Polish Journal of Environmental Studies Vol. 11, No. 4 (2002), 349-354

Seasonal and Multiannual Changes of Water Levels in Lakes of Northeastern Poland

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Received: 19 December, 2001
Accepted: 21 February, 2002

Abstract

Seasonal and multiannual hydrological changes were analysed in seven lakes of northeastern Poland on the basis of a 40-year series of everyday observations of the water level in the years 1961-2000. In the unmodified hydrological lakes occurs an unimodal cycle of variation in the water level with a spring maximum, whose magnitude depends on atmospheric precipitation in the form of snow in the period December-March. In lakes with hydrology transformed by man, seasonal water level changes depend on their economic function in the catchment. An anthropogenic increase in the amplitude of the varying water level in lakes is the factor intensifying the eutrophication of water bodies. Multiannual cycles of variation in lake levels take different spans of time depending on hydrological characters of the lakes.

Keywords: lake, hydrology, eutrophication, climate, NAO index.

Introduction

The character and magnitude of water supplies constitute the basic functional element of lake ecosystems. In contrast to rivers, lakes have a natural capability to retain waters from a basin, manifested by changes in water level. Lakes of the temperate zone have a periodical or constant character whose intensity varies in time and space. The magnitude of changes in filling the lake basin is proportional to the size of ratio between catchment area and lake capacity [1]. The pattern of seasonal changes in the level of lakes in northern Poland can vary, most frequently being uni- or bimodal [2]. Multiannual changes in the level of lakes above all depends on the situation of the lake in the catchment area, hydrologic and climatic conditions, and the character of water management [3, 4, 5, 6]

One of questions constantly discussed in hydrology is the problem of multiannual changes in water resources, strictly speaking the studies on the appearing directions and tendencies of the changes [5]. The determination of the direction of changes and the possible prognosis can be used as a basis for planning utilization of existing resources and also for projecting new hydrotechnical constructions. It is also significant in the aspect of possible future climatic and hydrologic changes [7].

Of almost 320 natural lakes lying in the Podlaskie province multiannual observations on water level have been conducted in only 10 objects. Regular observations started for the first time on Lake Serwy in 1889. The Institute of Meteorology and Water Management (IMWM) has a rich collection of data concerning lakes of seminatural conditions (Lakes Hancza, Wigry, and Rospuda) and also for many years used as retention reservoirs (Lake Rajgrodzkie). Hydrological observations also concern a part of lakes which since 1839 have been permanently included in the system of the Augustow Canal. On the basis of records collected in IMWM we have attempted to characterize the natural hydrological system of lakes in this part of Poland and to estimate the character of multiannual changes in the water level of lakes

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Table 1. Morphological parameters of the investigated lakes.

Lake	Catchment area [km²]	Area [ha]	Volume [Mm³]	Depth [m]		Hydrological transformations
				Max.	Mean	
Hańcza	41.4	311.4	120.4	108.5	38.7	none
Wigry	453.7	2118.3	336.7	73.0	15.8	none
Serwy	54.7	460.3	67.2	41.5	14.6	Artificial water lifting
Studzieniczne	31.6	250.1	22.1	30.5	8.7	Water level regulation – canal zone
Białe	43.0	476.6	41.7	30.0	8.7	Water level regulation – canal zone
Necko	913.6	400.0	40.6	25.0	10.1	Water level regulation – canal zone
Rajgrodzkie	1011.0	1503.2	142.6	52.0	9.4	Artificial water lifting

included in the system of water management. The determination of the specificity of these changes throughout a year and a multiannual period may be very useful in the interpretation of functional changes in lake ecosystems, particularly in estimating changes in water quality decisive in the utilization of water bodies for recreation.

Objects and Methods

The investigated lakes lying in northeastern Poland originated during the last Baltic glaciation. They represent the largest and the deepest lakes of the region (Table 1). Lake Serwy is the only outflow lake while the remaining lakes are flow-through. They are trough lakes of one main basin or of a few troughs forming a common water body. They all lie in the Baltic Sea catchment, two of them, Lakes Hancza and Wigry, lie in the catchment of the River Niemen, and the remaining ones in that of the River Vistula. From 1839 the Augustow Canal has connected the above-mentioned catchment basins. Three of the investigated lakes lie in its course, and Lake Serwy feeds waters to the highest sector of the canal in the zone of the natural watershed (Table 1). The forest cover of Lake Studziennicze and Lake Biale catchment reaches 90%, while the smallest 30% afforestation characterizes the basin of Lake Rajgrodzkie. In the basin of the River Niemen the water level of lakes is not artificially regulated.

