum lake area		Minimum lake area	
	% of the average annual	рік	% of the average annual	Year
Svitiaz	101	2007	85	2020
	101	2010	86	2004
	101	1999	88	2019
Liutsymer	100	2007	85	2020
	100	2010	86	2004
	100	1999	87	2019
Chorne Velyke	100	2007	79	2020
	100	2010	83	2004
	100	1999	87	2019

change in the color of the water (typically green) and a deterioration in the oxygen regime of the water body. The factors causing the bloom of water in a water body are manifestations of stagnant regime of water masses, an increase in water temperature in the summer and the presence of nutrients that serve as nutrients for phytoplankton. Therefore, it is clear that this phenomenon is seasonal (for our latitudes July – August), spreads in the shoreline area and in bays in the 10–15 cm thick upper layer of water. Despite the fact that Svitiaz Lake is one of the cleanest large lakes in Ukraine, it is also characterized by the phenomenon of water blooming in the second half of summer (Fig. 6).

Excessive blooming of water in water bodies is a cause for concern, which leads to a change in the hydrochemical regime of the water body due to a lack of oxygen, a noticeable decrease in the quality of water for users, and a deterioration in the living conditions of aquatic organisms. One of the reasons for exces-

Fig. 6. Water bloom in Svitiaz Lake (Shatsk Lakes), August 2023 (photo by Valentyn Khilchevskyi)

sive algal blooms can be due to anthropogenic impact: inflow of domestic wastewater, washing away from agricultural lands of nutrients (especially nitrogen and phosphorus) contained in mineral fertilizers.

A spatial comparative assessment of the long-term dynamics of the water bloom area of lakes Svitiaz, Liutsymer and Chorne Velyke was carried out by processing satellite images using the NDTI (for July 1985-2023). Fig. 7a shows the processed image of the satellite image of Chorne Velyke Lake at the maximum area of water bloom in 2004, and Fig. 7b shows minimal development of this phenomenon in 1991. Total area of water bloom on the surface of the lake (ΣF) was calculated by adding the areas of individual bloom fragments ($F_1, F_2, F_3, \ldots F_n$).

$$\Sigma F = F_1 + F_2 + F_3 + \ldots + F_n \quad (3)$$

In Svitiaz Lake, the area of water bloom (Fig. 8) over a long period of time varied from 0.01 km^2 in 2006-2010 (0.04% of the average annual area of the lake's water surface) to 1.16 km^2 in 2019 (4.43% of the average annual area of the lake's water surface). It has been established that an increase in the area of water bloom in the lake was characteristic for 1996, when it was 1.15 km^2 (4.39% of the average annual area of the lake's water surface), as well as during 2020-2022 (1.05–1.08 km^2), which was 4.0–4.12% of the average annual area of the lake's water surface. Low values of the area of water bloom in the lake – from 0.02 km^2 (0.07% of the average annual area of the lake's water surface) to 0.1 km^2 (0.5% of the average annual area of the lake's water surface) were characteristic for 1985–1990 and 2011–2016 (Table 3).

In Liutsymer Lake, the area of water bloom (Fig. 8) over a long period varied from 0.01 km^2 in 1990-1993 (0.2% of the average annual area of the lake's water surface) to 1.04 km^2 in 2000–2001 (23.5% of the average annual water surface area of the lake). An increase in the area of water bloom in the lake is characteristic of 1994–1998, when it was 0.1 km^2 (2.3% of the average annual area of the lake's water surface),

