Lake and lake - river hydro ecosystems of Belarus: the present state, economic use and anthropogenic transformation

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Abstrakt: The study of the intensity of human impacts anthropogenic eutrophication of Belarussian lakes is andertaken. The average indexis of the main hydrobionts are interpreted as indicators of the lakes-trophic status.

Key words: lake and lake-river ecosystems, anthropogenic changes, Belarus.

The numerous lake reservoirs of Belarus belong to its most important economic natural resources. They make up the natural regulators of both underground and ground waters; they are also the source of potable and industrial water, as well as other mineral and organic resources. Lakes are increasingly important as the ecological coefficients of the state of the natural environment, as reclamation areas, as tourist sites, and objects of aesthetic education, where people learn respect for nature and become aware of the necessity of the protection of the natural environment.

The geographical location of lakes and the lake-river systems is based on some regularities. The lakes of the Belarussian Lake District belong to the drainage area of the rivers Dvina and Niemen; they are related to the activity of the last continental glacier, and they occupy the bowls of the dam type (Narotch, Osveja, Driviaty); rain pipe type (Dolgoje, Boldug, Leskovskoje); evorsion type (Rudakowo, Zhenno, Svetloje); complex type (Krivoje, Otolovo); and the thermokarst type. These lakes create most often groups consisting of 30–40 genetically and hydrologically interconnected water reservoirs and make up complex lake-river systems, of which the most important are Braclavski, Narotchanski, Utchatski and other. The majority of northern lake reservoirs lie on moraine hills and plains, where the surface of lakes is 5–10% of the surface of the administrative region (Utchatski, Braslavski).

The next zone of location of the lakes – the south of the country – Polesie stretches over the whole East European Lowland. The origin of these lakes is connected with the changes of climate and glacial-isostatic processes of the late Glacial and Holocene. Valleys of this zone are made up of shallow lakes-bays (Tchervonoye, Vygonosianskoye) and karstic depressions in calcareous chalk rocks (Vulka, Somino, Lukovo).

The lakes in Belarus are generally small and only 1,072 of them belong to relatively large ones, whose area is greater than 0.1 km^2. All the lakes are characterised by a complex and also coherent internal structure: the slowing down of the circulation of water, differentiation of the morphometric coefficients and the degree of stratification of water mass, the size of admission of isolated circulation of waters, etc. The location of a great number of lakes in agricultural areas with diverse surface features and significant absolute heights (155–170 m) and steep slopes of valleys also

plays an important role. It favours the activation of erosive processes and intensification of the transportation of clastic material and biogenic elements to the sedimentation pool.

Long-term investigations of Belarussian lakes by the Institute of Physical Geography and the Lake Studies Laboratory of the Belarussian University have resulted in a natural-genetic and natural-economic classification based on the trophic state of the lakes, which makes distinction of lake reservoirs with varying degrees of oligotrophic, mesotrophic, eutrophic as well as dystrophic properties.

In the natural state Belarussian lakes have a set of coefficients characteristic of the zone of mixed forests. The basis of the hydrochemical regime is made up of the hydrocarbon (HCO_3^-) and calcium (Ca^{2+}) ions. General mineralisation ranges between 220–230 mg/l with indifferent or slightly basic reaction of the environment (pH 7.8–8.0). The content of organic substances is from 4–5 to 10–12 mgO /l $ChZT_{Mn}$, and BZT_5 ranges from 2 to 4 mgO_2 /l.

By the mid 20th century, including the post-war years, the state of the lakes had been characterised by stability, high ability of the self-cleaning and the high quality of water. It was favoured to a considerable degree by the low level of industrial and agricultural development, low population density, considerable distances between large cities, poorly developed transportation network, etc. The scientific and technical development since the 1970s have exerted a negative impact on the ecology of the lakes. The lake reservoirs were used to a great degree as the source of an unlimited supply of water to cities, industrial plants and agriculture; as receivers of sewage from cities and farms, and also of drainage waters from land improvement systems; the reservoirs were transformed into cooling facilities for power stations. Consequently, ecological problems emerged as a result of such use of the lakes, including the anthropogenic eutrophication of lakes and the technogenic transformation of lake reservoirs and the drainage area. The first problem was caused by the spontaneous penetration of biogenic substances, rapid growth of biological production, decrease in the ability of the lakes related to self-cleaning and their ecological stability. The water reservoirs pass to the hypertrophic stage with signs of contamination. Phytoplankton biomass achieves 30–40 g/m^3, pH above 9, BZT_5 over 6–7 mgO_2/l. The most unstable deep lakes in this situation turned out to be deep, clean lakes with signs of oligotrophy (Leskovitchskoje, Kruglik), as well as shallow water reservoirs (Zabielskoje, Kowalki, Bolojso, Kagalnoje).