The climatic conditions represent the pattern of weather typical of the moderate transition climate with observable continental influences [8]. The multiannual mean air temperature does not exceed 6°C, falling to -4.8°C in January. These are the lowest values in Poland apart from its montane part. Annual precipitation varies from 420-800 mm with the mean value of about 650 mm in the region. In the catchment of Lake Hancza only the annual precipitation is higher by 50-100 mm than in the remaining part of the region. The highest precipitation occurs from June to August and the smallest one in the winter period of December-February. Snowfall constitutes 20-25% of total annual precipitation on average.

Results of everyday records of water levels in seven lakes from the years 1961-2000 (chiefly the average monthly values) are used in the work. The calculation of the average monthly water levels was proceded by the reduction because the values from separate lakes varied within different ranges. In each data series concerning monthly averages a conventional constant (for each lake a different one) was subtracted. Its value was so established as to ensure value 1 for the minimum average monthly condition of each lake. The amplitude of water levels (Δh) throughout a month and the variability coefficient (V [%] = stand.deviation x 100/ average value) for hydrological years and for different months were accepted as measures of the water level variability. For each month Δh value was calculated as a difference between maximal and minimal water levels. Ah for November - April and May - October periods were calculated as a difference between monthly average water levels in these months. Analysis of the multiannual tendency in the monthly lake water level was based on the pattern of relative deviation (dH in %) calculated on the following way: dH [%] = H_m x 100 / H, were H_m is the monthly lake water level and H is an average multiannual lake water level in 1961-2000. Meteorological stations of the IMWM in Suwalki supplied climatic data, their fragments having been presented earlier [8]. We used the winter (means December - March) North Atlantic Oscillation (NAO), available at /www.cru.uea.ac.uk/. The NAO indicies express the difference of sea level pressures between Ponta Delgada/ Azores and Stykkisholmur/ Iceland, normalizated relative to the period 1864 to 1983. A positive winter NAO indicates predominating zonal circulation over the Atlantic leading to mild and rainy winters. The reverse situation is associated with low-pressure gradients over the Atlantic, usually bringing cold winters over Europe [14].

Results and Discussion

In the investigated lakes seasonal changes in water levels varied depending on the hydrosphere anthropogenic transformation degree. In lakes with a natural system of aquatic environment one distinct spring maximum occurs in the period April-May, being slightly manifested in Lakes Studzieniczne and Biale (Fig. 1). The smallest lake filling occurs in the period of early autumn (September-October), a minimum occurring

