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TRANSFORMATION PROCESSES IN THE RIVER-BASIN SYSTEM OF BYSTRYTSIA AND THEIR GEOINFORMATION-CARTOGRAPHIC MODELS

The problem of assessing the scales and direction of the development of transformation processes that occur in river systems and components of the natural environment of their basins under the influence of a wide range of factors in the long run, remains an urgent task. This is due to the diversity of human and societal impacts on river basin systems (RBS) and the need to assess the effects of global and regional climate change and their impact on water runoff, sediments and solutes discharges, the geoecological status of river basin systems. To a large extent, this applies to the river basin systems of the Carpathian region, thus the river basin system of Bystrytsia is being selected as a study object, as well as the right-bank tributary of the Dnister, located in Ivano-Frankivsk region and covering mountain (Ukrainian Carpathians) and foothill (Precarpathian) landscapes with peculiar natural and economic conditions. This RBS is typical for the Carpathian region, so the results will also reflect the situation in other RBS. The **aim** of the paper is the quantitative assessment of the scales and long-term trends in the development of transformation processes in the structure of the river basin system of Bystrytsia , the exploration of the range of factors responsible for these changes and their geoecological consequences and the reflection of the results on a series of cartographic models of RBS. The performed research is based on a complex technique, which combines methods of cartometric analysis of the structure of river systems on the basis of different time (1855, 1925, 1955, 1975, 2008) topographic maps of scale 1: 100 000; methods of analysis of the state of landscape components (soils, forest cover, land structure, etc.) and their long-term changes; methods of analysis of monitoring data on changes of objects and development of processes (water, sediments, and dissolved substances of runoff in rivers, manifestation of erosion, mudflow, landslide, karst, mining processes; industrial, agricultural, forestry and water management activities, sewage discharges, surface water and groundwater intake, etc.); methods of remote sensing data analysis and geoinformation-cartographic modeling. As a **result** of the performed research the conceptual model of transformation processes in river basin systems which occur under the influence of natural and anthropogenic factors is developed, parameters of structure of river systems are defined (number of rivers of different orders, their length, general order of RBS on each "time slice" of its state), the scale of development of transformation processes in RBS Bystrytsia from one time slice to the next and for the whole studied period, the degree of influence of natural and anthropogenic factors on these transformations and their geoecological consequences is revealed and estimated as well. A series of digital maps of RBS Bystrytsia have been compiled, which reflect the main results of the research. A set of environmental measures aimed at improving the river and basin system of Bystrytsia and measures to optimize nature management is substantiated.

Key words: geoecological conditions; geoinformation and cartographic models; river system; river basin system; transformation processes.

Introduction

The interest of geographical, economic, environmental and other sciences in studying changes in the environment and society under the influence of a wide range of factors, encourages researchers to develop methodologies and techniques for assessing their specific diversity, distribution (geography), intensity of development and various consequences for natural geosystems, mankind and society. Geographical features of the land surface, such as river systems and their basins, are no exception. From the standpoint of systems analysis, we call them multi-ordered river basin systems (RBS). We proposed the terms “transformation”, “transformation processes” for the set of changes in the structure of RBS, their state and functioning, which occur under the influence of both natural and anthropogenic factors [Kovalchuk, 1987, 1995]. The Dictionary of Foreign Words (1977, p. 676) defines transformation as “change, transformation of the kind, form, essential properties of something”, and transforming as “the process of reshaping, changing a certain object”. Since RBS are multicomponent formations, which combine natural, man-made and economic components, integrated into multi-order sub-basin geosystems, being in a natural state or a state altered by human activities, so the transformation processes encompass both individual components of geosystems and geosystems in general, including natural-economic ones. The intensity of transformation processes, their direction is significantly influenced by the level of economic development and specialization of the economy, natural-geographical conditions of RBS (relief, geological and tectonic structure, soil and vegetation cover, climatic factors, surface and groundwater, water supply level of population and economy, volumes of sewage waters and the degree of their purification, natural resource potential and the structure of its economic utilization, the resilience of geosystems to anthropogenic impacts and climate change, etc.) Basin systems are the geospatial basis for economic development planning and nature protection.

The purpose of the article is to identify the distribution and to assess the scales of the development of transformation processes in the river basin system of Bystrytsia (Eastern Carpathians) in the XIX–XXI centuries and to create a series of cartographic models that reflect these processes and their geoecological consequences.

During the development of human society, an economic changes are taking place, i.e. transformations, which are defined as "the process of reshaping of one economic system into another, accompanied by the demise of some elements, features, properties and the emergence of others" [Economic Encyclopedia, 2000, vol. 3, p. 687]. They are accompanied by changes in the types and scale of society's impact on the environment and its components and cause certain geoecological consequences for the environment.

Methods

Experience in this field shows that in order to determine the direction of transformational changes in the structure of river systems and landscape components of their basins and geoecological consequences of these processes, it is advisable to use the method of historical and geographical comparisons of "different time slices" of the studied objects [Kovalchuk, Krul, Romanchuk, 2008] using multi-time large-scale maps, space imagery and field research. From these positions, we conducted research on the river basin system (RBS) Bystrytsia, located in the Ivano-Frankivsk region within the Precarpathians and the Ukrainian Carpathians. Some of the obtained results are covered in this publication.

Results

The state of study of transformation processes in RBS. The main works. As the transformation processes in river systems and their catchments occur under the influence of a wide range of natural and anthropogenic factors, a huge number of works is dedicated to the assessment of the extent of their impact on RBS and components of their landscapes, the study of changes in states and mechanisms of functioning of river systems and basin geosystems, the development of erosion-accumulative and other exogenous processes in them, the solution of problems of nature optimization therein. Due to the impossibility of a systematic analysis of all of them (this may be the task of a separate study), in our review we will focus on studies of the transformation of the structure of river systems, its geoecological consequences and the communication of the obtained results.

The studies of transformation processes that are developing in river systems of Ukraine for a long time under the influence of natural and anthropogenic factors were initiated by I. P. Kovalchuk (1982, 1987) in the early 80's of the twentieth century. Thereafter they were proceeded by I. P. Kovalchuk, P.I. Shtoiko (1984, 1989) on the examples of river systems of Western Podillia, by I. P. Kovalchuk, S. I. Volos, L. P. Kholodko (1992) in the Western Bug basin and by I. P. Kovalchuk and M. A. Petrovska (2003) within Roztochya, I. P. Kovalchuk and A. V. Mykhnovych (2012) and O. V. Pylypovych in the river systems of the Dniester basin, I. P. Kovalchuk, Ya. B. Khomyn (1992), I. P. Kovalchuk and L. F. Dubis (1998) in the river basins of Transcarpathia, M.P. Chemerys (1994) in the river systems of Volyn Polissya, I. P. Kovalchuk, T. S. Pavlovska (2008) in the basin of the Goryn river, Y. O. Kiselyov in the basin of Siversky Donets, N. M. Ivanova, V. M. Golosov, I. P. Kovalchuk (2005) in the river systems of the Eastern European Plain, I. P. Kovalchuk, V. P. Krul, S. P. Romanchuk (2008) in different regions of Ukraine. Later such studies were being continued by I.P. Kovalchuk and V. S. Podobivskyi (2014) within the Gologor-Kremenets ridge, Yu. M. Andreychuk (2012) in Koropets river basin, O. I. Shvets (2013) in the Berezhnytsia river basin in Precarpathia, N. S. Kruta (2014) in the basin of Lug River, V. H. Smyrnova (2003) in Poltava region and others. O. V. Pylypovych and I. P. Kovalchuk (2017) have published a generalizing monograph, which from a geoecological point of view assesses both the state of the Upper Dnister river basin system and the transformation processes in riverbeds, river systems, land structure, water and sediments runoff, surface water quality, distribution and intensity of development of slope and channel exogenous processes in RBS of the Upper Dnister. Similar studies are also being conducted at Ternopil National Pedagogical University named after V. Hnatyuk. under the direction of L. P. Tsaryk [Bakalo, Tsaryk L., Tsaryk P., 2018]. Interesting results were obtained by Professor Yuriy Yushchenko of the Yuriy Fedkovych National University of Chernivtsi and his students – O. V. Palanychko, A. O. Kyryliuk, M. D. Pasichnyk, L. V. Kostenyuk and others. They concerned both the structure of the river systems of the Precarpathians and the Carpathians, and trends in the development of channel processes, changes in the morphology of floodplain-channel complexes of rivers, their ecological status. Research on similar topics is conducted at the Taras Shevchenko National University of Kyiv by Professor O. G. Obodovsky (2008, etc.) and his students – Z. V. Rozlach, O. S. Konovalenko, O. Ye. Yaroshevych. The research of Professor V. M. Samoylenko (2018) and his students – D. V. Ivanko, V. V. Plaskalnyi – is aimed at assessing the level of anthropization of geosystems of the Desna river basin and physical-geographical regions of Ukraine, and that of O. I. Mykytchyn and T. B. Skrobach (2018) – of the scales of changes in forest cover as a factor influencing the state of RBS Berezhnytsia.

