Limnol. Rev. (2020) 20, 1: 3-11
DOI 10.2478/limre-2020-0001

Spectral–time analysis of cycle fluctuations in lake water levels in Belarus and Poland

Alexander A. Volchak[1], Ivan Kirvel[2], Adam Choiński[3,*], Sergey I. Parfomuk[1], Pavel Kirvel[4], S. Sidak[1]

[1] Brest State Technical University, Moskovskaya, 267, 224017 Brest, Republic of Belarus, e-mail: volchak@tut.by (A.A.V.); parfom@mail.ru (S.I.P.)
[2] Pomeranian University in Słupsk, Partyzantow 27, Department of Environmental Analysis, 76-200 Slupsk, Poland, e-mail: ivan.kirvel@apsl.edu.pl
[3] Department of Hydrology and Water Management, Adam Mickiewicz University, Krygowskiego 10, 61-680 Poznań, Poland, e-mail: choinski@amu.edu.pl (* corresponding author)
[4] Belarusian State University of Informatics and Radioelectronics, Browki 6, 220013 Minsk, Belarus, e-mail: pavelkirviel@yandex.by

Abstract: On the basis of the mean volume of annual water levels of 25 lakes (9 Belarusian and 16 Polish) over a period of 55 years (1956-2010) spectral time analysis of water fluctuations has been executed. The choice of the lakes was based on two factors, i.e. the continuous period of observation and insignificant anthropogenic influence. The complex analysis of water level fluctuation cycles has shown that for Belarus the cycles observed most often were 3, 5 and 10-year cycles. Polish lakes also have three cycles, but in the majority of them they amount to 5 and 10-years. It can be assumed that this is impacted by the continental climate growing to the east. Most probably it is one of the key factors defining the diversity of water fluctuations in all the analyzed lakes.

Key words: Belarusian and Polish lakes, water level, fluctuations, spectral-time analysis

Introduction

The periods of cooling and warming, dry and wet periods alternate in time and the general state of water resources and their quality do not statistically change. At the same time, the study of water resources and impact of climate change and anthropogenic activities on runoff is an urgent worldwide task (Badrzadeh et al. 2015; Doycheva et al. 2017; Eum et al. 2016; Falter et al. 2015; Yang et al. 2019).

More than one method has been widely used to analyze and predict water resources, especially in lake level forecasting. The Soil and Water Assessment Tool (SWAT) can simulate water, sediment, and nutrient yield in a watershed by using input data from GIS and applying different agricultural practices, climate change, and land use (Bosch et al. 2011; Makarewicz et al. 2014; Schiefer et al. 2013). Nowadays, the use of artificial intelligence methods as an approach to solving complex nonlinear problems and lake level forecasting has increased (Myronidis et al. 2012; Shafaei and Kisi 2016; Shaghaghi et al. 2017; Shiri et al. 2016; Wang et al. 2009; Zaji et al. 2018; Zeynoddin et al. 2018). Another method of lake level fluctuation analysis and prediction is using data from long-term studies of ice phenology (Apsite et al. 2014; Jensen et al. 2007; Kostecki 2013; Nõges and Nõges 2014).

The aim of the present study was to attempt to explain the regularity of the mean annual water levels in Belarusian and Polish lakes for future lake level forecasting. The area under analysis, i.e. Belarus and Poland has been quite well researched from the point of view of a widely understood hydrology. Yet, in reference to water fluctuation levels there are still many questions to be answered. Answering them should allow forecasts of water fluctuation changes in the future (Loginov et al. 2008; Kirvel et al. 2018; Volchek et al. 2013).

Although water reservoirs are shaped under climate and natural conditions, anthropogenic impact is becoming more and more significant and in many cases it can be compared to a natural process persisting in the water regime. With sufficient information on water levels from many years of observation it is possible, owing to current information available and data processing, to show changes in water levels in lakes in a different way to that of previous years (Choiński et al. 2016; Kirvel et al. 2016).

Research studies on dynamics, in this case water fluctuation levels in time, transformation of water regime and hydrological regionalization should aim at water level change prognosis in lakes in the future (Volchak and Kirvel 2013; Volchak and Parfomuk 2018).

Natural phenomena, water reservoirs included, can be accompanied by cycle characteristics in time. Non-linear dynamic model applications, together with a small number of parameters, allows for the possibility of examining the physical mechanisms of water cycle fluctuations for many years. One of the methods of defining the cycles is a spectral-time analysis (Loginov and Ikonnikov 2003).

