STUDY OF FRAGMENTATION IMPACT OF SMALL RIVERBEDS BY ARTIFICIAL WATERS ON THE QUALITY OF WATER RESOURCES

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ORIGINALITY.

METHODOLoGY.

Purpose. Study the spatial distribution of artificial reservoirs in the Dnipropetrovsk region and fragmentation impact of small riverbeds on changes in the quality of water resources.

Methodology. Field studies on the current state of small river basins were carried out, rivers were selected on the principle of different geographical location and levels of anthropogenic impact. Analytical laboratory studies of water salt composition and methods of mathematical analysis were used to establish the dependence coefficients of water mineralization level and fragmentation of the river basin on the water flow regulation.

Findings. The structure of the spatial distribution of artificial reservoirs in the administrative districts of the region and their hydrological characteristics are generalized. It is shown that small volumes of accumulated water in relation to the total area of reservoirs are the cause of intensive heating and evaporation of water. Due to this, the hydrochemical parameters of water are worsen, which affects the environmentally safe water use. It was found that the level of mineralization, the content of sulphates and chlorides exceed the maximum acceptable concentrations in all studied rivers. There is a tendency of deterioration of water quality in the salt block, especially in rivers with significant regulation of artificial reservoirs. In this case, water salinity exceeds the norm by 7–12 times. Indicators of water mineralization of rivers with fewer ponds and less fragmentation of the river basin exceed the standards by 2–5 times.

Originality. It is determined that among the main factors of anthropogenic impact on the state of aquatic ecosystems is the fragmentation of riverbeds by artificial reservoirs, which turned rivers into cascades of water evaporating ponds. There is a close relationship between the factors of water flow regulation and the level of water mineralization (coefficient of determination $R^2 = 0.62$), as well as the coefficient of fragmentation of the river basin ($R^2 = 0.61$). This proves the possibility, in the conditions of research of small rivers, to estimate the degree of change (increase) of water mineralization level by the coefficient of water flow regulation $K_w$ and the coefficient of river fragmentation by the area $K_f$.

Practical value. The main directions and ways to normalize the ecological status of watercourses are given. The necessity of systematic study of the current ecological condition of small rivers of Dnipropetrovsk region and their basins is determined.

Keywords: river fragmentation, small river, artificial reservoir, water quality
mine largely the hydrogeological regime and hydrochemical composition of groundwater in the surrounding areas.

Thus, the issues of restoration, environmentally safe water use and water management need to be started with the rehabilitation of ecosystems in small river basins.

The aim of the study is to assess and analyse the spatial distribution of artificial reservoirs in the Dnipropetrovsk region and to study the potential impact of fragmentation of small rivers on changes in the salt composition of water resources.

Materials and methods. Information on the total number of ponds and reservoirs in the Dnipropetrovsk region of Ukraine was used in the research. The main indicators that were taken into account for individual areas are the following: the total number of artificial water bodies (ponds and reservoirs); water surface area; water volumes; medium depths; the relative area of the territory, which is the location of one reservoir.

During 2019–2020, expeditions were conducted on 5 rivers. The current state of water flows and ponds located on them was studied. 24 samples of water in ponds were taken to determine its mineralization, sulphate and chloride content (Fig. 1).

Researches of change processes of water quality on salt content in the rivers Zhovtenka, Nyzhnia Tersa, Zaplavka, Kilchenka and Hrushivka were carried out. Rivers were selected on the principle of different geographical location and the level of possible anthropogenic impact, namely:

1. The Zhovtenka River is located in the territory of the industrial area of the region; at the end of the XX century part of the ponds and 1 water storage were used as reservoirs of the city Kryvyi Rih sewage for irrigation of agricultural lands; a cascade of ponds was built in the upriver due to the significant impact on the water flow of the river is almost absent on all investigated rivers. Watercourses are cascades of ponds and reservoirs. According to research in the period of 2011–2015 [21], the total mineralization of water in the river basins of the Dnipropetrovsk region ranged from 1 to 3 g/l.

2. The Hrushivka River is located in the central part of the region. The catchment area of the Hrushivka River is 206.1 km². 6 ponds have been built along the riverbed, 11 more on its tributaries.

It should be noted that at the time of the survey, the water flow of the river is almost absent on all investigated rivers. Watercourses are cascades of ponds and reservoirs. According to research in the period of 2011–2015 [21], the total mineralization of water in the river basins of the Dnipropetrovsk region ranged from 1 to 3 g/l.

Indicators of mass concentration of sulphates, dry residue (solutes) and total chloride content in rivers were established as the subject of research during determining the quality of water by salt composition. Laboratory tests of selected water samples were performed in certified laboratories according to current standards:

1. Surface, groundwater and return water. Measurements performing method (MPM) of mass concentration of sulphates by titrimetric method.

2. Surface, groundwater and return water. Method for determining the mass concentration of dry residue (solutes) by gravimetric method.

