UDC 528.9

Khrystyna BURSHTYNSKA[1], Ihor BUBNIAK[2], Iryna ZAYATS[1], Sofiia BLAZHKO[3], Nazar HRYTSKIV[1]

[1] Department of photogrammetry and geoinformatics, Lviv Polytechnic National University, 12, S. Bandery Str., Lviv, 79013, Ukraine, email: khrystyna.v.burshtynska@lpnu.ua, iryna.v.dolynska@lpnu.ua, nazar.z.hrytskiv@lpnu.ua, [1] https://orcid.org/0000-0002-6013-0873
[2] Department of engineering geodesy, Lviv Polytechnic National University, 12, S. Bandery Str., Lviv, 79013, Ukraine, email: ihor.m.bubniak@lpnu.ua, https://orcid.org/0000-0002-3548-8785
[3] Statistical Office in Krakow, 3 Kazimierza Wyka str., Krakow, Poland, email: sofiia.k.tretiak@lpnu.ua

https://doi.org/10.23939/jgd2024.01.012

THE INFLUENCE OF GEOLOGICAL STRUCTURES ON THE CHARACTER OF THE CHANNELS OF RIGHT-BANK TRIBUTARIES OF THE DNIESTER RIVER

The proposed study aims to determine the influence of geological structures on the features of the channels of the largest right-bank tributaries of the Dniester River – the Stryi, Bystrytsia, and Limnytsia rivers. For this purpose, we conducted zoning of the river based on morphometric and hydrological characteristics. Three parts were identified: mountainous, pre-mountainous area and plain area, which differ significantly in channel properties, their changes over time, and deformation processes. Objective. Based on remote sensing images of various resolutions, the use of historical maps over time, and specialized maps, to investigate the nature of the channels of the right-bank tributaries of the Dniester: Stryi, Limnytsia, and Bystrytsia, from their sources to the estuarine part where they flow into the Dniester River, depending on the geological and lithological features of the surface. The main research methods involve the transformation of various materials from remote sensing, historical, and special maps for the purpose of studying specific phenomena of river processes. The methodology involves the preparation of input materials, including historical topographic maps, geological maps, satellite images, maps and images georeferencing, satellite image processing, river channel vectorization, analysis of river channels depending on geological structures. Results. Considering the morphology, valley width, manifestation, and development of channel processes, the Stryi, Bystrytsia, and Limnytsia rivers were categorized into three sections: mountainous, pre-mountainous and plain area with developed accumulative forms. In the mountainous section, all three rivers have single channels, while in the pre-mountainous section, multichannel patterns are observed, which have decreased from the 19th to the 21st century in terms of the width of multichannelity and the number of channels. This indicates a decrease in the flow modulus. For the plain sections of channels with undeveloped accumulative forms, a clear tendency towards dependence of channel type on structural-lithological features is traced. Originality. The paper has established the dependence of channel processes of right-bank tributaries of the Dniester River on geological and sedimentological structures of the Skole Beskids and Subcarpathian Depression. Practical significance. The results of monitoring channel processes need to be considered in addressing a range of tasks, including the construction of hydraulic structures, designing power transmission networks at river crossings, developing gas pipelines, determining flood zones, assessing the consequences of erosion after floods, land reclamation, establishing water protection zones, managing recreational and border lands, and establishing interstate borders along rivers.

Key words: channel processes, right-bank tributaries, The Dniester River, geological and sedimentological structures, satellite images, Skole Beskids, Precarpathian Depression, multichannelity.

Introduction

In recent decades, one of the most pressing issues has been the conservation of natural resources, due to climate change, food shortages which are still acute on some continents, and the scarcity of energy and water resources, including drinking water. Therefore, as early as 1992, the Balanced Management of Natural Resources Strategy was adopted in Rio de Janeiro. Under it the rates of natural resource replenishment should exceed the rates of their consumption. To ensure ongoing monitoring of natural resources, the world's leading countries make decisions based on information obtained through remote sensing methods using specialized equipment installed on spacecraft and unmanned aerial vehicles. The issue of scientific and technical developments related to resource conservation in Ukraine is a priority for further development of new scientific, managerial, and economic tasks related to rivers and requires in-depth study of the environment.

Directive No. 2007/60/EC of the European Parliament and the Council of the EU on the assessment and management of flood risks presents a plan of measures for the assessment and management of flood risks. It directly relates to the study of river characteristics, reducing negative impacts on human health, the environment, cultural heritage, and economic activities. The development of a flood protection plan is carried out by an Expert Group, which has experience and specific recommendations for flood protection. In Poland, the ISOK project "Country Protection Program from Extraordinary Threats" has been developed. It is aimed at creating a system that will improve the protection of the economy and society from extraordinary threats, including floods (ISOK).

Analysis of the literature

The consideration of the development of channel processes, and the issue of river channel deformations under natural conditions and anthropogenic loading, require detailed research. It should be noted that each river is studied separately due to different conditions. The study of river channel stability is closely intertwined with research on their horizontal deformations, the factors influencing them, their direction, and intensity. The main reasons for studying channel processes are indicated in the works [Shulyarenko, 1998; Burshtynska et al., 2023].

Due to the transportation of a significant amount of sediments from the mountains and the flood regime of the rivers of the Subcarpathian region, their channels are actively changing and deforming. In different conditions, the geological-geomorphological structure influences the flow differently, determining free or restricted conditions for the development of channel displacements, which affect the width of the valley bottom, the channel, and the floodplain. The flow of water itself and the geological-geomorphological structure are the leading natural factors of channel processes [Obodovsky, 2001; Hooke, 2006].

In the work [Beighley et al., 2009], a hydrological model is presented, which records annual total flow, annual peaks, seasonal patterns, and daily water level fluctuations for the Amazon basin.

Research enabled by new approaches and technologies for monitoring channel processes is presented in the works of [Burshtynska et al., 2019; Kokhan et al., 2020]. The horizontal displacements of the right-bank and left-bank tributaries of the Dniester River show significant differences. The right-bank tributaries are located within the Skole Beskids and the Precarpathian Depression, while the left-bank tributaries are situated on the Volhynian-Podolian Upland. The same work analyzes mathematical expressions for determining channel stability proposed by various authors. The tributaries of the Dniester River, namely the Stryi, Bystrytsia, and Limnytsia rivers, can be divided into three sections based on their morphology, valley width, manifestation, and development of channel processes: mountainous, pre-mountainous, and plain. In the mountainous part, the channels of all three rivers are single-channel, in the pre-mountainous part, there is multichannelity with different widths of multichannelity and the number of channels. Multichannelity has decreased from the 19th to the 21st century. For plain sections of channels with undeveloped accumulative forms, a clear tendency to depend on the type of channel on structural-lithological features is traced.