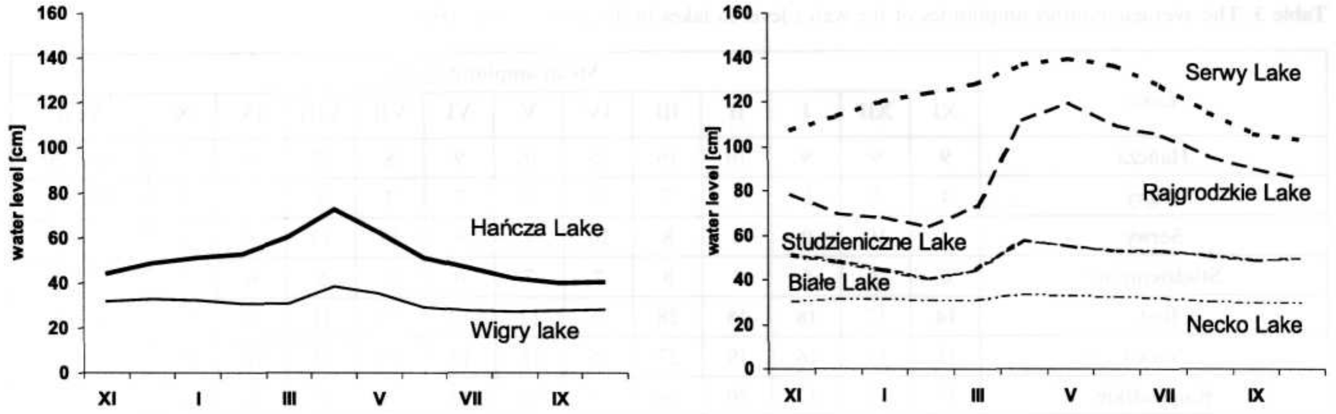


Fig. 1. Mean monthly lake water level, 1961-2000.

in February was found only in two lakes with an artificially regulated level.

The presented calculations show a decidedly greater variability in the water level of the investigated lakes than the values previously determined without the application of reduction [9,10]. In the period 1961-2000 the variability coefficients of monthly averages of levels in the different lakes were found in the interval 22-44% (Table 2). These values are several times greater than those obtained in earlier works and approximate to the variability coefficients of annual discharges in rivers of northeastern Poland [11].

In the deepest lakes of the non-regulated outflow and inflow the variability of water levels was similar in the separate months (Table 2). In the period April-July the water level in the lakes was more stable than in the remaining part of the year (Fig. 2), the average monthly amplitude not exceeding 10 cm (Table 3). The remaining analysed lakes are characterized by a greater variation of water level in different months owing to the regulation of their level. In the summer season the level of waters in the lakes of the Augustow Canal system was more uniform than in those of the non-regulated level. In the Canal it is the period of intensive navigation and constant sluicing. A different pattern of the variability coefficient throughout the year characterizes Lakes Serwy and Rajgrodzkie, which periodically play the role of retention reservoirs. In Lake Serwy the monthly amplitudes are smaller than in Lake Rajgrodzkie (Table 3). The highest variability of water levels in these lakes is observed in the autumn season (Fig. 2). In these lakes the variability of the water level is 2-3 times greater than in the remaining water bodies. This is effected by a greater accumulation of waters from surface runoff to compensate summer levels in rivers and in the canal.

In the analysed lakes anthropogenic increases in the variation of water levels can disturb the natural pattern of biogeochemical processes occurring in the littoral. In spring the intensified damming of lakes leads to the flooding of hydrogenous soils on flat shores, bringing about the leaching of nutrients and compounds of organic carbon dissolved in water [12]. An additional load effecting water eutrophication is supplied to the lakes. In summer in drained bottom sediments an intensified mineralization of organic matter occurs, leading to an increased supply of substances easily utilized by algae [13]. On account of the great amplitude of the water level variation in Lake Rajgrodzkie a gradual deterioration of

Table 2. Variability of average monthly water level in lakes in the period 1961-2000.

Lake	Monthly mean lake water level [cm]		Coefficient of variation [%]	Amplitude ± SD [cm]
	Mean	Maximum		
Hańcza	51	155	44.0	42 ± 19
Wigry	31	80	40.5	23 ± 9
Serwy	122	176	30.7	51 ± 21
Studzieniczne	32	43	27.9	11 ± 9
Białe	50	90	21.8	30 ± 11
Necko	50	91	21.5	29 ± 11
Rajgrodzkie	89	168	42.2	89 ± 26

Table 3. The average monthly amplitudes of the water level in lakes in the period 1961-2000.

Lake	Mean amplitude [cm]												
	XI	XII	I	II	III	IV	V	VI	VII	VIII	IX	X	Year
Hańcza	9	9	9	10	16	25	16	9	8	7	6	7	56 ± 20
Wigry	4	5	6	5	7	9	9	7	7	5	5	5	29 ± 11
Serwy	7	10	9	8	8	10	7	8	13	13	8	6	57 ± 22
Studzieniczne	6	7	6	8	8	7	7	6	6	5	6	7	17 ± 9
Białe	14	17	18	18	28	25	12	12	12	11	10	12	51 ± 19
Necko	15	17	16	19	27	25	15	13	13	13	16	15	48 ± 18
Rajgrodzkie	17	12	17	20	34	38	15	13	14	13	10	14	97 ± 29