Among foreign scientist , these questions are raised in the works of N. N. Ivanova, V. N. Golosov (2005, etc.), Dang M. N. et al (2013, 2019), Gregory K. I. (2006), Karoliny Mostowik et al. (2019), Min Xu et al. (2020), Pinto U. (2014), Van Denderen et al. (2019), Rossa O˜Briain (2019), etc.; in recent years more and more attention is paid to assessing the impact of climate change on the state and functioning of river basin systems, and on their changes.

The river system is most often represented in the form of a tree-like graph, in which two rivers of the first order, merging, form a river of the second order; two rivers of the second order, merging, form a river of the third order, etc. The river of the first order is a stream that begins with a source and ends with the confluence with another similar watercourse. This model of coding of watercourses in the river system is called the Strahler-Philosoph scheme. It is convenient for solving problems of hydrology, geomorphology, geoecology. We used it to assess the scale of transformation of the structure of river systems [Kovalchuk, etc., 1987; Kovalchuk, Shtoiko, 1989; Kovalchuk, Schuber, Shvets, Andreychuk, 2013].

The essence and types of transformation processes. What types of transformation processes occur in river systems and their basins under the influence of natural and anthropogenic factors? Influence of what factors is analyzed in researches? On the basis of which information base, such conclusions are drawn about the distribution, scale of development, geoecological, hydrological, geomorphological and landscape-geographical consequences of the transformation of river systems and landscape components in their basins?

In response to these and other questions concerning the study of transformation processes in RBS and the factors influencing them, we have developed a conceptual model of their structure (Fig. 1).

As can be seen from Fig. 1, among the whole spectrum of transformations occurring in the RBS, the following are distinguished: 1) transformations of river systems (their structure, length and number of rivers, their orders, streams and floodplains and erosion-accumulation processes in them); 2) transformation of properties of components and geosystems of the watershed; 3) transformation of the functioning of the river and basin subsystems of the RBS; 4) transformation of economic activity in the RBS (through its natural evolution and forced changes due to the need to take into account the range of adverse processes that develop in both river and basin systems under the influence of management).

Let us dwell in more detail on the essence of transformation processes in RBS of mountain and foothill regions. Here, the following transformations are taking place under the influence of the spectrum of factors: 1) *increase or decrease in length of rivers of different orders.* Reducing the length of rivers in river basin systems occurs primarily under the influence of economic activities – deforestation, plowing, agricultural, construction, industrial activities and intensification of erosion processes in watersheds, siltation of riverbeds by slope erosion products and their own sediments, lowering of groundwater levels, etc. The increase in the length of watercourses can occur under the influence of natural (increasing rainfall, rising groundwater levels, etc.) as well as anthropogenic factors (construction of reclamation and irrigation canals, construction of reservoirs and ponds, etc.); 2) *decrease or increase in number of rivers of different orders* (the causes are essentially the same as mentioned in paragraph 1); 3) *changes in the size of riverbeds* (width, depth, shape). This occurs under the influence of both natural and anthropogenic factors; 4) *changes in the distribution and ratio of bottom and side erosion and sediment accumulation in the riverbed* of one river or in the river system as a whole. Most often, these changes occur under the influence of activities in the catchment area and in the floodplain-river complexes of rivers; 5) *changes of morphology and morphometric characteristics of the floodplain-riverbed complex of rivers.* The reclamation works in floodplain complexes and hydraulic engineering works in riverbeds and riverside areas are here the main reasons; 6) *deteriorating or improving water quality of surface waters of rivers of different orders.* Here again the responsibility lies within human activity; 7) *decrease or increase in sediment runoff*, which most often is caused by deforestation of slopes and plowing of lands and intensification of erosion-accumulative processes; 8) *changes in the ratio between the intake of water from rivers and the discharge of wastewater to them*. Human activity is fully responsible for these processes; 9) *irregularity in water and sediment discharge increases under the influence of global and regional climate changes* – low water periods become longer, water levels in rivers during them are becoming lower; at the same time the degree of extremeness of floods and the extent of destruction caused by them are also increasing. The floods in the Carpathian region on June 20–30, 2020 are a vivid illustration of it; 10) *the structure of land use, water utilization and especially forest use* (prevalence of deforestation) is changing in water catchments of rivers of different orders. These changes have caused the transformation of water and sediment runoff both in watersheds and in riverbeds of various orders, large-scale destructions of hydraulic structures and roads, flooding of lands and settlements; 11) due to the influence of tourism and recreation activities, their influence on the state of mountain and river-valley landscapes and the processes developing therein is significantly increasing in connection with their active development in RBS Bystrytsia.

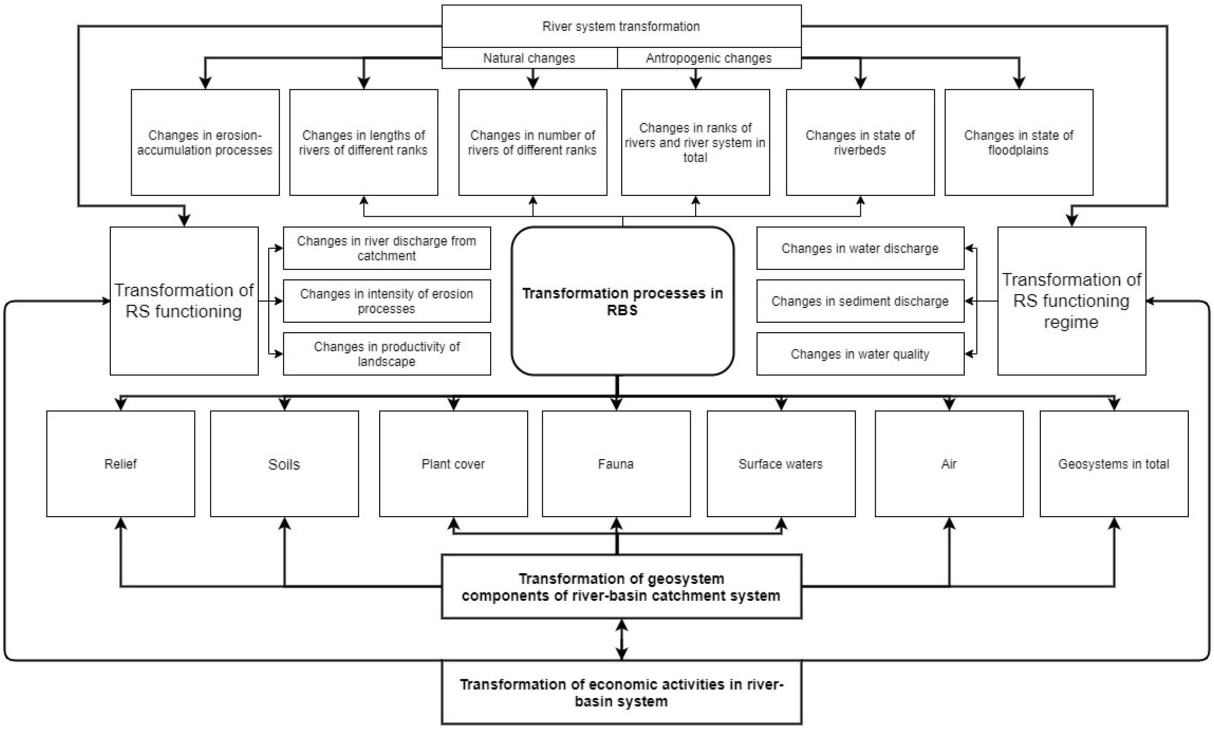

Fig. 1. Conceptual model of transformation processes in river-basin systems under the influence of natural and anthropogenic processes

Naturally, these transformation processes and factors influencing them are being studied by both domestic and foreign scientists. Among the range of factors, most attention is paid to anthropogenic impacts on river and basin systems (deforestation, plowing of sloping lands, construction of roads, pipelines, housing and industrial and recreational facilities, water management, extraction of minerals and building materials, water intake and wastewater discharge, etc.) and their geoecological consequences. Among the natural factors, climatic ones are being studied (precipitation, their intensity and spatio-temporal dynamics, the ratio of precipitation in the form of rain and snow, air and soil temperature), as well as biotic factors (the degree of vegetation cover development, its species diversity and discharge-regulating ability), properties of soils (infiltration and water holding capacity, anti-erosion resistance), hydrological factors (dynamics of water and sediment runoff, extreme floods and droughts, consequences of their impact on the state of riverbeds), as well as relief parameters (steepness and length of slopes, the form of their longitudinal and latitudinal profiles, vertical and horizontal dissection of the earth's surface), on which depend the distribution and intensity of exogenous processes and the suitability of the terrain for its economic use.

