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Shallowing of the Svityaz Lake in the context of regional climate change

Vitalina Fedoniuk¹, Maria Khrystetska², Mykola Fedoniuk¹, Ihor Merlenko¹, Serhiy Bondarchuk¹

¹Lutsk National Technical University, Lutsk, Ukraine, ecolutsk@gmail.com

²Shatsk National Nature Park, Svityaz, Ukraine

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Abstract. The paper analyzes the dynamics of the main climatic indicators in order to reveal the role of regional and local factors in the current changes in the water content of the Svityaz Lake (NW Ukraine). The current state of study of the water balance of the lake and the factors that form it are estimated. The main trends for changes in the levels and

regime of surface water, groundwater and artesian water in the territory of the Shatsk National Nature Park are identified. Quantitative data characterizing long-term and modern changes in water levels in the lake are presented. Shallowing of 2019 is characterized (the lowest water level over the last 50 years, reduction of the water mirror area by 8%). Based on statistical mathematical and cartographic analysis of climatic data provided by 17 meteorological stations in the region the dynamics of average annual, monthly and seasonal precipitation, evaporation and their spatial distribution were estimated. A significant increase in evaporation during the warm period of the year over the last decades (2000–2018) has been revealed. Changes in the amount and mode of precipitation over 2 long-term periods are estimated. The peculiarities of the dynamics of the main meteorological indicators in 2019 (average monthly and average annual air temperatures, relative humidity, precipitation amounts) were separately analyzed. Values of humidity coefficients and hydrothermal coefficients were calculated. The parts of the region with the lowest values of these indicators, including the catchment area of Lake Svityaz, are outlined and visualized on the map. The significant role of evaporation growth was confirmed given the consistent increase in air temperatures over the last 20 years. Given the Svityaz station data it is also calculated the correlation coefficients of water levels in the lake with the same indicators for the period since 1970. During the period of 2000–2018, a significant increase in the dependence of water levels on the hydrothermal coefficient of Selyaninov was established, which may indicate a decrease in the ecological stability of the lake and its increasing vulnerability to climate change.

Key words: Svityaz Lake, shallowing, water level, precipitation, evaporation, hydrothermal coefficient.

Обміління озера Світязь під впливом регіональних кліматичних змін

В.В. Федонюк¹, М.В. Христецька², М.А. Федонюк¹, І.М. Мерленко¹, С.П. Бондарчук¹

¹Луцький національний технічний університет, ecolutsk@gmail.com

²Шацький національний природний парк

Анотація. У роботі проведено аналіз динаміки основних кліматичних показників для виявлення ролі регіональних та локальних чинників у сучасних змінах водності озера Світязь. Оцінено сучасний стан вивченості водного балансу озера та чинників, що його формують. Проаналізовано основні визначені на сьогодні тенденції зміни рівнів та режиму поверхневих, підземних і ґрунтових вод на території Шацького природного національного парку. Наведено кількісні дані, що характеризують багаторічні та сучасні зміни рівнів води в озері. Охарактеризовано аномальне обміління 2019 р., проявами якого були мінімальний рівень води за останні 50 років та скорочення площі водного дзеркала на 8%. На основі математико-статистичного та картографічного аналізу кліматичних даних по 17 метеорологічних станціях регіону Західного Полісся проведено оцінку динаміки середньої річної, місячної та сезонної (теплий і холодний періоди року) кількості опадів, випаровуваності та їх просторового розподілу. Виявлено значне зростання випаровуваності у теплий період року протягом останніх десятиліть (2000–2018 рр.). Оцінено зміни кількості та режиму випадіння опадів за 2 багаторічні періоди. Проведено аналіз особливостей динаміки основних метеорологічних показників у 2019 р. (середні місячні та середні річні температура повітря, відносна вологість повітря, кількість опадів). Розраховано значення коефіцієнтів зволоження, що відображає співвідношення між середньою річною кількістю опадів та середньою річною випаровуваністю, а також гідротермічного коефіцієнта Селянинова. Визначено та візуалізовано на картах частини регіону із найменшими значеннями цих показників, які охоплюють в тому числі і водозбір озера Світязь. Підтверджено значну роль зростання випаровуваності на фоні поступового збільшення температур повітря протягом останніх 20 років. По станції Світязь також обчислено коефіцієнти кореляції рівнів води в озері із цими показниками,

починаючи із 1970 р. За проаналізований період у другій половині ХХст. виявлено відсутність сильних кореляційних залежностей рівнів води від середньорічної кількості опадів, випаровуваності та коефіцієнта зволоження, але з певним зростанням коефіцієнтів кореляції у багаторічному ході. За період 2000–2018рр встановлено суттєве зростання залежності рівнів води від гідротермічного коефіцієнта Селянинова, що може свідчити про зменшення екологічної стійкості озера та все більшу його вразливість до кліматичних змін.

Ключові слова: озеро Світязь, обміння, рівень води, кількість опадів, випаровуваність, гідротермічний коефіцієнт

Introduction. The Lake Svityaz, the deepest and one of the largest lakes in Ukraine, is the most famous object of the Shatsk National Natural Park (SNNP), and its lake area is one of the largest recreational systems of the region. The uniqueness and particular value of the park ecosystems has been also proved by its inclusion in the transboundary international biological reserve “Zachidne Polissya”.