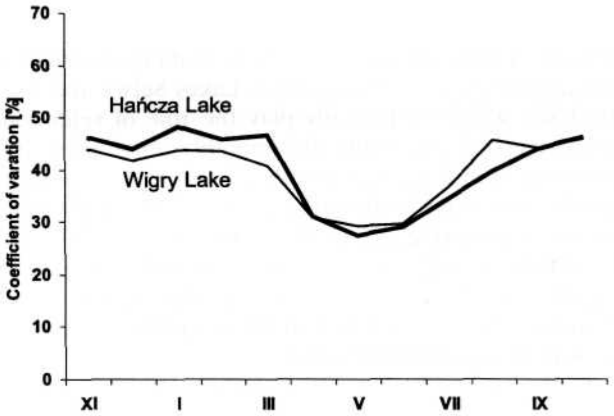
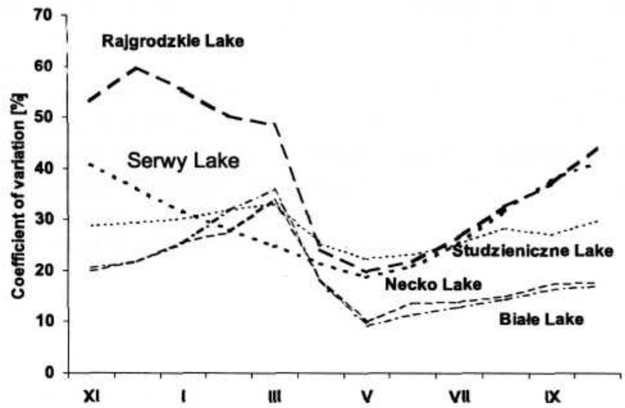


Fig. 2. Monthly coefficients of variation of lake water levels,



1961-2000.

water quality can be expected owing to the damming. Changes can also follow in the structure of hydrobionts. Long-term hydrological observations conducted on lakes and climate of the discussed region permit the determination of the chief factors that determine the variable level of the lakes of semi-natural environmental conditions. No statistically significant dependence was determined between total annual precipitation and the level of the lakes. Neither the variability of levels expressed by the amplitude of the annual conditions nor by the variability coefficient could be determined. However, a statistically significant dependence was found between total precipitation in the form of snow from December to March and the amplitude of levels in the period November-April and the annual amplitude (Fig. 4). Also, there occurs a distinct connection between total precipitation in the warm season of the year (May-October) and the amplitude of levels in the lakes (monthly averages) from this period (Fig. 5). As Figure 5 shows, in the warm part of the year in Lake Hancza an increase in the water level is observed when the precipitation exceeds 450 mm. In Lake Wigry this occurs with the precipitation of 350 mm. The above discussed relations distinctly show that the seasonal and annual changes in the water level of lakes with the semi-natural catchment in northeastern Poland chiefly depend on the magnitude of snowfall in the period December-March. In the investigated region (data from the meteorological stations of the IMWM at Suwałki) a distinct statistical dependence occurs between the share of snow in winter precipitation (December-March) and air temperature (in °C) and value of the North Atlantic Oscillation index (Fig. 6). It has been demonstrated earlier that the NAO influences the air

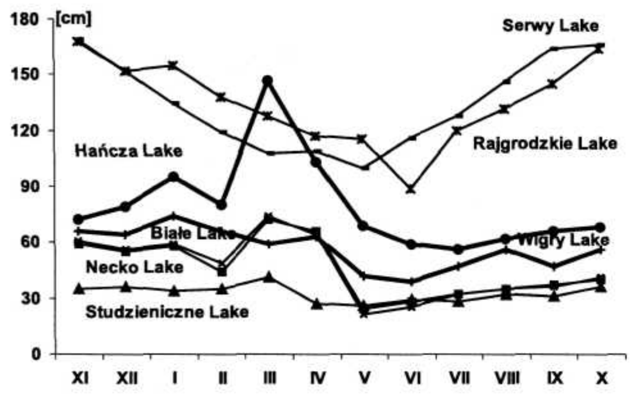


Fig. 3. Maximal monthly amplitudes of lake water levels, 1961-2000.