Information basis of research of transformation processes in RBS. We have used the following sources as an information basis for the studies of transformation processes in river systems and their catchments,: 1) large-scale (mostly of scale 1: 100,000 or close) topographic maps (XVIII–XX centuries); 2) different-time statistical information that reflects the nature and intensity of human economic impact on RBS (ratio of lands used for different purposes, share of arable land, share of forest cover in catchment areas, forest clear-cutting volumes, emissions of pollutants into the atmosphere and wastewater discharges into the river network, water intakes from rivers and groundwater horizons, etc.); 3) archival materials of geological expeditions, botanical and soil studies, data of hydrometeorological observations at hydrological and meteorological stations located in basin systems, information on extreme floods, droughts, mudflows, avalanches, landslides, manifestations of karst and other processes; 4) data of cadasters (of land, water, mineral resources, etc.); 5) scientific periodicals, monographs, reference books, encyclopedias, etc.

The scale of development of transformation processes. Based on these starting points and information and analytical base, we assess the scale of development of transformation processes in the river system Bystrytsia – right-bank tributary of the Dnister, located in Ivano-

Frankivsk region and covering the mountain and foothill parts of the Carpathians.

The river system of Bystrytsia is formed by integrating three subsystems – Bystrytsia-Solotvynska, Bystrytsia-Nadvirnyanska and Vorona. Bystrytsia flows into the Dniester on the north-eastern outskirts of Yezupil village. In the process of study of RBS Bystrytsia, a series of digital cartographic models (more than 100) were created, starting with a physical map (Fig. 2), hydrographic network models (Fig. 3) and river density (Fig. 4) and ending with a series of maps of anthropogenic pressure and geoecological status of its sub-basins [Kovalchuk A., Kovalchuk I., 2018].

These maps reflect both the composition (structure) of the river system and the natural conditions in its catchment, the factors influencing the condition and functioning of riverbeds, the components of basin geosystems and the geoecological situation therein They help to identify the degree of influence of changes in the natural environment on the scale and trends of transformation of the structure of river systems. The structure of the Bystrytsia river system was studied for the following temporal “cross-sections”: 1) 1855; 2) 1925; 3) 1955; 4) 1975; 5) 2008. The following topographic maps were used for this purpose: 1) Kummersberg atlas maps of 1855, scale 1: 115200 [Administrativ Karte…, 1855]; 2) WGI maps 1925–1933 (scale 1: 100000); 3–4) maps of the General Staff of the USSR from 1955 and 1975 and maps of the Kyiv Military Cartographic Factory from 2008 (scale 1: 100000); 5) spatial images for 2020 (resolution 10 m, scale 1: 100000).

The research algorithm included the following steps: 1) selection of sheets of topographic maps for one time slice on RBS Bystrytsia; 2) delineation of the RBS catchment boundary; 3) marking the rivers of I, II, III, IV, V and VI orders on the map; 4) counting the number of rivers of each order in the RBS and entering these data in the appropriate table; 5) determining the lengths of all rivers of each order and entering these data in the appropriate table; 6) construction of a stylized graph-scheme of the structure of the river system on the studied time slice of its state; 7) similar studies of the structure of the river system at each subsequent time slice of its state; 8) comparative analysis of the parameters of the structure of river system for each time slice and determination of indicators of transformation of the number and length of rivers of all orders (increased, decreased or unchanged number and length of rivers of different orders in the river system); 9) determining the role of natural and anthropogenic factors that led to the development of transformation processes in the structure of the river system of Bystrytsia; 10) justification of a set of measures aimed at improving the condition of small rivers, restoring their water content, optimizing the functioning of basin geosystems.

The results of studies of the structure of Bystrytsia river system on different time slices of its state and of the transformation processes are shown in Table 1, Table 2 and Table 3.

As can be seen from Table 1, the structure of the river system of Bystrytsia is dominated by rivers of the first order. Their number in different time slices decreases or increases by 0.14–2.6 % and is from 75 to almost 78 % of the total number of rivers in the RBS. The dominance of the smallest rivers is a priori a prerequisite for the development of transformation processes in the structure of the river system, i.e. drying out, length reduction in low-water periods and vice versa, restoring water discharge, increasing length or even changing order in water-rich periods, because the smallest and the most unstable elements are the first to respond to external influences, by transforming their own state.

The number of second-order rivers ranges from 18.34 % to 16.9 % in different years. These fluctuations are caused not only by changes in the number of existing second-order rivers, but are also connected with the transition of third-order rivers to the second-order ones (with the development of degradation processes) and the first-order to second-order ones (with increasing water content and conversion of gulches into permanent watercourses or construction of drainage canals in river valleys).

The share of third-order rivers at different stages of development of the Bystrytsia river system varies from 4.8 to 3.93 %, fourth-order rivers – from 1.5 to 0.6 %, fifth-order rivers – from 0.2 to 0.22 %, and rivers of order VI – from 0 to 0.1 %.

Absolute indicators (number of rivers of each order in the sub-basins of the river-basin system of Bystrytsia on five different time slices), which reflect the degree of saturation of the whole river system with watercourses of different orders, are given in Table 2. These data show that the difference between the largest and the smallest number of watercourses of different orders in the RBS Bystrytsia and its subsystems on 5 time slices was: 62 rivers (21.1 %) in the subsystem Bystrytsia-Solotvynska, 159 rivers (54.1 %) in the Bystrytsia-Nadvirnianska sub-basin, 58 watercourses (19.7 %) in the Vorona sub-basin and 15 rivers (5.1 %) in the Bystrytsia sub-basin proper. In general, the difference between the largest number of permanent watercourses of different orders in the RBS Bystrytsia and their smallest number in the period between 1855 and 2008 was 294 watercourses or 21.7 % of rivers of different orders.

It should be noted that the comparison of the obtained results with the data of research of transformation processes in the river systems of Western Podillya [Kovalchuk, Shtojko, 1992] testifies to rather high, but at the same time almost twice lower rates of development of transformation-degradation processes in river systems of the Precarpathians and the Carpathians, in comparison with river systems of Podillya region. Indirectly, this fact indicates a strong influence of climatic factors on the state of the river systems of the Carpathians and Precarpathians and their mode of functioning, and a stronger effect of anthropogenic factors (deforestation, plowing of sloping lands, drainage and reclamation works in river valleys) on the state and functioning of river-basin systems of Western Podillya.