Interesting research regarding the influence of geological structures on the state of the valley and floodplain of the Western Bug River is presented in the work of [Ostrowski et al., 2021]. The authors consider the influence of alluvial substrates on the formation of morphodynamics of the riverbed of the lowland river valley of the Bug River, a major river of the Polish lowlands. Eighty-one geological boreholes conducted in the riverbed allowed to distinguish 11 zones of sub-alluvial outcrops of bedrock, built from erosion-resistant deposits.

The determination of valley floor morphology was based on high-resolution multispectral satellite images in natural and near-infrared colors, which allowed for geological-geomorphological mapping of the valley floor surface. Based on the obtained results, it is indicated that the key factors controlling the morphodynamics of this floodplain are the outcrops of sub-alluvial bedrock. Under conditions of average and low flow, they are hidden under a layer of channel deposits. However, during significant floods, the water level in mountain streams increases, exposing the surfaces of protrusions, affecting the structure of flood flows and causing them to spread onto the floodplain in certain repeated zones. The result of this phenomenon is the creation of characteristic complexes of accumulative and erosional relief forms. Thirteen types of such forms have been identified. The analysis focused on the morphology and lithology of the valley floor and covered the area of the Bug River valley floor that was influenced by modern flood flows, i.e., the Holocene floodplain zones. Along the studied section within the boundaries of the Pleistocene upper terrace, traces of modern flood flows were also found. Due to this observation, the modern surface form should be considered as part of an active floodplain. However, it differs from typical Holocene floodplains characterizing river valleys.

In the research of [Volosetsky & Shpyrnal, 2014], it is noted that changes in the right tributaries of the Dniester River, such as the Stryi River, are significantly influenced by natural landscapes and human economic activity. On the other hand, anthropogenic activities, such as mining and construction works in the river valleys, lead to changes in the river channel and essential environmental problems. Significant horizontal displacements of the Stryi River channel, associated with lithological features, as well as hydrological and ecological disturbances of the channel and its floodplain, are discussed in the works of [Rudko & Petryshyn, 2014; Burshtynska et al., 2021].

The specific geological structure of the Precarpathian Depression with its thick deposits of gravel and sand has become not only a place for the extraction of this valuable raw material but also an area of significant environmental violations and losses. The authors note that the boulder-gravel-sand deposits within Ukraine are quite unevenly distributed. Significant reserves are concentrated in the Precarpathian regional Depression. They are formed by alluvial, diluvial, fluvioglacial, and aeolian deposits of the Quaternary age. They occur in the form of lenses and layer deposits with a thickness of up to 20–25 m at depths of 0-3m. Boulder-gravel-sand deposits are used in the construction industry. According to the materials of the Zhydachiv Water Management Authority, only one enterprise illegally extracted 65 thousand tons of gravel over two years (2006-2008).

Interesting studies on changes in river channels and riparian areas due to floods and raw material extraction are presented in the works of [Fryirs & Brierley, 2013; Morris & Kokhan, 2007].

The necessity of considering local river flow conditions, and their tectonic activity, including erosion and sedimentation processes is indicated in [Buffington, et al., 2014; Miller, et al., 2014] for understanding river landscape changes and addressing management tasks.

In the research of (Biedenharn et al., 2000), attention is drawn to the vegetation of the shoreline, bank stability, and even the configuration of the river channel, which have a significant impact on natural channel processes compared to stable channels.

In the case of lowland river valleys where river channels have developed within alluvial deposits (so-called alluvial rivers), the character of fluvial processes depends mainly on the hydrological regime of the catchment area. Significant thickness of alluvial deposits in such cases allows the channel to adapt freely to flow conditions. As a result, the evolution of the river system is reflected in the morphology and lithology of the floodplain [Grenfell et al., 2014; Krzemien, 2006].

The morphometric characteristics of the Tisza River and the specifics of horizontal displacements are mentioned in the works of [Pramanik, 2016; Burshtynska et al., 2016].

Floodplain morphology is typically used to assess the morphodynamics of river environments. Individual sets of relief forms can not only reflect the hydrological regime of the river but also contribute to the assessment of the dynamics of specific phenomena accompanying floodplain formation. They may be associated with successive stages of flooding, facilitating the assessment of the dynamics of such events and are potentially useful for flood forecasting [Wierzbicki et al., 2018, Burshtynska et al., 2023; Kovalchuk, 2003]. Identifying the specific morphogenesis of the floodplain surface can serve as a tool for using natural phenomena to manage the territory. The concentration of individual relief types can also indicate the specificity of fluvial processes on individual sections of the valley.

The research of [Janicke, 2000], mentions the work of the commission to monitor the state of rivers in Western Australia. It is argued that many rivers in Western Australia are degrading due to human activity regarding waterways, as well as external consequences of land use in the catchment basin.

Bank erosion and weed overgrowth, as well as damage by wildlife, are among the most urgent research problems [Watson & Busher, 2006]. The water quality deteriorates in many rivers due to pollution, and excessive sedimentation loads, and many rivers are becoming increasingly saline.

Purpose

The purpose of the paper is to investigate the nature of the channels of the right-bank tributaries of the Dniester: Stryi, Limnytsia, and Bystrytsia based on remote sensing images of various resolutions, the use of historical maps over time, and specialized maps. The study will focus on the area from their sources to the point where they meet the Dniester River, taking into account the geological and lithological features of the terrain.

Research task. The objective is to investigate the nature of the channels of the right-bank tributaries of the Dniester and changes in their characteristics depending on the section of their course. It is based on the processed methodology of monitoring river systems using topographic maps and satellite images of various resolutions over a long period. The task also involves investigating the dependence of the morphometric characteristics of the right-bank tributaries on the type of geological structures, and determining the relationship between the type of channel and these structures.

The object of the study is the characteristics of the Striy, Bystrytsia, and Limnitsya riverbeds, as well as their long-term morphodynamics from the 19th to the 21st century. Considering the main natural factors influencing the type of channel and its characteristics, special attention is paid to the geological and sedimentological structures in the region where these rivers flow. Using the ArcGIS software package, river monitoring has been carried out for 130 years, using topographic, geological, soil maps, and satellite images from different periods and of varying resolutions.