Characteristics of the studied lakes

The input data comprised the water levels (mean annual) of 25 lakes (9 Belarusian and 16 Polish) under 55 years of continuous observation (1956-2010). It should be mentioned that in Poland there are 7000 lakes with an area of more than 1 ha. They occupy a total area of approximately 2800 km^2. Their total water volume amounts to approximately 20 km^3 (Choiński 2007). In Belarus there are approximately 10 thousand lakes with a total area of approximately 2000 km^2 and water resources of 7 km^3. The research of water level fluctuations was based on data of the state hydrological services of Belarus and Poland. Out of the 25 studied lakes, 3 are located in the Greater Poland-Kuyavian Lakeland, 4 in the Pomeranian Lakeland, 9 in the Masurian Lakeland, 7 in the Belarusian Lakeland, and 2 in Belarusian Polesie.

The selection of lakes was based on two criteria: data continuity and lack of significant anthropogenic impact. Nowadays, even if lakes with an unaffected hydrological regime can be selected, practically all basins are to a lower or higher degree subject to certain anthropogenic pressure. Therefore, the hydrological regime of the studied lakes is quasi-natural (Volchak et al. 2017).

Characteristics of lakes and morphometric parameters of their basins and catchments determining water level fluctuations are presented in Tables 1 and 2 (Mironienko 1966; Choiński 2006; Volchak et al. 2017). The maximum distance between the lakes from west to east amounts to 710 km – Lake Sławskie 16°01’ E and Lake Senno 29°42’ E, and from south to north to 360 km – Lake Sławskie 51°54’ N and Lake Osveiskoe 56°01’ N.

The maximum altitude of the water surface amounts to 163.7 m a.s.l. in the case of Lakes Naroch and Miastro, and minimum to 0.1 m a.s.l. – Lake Jamno. The water volume of the studied lakes varies from 6.4 hm^3 (Lake Biskupińskie) to 710.0 hm^3 (Lake Naroch), whereas the mean volume of the studied lakes amounts to 121.0 hm^3. The maximum water depth in the lakes ranges from 2.3 m (Lake Vygonoschanskoe) to 74.2 m (Lake Wigry). The mean maximum water depth for the lakes amounts to 21.9 m. The mean depth varies from 0.7 m in the case of Lake Chervonoe to 15.4 m for Lake Wigry.

The exposure (openness) index was calculated as the ratio of a lake’s surface area to its mean depth. It varied from 0.18 (Lake Biskupińskie) to 60.92 (Lake Chervonoe). The mean value amounts to 8.93. The depth index was calculated as the ratio of a lake’s mean depth to its maximum depth. It varied from 0.18 (Lake Rajgrodzkie) to 0.57 (Lake Lukomskoe). The mean value amounts to 0.34.

The Ohle coefficient for the lakes was calculated as the ratio of a lake’s catchment area to the lake’s surface area. It varied from 2.35 (Lake Vygonoschanskoe) to 254.55 (Lake Ełckie), averaging 63.19.

The surface areas of the lake catchments are largely varied. The smallest is that of Lake Studzieniczne – 24.4 km^2, and the largest of Lake Roś – 3022 km^2. The mean value amounts to 539 km^2.

The types of the lake basins are particularly post-glacial, but also coastal and marshy basins occur. In terms of character of water exchange, the lakes are weakly flow-through or outflow lakes, and in terms of trophic status – mesotrophic, eutrophic, and dystrophic.

