Water balance of lake Lebedyne in modern climatic conditions

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SUMMARY

The purpose of the study is to clarify the reasons for the shallowing of the once picturesque, rather deep Lake Lebedyne, which is located near the city of Lebedin, Sumy region. For this, the water-balance method was applied. The water balance of the lake is the main characteristic of their hydrological regime and water exchange. For an objective assessment and with aim to identify long-term changes that have already occurred in the water exchange of the lake, the components of the water balance for modern (1991-2019) period was compared to a climatic norm (1961-1990). Based on calculations, it was found that, on average, the total volume of water inflow into the lake in the modern period has decreased compared to the period of the climatic norm by almost 16%. The volume of evaporation from the water surface of the lake increased by an average of almost 8,5%. If during the period of the climatic norm there was a certain accumulation of water in the lake, then in the modern period there is a natural depletion of the volume of water in the lake. The volume of water in the lake decreased by 40-45% approximately.

Introduction

In the Sumy region of Ukraine there is an interesting city with the poetic name Lebedyn. The town of Lebedyn is located on the river Vilshanka, on the outskirts of the town is Lake Lebedyne, surrounded by a pine forest. Recently, the once picturesque deep lake began to grow shallow, overgrown with reeds, and in the summer of 2019 p. has grown shallow to the very bottom. To find out the reasons for such events, the long-term changes in natural factors that predetermine the nutrition and water content of the lake, and its hydrological regime were studied.

Method and Theory

The water balance of the lake, which is determined by the processes of water inflow and loss, is the main characteristic of their hydrological regime, water exchange. The general of the equation of water balance of the lake has the following form:

$$\sum R - \sum L = \sum A + \eta \quad (1)$$

where: $\sum R$ - the sum of the components of the inflow in the water balance; $\sum L$ - sum of the components of the loss in the water balance; $\sum A$ - accumulative components; η - inconsistency of water balance (Galushchenko, 1987; Khilchevsky et al., 2008; Doganovsky and Orlov, 2011; Romanova et al., 2019; Khilchevskyi and Zabokrytska, 2020).

In general, receipt components include: R_r - inflow of water by rivers flowing into the lake and from the area immediately adjacent to the lake and does not have a permanent hydrographic network (slope inflow); R_{ug} - flow of water into the lake by an underground route; R_{pr} - water inflow due to precipitation on the lake surface; C_l - condensation of moisture on the surface of the lake.

Loss components include: L_r - flow of water from the lake along the rivers that flow from it; L_{ev} - losses for evaporation from the water surface of the lake (when it becomes overgrown, losses for transpiration are added); L_f - filtration (underground runoff) from the lake; L_h - water losses for household needs (irrigation, canals, water supply, etc.).

Accumulation components include: A_l - accumulation of water in the lake; A_g - accumulation of water in the soils of the banks with an increase in the level; A_{ch} - accumulation of water in the channel and floodplain within the estuarine section of the rivers flowing into the lake.

The specific gravity of various components of the lake's water balance is not equivalent and is determined by the climatic conditions of the catchment area, morphometric features of the lake, its flow rate, the ratio of the areas of the lake water surface to the catchment area, the level of economic activity, and the like. Often, some of the components are so small that they do not have any noticeable effect on the total runoff and may not be taken into account at all, for example, moisture condensation on the lake surface. Insignificant components A_g and A_{ch}. Some elements of the water balance may be absent altogether, for example, component L_r in closed lakes (Galushchenko, 1987; Khilchevsky et al., 2008).

The main role in the water balance of the lake usually belongs to: in terms of the inflow - of the surface inflow (R_r) and, to a lesser extent, precipitation that falls on the lake surface (R_{pr}), and in terms of losses - water runoff for waste water (L_r) and evaporation (L_{ev}), especially for closed lakes (Galushchenko, 1987; Doganovsky and Orlov, 2011).

The water balance for the period with increased moisture is characterized by an excess of the input components compared to the loss components, which leads to an increase in the accumulation component $\sum A$ and an increase in the water level in the lake. During the period with low moisture

content, the component of losses prevails over the part of the inflow, and the water level in the lake decreases.
Thus, based on the foregoing, for Lake Lebedyne, as for drain less reservoir, the equations of the lake's water balance, taking into account its main components, can be represented as:

$$R_r + R_{pr} - L_{ev} - L_f = \pm A_l \quad (2)$$

The calculation of the components of the lake water balance is carried out in a single dimension, most often in volumetric units (depending on the size of the lake - m^3, thousand m^3, million m^3, km^3) (Doganovsky and Orlov, 2011).

Results

For an objective assessment and in order to identify the changes that have already occurred in the water exchange of the lake, the components of the water balance for two periods were compared - the current one (1991-2019) and the period of the climatic norm (1961-1990).
The area of the lake's water surface in the period 1961-1990 was 0,52 km^2, and in the period 1991-2019. decreased to 0,49 km^2. The catchment area of the lake is 9,5 km^2.
Tables 1, 2, and 3 show the changes in the water-balance elements of the water flow into the lake, consumption from it and changes in the accumulation component for the two studied periods (Galushchenko, 1987; Sikan, 2007; Lukianets, 2010; Doganovsky and Orlov, 2011). It should be borne in mind that the average annual air temperature in the modern period (1991-2019) increased on average by 1 °C (according to the Lebedin meteorological station) compared to the period of the climatic norm (1961-1990).
The total volume of water inflow into the lake in the modern period decreased compared to the period of the climatic norm by almost 16% (Table 1). Of these, the inflow of water from the area adjacent to the lake (slope inflow - surface and subsurface) decreased by 17,8%, and the amount of atmospheric precipitation on the lake surface decreased by 11,7%.