In recent years, we observed a decrease in average water levels in the lakes, and in 2019 the lowest water level of the Lake Svityaz since the beginning of observation in the park (Chronicle of Nature of Shatsk NNP, 2020) was recorded. Due to the peculiarities of the morphology of the lake basin (wide shallow part), these changes, being well seen by the naked eye, caused significant concerns of the public. Since July 2019 the issue of lake shallowing has been raised at different levels of authorities, is widely covered in the media. The attention to the issue is certified by 4 petitions registered on the website of the President of Ukraine, a few extraordinary meetings of the Committee on Environmental Policy and Nature Management of the Parliament of Ukraine (November 12, 2019, February 13, 2020), establishing of working groups on the issues of Shatsk lake shallowing in the regional and all-Ukrainian level.

Scientific discussions of the problems took place, in particular, at the meeting of the Coordinating Committee of Shatsk Interdepartmental Scientific Research Ecological Laboratory (Shatsk Experimental Base of the Institute of Physics and Mechanics (IPM) named after Karpenko G.V. of the National Academy of Sciences of Ukraine, October 11, 2019), at the Interdepartmental Scientific and Practical workshop “Hydroecological situation of lakes in Volyn region: a problem or a catastrophe” (Lutsk NTU, 18.10.2019), at the meetings of working groups dealing with the problems of shallowing of the Shatsk Lakes (17.12.2019, 13.01.2020, 13.03.2020), meetings of the Regional Office of Water Resources in the Volyn region, the Pripjat Basin Councils, the Western Bug and San Councils, etc. The authors of this research were involved and attended almost all of the above-mentioned meetings, which allow them to assess problem coverage and to make stand out a number of insufficiently highlighted issues.

Review of previous research. Detailed water balance studies in the region began in the 1960s in connection

with the planning and conducting of the large-scale drainage reclamation. Significant researches were conducted by the Institute of Hydraulic Engineering and Land Reclamation (nowadays, the Institute of Water Problems and Land Reclamation) of the National Academy of Agrarian Sciences of Ukraine. In particular, the main income and expenditure components of the water balance, water exchange intensity, indicators of ecological sustainability of lakes, etc. have been evaluated (Romashchenko, Bakhmachuk, 2004; Yatsyuk et al., 2019]. Since the early 1990s and until now, high attention is paid to assessment of possible impact on water regime of Svityaz of the Khotyslav quarry in Belarus (Diatel, 2019; Yatsyuk et al. 2019; Zuzuk, Melnychuk, Zaleski, 2012).

The role of pressure waters, features of their occurrence, dynamics of levels have been studied in the works of Rivne geological expedition, Kovel hydrogeological and reclamation party. Generalized data are provided in the works of I.I. Zaleski (Zaleski, 2014a, 2014b).

Since 1985, the park staff has been conducting constant observations of surface water levels, the data of which, along with meteorological indicators, are being analyzed in the annual chronicles of nature. A continuous series of observations has been formed with regards to the Lake Svityaz. As for the other lakes, as well as groundwater and underground water levels in the region, monitoring data are available only for certain periods.

Since 2010, the system of Integrated Environmental Monitoring (IEM), organized by the IPM named after Karpenko G.V. of the National Academy of Sciences of Ukraine (Panasyuk, Yurchuk, Koshovy, Muravskyy et al., 2012). The system integrates networks of test sites, soil sections, wells, etc., the data of which are combined with the analysis of remote sensing data. The results are entered in put into the Geo-Information Atlas of the Shatsky Biosphere Reserve (Information-analytical system..., 2020).

Climatic studies of this area have been presented in many researches, starting with the monographs “Nature of Volyn region” (1975), “Climate of Shatsk National Park” (1995) and continuing with modern both special (Alokhina, Ivantyshyn, Korus, Koshovy, Popov, Rusyn, 2018; Diatel, Tsvietova, Saidak, 2018; Tarasyuk F., Tarasyuk N., 2017; Tarasyuk

N., Hanushchak, 2017) and general (Fesyuk, Puhach, Slashchuk et al., 2016; Ozero Svityaz..., 2008) works that reflect various aspects of the region's climate and its changes.

In general, based on the analysis of publications dedicated to changes in the water content of the lakes of the SNNP over the last decade, the following can be distinguished:

- the territory undergoes significant changes in climatic indicators, in particular, there is an increase in average air temperatures, increased evaporation and changes in precipitation;

- the average levels of groundwater and underground water that supply the reservoirs of the park are decreasing, and their seasonal decline begins earlier (in recent years more often it takes place in April-May, in previous years – in June-July);

- significant increase in the amplitude of fluctuations in groundwater levels. In some periods, the decline of groundwater levels has peculiar features that do not correlate with changes in natural factors;

- increasing of waste when flow down (groundwater supply during their operation);

- there is a tendency to a certain synchronization of decreasing water levels of most lakes in the park, although previously they differed significantly.

Most of these trends began to appear in 2014-2015, but some had appeared even earlier (Yatsyuk et al., 2019). It is logical to assume that the significant shallowing of the Lake Svityaz in 2019 was not a sudden one-time phenomenon, while it is a consequence of the longer processes.

Among the main factors of shallowing are regional reflections of global climate changes, hydrogeological changes, progressive uncontrolled growth of municipal water consumption in recreational areas of SNNP, neglected reclamation and water control systems and structures, probable impact on groundwater of Khotyslav quarry, as well as newly created plantations of irrigated agricultural crops (blueberries) (Bondarchuk S., Bondarchuk L., 2016; Diatel, 2019; Yatsyuk et al., 2019).