Table 1. Location and morphometric parameters of the studied lakes

Lake	Altitude	Coordinates [dd.mm]		Area	Volume	Depth [m]		Exposure	Depth Index	Ohle Ratio
	[m a.s.l.]	Lat.	Long.	[km²]	[hm³]	max	mean			
Białe	122.2	53°52’	23°03’	4.53	41.72	30.0	9.2	0.49	0.29	8.10
Charzykowskie	120.0	53°47’	17°30’	13.36	134.5	30.5	10.1	1.33	0.32	68.4
Drwęckie	94.8	53°43’	19°53’	7.80	50.14	22.0	6.4	1.21	0.26	130.1
Ełckie	119.9	53°49’	22°21’	3.85	57.42	55.8	14.9	0.26	0.27	254.6
Jeziorak	99.2	53°42’	19°37’	31.53	141.6	12.9	4.5	7.02	0.32	9.99
Nidzkie	117.9	53°36’	21°36’	17.50	113.9	23.7	6.5	2.69	0.26	9.83
Ostrzyckie	160.1	54°15’	18°06’	2.96	20.79	21.0	7.0	0.42	0.32	67.9
Rajgrodzkie	118.4-118.6	53°46’	22°38’	14.99	142.6	52.0	9.5	1.58	0.18	49.4
Roś	114.4	53°40’	21°54’	18.09	152.9	31.8	8.5	2.14	0.25	167.1
Studzieniczne	123.4	53°52’	23°07’	2.44	22.07	30.5	9.1	0.27	0.28	10.0
Wigry	131.9	54°03’	23°04’	21.15	336.7	74.2	15.4	1.33	0.21	23.0
Biskupińskie	78.6	52°48’	17°45’	1.07	6.40	13.7	6.0	0.18	0.40	73.7
Gopło	76.8-77.2	52°36’	18°22’	21.22	78.50	16.6	3.7	5.74	0.22	66.4
Jamno	0.1	54°17’	16°08’	22.32	31.53	3.9	1.4	15.8	0.36	22.5
Łebsko	0.2	54°43’	17°25’	70.20	117.5	6.3	1.7	41.9	0.25	25.7
Sławskie	56.9	51°54’	16°01’	8.23	42.66	12.3	5.2	1.59	0.42	24.4
Senno	142.1	54°49’	29°42’	3.13	26.83	31.5	8.6	0.37	0.27	21.7
Lukomskoe	163.5	54°39’	29°06’	37.71	249.0	11.5	6.6	5.71	0.57	4.75
NeschERDO	147.0	55°57’	29°03’	24.62	84.72	8.1	3.4	7.15	0.42	5.81
Osveiskoe	128.4	56°01’	28°07’	52.80	104.0	7.5	2.0	26.8	0.27	3.90
Driviaty	129.5	55°38’	27°01’	36.14	223.5	12.0	6.2	5.84	0.51	11.7
Miastro	163.7	54°52’	26°51’	13.10	70.10	11.3	5.4	2.45	0.48	9.16
Naroch	163.7	54°53’	26°41’	79.62	710.0	24.8	8.9	8.93	0.36	2.50
Vygonoschanskoe	151.0	52°39’	25°56’	26.00	32.10	2.3	1.2	21.1	0.52	2.35
Chervonoe	134.5	52°23’	27°56’	40.82	27.35	2.9	0.7	60.9	0.24	4.58

Methods

The analysis of the cycle fluctuations of water levels of the Belarusian and Polish lakes has been executed with the use of spectral-time analysis (STAN). The basis of the analysis is calculating the variance specters in comprised time distances (Loginov and Ikonnikov 2003).

The variance spectrum consists in a number of amplitudes of harmonic components the frequencies of which are compiled on an ordinate axe of the STAN diagram, whereas on the abscissa axe they correspond to one half of time window. The spectrum amplitude is defined by the level of brightness of the background, the brighter, the bigger the amplitude. The introduced legend of the STAN diagrams shows the intensity of the fluctuations.

While constructing the STAN diagram the adopted time length of the window was 18 years that is 1/3 of the observation time span. Figure 1 shows STAN-diagrams of water levels for some of the analyzed Belarusian and Polish lakes for the period 1956-2010.

Results and discussion

Practically, for all the lakes there exist short-period cycles of 3, 5 and 10-years. For 9 analyzed lakes there is a characteristic 10-years cycle (5-years only for Lake Rajgrodzkie). 7 lakes belong to two cycles, the majority of which are 5 and 10-years.

Table 2. Primary characteristics of the studied lakes

Lake	Type of basin	Catchment area [km²]	Character of water exchange	Trophic status
Białe	channel	36.7	weakly flow-through	mesotrophic
Charzykowskie	channel	914	weakly flow-through	eutrophic
Drwęckie	channel complex	1015	weakly flow-through	eutrophic
Ełckie	channel complex	980	outflow	eutrophic
Jeziorak	channel complex	315	weakly flow-through	eutrophic
Nidzkie	channel complex	172	weakly flow-through	eutrophic
Ostrzyckie	channel complex	201	outflow	eutrophic
Rajgrodzkie	channel complex	740	weakly flow-through	mesotrophic
Roś	channel complex	3022	weakly flow-through	eutrophic
Studzieniczne	channel	24.4	weakly flow-through	mesotrophic
Wigry	channel complex	487	weakly flow-through	mesotrophic
Biskupińskie	channel	78.9	outflow	eutrophic
Gopło	channel complex	1408	outflow	eutrophic
Jamno	channel	503	weakly flow-through	eutrophic
Łebsko	channel	1801	weakly flow-through	eutrophic
Sławskie	channel	201	weakly flow-through	eutrophic
Senno	channel	67.9	outflow	mesotrophic
Lukomskoe	channel	179	outflow	eutrophic
Nescherdo	channel complex	143	outflow	eutrophic
Osveiskoe	moraine	206	outflow	eutrophic
Driviaty	moraine	423	outflow	eutrophic
Miastro	moraine	120	outflow	eutrophic
Naroch	moraine	199	outflow	mesotrophic
Vygonoschanskoe	marshy	61.1	outflow	eutrophic
Chervonoe	marshy	187	weakly flow-through	dystrophic