Table 1 *Receipt elements in the water balance equation for Lake Lebedyne for the period 1961-1990 and 1991-2019*

period 1961-1990		
elements of receipt	*Volume, m^3*	*% of total revenue*
water inflow from the area adjacent to the lake (slope inflow - surface and subsurface)	921500	74,7
precipitation on the water surface of the lake	311480	25,3
total receipt	1232980	100
period 1991-2019		
elements of receipt	*Volume, m^3*	*% of total revenue*
water inflow from the area adjacent to the lake (slope inflow - surface and subsurface)	760000	74,4
precipitation on the water surface of the lake	274890	26,6
total receipt	1034890	100

As a result of a decrease in the volume of water inflow into the lake in the modern period, the volume of evaporation also decreased compared to the period of the climatic norm, but its percentage of the total inflow, comparing the periods under study, increased by almost 8,5% (Table 2).
That is, the volumes of evaporation from the water surface of the lake in the modern period increased by an average of 90000-95000 m^3 per year and, given that the Lake Lebedyne has been intensively overgrown lately, the proportion of transpiration in the total volume of evaporation has increased. The volume of filtration (outflow) from the lake is 75600 m^3 per year (Table 2).

Table 2 *Evaporation from the water surface of the lake (taking into account transpiration) and filtration in the equation of Lake Lebedyne water balance for the period 1961-1990 And 1991-2019*

period 1961-1990		
loss elements	*Volume, m^3*	*% of total revenue*
filtration (underground runoff) from the lake	75600	6,1
evaporation from the water surface of the lake and transpiration	1135250	92,1
period 1991-2019		
loss elements	*Volume, m^3*	*% of total revenue*
filtration (underground runoff) from the lake	75600	7,3
evaporation from the water surface of the lake and transpiration	1040490	100,5

Knowing the quantitative indicators of the main components of the water balance of Lake Lebedyne, it is possible to estimate the accumulation component of the water balance (Table 3) for the period of the climatic norm and the modern period using equation (2).
If during the period of the climatic norm there was a certain accumulation of water in the lake (+ 22130 m^3), then in the modern period there is a natural triggering (depletion) of the volume of water in the lake (- 81200 m^3).

Table 3 *Water balance of Lake Lebedyne*

elements of receipt (+), m^3		*loss elements (-), m^3*		Accumulation component the volume of water in the lake, A_l
water from the area adjacent to the lake (slope inflow), R_r	precipitation on the water surface of the lake, R_{pr}	evaporation from the water surface of the lake and transpiration, L_{ev}	filtration (underground runoff) from the lake, L_f	
period 1961-1990				
921500	311480	1135250	75600	+22130
period 1991-2019				
760000	274890	1040490	75600	-81200

For an approximate assessment of how much the volume of water in the lake W_l (m^3) has decreased in the modern period (1991-2019) compared with the period of the climatic norm (1961-1990), the formula was used to determine the volume of the spherical segment:

$$W_l = 3{,}14 \cdot h_{av\_max} \cdot \left(\frac{d_l^2}{8} + \frac{h_{av\_max}^2}{6}\right), \qquad (3)$$

where: h_{av_max} - average of the maximum depths of the lake for a certain period, m; d_l - diameter of the water surface of the lake, m (Doganovsky and Orlov, 2011).
Calculations are presented in Table 4.

Table 4 *Changes in the volume of water in the Lake Lebedyne W_l (m^3) in the modern period (1991-2019) compared with the period of the climatic norm (1961-1990)*

characteristic	*period 1961-1990*	*period 1991-2019*
h_{av_max}	2,3 m	1,5 m
d_l	725 m	680 m
W_l	475514 m^3	272240 m^3

The average value of the largest depths of the Lake Lebedyne for the period 1961-1990 – 2,3 m, and in the period 1991-2019 decreased to 1,5 m. The average value of the diameter of the lake's water surface in the period 1961-1990 - 725 m, in the period 1991-2019 - 680 m.
In the modern period, analyzing the calculations in Table 4, the volume of water in the Lake Lebedyne has decreased by about 40-45% compared to the period of the climatic norm.

Conclusions

In general, we believe that the shallowing that occurs with the Lake Lebedyne is to a greater extent a naturally conditioned process. In the modern period, an increase in air temperature, a decrease in the amount of precipitation and surface water runoff is clearly observed. Such situations are now on many lakes and rivers of Ukraine (Grebin, 2010; Obodovskyi et al., 2018, 2019; Chornomorets and Lukianets, 2019; Romanova et al., 2019; Khilchevskyi and Zabokrytska, 2020).
For a deeper study of this problem, it is necessary to study the characteristics of the lake and its drainage area, and with a certain frequency. Near the lake today there is a highway, a railway located on the catchment area, and this interferes with the surface runoff of water, which has the largest percentage of water entering the lake. It is necessary to organize the work on cleaning the lake and deepening its bottom. You also need to do something about the vegetation near the coast (reeds, etc.), which significantly increases evaporation due to transpiration.

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