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Processes of Natural Self-Cleaning of Small Watercourses with Increasing Anthropogenic Load in the Dniester River Basin

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ABSTRACT

Small river basins are complex self-regulatory systems, as well as indicators of the state of the environment due to the level of anthropogenic pressure. Since any changes in the regime of small rivers are reflected in the entire hydrographic chain, the problem of estimating the anthropogenic load on small rivers of Ukraine is relevant for modern hydrochemistry and hydroecology. The main sources of water pollution are industrial and domestic effluents, which increase the inflow of pesticides, heavy metal ions, etc. Aquatic ecosystems of small rivers are subject to intense mechanical and biochemical effects, and about 80% of pollutants are washed into water bodies. Water bodies located on the territory or near large cities and urban areas are particularly exposed to man-made pollution. In the territory of the Dniester river basin, natural landscapes are maximally preserved in comparison with other regions of Western Ukraine, but in modern conditions we observe an increase in the negative anthropogenic impact on the quality of natural waters. Hydrodynamic barriers or hydrodynamically active areas (HAA) of mountain rivers, which are significantly saturated with oxygen in the water flow, which activates the processes of biochemical and biological self-cleaning of natural waters, are important to increase the efficiency of self-purification processes. Natural biological cleaning of pollutants in small rivers is highly effective due to the overgrowth of aquatic vegetation. The aim of the work was to establish the ability of the aquatic ecosystem of a small river to self-purify on the basis of hydrochemical indicators of water quality. The compliance with sanitary and hygienic requirements of hydrochemical indicators of Kolodnytsia river water of the right tributary of the Dniester was analyzed and possible regularities of their changes were established, as well as the main factors of anthropogenic impact on a small river and the possibility of laboratory modeling of such rivers. It was found that in the Kolodnytsia River the processes of self-cleaning are quite active, which are caused by the hydrological characteristics of the river and the presence of hydrodynamically active areas in the foothills of the basin. Therefore, at present there is no steady excess of pollutants relative to the MPC.

Keywords: mountain rivers, surface waters, small rivers, natural self-cleaning, hydrodynamically active areas, channel processes.

INTRODUCTION

Water resources of small rivers are part of the general water resources and are often the main or even the only sources of local water supply. Small rivers are regulators of the water regime of landscapes, factors in maintaining balance and redistribution of moisture [Mitryasova and Pohrebennyk, 2018], contain most of Ukraine's freshwater reserves and play an important role in public life. According to experts, they account for 60% of Ukraine's total water resources. In particular, 60% of the water resources of these rivers are concentrated in Polissya and Forest-Steppe,

about 25% in the Carpathians and almost 12% in the steppe zones [Humeniuk et al., 2021].

Small river basins are complex self-regulatory systems, as well as indicators of the state of the environment due to the level of anthropogenic pressure. Since any changes in the regime of small rivers are reflected in the entire hydrographic chain, the problem of estimating the anthropogenic load on small rivers of Ukraine is relevant for modern hydrochemistry and hydroecology. The main sources of water pollution are industrial and domestic effluents, which increase the inflow of pesticides, heavy metal ions, etc. Aquatic ecosystems of small rivers are subject to intense mechanical and biochemical effects, and about 80% of pollutants are washed into water bodies. The accumulation of heavy metals in man-made pollution of rivers, lakes and other inland water bodies is associated with them. Particularly intensive man-made pollution is exposed to water bodies located in or near large cities and urban areas [Mitryasova and Pohrebennyk, 2018; Humeniuk et al., 2021; Eskov and Rosenberg, 2010].

Negligence and overexploitation of water resources reduces the efficiency of natural self-cleaning of river waters, as well as reducing the number of small rivers. About 10,000 such rivers have disappeared in Ukraine since 1991. The reason for this is not only climate change, but also increased anthropogenic pressure on the territory of small river basins. If this problem is not solved, it will worsen and its scale will grow catastrophically. Optimizing the ecological condition of these rivers and their watersheds through a scientific approach and raising environmental awareness is an important task for local communities [Bortnyk et al., 2021].