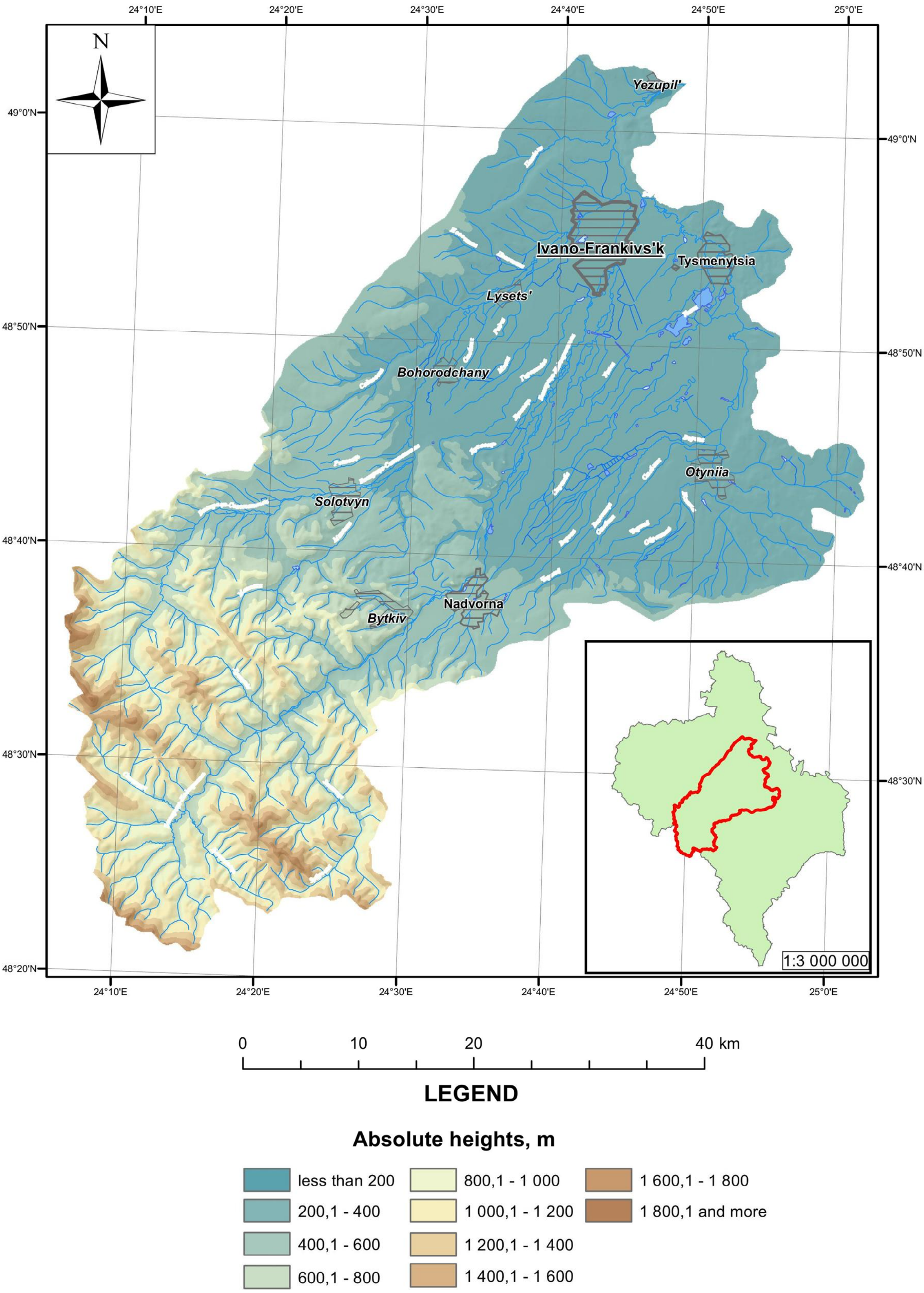

Fig. 2. Map model of relief and river systems of Bystrytsia RBS

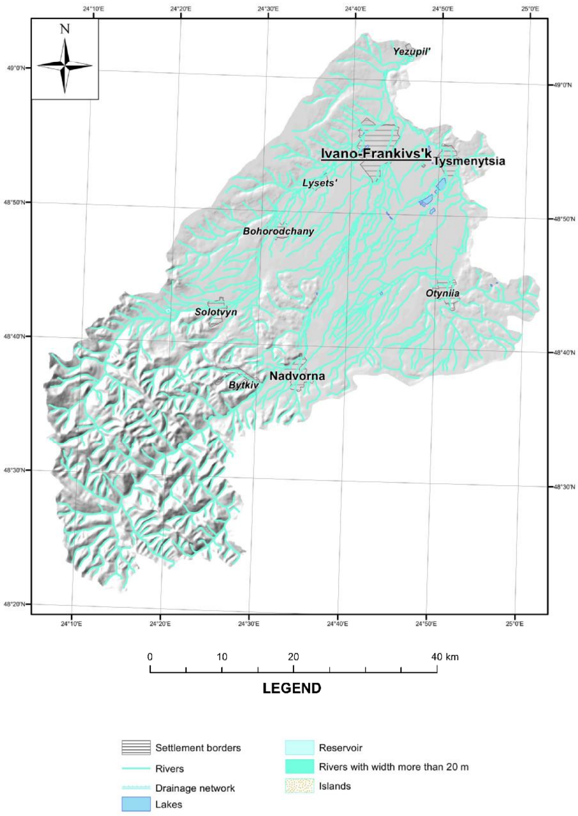

Fig. 3. Map model of hydrological network in Bystrytsia river basin

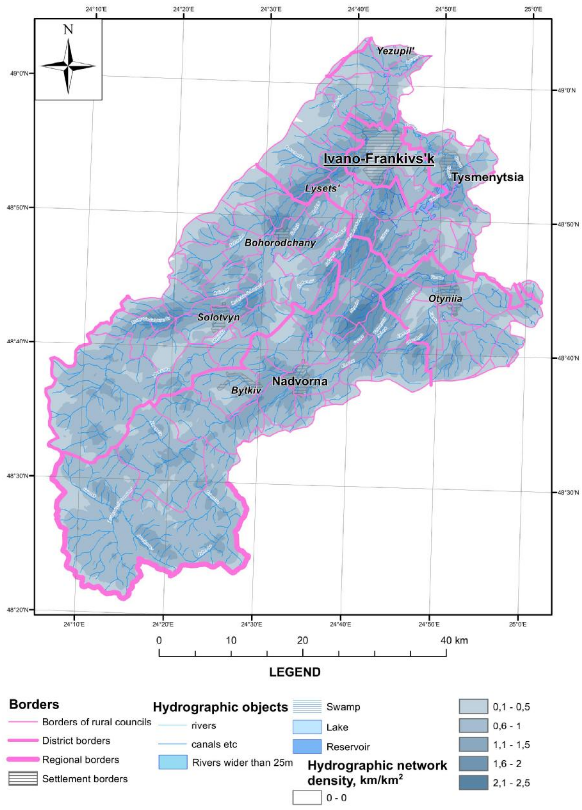

Fig. 4. Map model of hydrological network density in Bystrytsia river basin

Table 1

The structure of the river system of Bystritsia at different stages of its development (XIX–XXI century)

Year	Orders of rivers in Bystrytsia river system, the number of rivers of different order and their share from the total number of rivers, %												Total number of rivers in RBS
	I		II		III		IV		V		VI		I – VI
	number	% from total	num ber	% from total	num ber	% from total	num ber	% from total	num ber	% from total	number	% from total	number
1855	1016	75.14	248	18.34	65	4.80	20	1.50	3	0.22	0	0	1352
1925	1120	77.60	250	17.30	61	4.20	9	0.60	3	0.20	1	0.10	1444
1955	1162	77.70	259	17.30	59	3.93	12	0.80	3	0.20	1	0.07	1496
1975	1093	76.80	251	17.64	63	4.42	12	0.84	3	0.20	1	0.10	1423
2008	1068	77.84	232	16.90	56	4.10	12	0.87	3	0.22	1	0.07	1372

Table 2

Ratios of rivers of different orders in Bystrytsia river system (Ivano-Frankivsk region)

Bystrytsia river system and its subsystems	Years	Orders of rivers and their total number in Bystrytsia river system						Total number of rivers in river system
		I	II	III	IV	V	VI	I–VI
Bystrytsia-Solotvynska	1855	368	81	27	7	1	–	484
	1925	381	95	26	2	1	–	505
	1955	349	68	21	4	1	–	443
	1975	358	78	26	4	1	–	467
	2008	351	69	22	4	1	–	447
Bystrytsia-Nadvirnianska	1855	518	134	32	11	1	–	696
	1925	589	116	29	5	1	1	741
	1955	663	153	31	6	1	1	855
	1975	626	147	30	6	1	1	811
	2008	615	140	28	6	1	1	791
Vorona	1855	92	25	4	2	1	–	124
	1925	104	29	4	2	1	–	140
	1955	110	30	6	2	1	–	149
	1975	70	17	6	2	1	–	96
	2008	67	16	5	2	1	–	91
Bystrytsia	1855	38	8	2	–	–	1	48 + 1*
	1925	46	10	2	–	–	1	58 + 1*
	1955	40	8	1	–	–	1	49 + 1*
	1975	39	9	1	–	–	1	49 + 1*
	2008	35	7	1	–	–	1	43 + 1*

Note: 48 + 1* – River Bystrytsia is formed by the confluence of Bystrytsia-Soloytvynska and Bystrytsia-Nadvirnianska. In 1855, there were 48 tributaries of different orders in the basin of this section of the river, 6 of which flowed directly into the river Bystrytsia. 1* – is the main riverbed of the Bystrytsia River, stretching from the confluence of the Bystrytsia-Solotvynska and Bystrytsia-Nadvirnianska to the confluence with the Dniester River.

