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

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_{fr}^{s}.

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*

Introduction. Intensive development of economic activity in Ukraine requires the involvement of a significant amount of water resources. Fulfilling needs in water for energetics, industry, irrigation, water supply, etc., occurred including the creation of artificial water bodies [1]. As a result, a significant number of ponds and reservoirs were built throughout Ukraine [2]. It was established that the majority of ponds and reservoirs are concentrated in the steppe zone of the country. The developed industry and the need for irrigation in the region are main reasons for this. One of the most indicative for this is Dnipropetrovsk region of Ukraine. Currently in response to construction of artificial reservoirs, almost all small rivers in the south and in the central low water areas of Ukraine are regulated in the range of 70–100 % [3]. Regulation of small rivers leads to the loss of their transport function and reduces the self-cleaning ability [4]. The majority of small rivers do not have a constant water flow in fragmented areas throughout the calendar year. Such phenomena as silting and drying of ponds and small reservoirs have become systemic and numerous [5]. Significant deterioration of water resources quality and environmental safety of water use are consequences of this situation [6]. Significant climate change is an additional danger for environment and water security of Ukraine [7, 8].

Global and native tendencies in the development of the water industry [9], as well as attitudes to the acute problems of environmental safety for water resources, testify to the growing trend of studying the impact of artificial reservoirs on the biodiversity of aquatic and semi-aquatic ecosystems [10, 11]. Tendencies in changing the quality of water resources [12, 13], their effective management, protection and restoration [14] are studied. The issue of the negative consequences of regulating the water flow of small and medium-sized rivers is becoming more relevant, it indicates the need and practical implementation of disassembling dams and spillovers [15], restoring the water flow and ecosystems of small rivers [16, 17]. In Ukraine, a large network of hydrometric posts was created to study the hydrological regime and quality of water resources [11, 18]. As a rule, they were built on large and medium-sized rivers and, unfortunately, a significant number of them do not function today. Instead, the State Agency of Water Resources of Ukraine has introduced a project in the form of an interactive online map that provides open access to data on quality indicators and environmental assessment of water in the control section lines of observations [19, 20]. Thus, with a total of more than 5,000 rivers and streams within the Dnipropetrovsk region, according to the interactive map, only ~50 observation posts are active. The absolute absence of hydrometric observation posts for hydrochemical parameters of water resources in small river basins is a significant disadvantage of the water management complex. Due to this, today there is no database on hydrochemical indicators of water quality of both small rivers and ponds and reservoirs in their channels. Meanwhile, small rivers are the main supply arteries of large watercourses and deter-

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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 total of 34 ponds were built on the catchment area of 211.5 km^2.

2. The Nizhnia Tersa River is located in the Synelnykovo district; the main source of anthropogenic impact is agriculture; the river is actively used for fish farming and recreation; a cascade of ponds was built in the upriver due to the significant dissected relief (ravine-hollow); a total of 55 ponds and 2 reservoirs were built on the catchment area of 312 km^2, including 41 ponds on the tributaries.

3. The rivers Zaplavka and Kilchenka are located in the north of the Dnipro district; the territory of their water flows is mostly represented by plains; a significant impact on the water content of rivers is caused by agriculture and ploughing of arable land almost to the water edge; in the period from 1998 to 2006, a number of projects were carried out to clear the Kilchenka riverbed and arrange artificial gullies; in total, 11 ponds were built on the Zaplavka River catchment area of 256.8 km^2, and 12 ponds were built on the Kilchenka River catchment area of 112.1 km^2.

Fig. 1. Layout of river basins where water quality research was performed (Dnipropetrovsk region, Ukraine)

4. The Hrushivka River is located in the central part of the region. The catchment area of the Hrushivka River is 206.1 km^2. 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

$$K_{fr}^{l} = \frac{N}{L}; \quad K_{fr}^{s} = \frac{N}{S}, \tag{1}$$

where N – the total number of artificial reservoirs on the river, units; L – length of the river, km; S – river basin area, km^2.

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_w according to the formula

$$K_w = \frac{W_r}{W_n}, \tag{2}$$

where W_r – volume of regulated flow at the river catchment area, m^3; W_n – annual flow rates, m^3.