In the territory of the Dniester river basin, natural landscapes are maximally preserved in comparison with other regions of Western Ukraine, but in modern conditions we observe an increase in the negative anthropogenic impact on the quality of natural waters. Hydrodynamic barriers or hydrodynamically active areas (HAA) of mountain rivers, which are significantly saturated with oxygen in the water flow, which activates the processes of biochemical and biological self-cleaning of natural waters, are important to increase the efficiency of self-purification processes. Natural biological cleaning of pollutants in small rivers is highly effective due to the overgrowth of aquatic vegetation. At a flow velocity of about 1.5 km/h in a kilometer of runoff of such a river, the lead content in the water is reduced by half, and in benthos almost 6 times [Eskov and Rosenberg, 2010; Snitynskyi et al., 2021].

MATERIALS AND METHODS

Environmental protection activities in small river basins, regulated by the Water Code of Ukraine, prohibits changes in the topography and destruction of temporary riverbeds, streams and watercourses, as well as any other actions that would adversely affect the quality and quantity of river water. Comprehensive measures to preserve the water content of rivers and protect them from pollution are carried out by water users and land users whose lands are located in the river basin. However, under these conditions, all these prohibitions are constantly violated. As a result of anthropogenic pressure, the hydrochemical and hydrobiological regimes change, the sanitary condition deteriorates and the degradation of the landscape of river basins accelerates. Gradual decrease in water content and depth of rivers causes a decrease in their ability to natural self-cleaning processes [Bortnyk et al., 2021; Mali richky Ukrainy, 2017].

To prevent further deterioration of small rivers, it is necessary to conduct a comprehensive survey, to establish the ecological condition of each river, to choose the optimal and effective measures for its restoration. Improving the hydrological regime of small rivers is facilitated by clearing riverbeds, optimizing the regulation of their watercourses, and restoring riverheads. Cleaning of the river should take place in two directions, namely cleaning of debris, fallen trees and their branches, removal of excess vegetation, etc., as well as removal of silt and sediment, which is quite expensive and requires appropriate project documentation. In the urban parts of the watershed, the maintenance and restoration of water supply and sewerage systems, treatment plant, and overflow systems plays a crucial role in preventing river pollution. Construction or reconstruction of drainage systems reduces the flow from point and diffuse sources of surface runoff pollution. Important tasks are the cessation of unauthorized discharges of contaminated water and the functioning of natural landfills. Small rivers are often recreation areas and have a positive effect on the ecological properties of the area, which involves the organization of the coastal landscape

and recreational areas. Planning the territory of small river basins provides a permissible anthropogenic load on the use of water resources [Bortnyk et al., 2021; Mali richky Ukrainy, 2017].

The purpose of the paper is to establish the ability of the aquatic ecosystem of a small river to self-cleaning on the basis of hydrochemical indicators of water quality.

To achieve this goal, the following tasks are solved:

- to analyze compliance with sanitary and hygienic requirements of hydrochemical indicators of water of the river Kolodnytsia of the right tributary of the Dniester and to establish possible regularities of their changes;
- to establish the main factors of anthropogenic impact on a small river and the possibility of laboratory modeling of the flow of such rivers to establish the level of their ability to natural self-cleaning.

RESULTS AND DISCUSSION

In modern conditions, the state of water protection zones of small rivers with a sharply increased anthropogenic load is quite threatening. Due to significant reductions in runoff, a large number of small rivers ceased to exist. In connection with the violation of environmental legislation in the water protection zones of these rivers there are problems defining the boundaries of water protection zones and private construction on them, cluttering these areas with household waste, as well as unauthorized parking and other [Tsgoev and Ambalov, 2020].

Many of the small rivers of the Carpathian region flow through picturesque gorges. These places with their amazing beauty of recreational areas and clean air attract residents and guests to rest, but a large part of vacationers leave behind garbage. Given that these areas are visited by a large number of people, local entrepreneurs fence part of the water protection zones up to the water's edge and build them up with food establishments. The sanitary condition of these areas is satisfactory, but wastewater from these buildings without treatment enters watercourses and prevents free access to river banks.

The formal criteria for classifying a river as "small" are the catchment area, which does not exceed 2000 km^2, and its length up to 100 or 200 km. Along with these quantitative criteria, small rivers are characterized by an important qualitative indicator, which largely determines the indicative role of their water flow. As the catchment area decreases, the influence of local factors affecting the river basin increases. Thus, although in general the hydrological regime of a small river is naturally related to geographical zoning, it depends more on local factors of runoff formation than on large rivers [Bortnovskyi. 2021; Alekseevskyi, 2000].