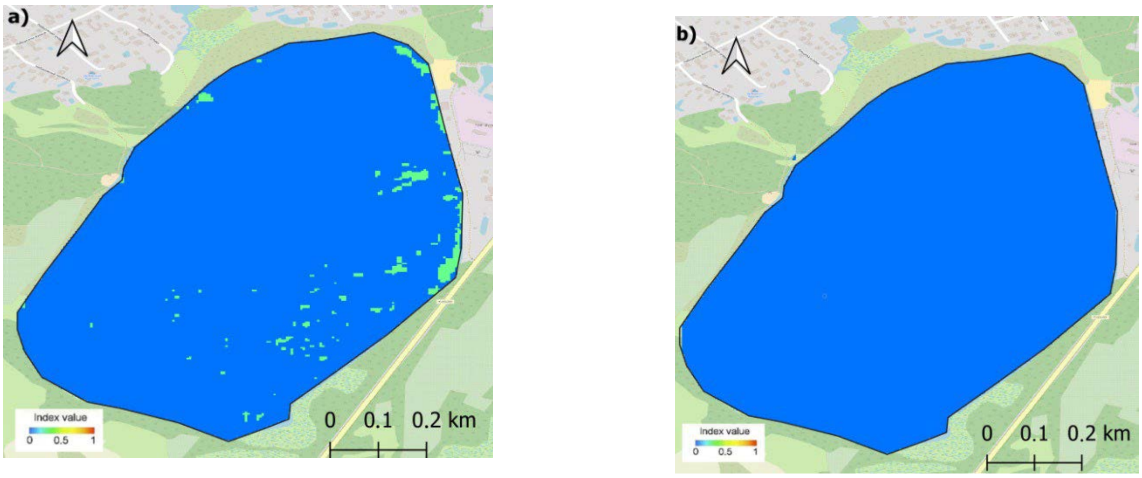

Fig. 7. Processed images of satellite images of Chorne Velyke Lake, showing the area of water bloom determined using the NDTI (1985–2023): a) maximum bloom – 2004; b) minimum bloom – 1991.

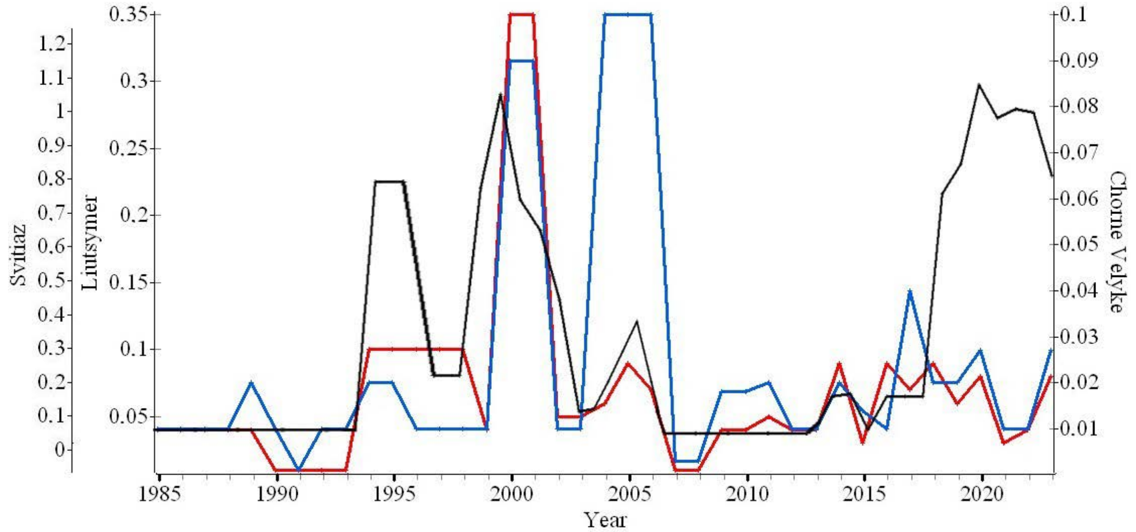

Fig. 8. Dynamics of the water bloom area of lakes Svitiaz, (black on the graph), Liutsymer (red) and Chorne Velyke (blue), determined from satellite images using the NDTI (1985–2023), km^2

as well as during 2005, 2014, 2016, 2018 (0.09 km^2) 2023 (0.08 km^2), which was 2.0-1.8% of the average annual area of the lake's water surface (Table 3).

In Chorne Velyke Lake, the size of the area of water bloom (Fig. 8) over the multi-year period of study varied from 0.001 km^2 in 1991 (0.1% of the average annual area of the lake's water surface) to 0.1 km^2 in 2004–2006 (11.9% of the average water surface area of the lake). An increase in the area of water bloom in the lake was characteristic of 2000–2001, when it amounted to 0.09 km^2 (10.7% of the average annual area of the lake's water surface) – Table 3. Overall, in the vast majority of years, the area of water bloom in Chorne Velyke Lake was 0.01–0.02 sq. km (1.2–2.4% of the average annual area of the lake's water surface).

4. The linkages between the dynamics of the water surface area of Svitiaz Lake, water levels in the lake and precipitation

It is known that due to the large water capacity in lakes, they are a hydrological buffer that prevents extreme events such as critical floods and flooding or droughts. In turn, climate change poses a threat to the continued existence of lakes.

We analyzed the average annual data on the water level at the hydrological station of Svitiaz Lake, the amount of precipitation at the Svitiaz weather station and the water area of Svitiaz Lake, determined from satellite images using the NDWI (1985–2023) – Fig. 9.