Technogenic transformations have also affected many lakes of Polesie as a result of land melioration, which caused a considerable lowering of water-table and a rapid decrease of drainage area, transformation of the lakes into reservoirs of potable and industrial water, embankment of lake bowls, loss of connections of lakes with rivers, etc. (Tchervonoye, Lukovo, Pogost).

On the basis of preference coefficients. the investigated lakes of Belarus (over 600) were divided into three groups according to degree of anthropogenic eutrophication (Tab. 1).

The average statistical coefficients of the groups of basic hydrobionts are proposed for the determination of the types of trophic lakes (number / biomass) (Tab. 2).

Table 1. Basic coefficients of anthropogenic eutrophication of Belarussian lakes

Coefficients (data from summer)	Anthropogenic eutrophication level		
	I	II	III
Transparence. M	3.0 – 5.0	1.0 – 3.0	Below 1.0
pH	do 8.5	8.5 – 8.7	Above 8.7
Chromatics (grad.)	Below 20	21 – 80	Above 80
$ChZT_{Mn}$. mgO/l	2.0 – 5.0	5.1 – 10.0	Above 10.0
BZT_5. mg/l	1.0 – 3.0	3.1 – 5.0	Above 5.0
PO_4^{3-} mgP/l	0.001 – 0.010	0.011 – 0.050	Above 0.050
Phytoplankton biomass g/m^3	1.0 – 5.0	5.1 – 10.0	Above 10.0
Ratio of phyto- to zooplankton biomass	1 : 1	5 : 1	10 : 1 and above

Table 2. The average statistical coefficients of phyto-, zooplankton and zoobentos in the summer period in the lakes of Belarus at various degrees of their eutrophication

Assemblage	Units	Mesotrophic lakes	Eutrophic lakes	Dystrophic lakes
Phytoplankton	million. kl./l	15.0 ± 6.8	41.8 ± 6.6	32.8 ± 24.5
	g/m^3	4.28 ± 1.74	8.56 ± 0.94	6.89 ± 4.75
Zooplankton	Thousand spec./m^3	150 ± 25	351 ± 25	230 ± 103
	g/m^3	1.3 ± 0.17	2.83 ± 0.15	1.71 ± 0.60
Zoobentos	spec./m^3	1290 ± 165	2112 ± 299	1881 ± 606
	g/m^3	12.1 ± 9.7	7.85 ± 0.62	8.15 ± 2.66

According to the degree of overgrowth, the lake of Belarus were conventionally divided into 5 types (very faintly overgrown, faintly overgrown, average overgrown, highly overgrown, completely overgrown). The macrophyte biomass, which determines the stock of plant resources of lakes, ranges between 0 to 0.5 kg of air dry substance on 1 m^2 of brushwood. According to the content size of macrophyte biomass, the lakes of Belarus can be divided into four groups (very low, low, average, high). On the basis of the investigations of the Lake Studies Laboratory, the species content of macrophytes in the lakes can be divided into three groups which correspond to their trophic state (Tab. 3).

Table 3. Characterisation of the composition of lake macrophytes

Species composition	Number of species	Type of lake
Poor	Up to 10	Low mineralised with features of oligotrophy, Hypereutrophic
Average	11 – 30	Eutrophic
Rich	Above 30	Mesotrophic

The natural-economic classification of lakes creates the possibility of including water reservoirs in economically significant groups, which differ in the potential of natural resources and economic use. The economic significance of water reservoirs consists in the use of the natural resources of the lakes – mineral, biological, recreational, power supply and other. The size of natural resources, their structure and accessibility determine the directions of use, choice and degrees of use of these resources. The natural resources of the environment as the source of material goods, in dependence of the kind and quality on the one hand, affect directly the public, and on the other, make up the object of its economic activity. The measure of the use of ecological resources changed dependent upon the period of the development of society, and in the contemporary period it is conditioned by: the quality of natural resources, their utility values, the level of development of productive forces of the society, the degree of the economic development of a given area. The result of every economic use of the ecological resources of lakes is their reduction (exhaustion) and changes in their quality (transformation, contamination, improvement, etc.).

The ecological-economic assessment of the character and the way of use of natural resources is based on criteria of three types: 1) economy; 2) anthropo-ecology; and 3) nature protection. The first determines the advisability and degree of exhaustion of natural resources; the second includes the assessment of the resources with regard to interaction with man (educational and recreational potential); the third is based on the determination of the general ecological value of natural resources or their individual kinds.