Table 3

Structural indicators of Bystrytsia river system (Ivano-Frankivsk region)

River order	Years	Total number of rivers of given orders	Total length of rivers of given orders, km	% from total length of rivers in river system	Average length of rivers of given order, km
1	2	3	4	5	6
I	1855	1016	1121.5	49.4	1.10
	1925	1120	1269.3	52.2	1.14
	1955	1162	1326.2	52.1	1.06
	1975	1093	1149.5	50.6	1.07
	2008	1068	1103.7	50.3	1.03
II	1855	248	508,4	22.4	2,05
	1925	250	539.9	22.2	2.16
	1955	259	557.7	21.9	2.15
	1975	251	504.2	22.2	2.01
	2008	232	489.7	22.3	2.11
III	1855	65	322.6	14.2	4.96

Cont. Table 3

1	2	3	4	5	6
	1925	61	327.5	13.5	5.37
	1955	65	342.1	13.5	5.26
	1975	63	299.8	13.2	4.76
	2008	56	285.7	13.0	5.12
IV	1855	20	151.4	6.7	7.57
	1925	10	137.1	5.6	13.71
	1955	12	146.5	5.8	12.2
	1975	12	147.2	6.5	12.27
	2008	12	145.3	6.6	12.11
V	1855	3	151.2	6.7	50.4
	1925	3	141.6	5.9	47.2
	1955	3	154.6	6.1	51.5
	1975	3	155.3	6.8	51.8
	2008	3	154.9	7.1	51.6
VI	1855	1	14.2	0.6	14.2
	1925	1	15.8	0.6	15.8
	1955	1	16.6	0.6	16.6
	1975	1	16.9	0.7	16.9
	2008	1	15.2	0.7	15.2

The next step in the analysis of transformation processes in RBS Bystrytsia was to compare the length of watercourses of each order on different time slices of the state of the structure of the Bystrytsia river system. The results of these studies are shown in Table 3. It shows that first-order rivers account for 49.4–52.2 % of the total length of rivers of different orders of this basin system in 5 time slices. The average length of these rivers at different time intervals ranges from 1.03 to 1.14 km. Such a small length of these rivers is a prerequisite for their significant susceptibility to anthropogenic influences. Therefore, they are primarily undergoing transformations – they are transforming from permanent watercourses into temporary ones or (with increasing anthropogenic impact on the natural landscapes of their catchments) cease to function as permanent watercourses at all.

The share of second-order rivers in the total length at different time slices reaches 21.9–22.4 %, and their average length is 2.01–2.16 km. These values indirectly indicate their low water content and significant susceptibility to changes with increasing inflow into the riverbed of products of slope erosion of soils.

As can be seen from Table 3, the total length of rivers of the III order does not exceed 13.0–14.2 % of the total length of rivers of all orders, and the total length of rivers of the IV–V orders is almost the same: 5.6–6.7 % and 5.9–7.1 %, respectively. At the same time, the average length of IV order rivers is 7.57–13.7 km, and that of V order rivers 47.2–51.8 km. These values indicate an increase in the capacity of rivers with increasing order, and hence a decrease in their susceptibility to the effects of anthropogenic impacts on the landscapes of their catchments.

To reflect the spatial heterogeneity of the factors influencing the RBS and the geoecological consequences of this influence, A. I. Kovalchuk created a series of cartographic models. Some of them are presented below. We will start the analysis with two most important factors – forest cover share in sub-basins (Fig. 5) and arable share in agricultural lands (Fig. 6). The forest cover of the sub-basins as of 2016 varies from 7.0–20.0 % in the Precarpathian part of the basin to 60–80 % and more in the Carpathian part. It continues to decline under the influence of deforestation, windfalls, pests and diseases.

Agricultural development of basin subsystems is best reflected in the level of plowing of agricultural land (Fig. 6), which in 2016 varied from a few to 20 % in the middle mountains of the RBS, from 20 to 50 % in the low mountains up to 60–80 % and more in middle and lower parts of Bystrytsia basin. It is established that the areas of the highest share of arable land coincide with the areas of active manifestation of slope erosion-accumulation processes and siltation of small riverbeds, their drying out and their transformation into temporary watercourses.