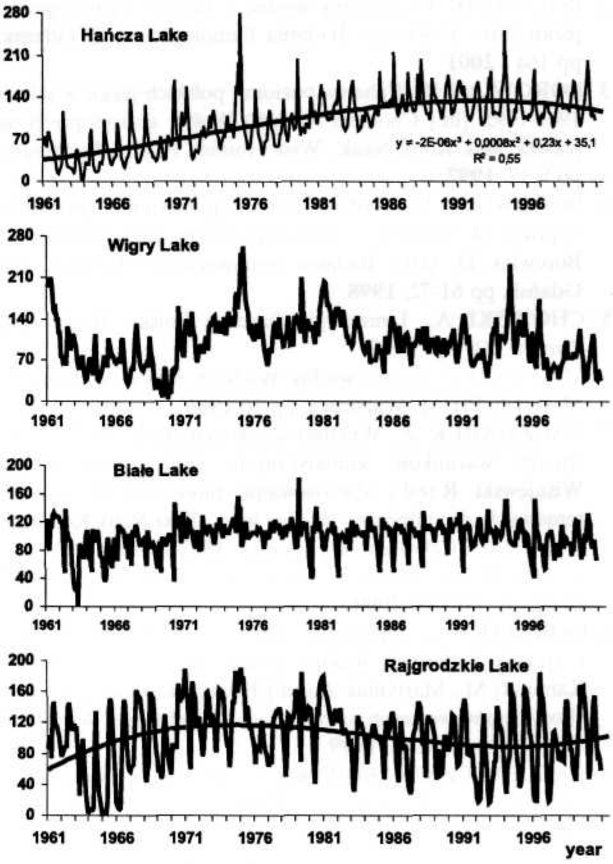


Fig. 4. Relative lake water levels (dH), 1961-2000 (see explanation in text).

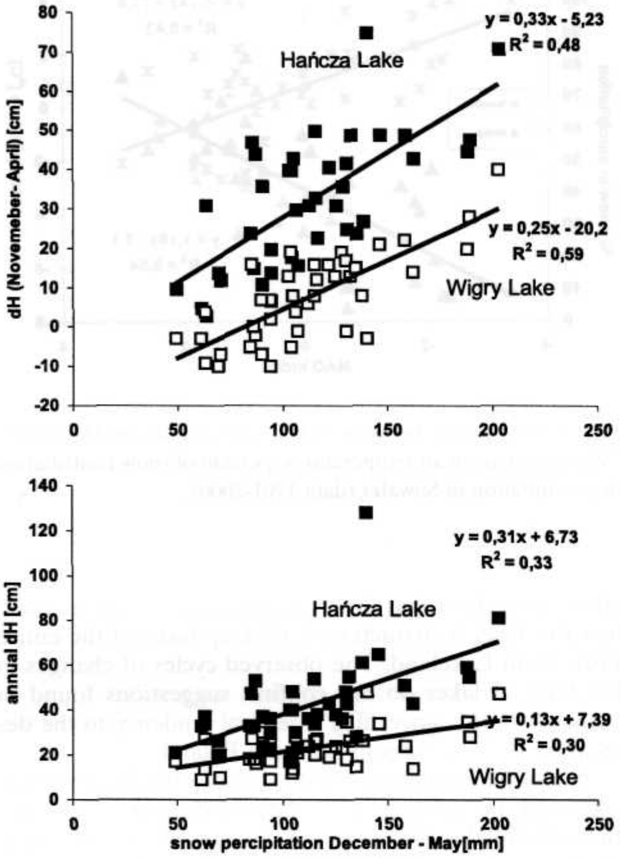


Fig. 5. Correlation between snow percipitation in period December-March and changes of mean monthly lake water level in November-April (A), and annual amplitude of mean monthly lake water level(B) (data from years 1961-2000).

and surface-water temperature [14] and ice conditions [15]. The NAO index illustrates the intensity of it. In conditions of the occurring climatic changes (the greenhouse effect), the value of the NAO index gradually increases in the winter season, as well as the western circulation of mild air masses [14, 8]. It can therefore be supposed that the spring stabilization of the water level and a reduced supply of nutrient-enriching substances to the lakes will be observed as a consequence of climatic changes in the lake district of northeastern Poland.