Cycles of 3 to 5-years have been separated for 4 lakes, whereas 3, 5 and 10-year cycles have been found for 4 Belarusian lakes. Only Sławskie Lake has 3 and 10 years cycle of water level fluctuation. The STAN analysis of the water level results has been compiled in Table 3.

The climate warming that has taking place, according to climatologists from 1986-1988, has impacted the water level cycles (Loginov and Volchek 2006). Since that time the characteristic presence of one 10-year cycle has concerned all the lakes. Only for Lake Roś does the cycle amounts to 5-year. Generally, it is accepted that 3 causes are responsible for cycles in nature. The majority of researchers claim that cycles result from geophysical-cosmic powers (Shnitnikov 1969) and secondly, they claim that cycles result from the fluctuations of the air-water systems (Sergin 1972) and, thirdly that such a process is incidental (Reznikovsky 1969).

While analyzing data in Table 1 one can notice that for the Belarusian lakes most cycles occurring simultaneously are 3, 5 and 10-years i.e. for lakes Driviaty, Lukomskoe, Miastro, Nescherdo. For Lake Senno 3 and 5-year cycles have been separated, for Lake Osveiskoe 5 and 10-years cycles. For the rest, however, with the largest areas (Vygonoschanskoe, Naroch, Chervonoe), only a 10-year fluctuation cycle has been determined.

For seven Polish lakes a 10-year water fluctuation cycle has been defined and in the case of