The assessment of the economic use of water reservoirs is based on several typological features of division or combination of facilities and phenomena according to the classification type. The following basic features can be distinguished: 1) the kind of utility resources; 2) the quality of resources; 3) the degree (range) of use (partial, total).

In dependence of the kind of resource utilisation, it is possible to distinguish the following: use of waters, consumption of water, fishery, fish farming, recreation, hydrotechnical melioration, sapropel extraction, plant harvesting and animal husbandry.

According to the degree and range of use of natural resources it is possible to distinguish: lack of use, partial use, and complex (versatile) use of water reservoirs.

The quality of utility resources is determined by the size and structure of the natural resource potential, and therefore, from the economic point of view it is necessary to distinguish: lakes according to the size of this potential (small, average, large), and according to its structure (complex, simple).

The combination of characteristics ought to provide a classification of the suitable types of lakes: lakes of large size and complex natural resource structure; the lakes of small size and a simple structure; and also different combination variants. The economic use involves several levels of the use of natural resources: total use of natural resources, economical use of natural resources, the preservation of natural resources and their reproduction (cultivation).

The possibilities of use or preservation of natural resources are determined by natural, scientific and technical as well as social and economic conditions. The rationality of the use of natural resources requires, and in some cases, involves a special procedure for maintaining the ecological equilibrium of the environment.

Taking into consideration the level of the present

management of water reservoirs, it is possible to talk about a certain level of anthropogenic transformations of the lakes. The expression of this phenomenon in numbers is difficult for the time being, but the most often applied criteria of assessment are: not transformed at all; the degree of transformation: partial, low, high, very high, or catastrophic transformation.

The distortion of individual units or ecosystem is the indicator of the degree of transformation in the whole according to the degree of overgrowth: changes in species composition, in the quantitative development of hydrobionts, quantitative changes of natural environment components, qualitative changes of the ecosystem (shift to a different production level). For a more detailed assessment, according to the present authors' opinion, a fundamentally new approach to the problem is necessary.

Table 4. The structure of the natural-economic classification of the lakes

Natural resource potential					
Structure	Simple		Size		High
					Medium
	Complex				Small
Exploitation	Reproductive			Total	
				Partia	
	Non-reproductive			Economical	
Use	Contemporary		Complex		
			Specialised		
	Prospective		No use		
Reproduction					
Interaction	Exhaustion		Changes	Slight	
				Considerable	
	Contamination			Catastrophic	
Function and priority use		Specialised		Fishery	
				Water economy	
		Complex		Recreactional	
				Excavation of sapropel	
				Power supply	
		Protection			
		Restoration			

The determination of the degrees of economic use and the transformation of water reservoirs aimed at their regulation and the preparation of recommendations for economical use of natural resources consists of two blocks: 1) the assessment of the ecological potential (the natural resources) of a water reservoir; 2) the assessment of the degree of exploitation and also qualitative changes of every kind of natural resources.

Estimating the potential, it is necessary to consider the size and class of the quality of natural resources. This assessment can be presented both in a numerical and conventional form – in degrees. The ratio of the two proposed coefficients can be assumed as the coefficient of ecological threat or resistance to anthropopressure. The scale of the size of this coefficient should consist of several degrees of impact: ecologically admissible, ecologically threatening, ecologically critical, ecologically catastrophic.

The combination of the above-mentioned characteristics in blocks provides the possibility of constructing a flexible structure of the natural and economic classification of lakes, in which all the structural blocks are connected and conditioned by a precise cause-and-effect dependence.

The component units of the natural and economic classification are: the object of the classification (lake natural resources), natural classification, economic classification. Every unit has coefficients and characteristics of several levels of detail and significance, introduced in the form of the „branches" of the classification correlation notions. The basis of this is the size, type of the natural resources of lakes, kind and degree of use and exploitation, coefficients of changeability of natural resources in lakes. Filling the structural blocks with quantitative coefficients and characteristics prepared in the particular classifications of lakes gives the possibility of obtaining an active (effective) method of the assessment of ecological potential and the determination of the designation and priority directions of economic use.