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 · 10^3 km. Also there are 5140 small streams and watercourses with a length of 15.2 · 10^3 km on the territory of the region. Today there are 101 reservoirs with a total capacity of ~900 · 10^6 m^3 and a water surface area of about 20 · 10^3 ha, as well as 3292 ponds with a total volume of ~275 · 10^6 m^3 with a water surface area of 18.8 · 10^3 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 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 km^2. 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 $55–630 \cdot 10^6$ m^3. 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 Table1.

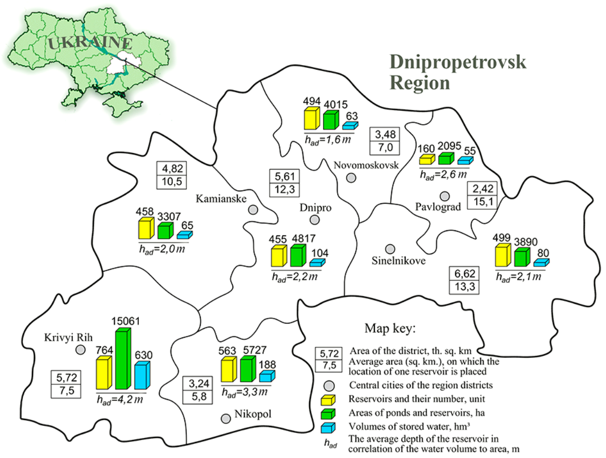


Fig. 2. Distribution of artificial reservoirs on the territory of administrative districts of Dnipropetrovsk region

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-

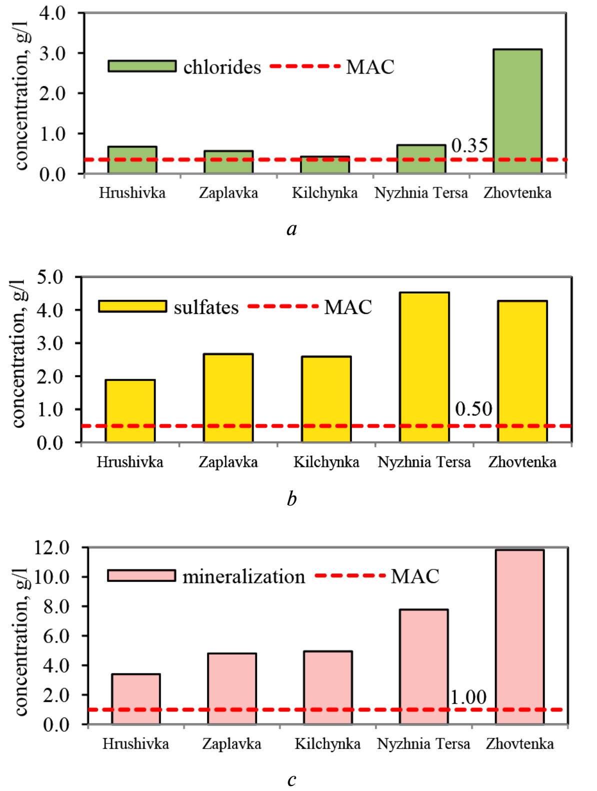


Fig. 3. Average indicators of water quality in ponds (g/l):

a – concentration of chlorides; b – concentration of sulphates; c – total mineralization of water

Table 1

Comparative characteristics of average water quality indicators with maximum acceptable concentrations

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

Table 2

Indicators of water flow regulation in the studied river basins

Indicator	River basin				
	Hrushivka	Zaplavka	Kilchynka	Nyzhnia Tersa	Zhovtenka
Catchment area, km^2	206.7	215	114.1	312	293
Water flow module, l/s · km^2	0.51	0.75	0.75	0.54	0.58
Annual flow rate W_o, 1 · 10^6 m^3	3.32	5.09	2.7	5.2	5.36
Regulation volume $W_з$, 1 · 10^6 m^3	4.14	4.29	3.89	8.16	9.83
Water flow regulation coefficient K_w	1.24	0.84	1.44	1.57	1.83
Fragmentation coefficient K^s_{fr}	5.3	4.3	10.7	17.6	16.1

tween water mineralization in rivers and the fragmentation coefficient by area K^s_{fr} with the value of quantitative regulation of river flow has been established (Fig. 4).