The last factors are popular in the media, although as of today there are no objective evidence of such an impact. The results of the modelling show the probability of reducing the level of the lake Svityaz by 20 cm due to drainage during the operation of the Khotyslav quarry, subject to its depths of 45 m (Diatel, 2019). Nowadays, its depth is 12 m, no negative impact has been identified (Volyn Regional..., 2019). Regarding water consumption for blueberry cultivation, the maximum possible indicators are estimated at up to 0.6-1.1 million m³ per season (according to Dr. Shevchuk and calculations made by the Institute

of Water Problems and Land Reclamation (Yatsyuk et al., 2019). This is, for comparison, no more than 5-7% of the average annual evaporation indicator for the Lake Svityaz, however, these issues require further detailed study and monitoring.

To date, the most complete analysis of the main shallowing factors of the Shatsk Lakes is given in the Concept of the Shatsk Lake Conservation Program, presented in December 2019 by the scientists from the Institute of Water Problems and Land Reclamation (Yatsyuk et al., 2019).

Despite considerable attention paid to this problem, most of these works present the results of only local research within the SNNP. Therefore, **the purpose** of this research is to analyze and compare the dynamics of both local and regional climatic indicators to identify their impact on the change in water content of the Shatsk Lakes.

Materials and methods. The source materials for the study were archives of meteorological information posted on the resources of the World Data Centers and the web service of European Climate Assessment & Dataset (ECA & D). Analysis and calculations of climatic indicators were performed for 17 meteorological stations located in Volyn region and in adjacent regions – stations of Svityaz, Lutsk, Kovel, Lyubeshiv, Manevychi, Volodymyr-Volynsky (Volyn region), Rivne, Dubno, Sarny (Rivne region), Brody, Rava-Ruska, Kamianka-Buzka (Lviv region), Pinsk, Pruzhany (Republic of Belarus), Terespil, Wlodawa, Zamość (Republic of Poland) for the period of 1970-2019. For some periods with no actual observation data E-OBS modeling materials were used, the acceptability (reliability) of which, in particular, for the Volyn region, was confirmed by research (Shedemenko, Krakovska, Gnatiuk, 2012).

Dynamics of lake water levels of the Svityaz was analyzed for the period of 1970-2019 according to the observations carried out at the Svityaz meteorological station and at the Shatsk NNP.

Using statistical methods, the average values of precipitation, air temperature, relative humidity for each weather station for the months, warm and cold periods of the year, for the year and for the entire study period have been calculated.

On the basis of empirical calculation methods evaporation, humidification coefficient and hydrothermal coefficient have been determined.

The calculation of evaporation was carried out according to the well-known method of N.M. Ivanov (which is often called V. Romanenko's formula in Western literature) (Xu, Singh, 2001), which takes into account the average monthly indicators of temperature and relative air humidity. The coefficient of

humidification of the territory was defined as the ratio of precipitation to evaporation for the respective monthly or annual periods. As it is known, evaporation means the maximum possible evaporation under these temperature conditions, not limited to moisture reserves (mm).

Among the alternative methods for calculating evaporation from the surface of the water mirror, the methods of L. Turc (1954) and Thornthwaite C. W (Xu, Singh, 2001) have been also used to verify the obtained results.

The hydrothermal coefficient of Selyanynov, which is defined as the ratio of precipitation for the period with average daily air temperatures above 10 ° C (period of active vegetation) to the sum of air temperatures for the same period divided by 10, has also been calculated.

The spatial distribution of the calculated indicators is represented by GS Surfer cartographic means using methods of interpolation of local polynomials and radial basis function. To estimate the change in the surface of the lake, the methods of automatic classification of Sentinel-2 satellite images according to the NDWI indicator in EOS LandViewer were used.

Results and discussion. The analysis of archival data on the water levels of Lake Svityaz for the period of 1970-2019 showed that they have a pronounced seasonal dynamic with low winter, maximum spring and minimum summer-autumn indicators. Fig. 1 presents typical intra-annual fluctuations of lake water

ciated with the previously conducted drainage reclamation), the highest - 163.79 m in 1981. During the existence of the park, the difference between the maximal and minimal levels was even smaller (up to 40 cm was average annual, up to 60 cm was average monthly indicator). However, in 2019 this amplitude has significantly increased. Starting from July, water levels fell below the previous minimums of 1994 and 2015, and in autumn (level 162.92 m) – less than the long-term minimum of 1972. The examination in October 2019 revealed a deviation of the water body from the shoreline from 3-5 m to 40-90 m in different areas (Chronicle of Nature of Shatsk NNP, 2020).

To estimate the total area of water surface reduction, a number of space images were analyzed using automatic classification in several combinations of multispectral image channels (in LandViewer service by EOS Data Analytics). The Normalized difference water index (NDWI) is most often used to estimate changes in the area of water bodies, which identifies the water surface well by estimating the ratio of reflected radiation in the near and short-wave infrared ranges (Xu, 2006). Having automatically classified images from the Sentinel-2 satellite, data on the ratio of areas with different values of the NDWI index for individual dates from autumn 2018 to autumn 2019 were obtained (Fig. 2).