Anthropogenic impact on production activities in the watershed affects many components of the landscape, and its impact can be common to different natural areas, namely wastewater discharge, runoff from urban areas and others, and caused by the peculiarities of zonal nature management. The most common consequence of the impact on water runoff is the transformation of vegetation and soil cover in the river basin. It is determined mainly by the specifics of agronomic measures on agricultural land, including plowing across the slopes, regulation of pasture intensity, etc. [Bortnovskyi, 2021; Yasinskii, 2012].

The degree of pollution of natural waters is caused by their interaction with various sources of minerals and chemicals available in the river network [Arihilam N. and Arihilam E., 2019; Khatri and Sanjiv, 2015]. Therefore, the problem of the feasibility of river water quality control remains extremely relevant now. In addition to direct measurements of pollutant concentrations, forecasting models need to be developed to determine the intensity of effluents from point and non-point sources that pose the greatest potential threat. The development of the model involves solving the inverse problems of water quality control. At the same time, determining the mass flow of pollutants entering the river from these sources of pollution located in the catchment area is quite problematic [Filimonov et al., 2021].

When analyzing the distribution of concentrations of chemical elements in a watershed, the term "geochemical field" is often used, which is a territory with similar physicochemical conditions, including the chemical content of the elements. This field can be relatively homogeneous, smoothly variable or complicated by local anomalies. Thus, the distribution of the specific mass flow of pollutants entering the river will directly depend on the homogeneity of the geochemical field, which is a decisive factor in creating models of diffuse runoff. The research [Filimonov et al., 2021] uses a one-dimensional model to calculate

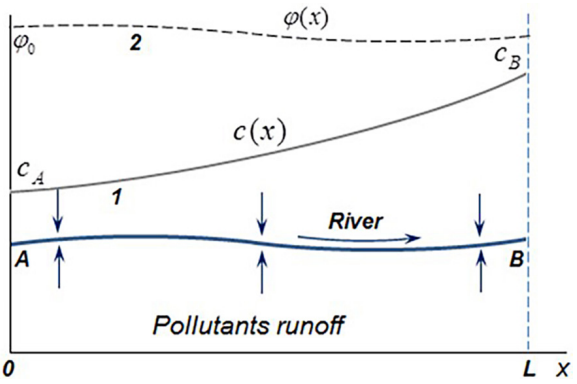


Figure 1. Distribution scheme: 1 – concentrations of pollutants; 2 – functions of the source of pollution on the river section of length L [Filimonov et al., 2021]

concentration fields taking into account the diffusion of pollutants in the studied section of the river. The model gives estimates of the mass flow rate of stationary diffuse effluents using the optimization method for conservative impurities. In the scheme of Figure 1 shows the distribution of pollutant concentrations in the channel.

The process of decentralization in Ukraine provides opportunities for local solutions to the problems of small rivers. Ecological community development projects help to improve the ecological condition of rivers through scientifically sound functional zoning in the river basin, organization of local community water management system, spatial planning of coastal river zones, creating a comfortable environment for recreation, etc. [Bortnyk et al., 2021].

The problem of preservation and restoration of small rivers in Ukraine has been exacerbated not only by climate change, but largely by increasing anthropogenic impact in river basins. Legal regulation of the environment regime remains formal and does not involve the problem [Bortnyk et al., 2021]. The indicative role of water runoff of small rivers is due to the close connection with the landscape conditions of watersheds, which in turn are affected by economic activity. Anthropogenic changes in water runoff, expressed in the increase of its annual amplitude, are determined by the direct transformation of soil and vegetation cover of watersheds, which causes changes in the ratio of surface and groundwater runoff. Indirect impact is to increase the runoff of sediments that exceed the erosion-transport value and contribute to siltation of watercourses and their partial degradation [Bortnovskyi, 2021].

In the territory of the Stryi river basin, the natural landscapes are maximally preserved in comparison with other regions of Western Ukraine, but in modern conditions we observe an increase in the negative anthropogenic impact on the quality of natural waters. Hydrodynamic barriers or hydrodynamically active areas of mountain rivers are important for increasing the efficiency of self-cleaning processes, where the water flow is significantly saturated with oxygen, which activates the processes of biochemical and biological self-cleaning of natural waters. The presence of HAA in the mountainous and foothill areas of the rivers of the Carpathian region contributes to the processes of natural self-cleaning of natural waters. On the basis of the laboratory of sewage treatment plants of ME "Stryivodokanal" researches of factors and conditions of formation of chemical composition of natural waters of the basin of the river Stryi, and also sites of considerable anthropogenic influence were carried out. This allowed for more detailed monitoring of the quality of natural waters of the basin, focusing more on the identified problem areas of negative impact [Snitynskyi et al., 2021a; Snitynskyi et al., 2021b].