The rivers flow within the scope of two structures: the Skole Beskids and the Subcarpathian Depression. The right-bank tributaries (Bystrytsia, Limnytsia, Stryi, and others), originating in the Carpathians, intersect the external and internal boundaries of the Subcarpathian Depression.

Methodology

The study examines the influence of geological structures on the character of the right-bank tributaries of the Dniester: Stryi, Limnytsia, and Bystrytsia. The schematic location of the right-bank tributaries in the Dniester basin is provided in Fig. 1.

According to the morphometric characteristics of the rivers and the analysis thereof, they have been divided into three parts: mountainous, pre-mountainous, and plain.

The main processes of the methodology are depicted in the structural scheme (Fig. 2). They include: preparation: historical topographic maps; geological maps; satellite images; map and image registration; satellite image processing; river channel vectorization; overlaying river channels on the geological map; analysis of river channels according to geological structures.

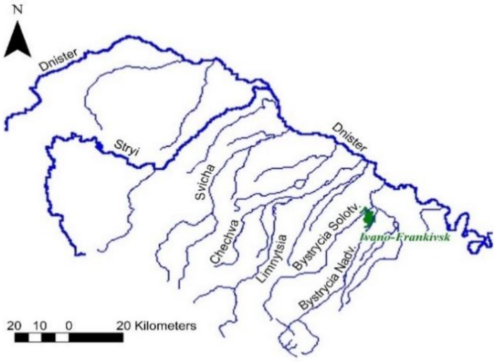

Fig. 1. Position of right-bank tributaries in the Dniester River basin.

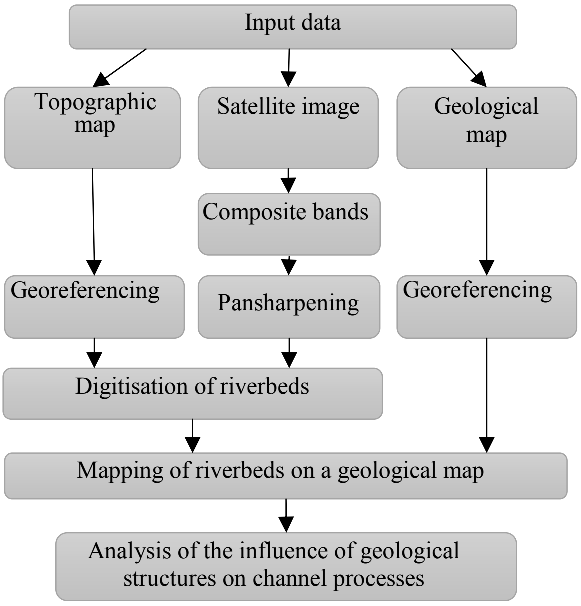

Fig. 2. Structural scheme of the research.

Geological and sedimentological structures

The right-bank tributaries of the Dniester River intersect two higher-order structures – the fold-thrust belt of the Ukrainian Carpathians and the Precarpathian Depression, which is also superimposed on the platform. In the fold-thrust belt, a number of structural units – covers – have been distinguished [Bubnyak I. & Bubnyak A, 1997]. They flow through two covers of the Ukrainian Carpathians – the Krosno and Skole units. Two other covers – the Borislav-Pokut and Sambir units – belong to the Precarpathian Depression [Nakapelyukh et al., 2018]. The Bilche-Volytska zone (External) of the Precarpathian Depression, an autochthonous tectonic unit, adjoins from the east to these structures. All the mentioned covers (except for the Sambir one) consist of formations with ages ranging from the Cretaceous to the Neogene. The main mass of the covers is composed of interbedded sandstones, conglomerates, and argillites, forming the so-called flysch. The thickness of the flysch complex in the thrust state is 12 km. Cretaceous deposits in the studied region were formed under two distinctly different tectonic and paleogeographic conditions – platform and geosynclinal. The direction of the river channel in most of the rivers is determined by tectonic factors, namely by regional faults transverse to the Carpathians. Part of the tributaries of the Stryi River is also controlled by smaller faults and fractured zones, which have a fairly regular arrangement [Hintov et al., 2011]. Although there are exceptions, for example, the meander of the Stryi River in the area of the village of Rybnyk may be due to the composition and mechanical properties of the mountain rocks.

The situation is significantly different in the Bilche-Volytska zone of the Precarpathian Depression. The depression is filled with upper molasses and Quaternary deposits, which differ lithologically and mechanically from the flysch. Here, in our opinion, the main factors influencing the deformation of the riverbed are lithological.

Study of the Stryi River

The Stryi River is the largest right tributary of the Dniester, originating in the Skole Beskids at an altitude of 1120 meters. The length of the river is 232 km, and the basin area is 3060 kmI. In the mountainous part, the river flows in a narrow valley, with an average channel width of 30-50 m. In the hilly part, the width of all branches can reach 120 m. In the plain part, the width does not exceed 80 m. For monitoring the Stryi River, the following were used: topographic maps at scales of 1:100 000 (1886 and 1989); satellite images obtained from Landsat 7 (2000) and Sentinel 2 (2016), with a high-resolution image from Bing used for the mountainous part; maps of Quaternary deposits (1970) and a soil map at a scale of 1:200000 (1967). The monitoring methodology of the Stryi River with research details is presented in [Burshtynska et al., 2021; Tretyak, 2018]. The main hydrological and morphometric characteristics of the Stryi River are presented in Table 1.

Table 1

The main Characteristics of the Stryi River

River Characteristics	Mountainous Section	Pre-mountainous Section	Plain Section
The main hydrological and morphometric characteristics			
Width, m	10–90	30–120	30–80
Depth, m	0.5–1.5	1.0–2.5	3.5–4.0
Velocity, m/s	0.9	0.4	0.2
Slope m/km	5	1.7	0.8
Meteorological and Hydrological Characteristics			
Atmospheric precipitation, mm	1200	900	800
Average Annual Flow, mi/s	20	35	50

The mountainous part. The mountainous section of the river is characterized by the presence of a single channel. The elevation drop from the source to the exit of the river onto hilly terrain is approximately 750 meters over a distance of 150 kilometers, averaging about 5 meters per kilometer. A segment of the riverbed of the Stryi River in the mountainous region is shown in Fig. 3.

Fig. 3. Fragment of digitized riverbeds in the mountainous section of the Stryi River.