Therefore, for example, it was found that in April 2019 (level 163.29 m) the area under water was 74 hectares larger than in November 2018 (level of 163.17 m), but in the summer months it began

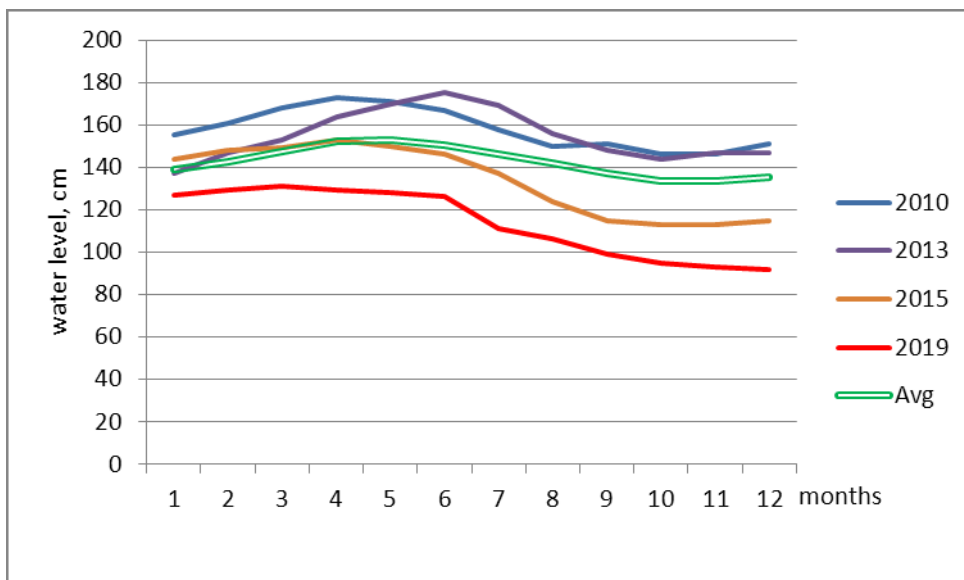


Fig. 1. Intra-annual fluctuations of lake water levels in high-water (2010, 2013) and low-water (2015, 2019) years.

levels in high-water and low-water years.

At the same time, the amplitude of the levels is small, for a long period it was less than 0.9 m. The lowest level was recorded in 1972-162.97 m (asso-

to decline rapidly, and at a minimal level (162.92 m in autumn 2019) it was already 155 ha smaller than the spring indicators. The amplitude of the analyzed values for the studied period was about 251 ha.

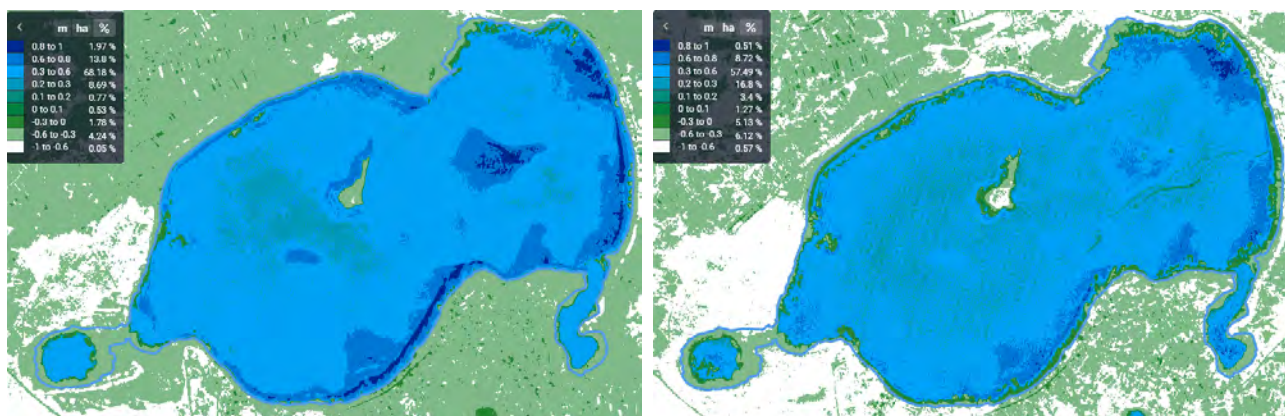


Fig. 2. Results of comparison of pictures Sentinel-2 dated 02.04.2019 (left) and dated 01.11.2019 (right) by means of automatic classification according to NDWI using EOS LandViewer.

Further we will consider the main climatic indicators that can significantly affect the reduction of water content of the lake, in the temporal and regional context.

Precipitation. Analysis of precipitation dynamics in the XXI century according to 17 meteorological stations in the region showed that, despite some low-water years, the average annual precipitation increased by 20-45 mm (Fig. 3), which is 3-10% of the climatic norm.

However, the average monthly precipitation indicators are characterized by a very high variability. An increase in precipitation is evidenced in January, March, April and May. In other months of the year there is mainly a decrease in the average monthly precipitation (the largest decrease was observed in February, June, August).

At the same time, the annual number of days with precipitation decreased by 25-30%. For example, for Svityaz meteorological station at the climatic norm of 164 days with precipitation per year, the average

value for the period 2000-2018 is 121 days. The dynamics of precipitation during the year also changed: the distribution of rainy days became more uniform over the seasons. Thus, on Svityaz weather station the ratio of days with precipitations of the cold and warm period makes 54/67, and average value in the region is 60/82.

Against a slight increase in the average annual precipitation, compared to the climatic norm, some years become arid (for example, 2015, 2019). In 2019, only 4 of the 17 weather stations had a positive deviation in precipitation compared to the climatic norm. At other stations, a decrease in the annual precipitation was recorded, the most significant was for Lyubeshiv, Terespol, Zamość, Svityaz and Lutsk (Fig. 4).