Table 5. The criteria and coefficients of the natural resource potential in the natural - economic classification of lakes

I. Structure of natural resource potential:			
Simple	One kind of resources predominates		
Complex	Two or more equal kinds of resources predominate		
II. Volume of natural resource potential:			
Water resources			
Size	Volume (million m³)		Water circulation (years)
High	> 9		Below 2
Average	3 – 9		2 – 7
Small	< 3		Above 7
Mineral resources			
Size	Geological resources (milion m³)		Balance resources (milion m³)
High	15.1 – 120.0		10.1 – 90.0
Average	10.0 – 15.0		0.5 – 10.0
Small	< 1.0		< 0.5
Biological resources			
Fish resources			
Size	Fish products (kg / ha)		Annual fishing (quintals)
High	> 20		> 50
Average	5 – 20		10 – 50
Small	<5		< 10
Plant resources			
Size	Resources (thousand of tonnes of air dry mass – PSM)	Biomass (kg / m²)	Growth level (%)
High	> 1.0	> 0.300	70 – 100
Average	0.5 – 1.0	0.200 – 0.300	35 – 70
Small	< 1.0	< 0.200	< 35
Recreational resources			
Size	Zone area (thousand of hectares)		Capacity (person / hectare)
High	> 25		> 25
Average	10 – 25		15 – 25
Small	< 10		< 15
Scientific and informational resources: not assessed acc. to size			
III. Quality of natural-resource potential			
Water resources			
Quality	In acc. with sanitary standards of water use		
High	In acc. with all kinds of water use		
Medium	In acc. with one kind of water use		
Low	Not in acc. with any standard		
Mineral resources			
Quality	Characterisation		Sapropel class
High	$A_c > 50 \%$		O1 – O4; Kp1; Kp3; K1; C1
Medium	$A_c = 50 – 70 \%$		Kp2; Kp4; Kp5; K2; C2 – C5
Low	$A_c - 70 – 85 \%$		Kp4; K2; C3 – C5
Biological resources:			
Fish			
Quality	Characterisation		
High	Species of valuable consumer fish		
Medium	Industrial use of fish species		
Low	Low quality consumer fish species		
Plants			
Quality	Characterisation		
High	Raw material for agriculture, pharmacology, perfume industry		
Medium	Industrial raw material		
Low	Not usable in economy		
Degree of changes	Characterisation		
Slight	Coefficient changes of ecosystems below 10% or within medium long-term values		
Significant	Coefficient changes below 20% or within values for this species		
Catastrophic	Coefficient changes above 20% or related to shift to another level (type)		

On the basis of the quantitative assessment of resources and resource-generating characteristics, the following system of criteria and coefficients of the natural-resource potential of the lakes of Belarus (Tab. 5) is proposed. The interaction of man with the ecological potential of lakes can be monitored indirectly on the basis of documentary data or land register information about the current state of water reservoirs used economically as well as on the basis of the computational and empirical coefficients, which correspond. to natural, original values of ecosystems. The results obtained should serve as the basis for making a decision about actions concerning the protection and the economical use of water reservoirs.

The assessment of the natural-economic potential of the lakes of Belarus provides a basis for distinguishing lakes with a predominant type of the resource structure: fish (31.0%), sapropel (30.0%), water (24.7%), education (8.7%), recreation (4.6%), power supply (c. 1.0%). The lakes with the type of complex structure make up 13.6% and those with the simple type – 86.4%. From the total number of the lakes examined 64.4% have a small potential; 19.0% – an average potential; and 16.6% – a large one. According to the quality of the natural resource potential, lakes of average quality are predominant – 70.6%; a high quality of the natural resource potential have 17.5 % of the lakes; and 11.9% have a low quality. According to the degree of anthropogenic transformations, 7.6% of the lakes have an insignificant degree; 4.5% – a considerable one; and 2.9% – a catastrophic one. For 85.0% of the lakes the degree of anthropogenic transformations was not determined. The present classification allowed to prepare preference recommendations for priority directives of the economic use and the ways of protection and preservation of resources.

Moreover, positive changes in regeneration of the limnosystems and the protection of lakes carried out by the workers of the Institutes of Biology and Geography, the Belarussian University and the Ministry of Natural Resources and Environmental Protection should be emphasised.

In recent years in the area of the whole country, 24 protected natural zones of the total area of 4,222 km² have been created on the basis of lake reservoirs: reserves, partial reserves and national parks: National Park „Braslavskye Lakes"; reserves of Narotchanski, Pripiatski; and 21 partial reserves. The quantity of lakes on protected areas now exceeds 200 and their total area is 468 km². At present the protected natural resources of Belarus consist of: 4 national parks, 3 reserves, 74 partial reserves, 183 relics of nature. The general area of protected natural territories is c. 800,000 hectares, which is 3.8% of the territory of the country, 154 lakes of the total area of 20,000 hectares are situated within the borders of protected areas, which is 2.5% of the protected territory of the country.