Since the river valley in the mountainous region is predominantly narrow with steep flow, several points were selected in this section to determine the channel displacements, as the channels practically overlap in this area. The maximum displacement value obtained for the years 1886–2016 is 200 meters, indicating relatively minor displacements reaching 100–150 meters over the 130-year period.

Pre-mountainous area. As the monitoring results show, upon exiting the mountainous region and entering the pre-mountainous area, we observe a phenomenon known as braiding for all investigated right-bank tributaries of the Dniester River. This phenomenon depends on the morphometric and hydrological characteristics of the channel (Fig. 4). Table 2 provides the values of braiding width and the number of channel arms determined for different years.

Table 2

The number of channels and the measured width of the braided channel

№ тpoints	1886 y.		1989 y.		2000 y.		2016 y.	
	Width of the braided channel (m)	Number of channels	Width of the braided channel (m)	Number of channels	Width of the braided channel (m)	Number of channels	Width of the braided channel (m)	Number of channels
1	1520	4	445	3	450	2	0	1
2	670	2	430	3	0	1	0	1
3	1355	5	235	1	0	1	0	1
4	945	4	565	2	375	3	1035	4
5	390	3	595	2	560	5	255	2
6	520	3	0	1	55	2	260	2
7	785	5	0	1	0	1	0	1
8	1170	4	0	1	240	2	0	1
9	810	2	190	2	685	2	0	1

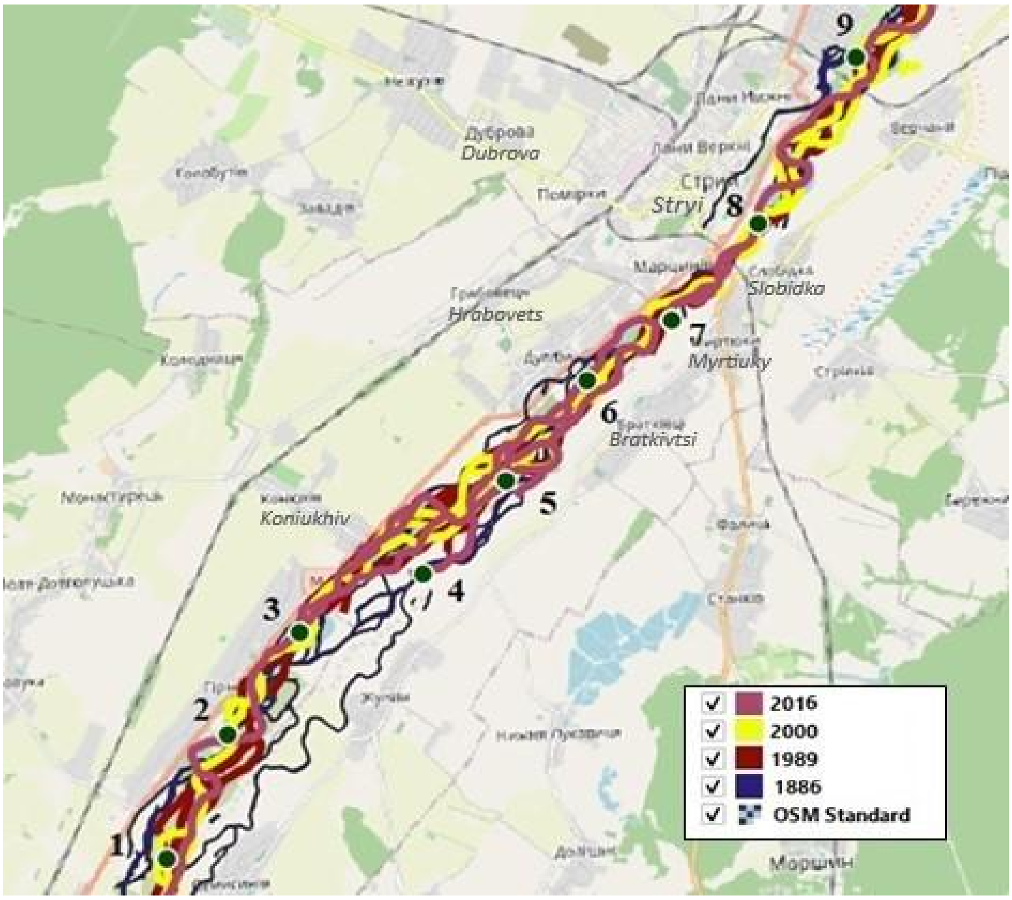

Fig. 4. Fragment of digitized river channels of the pre-mountainous section of the Stryi River.

In 1886, the width between the outermost branches of the river channel reached 1.5 km, with 4-5 branches. In the last decade (1989, 2016), the width of the multichannel system decreased by half, but in 2016, at sction 4, we observed a multichannel width of 1.0 km with 4 branches. The general trend of decreasing multichannelity is primarily caused by climate change and anthropogenic factors, including water abstraction for residential and industrial purposes.

The plain section. The most complex part regarding changes and the water regime of the river is the Stryi channel, which flows through the plain part of the terrain until it joins the Dnister River (Fig. 5). The length of the plain section of the Stryi River (from the village of Hnizdychiv, Stryiskyi district, to its confluence with the Dnister River near the city of Zhydachiv, Lviv region) is 18 km.

In this section, the Stryi River has a very winding channel with a significant number of meanders and abandoned riverbeds, and in some areas, the terrain is marshy [Horyshny, 2014].