According to several regional climate models indicators, such situation should not become typical, most forecasts do not predict (Krakovska, Palamarchuk, Gnatiuk, Shpytal, Shedemenko, 2017) a significant reduction in precipitation in the region. However, even if the annual precipitation

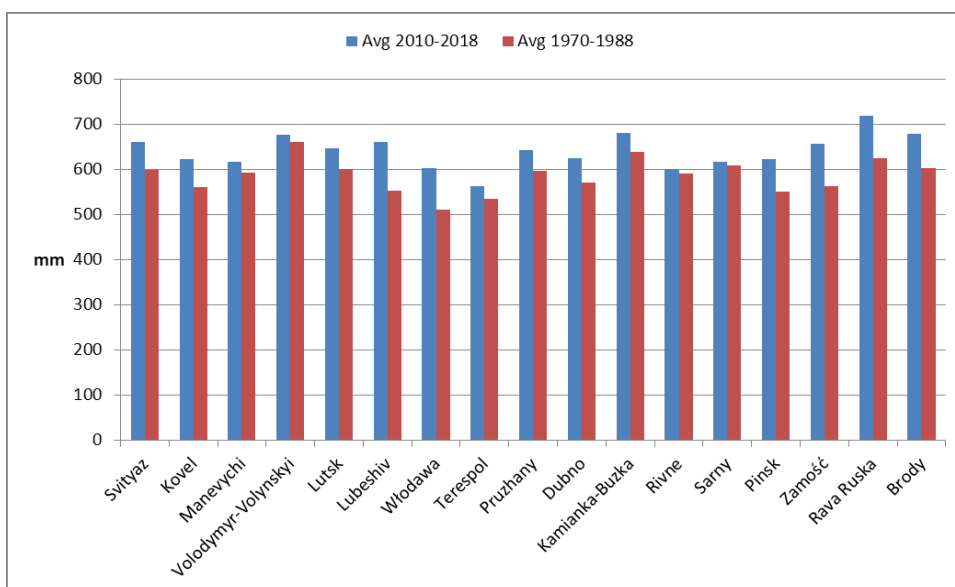


Fig. 3. Comparative diagram of the average annual precipitation at 17 weather stations in the region

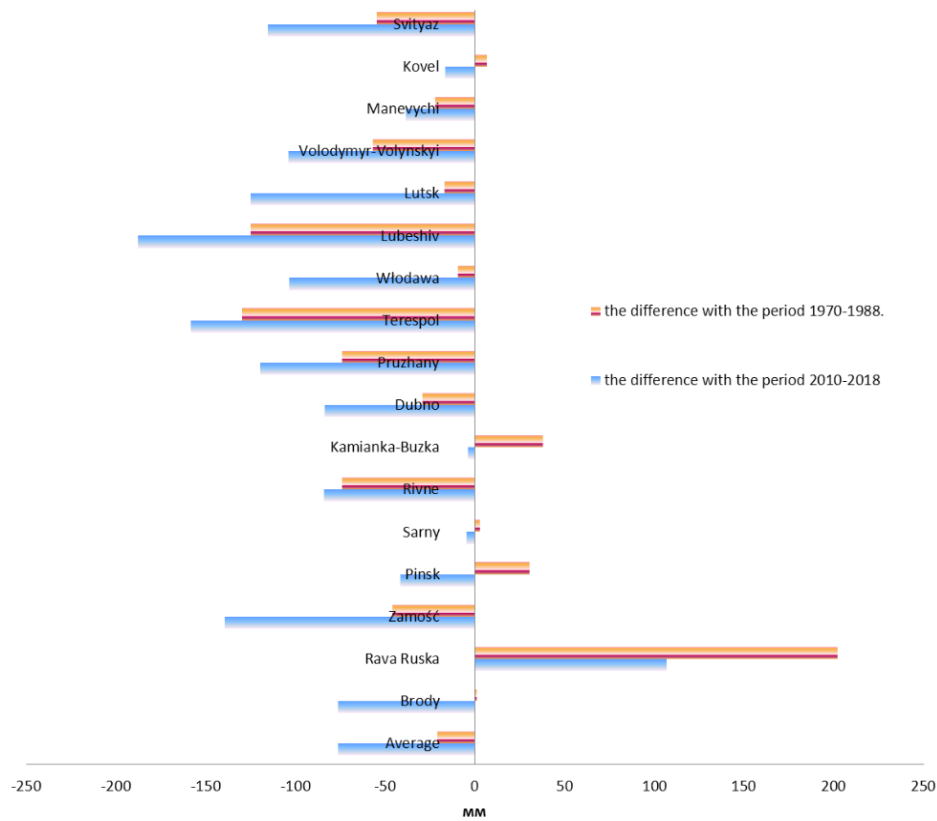


Fig. 4. Deviation of precipitation in 2019 at meteorological stations in the region compared to previous periods

is maintained at the level of the previous period or slightly increased, evaporation becomes a significant factor in reducing water content.

To compare the dynamics of *evaporation* from the surface of the water mirror of the Lake Svityaz during the period of global climate change, two periods were analyzed: 1970-1988 and 2000-2018. The archival data of the Svityaz meteorological station, which is located almost on the lake shore, were used. The analysis of meteorological indicators of 2019 is carried out separately. The choice of such time segments is caused both by existence of continuous series of data for this time, and by representativeness of the corresponding periods.