In the discussed 40-year period of records concerning the water level in the lakes of northeastern Poland cycling changes in the water level could have been observed. Lakes Rajgrodzkie and Wigry are characterized by the 21-22-year cycle of changes (Fig. 3) The periods of the cycles are identical in earlier papers [1, 6, 16]. For one of the cycles a maximum occurred in 1979 and 1980 and its end in 1991. In Lake Wigry the cycle of changes is more readable than in Lake Rajgrodzkie, where the natural cycle is masked by water management effects. In Lake Wigry the mean amplitude of variation in the cycle is small, in the order of 20-25 cm, while in Lake Rajgrodzkie it slightly exceeds 50 cm. In Lake Hancza in multiannual records the character of changes in the water level was different to a small degree. The cycle of these changes is longer because in the analysed period an ascending part from 1963 (a minimum) to 1990 (a maximum) was only documented, a small decrease occurring in the period 1991-2001. In Lake Hancza the length of one cycle of changes takes a decisively longer time than in Lakes Wigry or Rajgrodzkie, this also being suggested by the calculation of the theoretical time of water exchange. The preliminary estimate suggests 54-55 years as the length of one cycle in Lake Hancza. A similar length of the cycle and the period of variation were noted in Lake Tauragnas, the deepest lake of Lithuania [17]. The

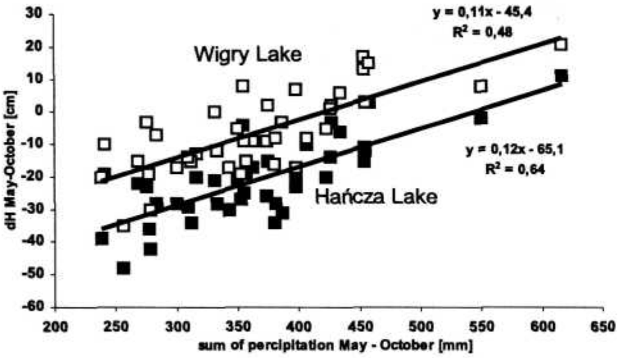


Fig. 6. Correlation between percipitation and lake water level in May-October (data 1961-2000).

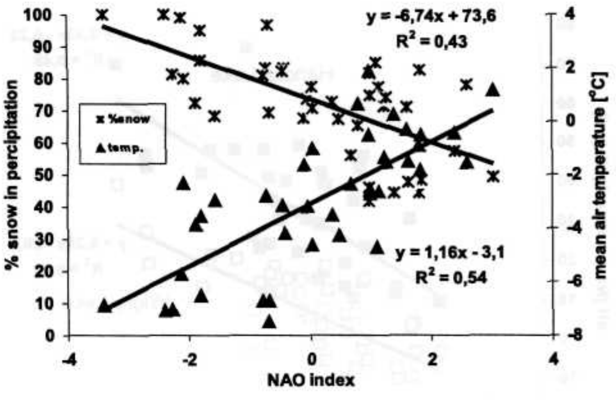


Fig. 7. Correlation between NAO index values in December--March and mean air temperatures, percent of snow contribution in precipitation in Suwalki (data 1961-2000).

above data show that this type of multiannual variability in water level is characteristic of deep lakes of the entire Lithuanian Lakeland. The observed cycles of changes in the level of lakes do not confirm suggestions found in earlier data [6] concerning a general tendency to the decreasing level of lakes in northern Poland.

No long-term changes really occur in the level of some lakes with the artificially regulated water level, e.g. Lake Biale included in the system of the Augustow Canal (Fig. 3) while in the neighbouring lakes the natural cycle of changes in their level has been completely leveled

The presented variability of water levels in the lakes of northeastern Poland in multiannual and annual cycles documents the current dynamics of water resources in lakes and different effects of human activity on the hydrological system of surface waters. Statistical analyses also show a close connection between the variable lake water level and the climatic traits of winter seasons. The presented anthropogenic varied changes in the level of lakes, sometimes neglected in limnological papers, are frequently significant in intensifying the nutrient-enrichment rate in lakes and in aquatic organism community transformation.

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