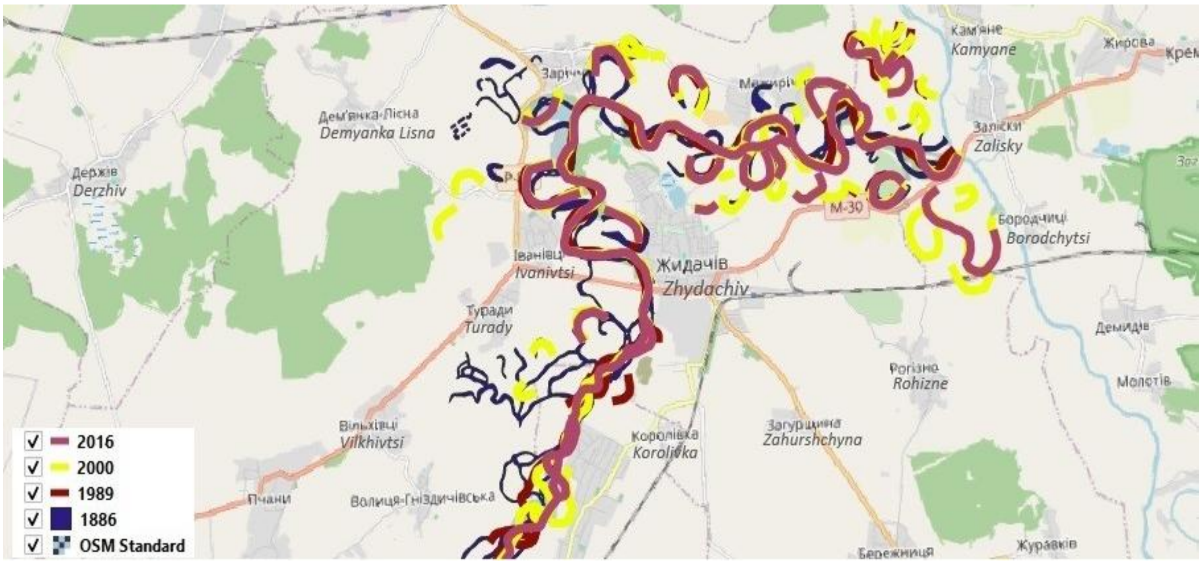

Fig. 5. The location of the Stryi River in the plain section.

The most interesting meanders occur near the village of Rybnyk and the town of Zhydachiv, where the river flows in several different directions for several kilometers. This section of the river's course is most influenced by the geomorphological structure characteristic of the Precarpathian Depression. The Quaternary deposits of the Precarpathian Depression in this area are represented by four types: ancient, middle, new and modern. The new type is associated with a continuous cover of loamy forest clays. The modern type includes sandy-gravelly-clayey deposits of river floodplains, alluvial cones, marshes, and alluvial-deluvial formations. Erosion processes affect both the riverbeds themselves and the riparian territories. The intensive extraction of gravel and sand from riverbeds, as well as the development of deposits of boulder-gravelly-sandy rocks in the mountain rivers of the Dnister, Stryi, Svicha, and Opir in the Lviv region, are threatening processes that have a negative impact on the environmental condition of the area. (Rudko & Petryshyn, 2014). The magnitudes of horizontal displacements of the Stryi River channel reach 1100 m, 1350 m, and are the largest in the series of studies on horizontal displacements of the Dnister River and its tributaries (Burshtynska et al., 2021, Tretyak, 2018).

Table 3 shows the number of old riverbeds and islands, and calculates the total area of old riverbeds for the plain section of the Stryi River near the town of Zhydachiv.

The reduced area of old riverbeds in 1989 can be explained by the fact that only the larger-sized old riverbeds are marked on the map, as well as those that significantly differed in the field due to contrast.

Table 3

The number of old riverbeds and islands

Years	Number of old riverbeds	Total area of old riverbeds, hectares	Number of islands
1886	20	128.7	12
1989	20	95	6
2000	20	141.5	2
2014	12	104.1	2

The old riverbeds, as parts of the former river channel, allow for the reconstruction of the river's course and the study of its changes depending on natural or anthropogenic factors. Satellite imagery has significant advantages over cartographic material for this purpose.

Analysis of river processes of the Bystrytsia River

The Bystrytsia River is formed by the confluence of the Solotvynska Bystrytsia and the Nadvirnianska

Bystrytsia. The Bystrytsia has a length of 17 km, and its tributaries, the Nadvirnianska Bystrytsia and the Solotvynska Bystrytsia, are 94 km and 82 km long, respectively. Almost annually, the Bystrytsia River experiences spring and summer floods [Dubis & Kuzio, 2016; Tretyak, 2018].

The main hydrological and morphometric characteristics are as follows: the river valley is asymmetrical, with the right bank steep (on the edge of the Pokutian Upland), high, and mostly covered with forests; the left bank is gentle and cultivated. The riverbed is meandering, with a width of 35–80 m and a depth of 0.2–4 m. The river gradient is 1.57 m/km. The average density of the river network is 1.3 km/kmI, and the average multi-year water runoff module is 18.68 mi/s/kmI. Floods occur. The average water flow rate is 29 mi/s [Dubis & Kuzio, 2016].

Monitoring was carried out over a 106-year period using topographic maps at a scale of 1:100,000 (1910 and 1989), satellite images from Landsat 7 – 2000 and Sentinel 2 – 2016, and maps at a scale of 1:200,000: of Quaternary deposits from 1970 and soil cover from 1969. The Nadvirnianska Bystrytsia is divided into three parts: mountainous, pre-mountainous, and plain. The Solotvynska Bystrytsia is divided into two parts: mountainous with pre-mountainous and plain.

The Bystrytsia River flows through the plain part of the territory, which belongs to the Bilche-Volytska zone of the Precarpathian Depression. The tributaries of the Bystrytsia – the Solotvynska and Nadvirnianska Bystrytsias – originate from the Skole Beskids, and they are divided into two parts: mountainous and pre-mountainous.

Mountainous part. The mountainous part of the basin of the Nadvirnianska Bystrytsia River is located in the Skole and Watershed-Vorokhta Carpathians and is in the Nadvirnyansky district of the Ivano-Frankivsk region. The basin of the Solotvynska Bystrytsia is located in the Precarpathian Depression and the Skole Carpathian zone. The length of the mountainous part of the Nadvirnianska Bystrytsia River is 12 km (from the village of Maksymets to the village of Pasichna in the Nadvirnyansky district of the Ivano-Frankivsk region). The length of the mountainous part of the Solotvynska Bystrytsia tributary is 33 km (from the foot of the Syvulia mountains to the village of Porohy in the Ivano-Frankivsk district of the Ivano-Frankivsk region). The overlay of the riverbeds of the mountainous parts of the Nadvirnianska Bystrytsia and the Solotvynska Bystrytsia Rivers on the map of 1989 is shown in (Fig. 6) [Dubis & Kuzio, 2016].

Measured at 3 points of channel displacement for both tributaries. Displacements in this section reach: for Bistritsa Nadvirnianska – 540 m (1910–1989), for Solotvynska – 285 m (1910–1989). The average displacement values for the periods (1989–2000) and (2000–2016) are approximately 100–150 m. [Tretyak, 2018].