The table 1 presents a summary of the calculation of average monthly and annual values of air temperature, relative humidity, precipitation, evaporation and humidity for the two studied time periods.

According to the statistical analysis, over the last 19 years a significant increase in evaporation has been observed at the Svityaz meteorological station: both calculation methods have shown the actual average annual value of evaporation in the range of 635-650.6 mm / year. At the same time, the average annual precipitation for the same period was 574.6 mm. The growth of the average annual precipitation occurred within 6.5%, while the growth of the average annual

evaporation rate ranged from 15% (calculated according to the method of L. Turc) to 25% (calculated according to the method of N. Ivanov). It seems to us the calculation according to the method of N. Ivanov is more accurate, since it takes into account a wider range of climatic parameters and has repeatedly tested in temperate-continental climate (Xu, Singh, 2001). The Fig.5 clearly shows the current trends in recent decades, the growth of evaporation rate and decrease in humidity coefficient, especially in summer, compared to the period of 1970-1988.

Analysis of the dynamics of evaporation by months of the year shows that a particularly progressive growth of this indicator is observed in the warm period. This obviously correlates with the fact that evaporation is directly proportional to the temperature of air and water. If in November-March the evaporation for the period of 1970-1988 and of 2000-2018 is almost the same, then in April-October the average monthly increase in evaporation is from 20 to 50% in the period of 2000-2018 (compared to the period 1970-1988).

Comparison of average monthly values at the Svityaz meteorological station indicates that the average monthly evaporation for the period 2000-2018 consistently exceeds the average monthly precipitation by 20-30% from April to September, and in August the indicator can reach 50%.

Table 1. Average monthly values of climatic indicators in the Svityaz meteorological station (comparison of 2 periods, 1970-1988 and 2000-2018)

Month of the year	Air temperature, T, °C		Relevant Humidity of air, F, %		Precipitation amount, R, mm		Evaporation, W, mm (acc. to L. Turc)		Evaporation, W, mm (acc. to N.M. Ivanov)		Humidification coefficient	
	1970-1988	2000-2018	1970-1988	2000-2018	1970-1988	2000-2018	1970-1988	2000-2018	1970-1988	2000-2018	1970-1988	2000-2018
January	-3.7	-2.7	82	83	32.5	34.2	15.1	19.3	14.7	15.2	2.21	2.25
February	-3.6	-2.1	81	80	24.5	34.7	15.3	20.6	15.7	18.9	1.56	1.84
March	1.8	2.4	79	76	32.2	35.5	26.7	30.1	27.1	32.4	1.19	1.09
April	6.2	9.5	74	69	30.2	38.8	36.0	45.2	45.6	66.4	0.66	0.58
May	14.5	14.8	79	70	51.3	64.1	65.9	69.3	58.9	85.5	0.87	0.75
June	16.8	17.7	77	71	74.9	75.6	77.7	85.0	72.3	95.2	1.04	0.79
July	17.9	20.3	79	72	83.9	82.6	84.2	102.1	69.6	103.4	1.2	0.80
August	17.4	19.3	78	72	54.0	47.9	80.1	95.2	71.2	98.9	0.76	0.48
September	13.3	13.9	81	78	51.7	45.7	60.5	65.1	50.2	59.9	1.03	0.76
October	7.6	8.4	84	81	35.5	40.3	41.7	45.0	30.6	38.2	1.16	1.05
November	3.1	4.2	85	86	31.3	35.6	24.6	34.1	21.3	21.5	1.47	1.66
December	-1.8	-0.5	85	86	36.4	39.6	18.2	23.9	14.5	15.1	2.51	2.62
Average per year (or total)	7.4	8.8	80.3	77.0	538.4	574.6	546.0	635.0	491.7	650.6	1.09	0.88

We will separately analyze the meteorological indicators of 2019 at the Svityaz meteorological station, because that year the area of the lake’s water mirror has rapidly decreased. 2019 appeared quite arid, for 12 months the precipitation was 12% (-70 mm) less than the average value for the period 2000-2018, in warm period the deviation of the precipitation amount from the average is 15% (-65 mm). At the same time, there was further increase in average monthly air temperatures. As a result, for the first time during the period of instrumental observations, the average

annual air temperature exceeded the mark of 10 ° C (+10,4 ° C). Accordingly, evaporation processes intensified: the deviation is positive for 9 months out of 12, for almost the entire warm period of the year (except May). The total increase in evaporation for 12 months of 2019 was 74.5 mm (+ 11.5%) compared to the average value for 2000-2018, while the increase in evaporation in the warm period of 2019 was 71.5 mm (+12 %), i.e. evaporation exceeded the average values for the last 20 years by 10-12%. Such an increase in the expenditure part of the water balance together