We conducted field and laboratory research on the Kolodnytsia River, which is a right tributary of the Dniester River. It river source are on the northeastern slopes of one of the Oriv ridges near the village of Zimivky, flows mainly to the northeast and partly to the north within Drohobych, Stryi and Mykolaiv districts of Lviv region and has 8 tributaries (Fig. 2). The total length is 69 km and the area of the basin is 323 km. The riverbed is generally 4 to 8 m wide, but its maximum width is up to 35 m. The average river depth is in the range of 0.5–1 m, but there are places with depths close to 3 m. The slope of the river is 1.3 m/km, in the upper reaches of the river is typically mountainous, and below is flat (Fig. 3) [Kolodnytsia river].

It was found that in the Kolodnytsia River the processes of self-cleaning are quite active, which are caused by the hydrological characteristics of the river and the presence of hydrodynamically active areas in the foothills of the basin. Therefore, at present there is no steady excess of pollutants relative to the MPC.

To verify the results of theoretical and field research, an existing experimental setup was designed and improved, which provided conditions for modeling the flow on the HAA of mountain

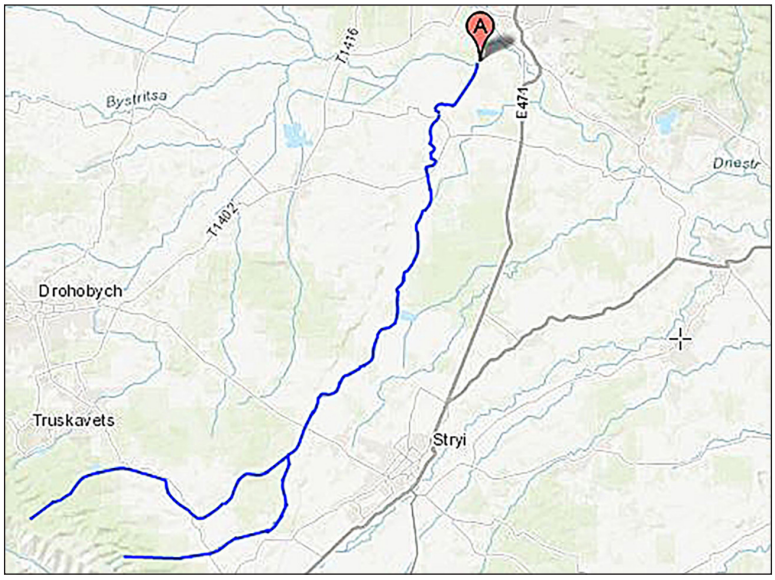


Figure 2. River network of the Kolodnytsia River to the confluence with the Dniester River

a) b)