3. Determination of the total chloride content. Titration with silver nitrate using chromate as an indicator (Mohr method).

To conduct an operational assessment of the level of anthropogenic impact on rivers, it is proposed to introduce a coefficient of river fragmentation ($K_{fr}$). It should be calculated by the ratio of the total number of artificial water bodies to the length of the river or to the area of the catchment area

$$K_{fr} = \frac{N}{L}$$

where $N$ – the total number of artificial reservoirs on the river, units; $L$ – length of the river, km; $S$ – river basin area, km².

To establish the relation between the fragmentation coefficients and the generally accepted indicator of regulation, calculations of the regulation degree of water flow in the studied river basins in the Dnipropetrovsk region were performed.

For this purpose, the following hydrological values are determined [22–24]:

- catchment area (using QGIS geographic information system and reference sources);
- water flow module of the river basin location;
- volume of regulation and regulation factor $K_r$ according to the formula

$$K_r = \frac{W_{fr}}{W}$$

where $W_{fr}$ – volume of regulated flow at the river catchment area, m³; $W$ – annual flow rates, m³.

Results and discussion. According to the regional office of water resources in Dnipropetrovsk region, the hydrographic network of watercourses is represented by 291 rivers with a total length of about 6.6 · 10³ km. Also there are 5140 small streams and watercourses with a length of 15.2 · 10³ km on the territory of the region. Today there are 101 reservoirs with a total capacity of ~900 · 10⁶ m³ and a water surface area of about 20 · 10³ ha, as well as 3292 ponds with a total volume of ~275 · 10⁶ m³ with a water surface area of 18.8 · 10³ ha. At the same time, the total volume of water use in the Dnipropetrovsk region during the period from 1990 to 2018 decreased by 4 times in almost all areas: industry, housing and utilities, irrigation and others. Provision of water management needs is

\[1 \text{ Layout of river basins where water quality research was performed (Dnipropetrovsk region, Ukraine)}\]
mainly due to large reservoirs and main canals. As a rule, during the studied period the number of built ponds increased thrice. That means, there is an obvious imbalance between the demand for water and the creation of additional volumes through the construction of new facilities.

The location of reservoirs in the Dnipropetrovsk region is different (Fig. 2). The largest concentration of 764 reservoirs is in Kryvyi Rih district, and the smallest amount of 160 ponds – in Pavlograd district. The average area of one pond is 10.2 km². The total area of the water surface varies from 2,095 ha to 15,061 ha, and the volumes of accumulated water vary in the range of 55–630 \times 10^6 m³. According to the calculated ratio of water volume to the occupied area of the water surface, the average depth of ponds varies between 1.6–4.2 m. Insignificant depths of ponds in relation to their area cause intense heating of water and its evaporation. As a result, the salt composition of water changes, its mineralization increases. Taking into account current climate change and the reduction of river water levels by 1.5–2 times, this situation is a threat to environmentally safe water use.

In order to study the current ecological status of small rivers in the Dnipropetrovsk region, the work have been begun on creating a database to develop an algorithm for solving the problem of improving the environmental safety of water resources of small rivers.

The research results of water quality in the form of averages on such parameters as mineralization, sulphates and chlorides are presented in Fig. 3.

The sulphate content exceeds the maximum acceptable concentration (MAC) at all test sites. The average concentration of sulphates ranges from 1.889 (Hrushivka River) to 4.527 g/l (Nyzhnia Tersa River). The excess of all studied indicators of water quality over the normative limits are presented in Table 1.

The results of water quality studies showed that all indicators exceeded the maximum acceptable concentrations. The total mineralization of water exceeds norm by 3 to almost 12 times; chlorides content by 1.2–9 times; sulphates by 4–9 times. The obtained indicators differ significantly from the data of 2011–2015 [21], which indicates a tendency to deteriorate water quality and increase the overall level of its mineralization.

Today, one of the factors influencing the deterioration of water quality is the rapid change in climatic conditions and the increase of periods with high temperatures in the warm seasons. Climate change, obviously, can lead to a decrease in the degree of water exchange in artificial reservoirs, which can be assessed by determining the coefficient of water flow regulation. It was established according to formula 2 for the studied basins of small rivers in the Dnipropetrovsk region (Table 2).

The analysis of the obtained calculations shows that the rivers Zhovtenka and Nyzhnia Tersa have the highest coefficient of water flow regulation among the studied objects. Certain degree of fragmentation of these rivers by artificial reservoirs is also indicative. A significant (close) correlation be-