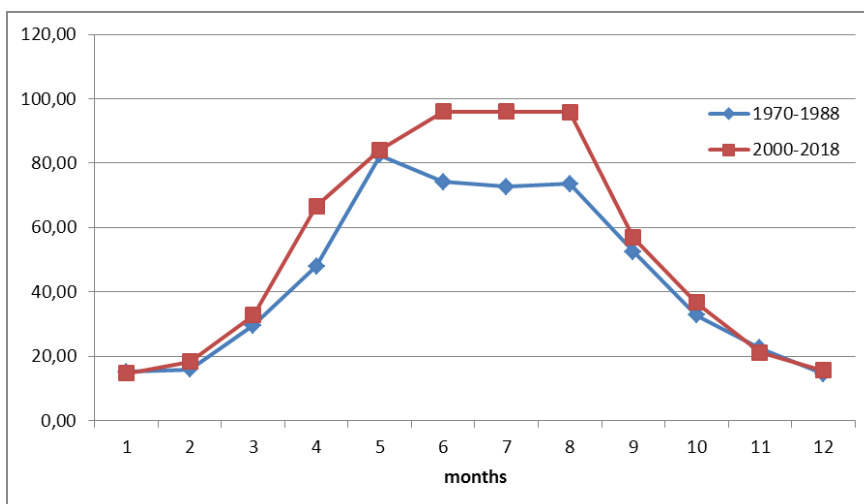


Fig. 5. Average monthly values of evaporation at the Svityaz meteorological station for long-term periods

with a decrease in the amount of precipitation could give a total decrease in the water level of up to 21-30 cm. Abnormally high values were also recorded for groundwater evaporation – in some wells along with lateral runoff these values reached 740 mm (and 980 mm in the previous, 2018 year) (Yatsyuk et al., 2019), which also had a very negative impact on the water content of the lake.

We would like to emphasize, that according to the analysis of the temperature indicators for 17 meteorological stations in 2019, a similar increase in average temperatures was recorded throughout the region, but there are some differences in the integrated humidity indicators. According to the humidity coefficient, 8 from 17 stations in 2019 had values slightly higher than 1.0, and 9 stations – less than 1.0, which indicates a lack of humidity (in particular, Terespil 0.74, Lyubeshiv 0.85, Pruzhany and Wlodava 0.91, Lutsk, Volodymyr-Volynskyi, Svityaz – from 0.94 to 0.97). Similar distribution is attributed to the values of the hydrothermal coefficient HTC (Fig. 6).

As it can be seen, the lowest values of HTC (0.9-0.95) are typical for the Upper Pripyat lowland and the Shatsk lakes. HTC less than 1 are typical for the slightly arid climate.

Correlation analysis of water levels in Svityaz with separate series of long-term climatic data. The paper (Alokhina et al., 2018) indicated that the most

significant correlation (-0.5) was found with the TSI (total solar radiation), which, apparently, indirectly affects most other meteorological indicators.

The pairwise correlation coefficients between the water level in the lake and such meteorological indicators as evaporation, precipitation, humidification coefficient, hydrothermal coefficient (HTC) were determined in our study. For the entire period from 1970 to 2018, the average values of correlation coefficients are small: between lake water levels and evaporation 0.21, between lake water levels and annual precipitation 0.18; between the water levels of the lake and the humidity coefficients 0.21-0.25. Nevertheless, if the calculation is carried out with an offset of 1 year (i.e. the water level of the current year is compared with the climatic indicator of the previous year), the correlation with precipitation and hydrothermal coefficient increases to 0.46-0.49.

However, significant changes in the correlation between the mentioned parameters have been revealed in the last 2 decades. Since 2000, the correlation between lake water levels and evaporation is -0.49, and the correlation with the hydrothermal coefficient is 0.66. Instead, during this period, in fact, the relationship with the humidity coefficient (according to N. Ivanov), remains unchanged and the correlation with the annual amount of precipitation decreases sharply (to less than 0.1 indicator, while in 1970-1988

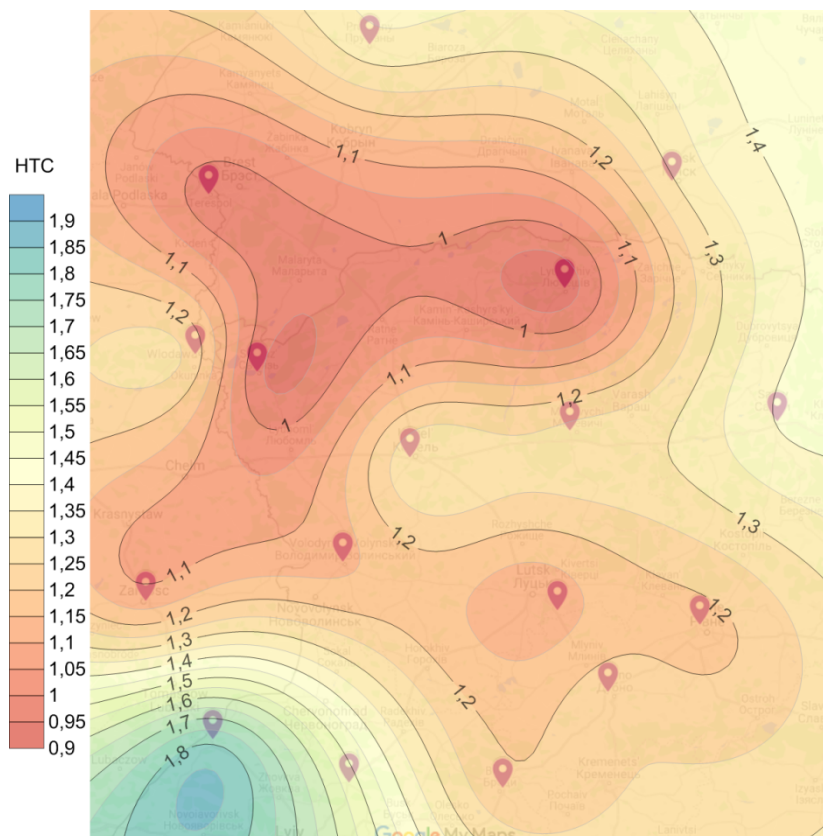


Fig. 6. Distribution of HTC (hydrothermal coefficient) in the region in 2019.

it was up to 0.5). Thus, among the considered parameters the HTC coefficient turned out to be the most significant.