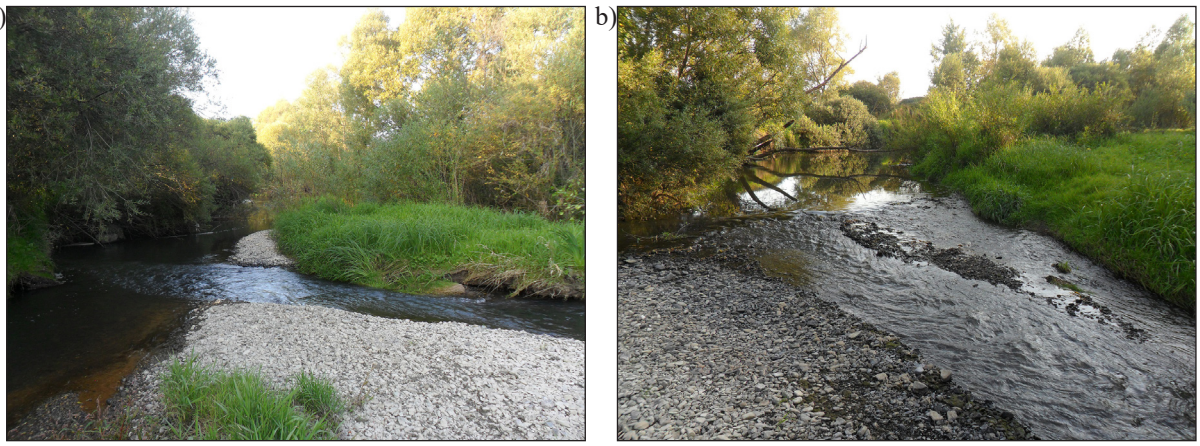
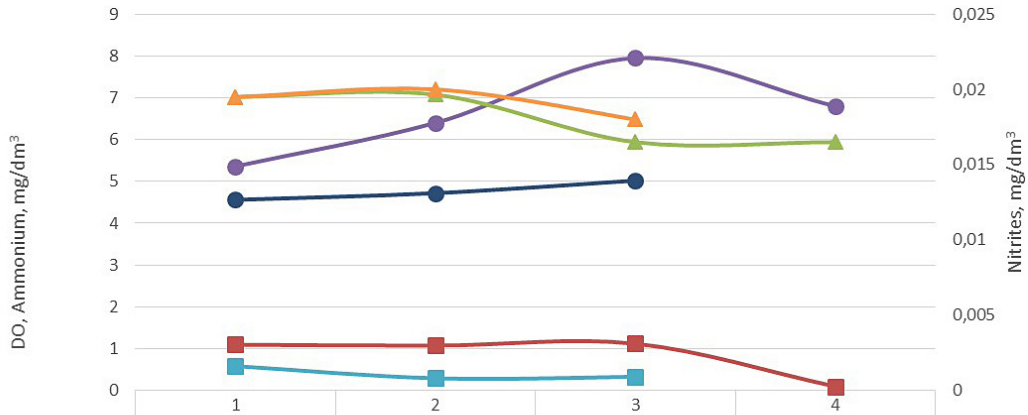


Figure 3. General view of the Kolodnytsia riverbed



	1	2	3	4
1. Ammonium	1,0959	1,0726	1,1192	0,0959
3. DO	5,36	6,4	7,95	6,8
4. Ammonium	0,5829	0,29145	0,3264	
6. DO	4,56	4,72	5,02	
2. Nitrites	0,0195	0,01965	0,0165	0,0165
5. Nitrites	0,0195	0,02	0,018	

Figure 4. Comparative analysis of changes in the average values of the chemical composition of water in the model HAA with the results of field research (17 experiments)

rivers in accordance with the laws of similarity theory and the principles of hydrodynamic modeling. Based on the results of the analysis of field observations in the foothills of rivers, as well as regulatory and project documentation, the limits of the main active factors were determined, namely Freud's number, flow depth and flow velocity, which are decisive in studying the impact of HAA on flow self-cleaning processes [Snitynskyi et al., 2021a].

In Figure 4 shows the results of laboratory studies of water flow in the tray on the model site and the natural hydrodynamically active area. In the laboratory of the Department of Hydraulic Engineering and Water Engineering of Lviv Polytechnic National University, samples were taken from three points, and in the full-scale HAA from four, modeling the area of restoration and stabilization of river flow. The results of the experiments confirm the similarity of the processes of natural self-cleaning of river waters in the laboratory and the real flow of mountain rivers. Given the complexity of field observations, the possibility of experimental laboratory reproduction of these processes, subject to similarities and criteria for modeling hydraulic phenomena. When the flow passes through HAA, we see its significant oxygen saturation, which helps reduce ammonium and nitrite pollution.

CONCLUSIONS

The condition of a small river is an indicator of water safety of natural surface waters. Large watersheds are influenced by many factors, which makes it possible to identify and predict possible negative factors. In order to prevent and reduce the sources of man-made pollution of the aquatic environment of large rivers, it is necessary to analyze in detail the state of water quality of small rivers. The connection with the landscape-ecological situation in the basin allows us to consider the study of spatio-temporal variability of water runoff of small rivers as a geo-ecological task. Its solution is important for the development of practical recommendations for the organization of environmental management at the basin level. The diversity of landscape and ecological conditions is the basis for the possibility of using differentiated approaches to the management of small river basins and their water resources.

Further studies of the flow structure will allow to offer refined calculation dependences and modern scientific methods for estimating the processes of self-cleaning of surface waters and anthropogenic load in mountain river basins to calculate the optimal volumes of wastewater discharges from treatment plants ME "Stryivodokanal".

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