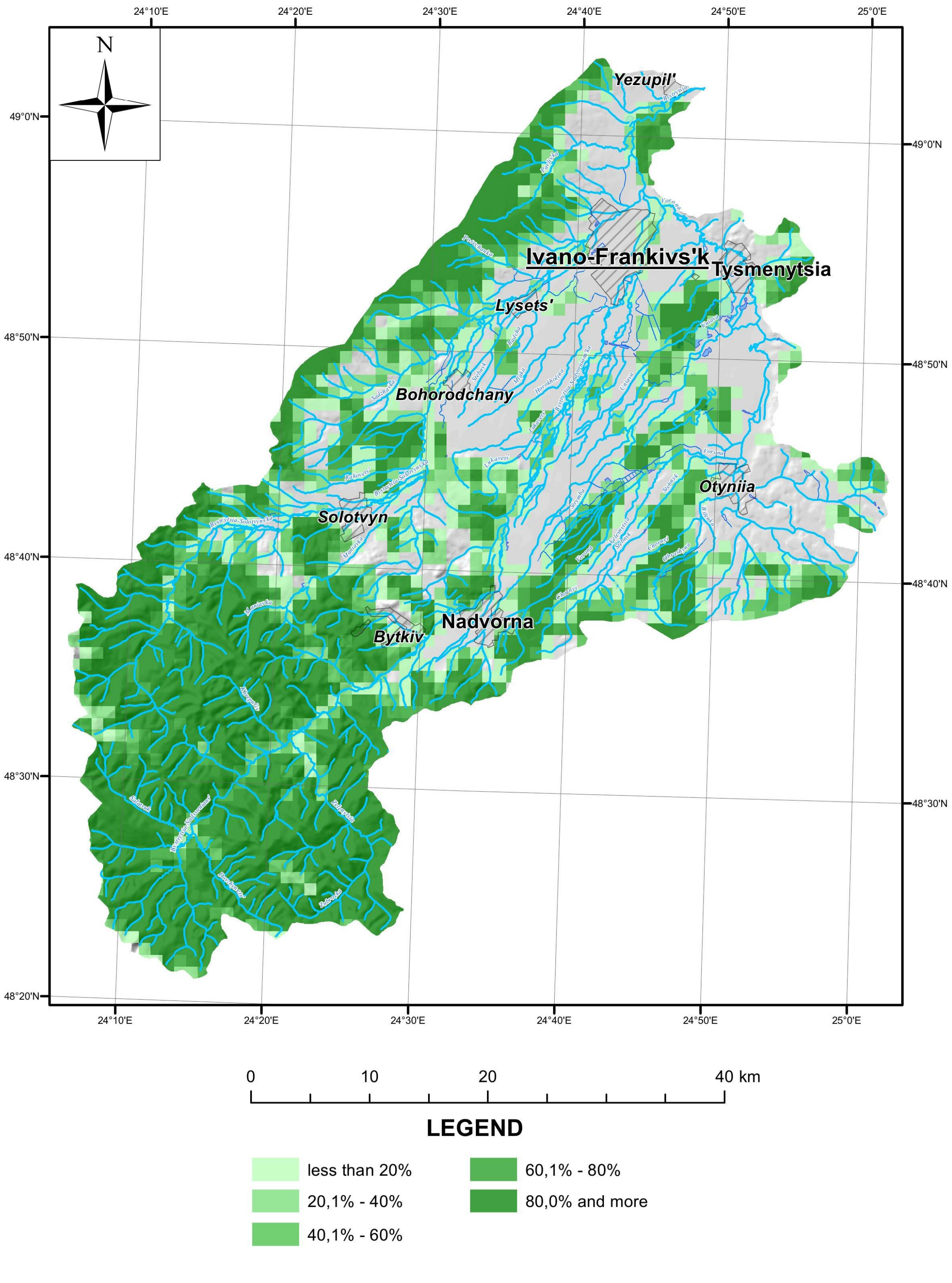

Fig. 5. Total forest cover of Bystrytsia RBS sub-basins, as of 2016

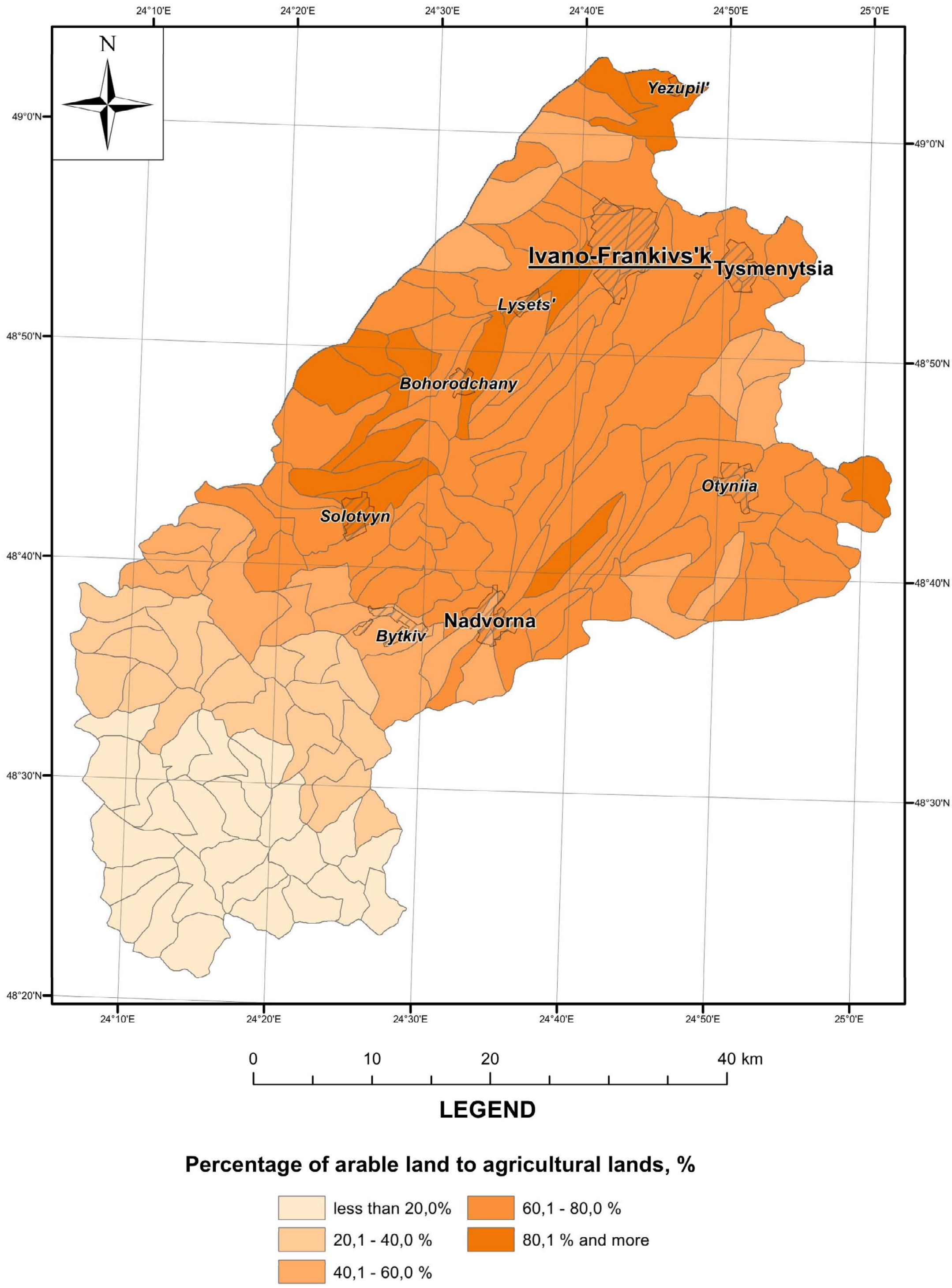

Fig. 6. Share of arable in agricultural lands in Bystrytsia sub-basins

The next factor influencing the ecological conditions of the rivers of RBS Bystrytsia and of the surface layer of air is industry.

One of the indirect indicators suitable for cartographic representation of its spatial distribution may be the share of industrial lands in each sub-basin of the studied RBS. The created cartographic model (Fig. 7) shows that the greatest influence on the rivers is exerted by industrial and utility enterprises of Ivano-Frankivsk, Tysmenytsia, Nadvirna, Bytkiv, Bohorodchany, Solotvyno. This effect is manifested primarily in the intake of surface waters and the discharge of insufficiently treated wastewater. Another factor influencing the condition and functioning of river systems is the pressure from transportation (road network).

Its indicator (the share of transport lands in the structure of the RBS land use) is shown in Fig. 8.

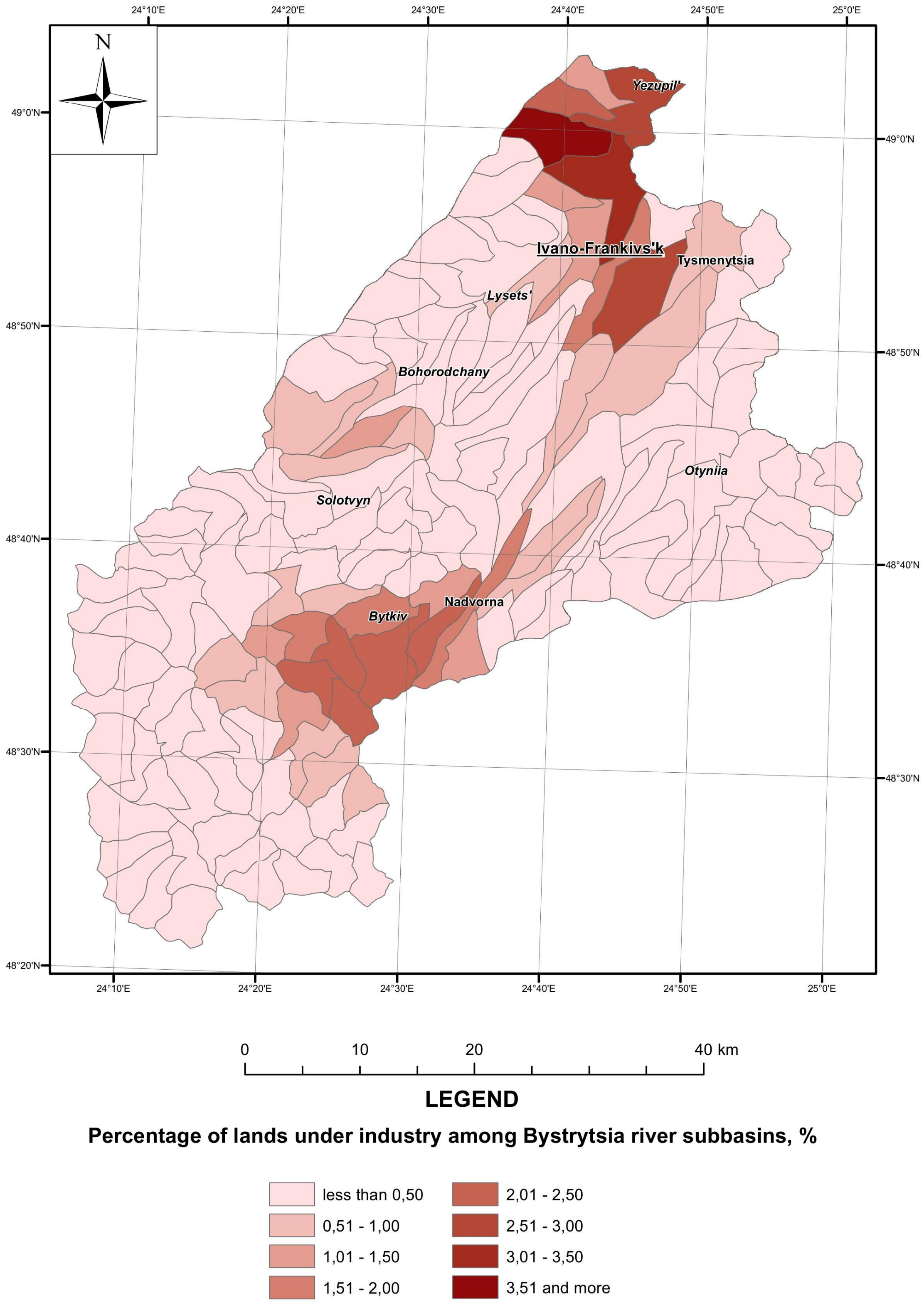

Fig. 7. Share of industrial land use in land use structure of Bystrytsia RBS sub-basins