It follows that water inflow to the lake is less and less determined only by the annual amount of precipitation, their relationship with evaporation in the warm season is more important. In The Fig. 7 shows graphs of changes in lake water levels and hydrothermal coefficient of Selyaninov for the corresponding period.

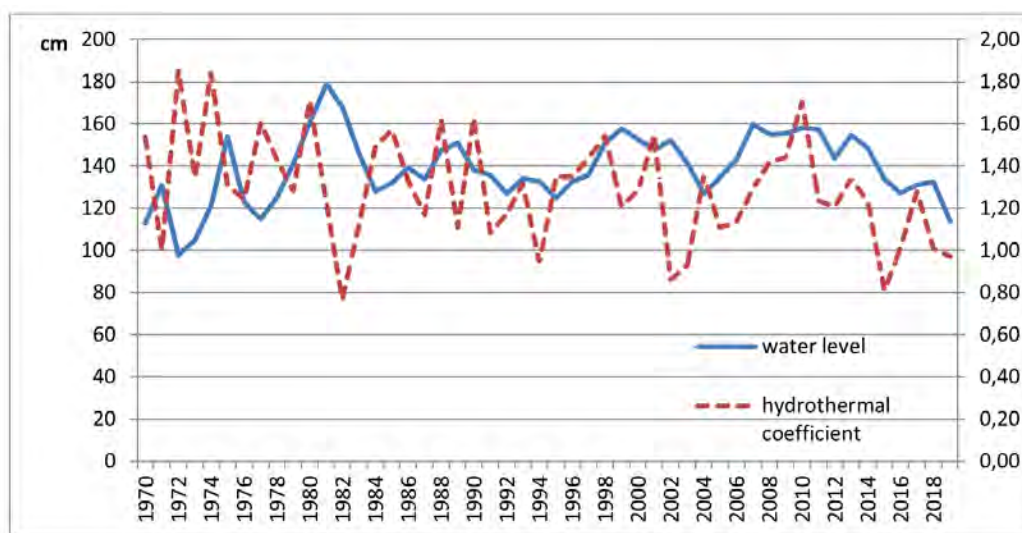


Fig. 7. Long-term dynamics of the water level of the Lake Svityaz and the hydrothermal coefficient.

As we can see from the graphs, these curves have not been consistent for a long time, but since 2005 their course has been synchronized. The correlation coefficient between these indicators for 2005-2018 is 0.74. That means, the water level in the lake becomes increasingly dependent on the dynamics of climatic condition, which, in particular, means a decrease in the sustainability of the hydro ecosystem. Most likely, this stability was previously provided by significant groundwater and underground water supply. Now with groundwater and underground water levels falling down, their stabilizing role for the Lake Svityaz is also declining.

Conclusions.

1. The water level of Lake Svityaz in 2019 reached the minimal values for almost 50 years of observations. The field surveys conducted in October 2019 showed that the shoreline receded in some areas of the lake at a distance of up to 90 m. The analysis of multispectral space images according to the NDWI index show a reduction in the area of the water mirror by 8-10%.

2. Comparison of climatic indicators for the period of 1970-1988 and of 2000-2018 showed that:

- the average annual precipitation indicator did not decrease either at the Svityaz meteorological sta-

tion or in the region as a whole. At the same time, the number of days with precipitation decreased, especially in the warm period. In some years, the annual precipitation amount is significantly lower than the climatic norm. In 2019 most meteorological stations in the region recorded a negative deviation of the annual amount of precipitation;

- the average annual evaporation rate for Svityaz meteorological station increased by 16-32% (accord-

ing to calculations by various methods), the largest increase is recorded in the period from April to October. Indicators for other weather stations reflect the same trend.

- integrated indicators of the ratio of precipitation and evaporation in the region have mainly also decreased, but they have significant spatial differences. For Svityaz, the average annual moisture content decreased by almost 20%, the hydrothermal coefficient (according to Selyaninov) – by 9%. The lowest indicators in the region in 2019 were recorded in the northern districts of Volyn region (including the territory of SNNP) and adjacent districts of Belarus.

3. The dynamics of the water level in the lake for the period of 1970-1988 did not show strong dependencies on the annual meteorological indicators. Since 2000, and especially clearly since 2005, the correlation of water levels with the hydrothermal coefficient has been significantly increasing. This is caused, firstly, by growing effect of increasing average annual and monthly air temperatures and increasing evaporation rates in the warm season; secondly, by reducing of the integrated ecological sustainability of natural wetlands and forest landscapes in the region, significantly changed over the past 50 years under the influence of anthropogenic activity; and thirdly, by the

decline in groundwater and underground water levels, which has occurred gradually in recent years, both under the influence of the global warming and a number of man-made factors.

The “butterfly effect” is well known: even minor events in the past can have a significant impact on the future. Large-scale drainage and reclamation works in the second half of the twentieth century in the area of Ukrainian Polissya, deforestation and other forms of economic development are likely to have reduced the sustainability of natural ecosystems, and they have been found to be very vulnerable to recent global climate change.

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