In the use of the natural resources of water reservoirs it is necessary to take into account the specificity of every reservoir and its hydrosystem. The assessment of the natural-resource potential of the Belarussian lakes permitted to determine the priority basic recommendations of their use taking into consideration their biological state and natural resources. This will help to limit the negative changes in the ecosystems as a result of the economic utilisation of the lakes.

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Streszczenie

Liczne zbiorniki jeziorne Białorusi należą do jej najważniejszych gospodarczych zasobów przyrodniczych. Stanowią one regulatory naturalne wód podziemnych i powierzchniowych, są również źródłem wody pitnej i użytkowej, a także bogactw mineralnych i organicznych. Wzrasta znaczenie jezior jako ekologicznego wskaźnika środowiska przyrodniczego, jako obiektów rekultywacji, turystyki, wychowania estetycznego ludności, jej szacunku dla przyrody i uświadomienia konieczności ochrony środowiska przyrodniczego.

Położenie geograficzne jezior i systemów jeziorno-rzecznych oparte jest na pewnych prawidłowościach. Klasyczne dla strefy Pojezierzy Bałtyckich Jeziora Pojezierza Białoruskiego należą do zlewni rzek Dźwiny i Niemna, związane z działalnością ostatniego lądolodu.

Następna strefa lokalizacji jezior – południe kraju – Polesie ciągnie się przez całą Nizinę Wschodnioeuropejską. Geneza tych jezior jest związana ze zmianami klimatu i procesami glacjoizostatycznymi późnego glacjału i holocenu. Kotliny tej strefy

stanowią płytkie jeziora-zalewy (Czerwonoje, Wygonosianskoje) i zagłębienia krasowe w skałach wapiennych kredy (Wulka, Somino, Lukowo).

Na ogół jeziora Białorusi są niewielkie i tylko 1072 z nich względnie należą do stosukowo dużych, mających powierzchnie większą niż 0,1 km².

Wieloletnie badania jezior Białorusi przez Instytut Geografii Fizycznej i Laboratorium Jezioroznawstwa Białoruskiego Uniwersytetu doprowadziły do opracowania, w oparciu o stan troficzny jezior, klasyfikacji przyrodniczo-genetycznej i przyrodniczo-gospodarczej, wyodrębniając zbiorniki jeziorne o właściwościach oligotroficznych, mezotroficznych, eutroficznych różnego stopnia i dystroficznych.

Do połowy XX wieku, w tym w latach powojennych stan jezior w kraju odznaczał się stabilnością, wysoką zdolnością samooczyszczania i wysoką jakością wody. Sprzyjał temu w znacznym stopniu niski poziom rozwoju przemysłu i rolnictwa, niewielka gęstość zaludnienia, znaczne odległości między dużymi miastami, słabo rozwinięta sieć komunikacyjna itp. Rozwój naukowo-techniczny od lat 70-ch poczynając spowodował negatywny wpływ na ekologię jezior.

Przyrodniczo-gospodarcza klasyfikacja jezior stwarza możliwość połączenia zbiorników wodnych w liczące się gospodarczo grupy, różniące się potencjałem zasobów naturalnych i jego gospodarczym wykorzystaniem.

Ekologiczno-ekonomiczna ocena charakteru i sposobu użytkowania zasobów naturalnych opiera się na kryteriach trzech typów:

1) gospodarczego;
2) antropoekologicznego;
3) przyrodoochronnego.

Pierwszy określa celowość i stopień wyczerpania zasobów, drugi obejmuje ocenę zasobów pod kątem współdziałania z człowiekiem (potencjał informacyjny, rekreacyjny), trzeci opiera się na ustaleniu ogólnej wartości ekologicznej zasobów lub poszczególnych ich rodzajów.

Ocena użytkowania gospodarczego zbiorników wodnych bazuje się na kilku cechach typologicznych dzielenia lub łączenia obiektów i zjawisk według typu klasyfikacyjnego. Za cechy podstawowe można wyodrębnić: 1) rodzaj zasobów użytkowych; 2) jakość zasobów; 3) stopień (zakres) użytkowania (częściowe, całkowite).

Przy użytkowaniu zasobów przyrodniczych zbiorników wodnych należy koniecznie uwzględniać specyfikę każdego zbiornika i jego hydrosystemu. Ocena potencjału przyrodniczo-zasobowego jezior Białorusi pozwoliła określić priorytetowe kierunki podstawowe ich użytkowania biorąc pod uwagę statut biologiczny i zasoby przyrodnicze, co da możliwość ograniczenia negatywnych zmian w ekosystemach w wyniku ich zagospodarowania.