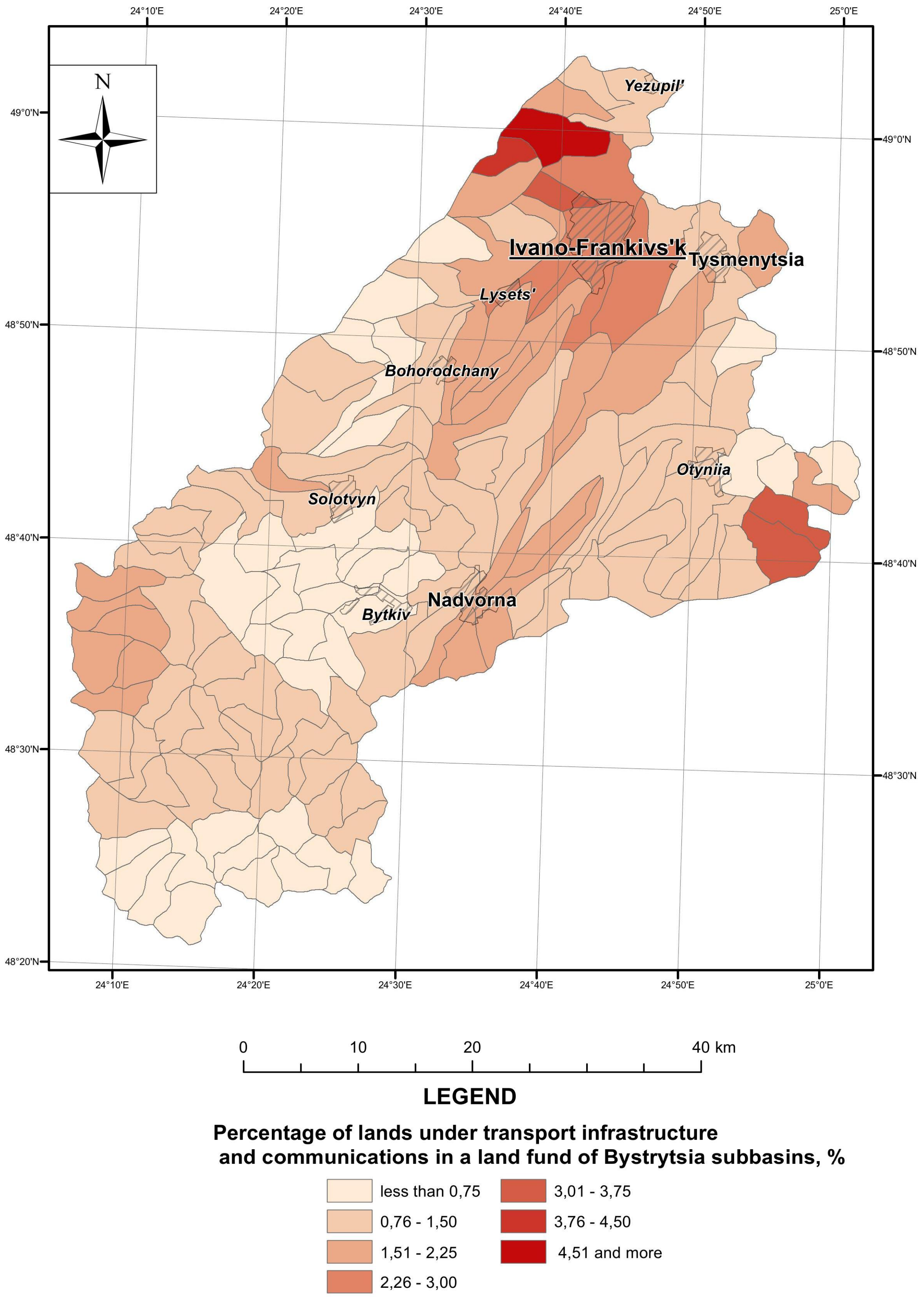

Fig. 8. Share of land of transportation and infrastructure land use in land use structure of Bystrytsia RBS sub-basins

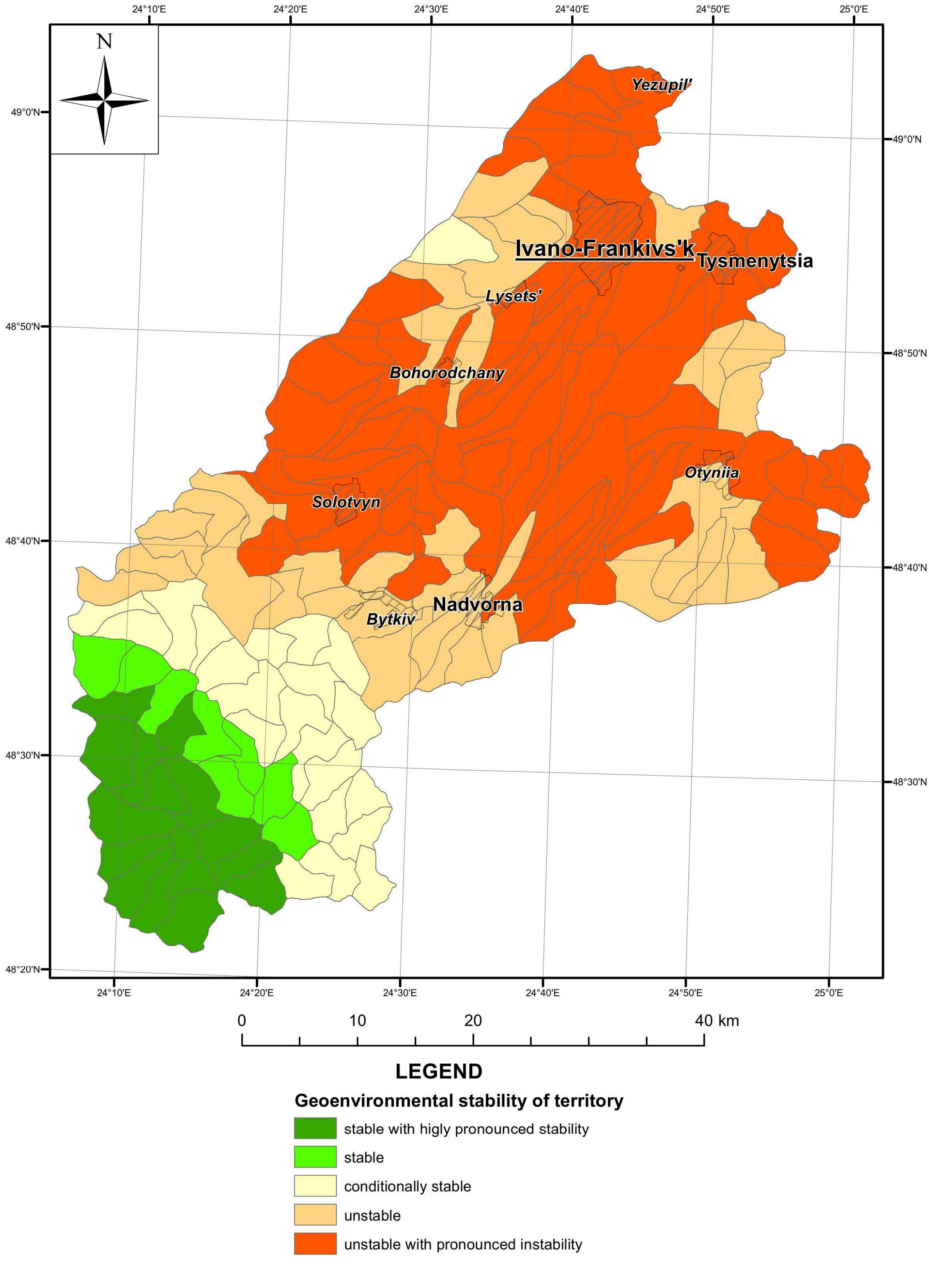

Fig. 9. Assessment of the level of geoenvironmental stability for Bystrytsia RBS sub-basins (calculated with method proposed by E. Klementova, V. Heinige, 1995)

According to the obtained indicators (Fig. 8), a significant part of the RBS surface is occupied by a fairly dense network of roads, bridges over rivers, power lines, pipelines and their service infrastructure. These structures have a significant impact on the functioning of river systems, especially during extreme floods and high waters. They can cause intensification of channel processes (bottom and side erosion, sediment accumulation, etc.) and thus worsen the hydroecological condition of floodplain-channel complexes of RBS Bystrytsia.