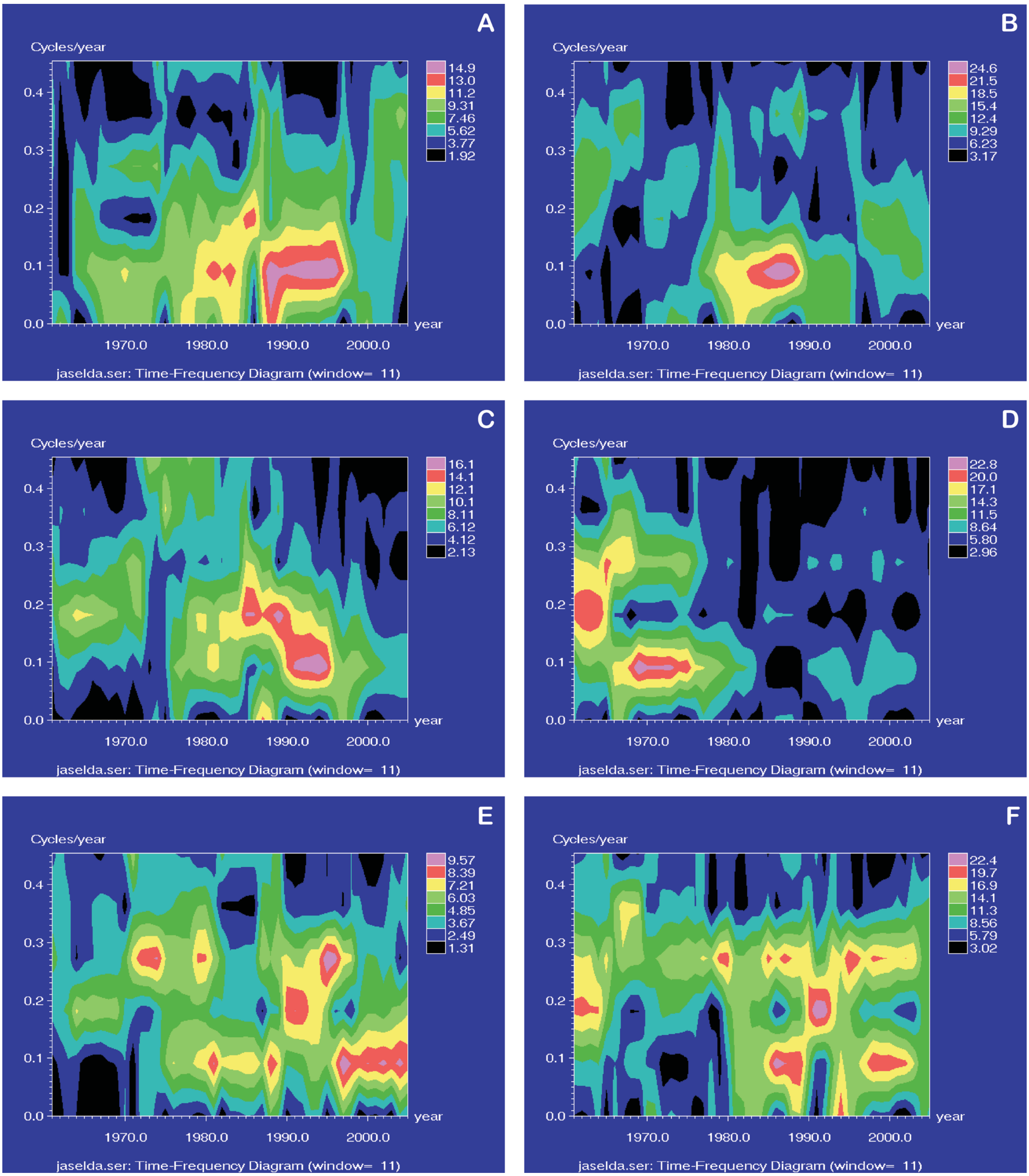

Fig. 1. STAN-diagrams of water levels for Belarusian and Polish lakes: A – Lake Ełckie, B – Lake Vygonoschanskoe, C – Lake Biskupińskie, D – Lake Osveiskoe, E – Lake Miastro, F – Lake Lukomskoe

Table 3. Cycles in time dimensions of lake water levels in Belarus and Poland

No*	Lake	Cycle lenght	Cycle period	No*	Lake	Cycle lenght	Cycle period
1.	Sławskie	3 10	1961-1965 1987-1989	14.	Białe	5 10	1965-1967 1961-1964
2.	Jamno	10	1988-1995	15.	Wigry	10	1969-1974
3.	Łebsko	3 5	1961-1969 1964-1967	16.	Studzieniczne	10	1990-1999
4.	Charzykowskie	5 10	1975-1984 2000-2003	17.	Vygonoschanskoe	10	1982-1989
5.	Biskupińskie	5 10	1985-1990 1991-1995	18.	Naroch	10	1997-2005
6.	Ostrzyckie	10	1967-1977	19.	Miastro	3 5 10	1972-1980 1990-1996 1997-2005
7.	Gopło	5 10	1984-1988 1989-1995	20.	Driviaty	3 5 10	1966-1969 1961-1965 1987-1989
8.	Jeziorak	5 10	1984-1987 1988-1991	21.	Chervonoe	10	1975-1986
9.	Drwęckie	5 10	1980-1985 1986-2001	22.	Osveiskoe	5 10	1961-1965 1967-1975
10.	Nidzkie	10	1982-1990	23.	Nescherdo	3 5 10	1979-1998 1961-1964 1985-2002
11.	Roś	3 5	1967-1980 1986-1994	24.	Lukomskoe	3 5 10	1979-1999 1961-1964 1985-2003
12.	Ełckie	10	1987-1997	25.	Senno	3 5	1961-1965 1966-1971
13.	Rajgrodzkie	3 5	1961-1967	* numeration in accordance with that included in Fig. 2			

five lakes a 5 and 10-year cycle, in two lakes a 3 and 5-year cycle, for Lake Sławskie 3 and 10-years cycles and only for Lake Rajgrodzkie is there one 5-year long cycle. One can suspect that the continental climate extending in the eastern direction appears to be one of the key factors impacting the discovered regional fluctuations of water levels in lakes. Depending on the number of short time cycles, the lakes have been divided into 3 groups (Table 4). The first and the biggest incorporates 12 lakes with 3, 5 and 10-year cycles, 9 lakes belong to the second group of 10-year cycles and the third incorporates only 4 lakes with a 3 and 5-years cycle.

In Figure 2 the cycle differentiation of time divisions in the areas of Belarus and Poland has been shown.