<table>
<thead>
<tr>
<th>River</th>
<th>Mineralization, g/l</th>
<th>exceeding MAC, times</th>
<th>Chlorides, g/l</th>
<th>exceeding MAC, times</th>
<th>Sulphates, g/l</th>
<th>exceeding MAC, times</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hrushivka</td>
<td>3.40</td>
<td>3.4</td>
<td>0.672</td>
<td>1.9</td>
<td>1.889</td>
<td>3.8</td>
</tr>
<tr>
<td>Zaplavka</td>
<td>4.81</td>
<td>4.8</td>
<td>0.565</td>
<td>1.6</td>
<td>2.668</td>
<td>5.3</td>
</tr>
<tr>
<td>Kilchynka</td>
<td>4.95</td>
<td>5.0</td>
<td>0.426</td>
<td>1.2</td>
<td>2.592</td>
<td>5.2</td>
</tr>
<tr>
<td>Nyzhnia Tersa</td>
<td>7.77</td>
<td>7.8</td>
<td>0.711</td>
<td>2.0</td>
<td>4.527</td>
<td>9.1</td>
</tr>
<tr>
<td>Zhovtenka</td>
<td>11.82</td>
<td>11.8</td>
<td>3.092</td>
<td>8.8</td>
<td>4.272</td>
<td>8.5</td>
</tr>
<tr>
<td>MAC</td>
<td>1.00</td>
<td>–</td>
<td>0.350</td>
<td>–</td>
<td>0.500</td>
<td>–</td>
</tr>
</tbody>
</table>

**Table 1**

Fig. 2. Distribution of artificial reservoirs on the territory of administrative districts of Dnipropetrovsk region

Fig. 3. Average indicators of water quality in ponds (g/l):

a – concentration of chlorides; b – concentration of sulphates; c – total mineralization of water
tween water mineralization in rivers and the fragmentation coefficient by area $K_{fr}$, with the value of quantitative regulation of river flow has been established (Fig. 4).

The calculated coefficient of determination $R^2$ between these factors ranges from 0.61 (for the fragmentation coefficient) to 0.62 (for water mineralization), which proves the possibility, in the Dnipropetrovsk region, to assess the degree of change (increase) in the level of water mineralization by the regulation factor runoff $K_r$ and river fragmentation coefficient by area $K_{fr}$.

**Conclusion.**

1. A significant imbalance in the consumption of water resources with the available number of ponds and reservoirs in the Dnipropetrovsk region was revealed. In the conditions of the climate change and low quality of water resources, this situation has negative consequences for the environmentally safe water use in small river basins, which is expressed in the deterioration of hydrochemical indicators of water quality.

2. According to the results of the study of 24 water samples, it was found that the total mineralization, chloride and sulphate content exceed significantly the standard maximum acceptable concentrations. Exceedances for all indicators range from 2 to 12 times.

3. A close relation has been established between the factors of water flow regulation and the level of water mineralization (coefficient of determination $R^2 = 0.62$), as well as the coefficient of fragmentation of the river basin ($R^2 = 0.61$). In the conditions of research of small rivers in Dnipropetrovsk region, the obtained data prove the relation between the deterioration of hydrochemical indicators of water quality and the level of fragmentation of the river basin. This makes it possible to estimate the degree of change (increase) in the level of water mineralization by the coefficient of water flow regulation $K_r$ and the coefficient of river fragmentation by the area $K_{fr}$.

The rivers Zhovtenka and Nyzhnia Tersa, in the basins of which the largest number of ponds have been built, have much worse indicators of water resources quality in comparison with the rivers Kilchenka, Hrushivka and Zaplavka.

4. The main reasons for the significant deterioration of aquatic ecosystems of small rivers of Dnipropetrovsk region are the following: regulation of water flow and creation of artificial reservoirs; the absence of fixed boundaries of water protection zones and riverside protection strips, and as a consequence the ploughing of adjacent agricultural lands to the water edge; lack of systematic monitoring studies on the hydrological regime and physico-chemical indicators of water quality; the presence of frequent facts of pollution and littering of small rivers due to irresponsible economic activity. In general, there is an ecological non-conformance of the state of small river basins.

5. In order to improve the situation with the preservation of small river ecosystems and their restoration, it is necessary to introduce state and regional programs to review the ecological and economic practicability of further operation of ponds and to carry out their gradual elimination.

**References.**


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**Table 2**

Indicators of water flow regulation in the studied river basins

<table>
<thead>
<tr>
<th>Indicator</th>
<th>River basin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Catchment area, km²</td>
<td>Hrushivka</td>
</tr>
<tr>
<td></td>
<td>206.7</td>
</tr>
<tr>
<td>Water flow module, l/s · km²</td>
<td>0.51</td>
</tr>
<tr>
<td>Annual flow rate $W_{fr}$, 1 · 10⁶ m³</td>
<td>3.32</td>
</tr>
<tr>
<td>Regulation volume $W_r$, 1 · 10⁶ m³</td>
<td>4.14</td>
</tr>
<tr>
<td>Water flow regulation coefficient $K_r$</td>
<td>1.24</td>
</tr>
<tr>
<td>Fragmentation coefficient $K_{fr}$</td>
<td>5.3</td>
</tr>
</tbody>
</table>

Fig. 4. Relation between water flow regulation coefficient $K_r$ with river fragmentation coefficient by area $K_{fr}$ (a) and water mineralization in rivers (b)