Analysis of the graphs (Fig. 9) shows there is a tendency for a mutual relationship between the dynamics of the characteristics being studied.

In order to quantify this linkage, pair correlation coefficients (r) were calculated between the characteristics under study with series in which the number of values is 39.

Table 3. Area of water bloom in the Shatsk lakes for characteristic years, determined from satellite images using the NDTI (1985-2023), % of the annual average

Name of the lake	Maximum water bloom area		Minimal water bloom area	
	% of the average annual lake area	Year	% of the average annual lake area	Year
Svitiaz	4.43	2019	0.04	2006-2010
	4.39	1996	0.07	1985-1990
	4.12	2021	0.5	2011-2016
Liutsymer	23.5	2000-2001	0.2	1990-1993
	2.3	1994-1998	0.7	2015, 2021
Chorne Velyke	11.9	2004-2006	0.1	1991
	10.7	2000-2001	0.4	2007-2008

The correlation coefficient between the area of Svitiaz Lake and water levels in the lake is r = 0.7; between the lake area and precipitation – r = 0.6; between the water level in the lake and precipitation – r = 0.6. Correlation coefficients are significant according to Student's t-test.

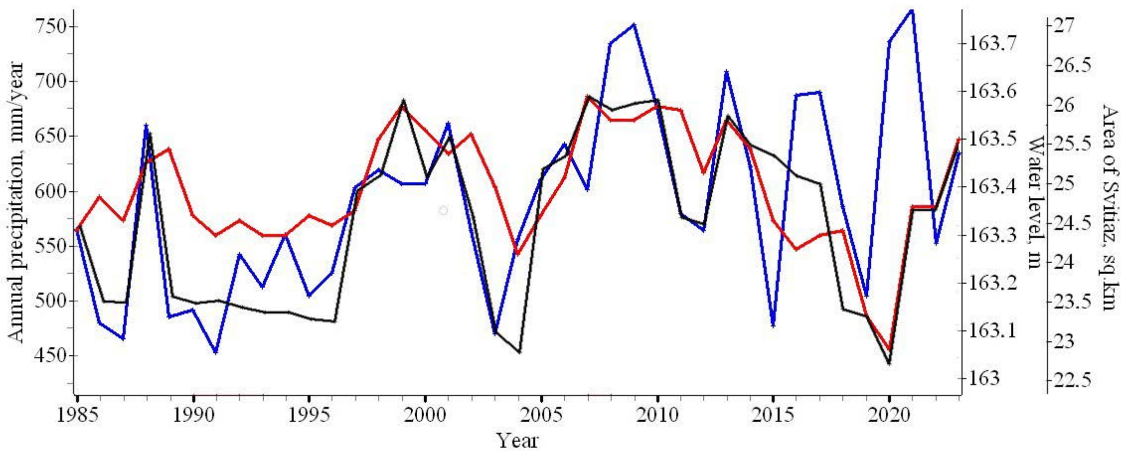

Fig. 9. Dynamics of the area of Svitiaz Lake – km^2 (black color on the graph), water level – m (red) and the amount of precipitation (mm) at the Svitiaz weather station (blue) for 1985–2023.

Conclusion

1) The area of the water surface of the Shatsk lakes (Svitiaz, Liutsymer and Chorne Velyke) over a long period (1985–2023), studied using satellite images using the NDWI, ranged from the average annual value: Svitiaz – 85-101%; Liutsymer – 85–100%; Chorne Velyke – 79–100%.

2) The area of water bloom in these lakes over a long-term period (1985–2023), studied using satellite images using the NDTI, ranged from the average annual value of the lake's surface: Svitiaz – 0.04–4.43%; Liutsymer – 0.2–7.9%; Chorne Velyke – 0.1–11.9%.

3) Among the studied lakes, minimal water bloom was observed in the largest of them, Svitiaz, which indicates its better ecological condition. The maximum bloom of water is typical for the small Chorne Velyke Lake.

4) Variations in the area of the water surface of lakes, water level and the amount of precipitation are interconnected, which was demonstrated based on the example of Svitiaz Lake. The obtained pair correlation coefficients (r) between these characteristics are 0.6–0.7.

5) In 2023, the water surface area of Svitiaz Lake was the largest in the last 10 years, as the water level in the lake was also the highest for a decade, which is mainly due to significant snow reserves in winter.

6) The use of remote sensing methods in the study of morphometric parameters of lakes allows us to identify environmental problems in advance. An in-depth study of these problems must be carried out in situ using instrumental methods, water sampling and chemical and hydrobiological analysis of the water.

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