The most extensive area has been defined for the second group i.e. a 10-year cycle fluctuation. It covers the area of Lake Jamno in the west to Lake Chervonoe in the east. The typical representatives of the first group are STAN diagrams of lakes: Driviaty, Miastro and Lukomskoe. This statement overlaps with that referring to the groups of lakes separated earlier according to spectral analysis (Volchak et al. 2017). The smallest area is covered by 3 enclaves comprising 4 lakes with 3 and 5-year cycles. One can assume that it has been impacted by local factors, surely not that of climate. The data of different characteristics of analyzed lakes (in Table 1 and Table 2) do not inhibit the common features qualifying for fluctuations in this sphere. In the case of Lake Łebsko some influence may be exerted by the

Table 4. Group divisions according to the character of the water level spectrum

No*	Lake	Group	No*	Lake	Group
1.	Sławskie	1	14.	Białe	1
2.	Jamno	2	15.	Wigry	2
3.	Łebsko	3	16.	Studzieniczne	2
4.	Charzykowskie	1	17.	Vygonoschanskoe	2
5.	Biskupińskie	1	18.	Naroch	2
6.	Ostrzyckie	2	19.	Miastro	1
7.	Gopło	1	20.	Driviaty	1
8.	Jeziorak	1	21.	Chervonoe	2
9.	Drwęckie	1	22.	Osveiskoe	1
10.	Nidzkie	2	23.	Nescherdo	1
11.	Roś	3	24.	Lukomskoe	1
12.	Ełckie	2	25.	Senno	3
13.	Rajgrodzkie	3	* numeration in accordance with that included in Fig. 2		

Group 1 – 3, 5 and 10-years cycles, Group 2 – 10-years cycles, Group 3 – 3 and 5-years cycles

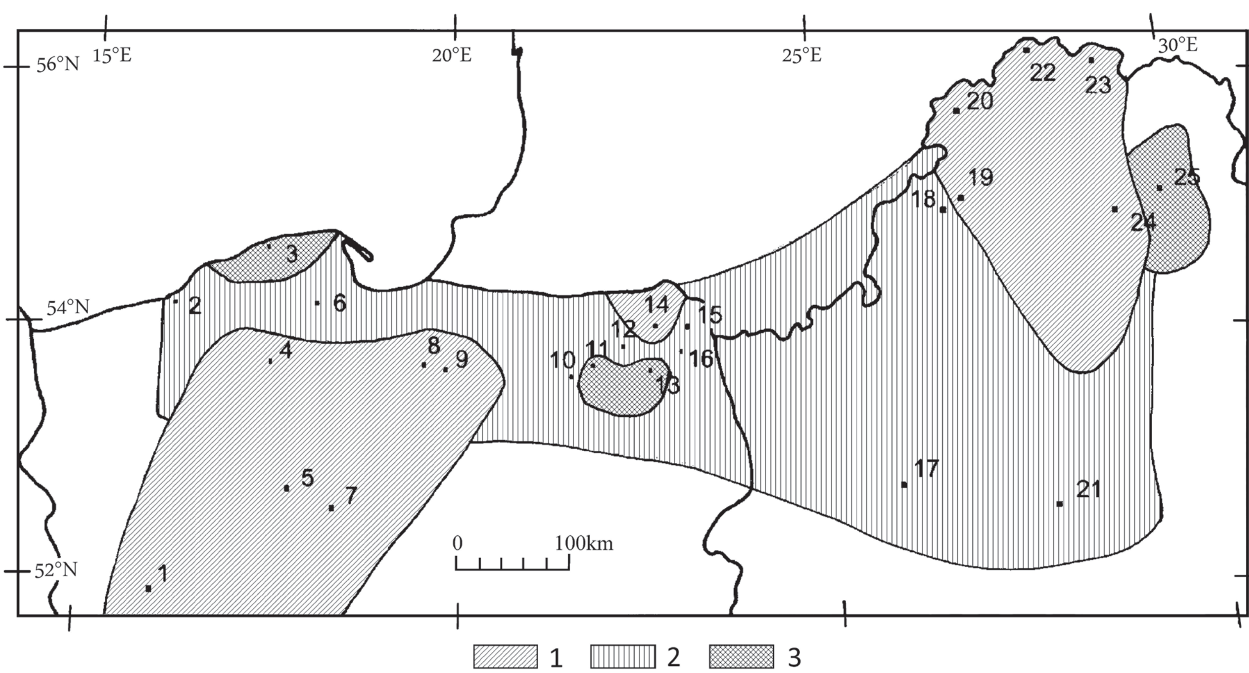

Fig. 2. Cycle differentiation of time divisions in the areas of Belarus and Poland: Group 1 – 3, 5 and 10-year cycles, Group 2 – 10-year cycles, Group 3 – 3 and 5-year cycles