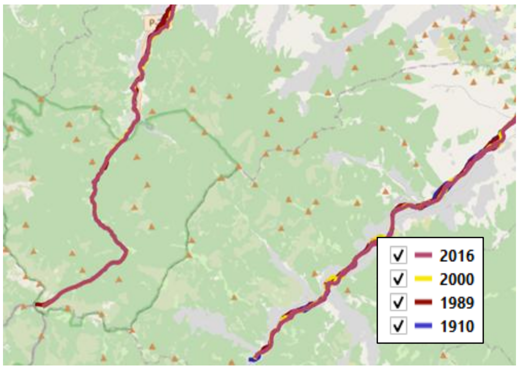

Fig. 6. General view of the digitized riverbeds of the mountainous parts of the tributaries Bystrytsia Nadvirnianska and Bystrytsia Solotvynska.

Pre-mountainous part. In the pre-mountainous part Bystrytsia Nadvirnianska river is characterized by multichannelity and intertwining of channels in some parts of the riverbed (Fig. 7).

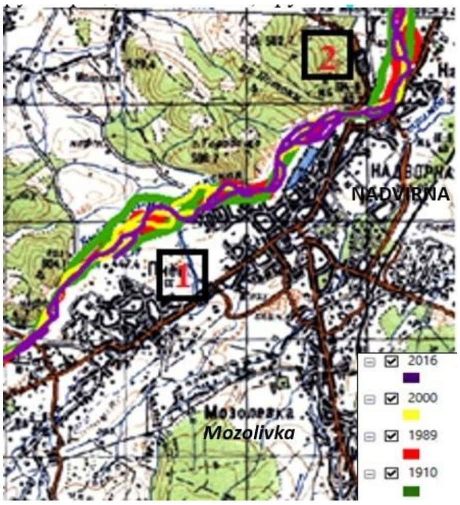

Fig. 7. General view of digitized riverbeds of Bistritsa Nadvirnianska in the pre-mountainous part.

Two sections with significant multichannelity were noted; their width was measured at two sites. The results are presented in Table 4. The maximum width of multichannelity is 710-755 m, with the riverbed divided into 2-3 channels.

Table 4

The width of the multichannelity in the pre-mountainous part of the Bystrytsia Nadvirnianska River

Years	Maximum width of multichannelity, (m)			
	Section 1		Section 2	
	Multichannelity width (m)	Number of channels	Multichannelity width (m)	Number of channels
1910	330	2	512	2
1989	545	2	700	3
2000	565	3	710	2
2016	755	1	670	3

In Fig. 8, the channel type of the Bystrytsia tends towards channel branching. The confluence of the Bystrytsia Solotvynska and Bystrytsia Nadvirnianska, as well as the beginning of the Bystrytsia itself, is a special area for these three rivers. [Dubis & Kuzio, 2016].

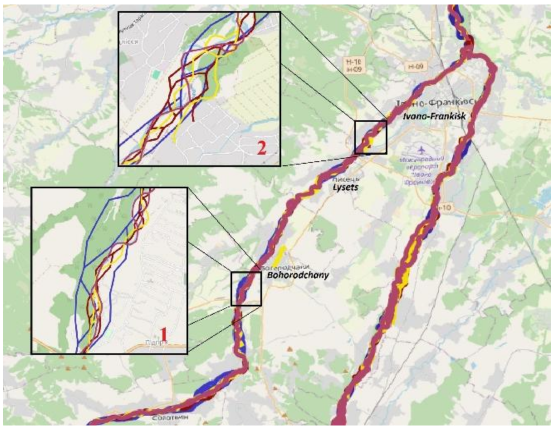

Fig. 8. General view of digitized channels of the pre-mountainous part of the Bystrytsia River with the tributaries Bystrytsia Nadvirnianska and Solotvynska

The width of the braided channel and the number of channels were measured at several points of the Bystrytsia Solotvynska, and the results are presented in Table 5.

Table 5

The number of channels and the measured width between the extreme channels in the pre-mountainous part of the Bystrytsia Solotvynska River

Year	Maximum width of multichannelity (m)			
	Section 1		Section 2	
	Multichannelity width (m)	Number of channels	Multichannelity width (m)	Number of channels
1910	760	3	340	2
1989	510	3	600	3
2000	280	2	330	2
2016	180	2	–	1

According to the depiction of the 1910 section, multiple channels are visible, with the width of the channel formation strip ranging from 300 to 800 meters, and the channel divided into 2–3 branches. On the map from the Soviet period, the width of the multichannel area is smaller, with a maximum value of 600 meters. Based on the 2000 image, some changes in multichannelity compared to the 1989 riverbed are noticeable, with the width of the multichannel area decreasing to around 400 meters. According to modern satellite images from 2016, the width of the multichannel area decreases to 180–200 m.

The plain section. In addition to the braiding, an area of river meandering has been observed in the plain section of the Bystrytsia River. A segment of the river meandering is depicted in Fig. 9.

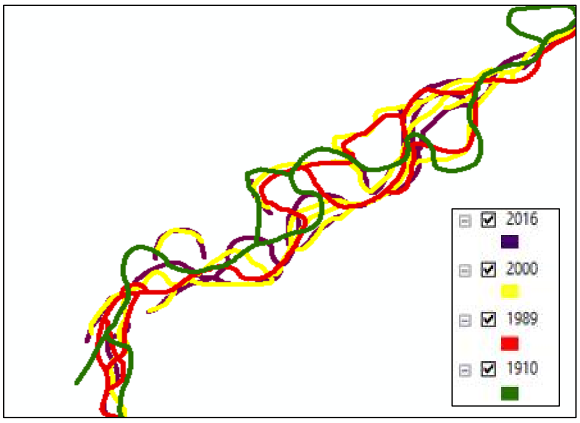

Fig. 9. Fragment of river meandering of the Bystrytsia River in the plain section at its confluence with the Dniester.

Regarding the analysis of this phenomenon, various explanations are presented in the specialized literature. In the research by [Starkel et al., 2015], attention is drawn to the evolution of river systems in Central-Eastern Europe, reflecting the main phases of climatic changes over the period of 60-8 ka cal BP, recorded in ice core data from Greenland and their isotopic curves.

The Greenland ice core isotopic curve shows many more fluctuations and stages than the river record of the same period, especially during the interglacial phase. For a certain period, this region was covered by permafrost, although during parts of the studied period, warm summers coexisted, promoting the emergence of forest cover. These factors together controlled the characteristics of the river regime and sediment load, creating variable tendencies of erosion or aggradation from meandering to braiding. Permafrost was alternated by floods and snowmelt, leading to braiding. Dense vegetation reduced sediment supply and stabilized the meandering of the riverbed. Significant changes that occurred in the valleys of rivers surrounded by mountains are emphasized, especially during the unstable interglacial, when the supply of sediment from higher vegetative zones increased. This system, controlled by climate and vegetation, was altered by other factors, including tectonics, wind activity in arid periods, valley blocking by ice sheets, meltwater inflows, and sea level fluctuations.