One of the final results of cartographic modeling of transformation processes in the river-basin system of Bystrytsia is the assessment of geoenvironmental stability of landscapes in the sub-basins of RBS Bystrytsia. It was performed according to various methods. Here we present a cartographic model (Fig. 9), compiled according to the method of E. Klementova and V. Heinige (1995). As can be seen from the map, according to the ratio of ecologically stable (forests, meadows, perennial plantations, pastures) and ecologically unstable lands (arable land, eroded, ravine-affected lands, rocky lands, industrial lands, roads, buildings, etc.) there are 5 categories of basins subsystems: 1) stable, with pronounced stability; 2) stable; 3) conditionally stable; 4) unstable; 5) unstable with pronounced instability. The first two categories are found in the middle mountainous forested part of the basin, relatively stable – in the upper part of the low mountains, unstable – in the rest of the low mountains part of the catchment, and unstable with pronounced instability – in the low, mostly flat, terraced, highly affected by human activities part of RBS Bystrytsia.

Scientific novelty and practical significance

For the first time for the Bystrytsia river basin system, quantitative indicators have been obtained of the scale of development of transformation and degradation processes occurring in the structure of the river system (siltation, drying out, reduction of the number and length of low-ranking rivers, water content reduction, etc.) and in their catchment areas for more than 150-year period. A series of large-scale digital maps have been compiled, which reflect the geo-ecological condition of this RBS and the factors influencing it.

The results of studies of transformation processes in RBS Bystrytsia allow to propose the following practical steps – priority environmental measures in the basin of this river:

- development and implementation of a comprehensive project to create water protection zones of the main rivers of the Bystrytsia basin and their tributaries, flood dams to protect settlements, lands and communications from flooding and inundation during extreme floods;
- due to climate change and the increased frequency of extreme hydrological processes (extremely high floods and large-scale destruction and damage they cause to the population, settlements, lands and communications and extremely low water levels during droughts, which cause a range of negative hydroecologic processes primarily in the watercourses of different orders) it is extremely important to periodically clear the rivers both after the passage of such floods and before them, as well as to repair existing dams and strengthen riversides, and to the create new protective engineering structures;
- development of projects of the second and third belts of sanitary protection zones of all without exception water intakes and enterprises that pose hydroecological threats to Bystrytsia and its tributaries and the population living in its basin;
- development of projects for the creation of new nature protection areas of different ranks in the Bystrytsia basin and their combination into an ecological network;
- substantiation and implementation of a set of measures to clear the riverbeds and restore the optimal functioning of small rivers – tributaries of the Bystrytsia – and improve their ecological condition;
- repair of emergency sections of riverbed dams and riverside protective engineering structures of Bystrytsia and its tributaries (in locations of intensive lateral erosion);
- creation of a single information database to reflect the ecological status of the Bystrytsia river basin, the location of sources of anthropogenic pressure on basin and valley landscapes, the scale of its impact on the river and catchment geosystems, the risks of breakage of existing hydraulic structures (dams on ponds and reservoirs, flood-protection dams, etc.);
- development of an emergency action plan in the Bystrytsia river basin and its sub-basins – Bystrytsia-Solotvynska, Bystrytsia-Nadvirnianska and Vorona;
- development of a system of warning the population about flood danger and environmental risks in the Bystrytsia river basin;
- development and implementation of measures for the preservation and restoration of forest cover of mountain and foothill landscapes in the RBS;
- development of measures to preserve the resort and recreational potential of the Bystrytsia basin and its rational use.

Conclusions

1. The analysis of the structure of river systems for 5 different time slices of its state (1855, 1925, 1955, 1975, 2008) carried out according to the described method enables to state that under the influence of natural and anthropogenic factors the following morphometric indicators have changed from one time slice to another: the order (rank) of river systems, the number of rivers of each order and their length, the

total number of rivers of all orders. The smallest rivers of I–II orders underwent the largest transformations: their number and length significantly decreased (at certain stages under the influence of reclamation works it could as well increase). These changes provoked the transformation of water and sediments runoff, the intensification of channel and slope erosion-accumulation processes, changes in the hydroecological state and in the morphology of small riverbeds and floodplains. The scale of the changes is reflected in a series of cartographic models and in the final tables. The obtained data can serve as an information and analytical basis for the development of a set of runoff-regulating, soil protection, environmental measures.

2. Studies show that the complex geo-ecological condition of RBS Bystrytsia, rather large scales of the development of transformation processes, which cover both river systems and catchment landscapes and their components require immediate action to reduce the negative impact of both rivers on the surrounding floodplain and terrace geocomplexes, agricultural lands, settlements and communications, and the processes occurring at river catchments and influencing a condition and functioning of their channels.

3. We see prospects for research in more detailed studies of the impact of global and regional climate change on the hydroecological state of river systems and their functioning, as well as continuing to monitor the impact of deforestation on the development of erosion and degradation processes in watersheds and riverbeds.

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ТРАНСФОРМАЦІЙНІ ПРОЦЕСИ У РІЧКОВО-БАСЕЙНОВІЙ СИСТЕМІ БИСТРИЦІ ТА ЇХ ГЕОІНФОРМАЦІЙНО-КАРТОГРАФІЧНІ МОДЕЛІ

Проблема оцінювання масштабів і спрямованості розвитку трансформаційних процесів, які відбуваються у річкових система і компонентах природного середовища їх басейнів під впливом широкого спектра чинників у багаторічному аспекті, залишається актуальним завданням. Це зумовлено урізноманітненням видів впливу людини і суспільства на річково-басейнові системи (РБС) та необхідністю оцінювання наслідків глобальних і регіональних змін клімату та їх впливу на режим стоку води, наносів і розчинених речовин, геоекологічний стан річково-басейнових систем. Великою мірою це стосується річково-басейнових систем Карпатського регіону, тому об’єктом дослідження вибрано річково-басейнову систему Бистриці, правобережного допливу Дністра, який розташований в Івано-Франківській області та охоплює гірські (Українські Карпати) і передгірські (Передкарпаття) ландшафти, відмінні за природно-господарськими умовами. Ця РБС типова для Карпатського регіону, тому отримані результати відображатимуть ситуацію і в інших РБС. **Метою** статті є кількісна оцінка масштабів і багаторічних тенденцій розвитку трансформаційних процесів у структурі річково-басейнової системи Бистриці, визначення спектра чинників, відповідальних за ці зміни, та їхніх геоекологічних наслідків і відображення отриманих результатів на серії картографічних моделей РБС. В основу виконаних досліджень покладено **комплексну методику**, яка поєднує: методи картометричного аналізу структури річкових систем на основі різночасових (1855, 1925, 1955, 1975, 2008 рр.) топографічних карт масштабу 1:100 000; методи аналізу стану компонентів ландшафтів (ґрунтів, лісового покриву, структури угідь тощо) та їх багаторічних змін; методи аналізу даних моніторингу змін об’єктів та розвитку процесів (стоку води, наносів, розчинених речовин у річках, прояву ерозійних, селевих, зсувних, карстових, гірничо-видобувних процесів, промислової, сільськогосподарської, лісо- і водогосподарської діяльності, скидання стічних і забору поверхневих та підземних вод тощо); методи аналізу даних ДЗЗ та геоінформаційно-картографічного моделювання. У **результаті** виконаних досліджень розроблено концептуальну модель трансформаційних процесів у річково-басейнових системах, які відбуваються під впливом природних та антропогенних чинників, визначено параметри структури річкових систем (кількість річок різних рангів, їх довжини, загальний ранг РБС на кожному “часовому зрізі” її стану), масштаби розвитку трансформаційних процесів у РБС Бистриці від одного зрізу стану до наступного і за увесь досліджуваний період, виявлено та оцінено ступінь впливу природних й антропогенних чинників на ці трансформації та їхні геоекологічні наслідки. Укладено серію цифрових карт РБС Бистриці, які відображають основні підсумки проведеного дослідження. Обґрунтовано комплекс природоохоронних заходів, спрямованих на покращення геоекологічного стану річково-басейнової системи Бистриці та заходів з оптимізації природокористування.

Ключові слова: геоекологічний стан; геоінформаційно-картографічні моделі; річкова система; річково-басейнова система; трансформаційні процеси.

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