direct impact of the Baltic Sea. In the case of 3 others it might be due to some local factors of similar underground feeding, which constitute the rate of exchange and water balance in the long term. The third division, consisting of the biggest group of lakes is made up of 2 groups of large area lakes – 6 in the west and 5 lakes in the east as well as one enclave (Lake Białe) in the central part of the analyzed area. In this case analysis of the lake characteristics also failed to give a positive result in defining common traits impacting the analyzed cycle. Defining the above divisions, that is 3, 5 and 10-years, can have a regional cycle character.

Conclusion

Cycle fluctuations in the analyzed area have an extra-regional character and the greatest impactful factor can be the continental climate. Regional factors can modify the pattern as well and also those of a small range of activity, mainly local ones. Defining precisely which factors impact the cycles the most is currently very difficult. In the future this could be achieved by defining water balance in analyzed lakes. The presented results can be used as an initial data for level prediction for the Belarusian and Polish lakes.

References

Apsite E., Elferts D., Zubanics A., Latkovska I., 2014, Long-term changes in hydrological regime of the lakes in Latvia, Hydrol. Res. 45(3): 308–321.

Badrzadeh H., Sarukkalige P.R., Jayawardena A.W., 2015, Hourly runoff forecasting for flood risk management: Application of various computational intelligence models, J. Hydrol. 529: 1633–1643.

Bosch N.S, Allan J.D., Dolan D.M., Han H., Richards R.P, 2011, Application of the soil and water assessment tool for six watersheds of Lake Erie: model parameterization and calibration, J. Great Lakes Res. 37(2): 263–271.

Choiński A., 2006, Katalog jezior Polski (Catalog of Polish lakes), Wydaw. Nauk. UAM, Poznań, 599 pp.

Choiński A., 2007, Limnologia fizyczna Polski (Physical Limnology of Poland), Wydaw. Nauk. UAM, Poznań, 547 pp.

Choiński A., Ptak M., Ławniczak A., 2016, Changes in water resources of Polish lakes as influenced by natural and anthropogenic factors, Pol. J. Environ. Stud. 25(5):1883–1890.

Doycheva K., Horn G., Koch C., Schumann A., König M., 2017, Assessment and weighting of meteorological ensemble forecast members based on supervised machine learning with application to runoff simulations and flood warning, Adv. Eng. Inform. 33: 427–439.

Eum H.-I., Dibike Y., Prowse T., 2016, Comparative evaluation of the effects of climate and land-cover changes on hydrologic responses of the Muskeg River, Alberta, Canada, J. Hydrol. Reg. Stud. 8: 198–221.

Falter D., Schroter K., Dung N.V., Vorogushyn S., Kreibich H., Hundecha Y., Apel H,. Merz B., 2015, Spatially coherent flood risk assessment based on long-term continuous simulations with a coupled model chain, J. Hydrol. 524: 1182–1193.

Jensen O., Benson B., Magnuson J., Card V., Futter M., Soranno P., Stewart K., 2007, Spatial analysis of ice phenology trends across the Laurentian Great Lakes region during a recent warming period, Limnol. Oceanogr. 52(5): 2013–2026.

Kirvel I., Volchak A., Parfomuk S., 2016, Modeling of the trajectory of the level fluctuations in Lake Naroch, Quaest. Geogr 35(1): 57–62.

Kirvel I., Volchak A., Parfomuk S., Kirvel I., Machambietova R., 2018, Analysis of water resources in Belarus in view of climate changes, Baltic Coastal Zone 22: 5–15.

Kostecki M., 2013, Differences in ice cover in the anthropogenic reservoir of Pławniowice in the years 1986-2012, Arch. Environ. Prot. 39(4): 3–14.

Loginov V., Ikonnikov V., 2003, Spektral’no-vremennoi analiz urovennogo rezhima ozer i kolebanii raskhodov vody krupnykh rek Belarusi (Spectral-time analysis of the level mode of the lakes and fluctuations of consumption of large rivers in Belarus), Prirodopolzovanie 9: 25–33 [in Russian].