Another explanation, which does not delve into the historical epochs of the development of river systems in the Eastern European part of the continent, is encountered in the work by [Zolezzi et al., 2012]. This study emphasizes that braiding is the result of complex processes between water velocity and characteristics of the bed and bank substrate. Transitional forms between sinuosity and braiding arise with sufficient intensity of channel width oscillations. Based on modeling, the authors investigate the morphodynamic relationships between spatial curvature and width oscillations in river meanders and related bed models.

Since the Bystrytsia River flows through a densely populated region (Ivano-Frankivsk city), measures are taken to protect it, including: afforestation of riverbanks; reinforcement of riverbanks against floods; separation of industrial and household sewage to ensure their purification before discharge into the river; use of water treatment systems by industrial enterprises; creation of hydrological nature reserves.

For the river runoff of the right-bank tributaries, frequent water level rises are characteristic throughout the year. In years with high water levels, floods occurred quite often: in 1955, 1969, 1980, 2001, 2008, 2020, and stable water levels were observed from September to December. In particular, floods that occurred in the summers of 2008 and 2020 due to intense thunderstorms and, as a result, a rapid rise in water levels in rivers caused significant damage to the economies of cities and infrastructure in Western Ukraine. They resulted in significant economic and environmental losses and were among the largest in the history of Western Ukraine over the past century. (Dubis & Kuzio, 2016).

Analysis of the channel processes of the Limnytsia River

The Limnytsia River has a length of 122 km. Its riverbed is rocky and branches into channels internally. The river has been analyzed over a 106-year period using topographic maps at a scale of 1:100,000 (1910 and 1989), satellite images from Landsat 7 (2000) and Sentinel (2016), as well as maps at a scale of 1:200 000 representing the quaternary deposits (1970) and the soil cover (1969). The river is conventionally divided into three parts: mountainous, pre-mountainous, and plain.

The mountainous part. In fig. 10 the riverbeds from different time periods overlaid on the 1989 map of the mountainous part of the Limnytsia River are depicted.

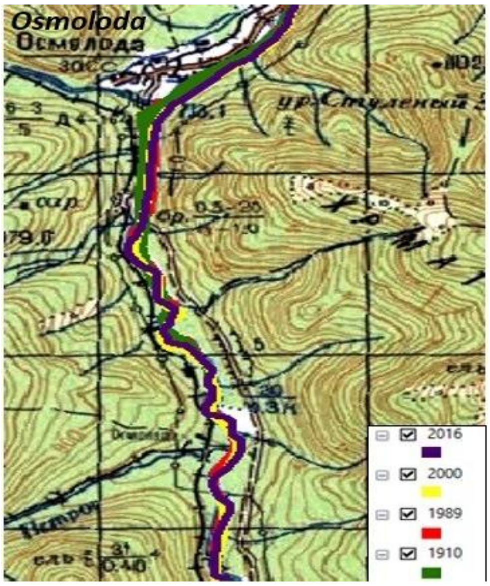

Fig. 10. Fragments of digitized riverbeds in the mountainous part of the Limnytsia River based on topographic maps and satellite images.

In the mountainous section of the Limnytsia River, there are almost no noticeable displacements observed. Only one section with a displacement of 250 meters for the period from 1910 to 1989 is detected. During the periods of 1989-2000 and 2000-2016, the riverbeds show displacements within the margin of measurement error.

Pre-mountainous area. This stretch is marshy, spanning 29 km (from the village of Yasen in the Rohatyn district to the village of Tuzhyliv in the Kalush district of the Ivano-Frankivsk region). The Kalush local prosecutor's office has confirmed instances of illegal extraction of sand-gravel mix from the Limnytsia Riverbed within the Kalush district.

The river exhibits a characteristic multi-channel pattern, with the channel dividing into 3 branches. (Fig.11).

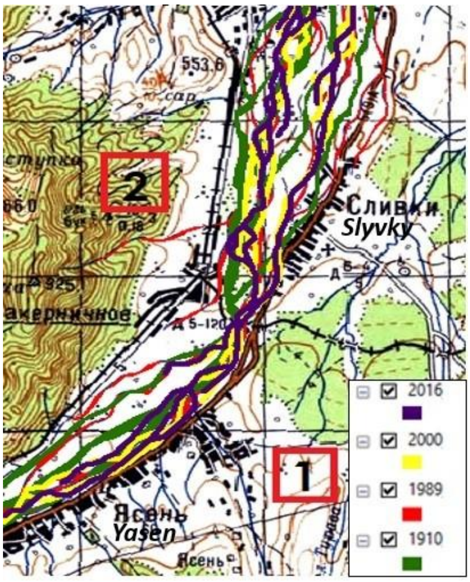

Fig. 11. Fragments of digitized channels of the pre-mountainos part of the Limnytsia river.

Two sections were selected where significant braiding was observed, and their width was measured for different periods (Table 6).

Table 6

The width of the multichannelity in the pre-mountainous part of the Limnytsia River

Роки	The width of the multichannelity (m)			
	Section 1	Section 2		
	Multichan-nelity width (m)	Number of channels	Multichan-nelity width (m)	Number of channels
1910	1280	3	1236	4
1989	1470	3	1145	5
2000	812	2	1346	3
2016	775	2	1287	2

The width of the braided section reaches about 1.5 km. However, as seen from Table 6 in section No. 1 (Fig. 10), in 2016 it had already decreased to 775 m, while in section No. 2 the width of the braided section remained unchanged.

The plain part. The length of this part of the river is 35 km (from the village of Tuzhyliv in Kalush district to the place where the river flows into the Dniester River (Kalush district of Ivano-Frankivsk region). The largest floods on the Limnytsia River occurred in 1929, 1941, 2008, and 2020.

This part is similar to the previous one and is also marshy. The riverbed is characterized by braiding (Fig. 12).

Measurements of horizontal maximum displacements of the riverbed have been carried out in 2 sections (Fig. 12). The maximum displacement value obtained for the years 1910-1989 is 490 m, for the years 1989-2000 – 250 m, for the years 2000-2016 – 190 m. The greatest displacements occurred in the years 1910-1989. In some places, the river shifted towards the natural riverbed of 1910. [Tretyak, 2018].