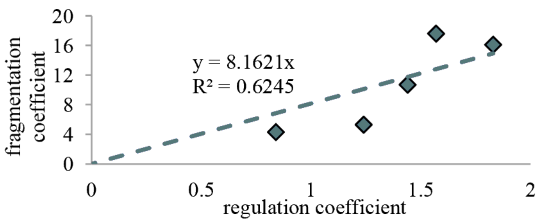
The calculated coefficient of determination R^2 between these factors ranges from 0.61 (for the fragmentation coefficient) to 0.62 (for water mineralization), which proves the possibility, in the Dnipropetrovsk region, to assess the degree of change (increase) in the level of water mineralization by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

Conclusion.

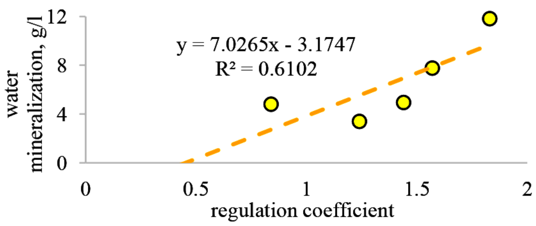
1. A significant imbalance in the consumption of water resources with the available number of ponds and reservoirs in the Dnipropetrovsk region was revealed. In the conditions of the climate change and low quality of water resources, this situation has negative consequences for the environmentally safe 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 = 062), 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



a



b

Fig. 4. Relation between water flow regulation coefficient K_w with river fragmentation coefficient by area K^s_{fr} (a) and water mineralization in rivers (b)

to estimate the degree of change (increase) in the level of water mineralization by the coefficient of water flow regulation K_w and the coefficient of river fragmentation by the area K^s_{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 physic-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.

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Дослідження впливу фрагментації русла малих річок штучними водоймами на якість водних ресурсів

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Мета. Дослідження просторового розподілу штучних водойм на території Дніпропетровської області та впливу фрагментації русел малих річок на зміни якості водних ресурсів.

Методика. Виконані польові дослідження сучасного стану басейнів малих річок, що обрані за принципом різного географічного розташування й рівнів антропогенного впливу. Застосовані аналітичні лабораторні дослідження сольового складу води та методи математичного аналізу для встановлення коефіцієнтів залежності рівня мінералізації води та фрагментації річкового басейну від зарегулювання стоку.

Результати. Узагальнена структура просторового розподілу штучних водойм по адміністративним районам області та їх гідрологічні характеристики. Показано, що незначні об'єми накопиченої води по відношенню до загальної площі водойм є причиною інтенсивного прогрівання й випаровування води. У зв'язку з цим погіршуються гідрохімічні показники води, що впливає на екологічно безпечне водокористування. Встановлено, що рівень мінералізації, вміст сульфатів і хлоридів перевищують гранично допустимі концентрації на всіх досліджуваних річках. Відмічається тенденція погіршення якості води по сольовому блоку перш за все на річках, що мають значне зарегулювання штучними водоймами. У цьому випадку мінералізація води перевищує нормативні показники у 7–12 разів. Показники мінералізації води річок, на яких створено меншу кількість ставків і які мають меншу фрагментацію річкового басейну, перевищують нормативи у 2–5 разів.

Наукова новизна. Визначено, що серед основних чинників антропогенного впливу на стан водних екосистем є фрагментація русел штучними водоймами, які перетворили річки в каскади ставків-випаровувачів води. Встановлено достатньо тісний зв'язок між факторами зарегулювання стоку та рівнем мінералізації води (коефіцієнт детермінації $R^2 = 0{,}62$), а також, коефіцієнтом фрагментації річкового басейну ($R^2 = 0{,}61$). Це доводить можливість, в умовах дослідження малих річок, оцінювати за коефіцієнтом зарегулювання стоку K_w і коефіцієнтом фрагментації річки за площею K^s_{fr} ступінь зміни (збільшення) рівня мінералізації води.

Практична значимість. Наведені основні напрями та шляхи для нормалізації екологічного стану водотоків. Визначена необхідність системного вивчення сучасного екологічного стану малих річок Дніпропетровської області та їх басейнів.

Ключові слова: *фрагментація річки, мала річка, штучна водойма, якість води*

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