Loginov V., Volchek V., 2006, Vodnyi balans rechnykh vodosborov Belarusi (Water balance of river basins of Belarus), Izd. Tonpik, Minsk,160 pp [in Russian].

Loginov V., Volchek V., Parfomuk S., 2008, Sovremennye izmenenia vodnykh resursov Pespubliki Belarus’ (Current changes of the water resources in the Republic of Belarus), Geografia i prirodnoye resursy 4: 149–154 [in Russian].

Makarewicz J., Lewis T., Rea E., Winslow M., Pettenski D., 2014, Using SWAT to determine reference nutrient conditions for small and large streams, J. Great Lakes Res. 41(1): 123–135.

Mironenko Z.I. (ed.), 1966, Resursy poverkhnostnykh vod SSSR. Belarusia i Verkhnee Podneprov’e (Surface water resources of the USSR. Belarus and Upper Dnieper), Gidrometizdat, Leningrad, 720 pp [in Russian].

Myronidis D., Stathis D., Ioannou K., Fotakis D., 2012, An integration of statistics temporal methods to track the effect of drought in a shallow Mediterranean Lake, Water Resour. Manag. 26(15): 4587–4605.

Nõges P., Nõges T., 2014, Weak trends in ice phenology of Estonian large lakes despite significant warming trends, Hydrobiologia 731(1): 5–18.

Reznikovsky A.Sh. (ed.), 1969, Vodnoenergeticheskie raschety metodom Monte-Karlo (Water-energy calculations by Monte Carlo method), Izd. Energia, Moskva, 303 pp [in Russian].

Schiefer E., Petticrew E., Immell R., Hassab M., Sonderegger D., 2013, Land use and climate change impacts on lake sedimentation rates in western Canada, Anthropocene 3: 61–71.

Sergin V., 1972, Kiberneticheskoe modelirovanie fizikogeograficheskikh system (Cybernetic modeling of physical-geographical systems), Izv. AN SSSR 1: 130–136 [in Russian].

Shafaei M., Kisi O., 2016, Lake level forecasting using wavelet-SVR, wavelet-ANFIS and wavelet-ARMA conjunction models, Water Resour. Manag. 30(1):

79–97.
Shaghaghi S., Bonakdari H., Gholami A., Ebtehaj I., Zeinolabedini M., 2017, Comparative analysis of GMDH neural network based on genetic algorithm and particle swarm optimization in stable channel design, Appl. Math. Comput. 313: 271–286.
Shiri J., Shamshirband S., Kisi O., Karimi S., Bateni S., Nezhad S., Hashemi A., 2016, Prediction of water-level in the Urmia Lake using the extreme learning machine approach, Water Resour. Manag. 30(14): 5217–5229.
Shnitnikov A., 1969, Vnutrivekovaia izmenchivost' komponentov obshchei uvlazhnennosti (Interdecadal variability of the components of the total moisture), Izd. Nauka, Leningrad 244 pp [in Russian].
Volchak A., Choiński A., Kirviel I., Parfomuk S., 2017, Spectral analysis of water level fluctuations in Belarusian and Polish lakes, Bull. Geogr. Phys. Geogr. Ser. 12:51–58.
Volchak A., Kirvel I., 2013, Lake water level variations in Belarus, Limnol. Rev. 13(2):115–126.
Volchak A., Parfomuk S., 2018, Assessment of changes in the Viliya River runoff in the territory of Belarus, Limnol. Rev. 18(4):185–196.
Volchek A., Kirvel I., Parfomuk S., Makhambetova R., 2013, The present-day condition of water resources in Belarus, Limnol. Rev. 13(4): 221–227.
Wang W., Chau K., Cheng C., Qiu L., 2009, A comparison of performance of several artificial intelligence methods for forecasting monthly discharge time series, J. Hydrol. 374(3-4): 294–306.
Yang Q., Zhang H., Wang G., Luo S., Chen D., Peng W., Shao J., 2019, Dynamic runoff simulation in a changing environment: A data stream approach, Environ. Modell. Softw. 112: 157–165.
Zaji A., Bonakdari H., Gharabaghi B., 2018, Reservoir water level forecasting using group method of data handling, Acta Geophys. 66(4): 717–730.
Zeynoddin M., Bonakdari H., Azari A., Ebtehaj I., Gharabaghi B., Madavar H., 2018, Novel hybrid linear stochastic with non-linear extreme learning machine methods for forecasting monthly rainfall a tropical climate, J. Environ. Manag. 222: 190–206.