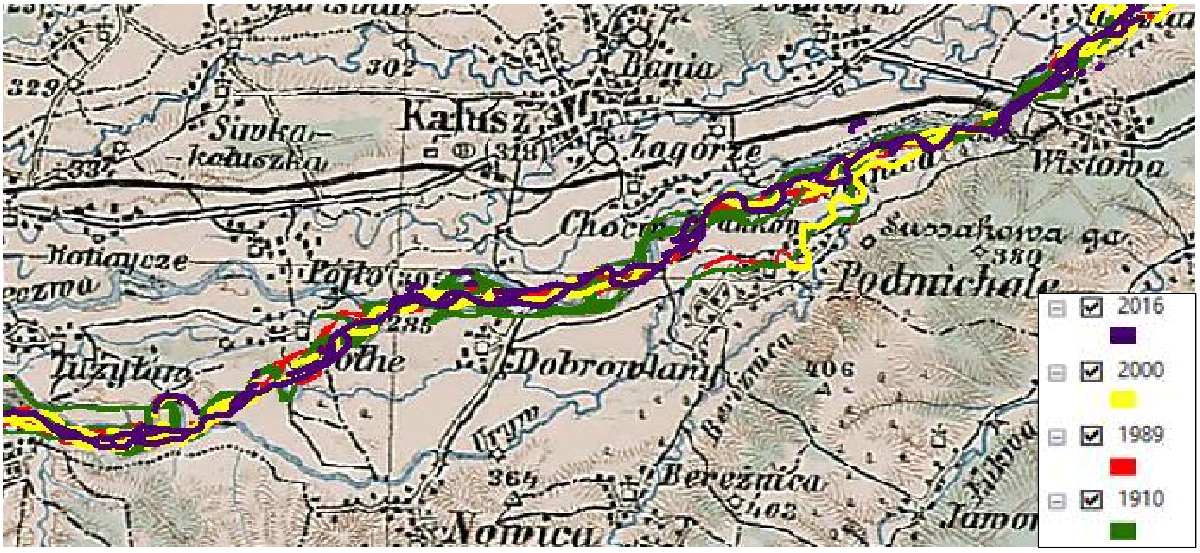

Fig. 12. Fragments of digitized channels of the plain part of the Limnytsia River.

In some places, the riverbed of different years branches into two channels and intertwines. The width of the valley in this section is significant, reaching 3,5 km.

Analysis of soil and geological maps of right-bank tributaries

An analysis of the map of quaternary deposits of the Stryi River indicates a meandering character of the riverbed with images of both older and newer formations. The main deposits indicated are: sand with gravel, pebbles, clay, and alluvial deposits. The quaternary map presents various lithologically composed formations associated with the terrace structure of the floodplain, particularly notable is the solid layer of loamy clays and sandy-gravelly-clayey deposits. The floodplain area of the plain part of the Stryi River is characterized by loamy-sandy and loamy-podzolic, humus-rich, gleyed, and meadow gley soils, their mechanical basis being sands and light clays that are easily eroded.

Near the riverbed, the main deposits of the Bystrytsia River are aeolian-deluvial and deluvial. The lithological composition is characterized by the presence of clays, sands, and in some areas gravel and peat can be observed. The riparian territory of the Bystrytsia River is characterized by meadow soils mainly on alluvial and deluvial deposits and podzolic soils. Peat and peat-soil soils are also noted. Mechanical composition: sands, loams, and gravel.

The map of quaternary deposits of the Limnytsia River presents the main deposits, which are gravel, clay, and alluvial deposits. The quaternary map presents various lithologically composed formations associated with the terrace structure of the floodplain, particularly notable is the channel facies and aeolian-diluvial deposits. Also noted are outcrops of native rocks. The riparian territory of the Limnytsia River is characterized by loamy-sandy and loamy-podzolic, humus-rich, gleyed, and meadow gley soils, their mechanical basis being sands and light clays that are easily eroded, causing channel displacement. [Kravchuk, 1999; Tretyak, 2018].

Results

Analysis of the relationship between river processes of right-bank tributaries and geological structures.

Let us overlay the files of right-bank rivers of the Dnister of different years used for studying the influence of geological structures on the tectonic map with a scale of 1:200,000 (Fig. 13).

The map shows the boundaries of tectonic plates and the zones of their junction. Zone I represents the main tectonic folded-thrust belt of the Ukrainian Carpathians; the Precarpathian Depression zone consists of two structures characterized by significant differences. The Inner Precarpathian Depression – Zone II and the Outer Precarpathian Depression, also overlaid on the platform – Zone III.

The rivers Stryi, Limnytsia, and Bystrytsia originate in the Carpathian Mountains. The mountainous part of the right-bank tributaries belongs to the folded-thrust belt of the Carpathians. The Carpathians are young folded mountains composed of layers of various sedimentary rock formations – soft marl, hard sandstone, pliable clay, and limestone. They were deposited on the bottom of an ancient Mesozoic sea and were uplifted to the surface during the orogenesis. In front of the Carpathian front lies the Precarpathian Depression, filled with molasse formations. These tectonic elements determine the nature of the river system in the studied region.

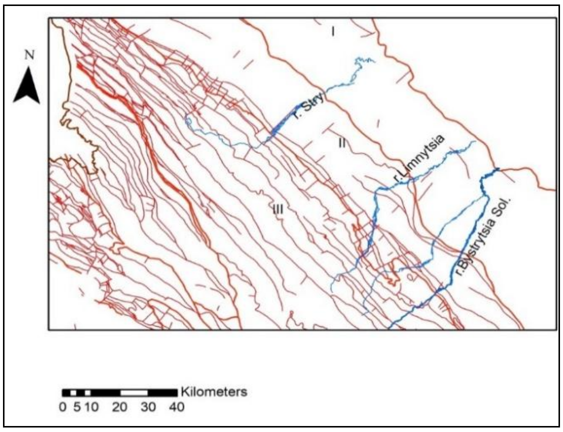

Fig. 13. Studied rivers on the structural maps based on the Geological Map of the Ukrainian Carpathians and Adjacent Basins. These maps delineate the following zones: I – Outer zone of the Ukrainian Carpathian Foredeep; II – Inner zone of the Ukrainian Carpathian Foredeep; III- Carpathians

In the mountainous part, the channel of the Stryi River is single-channel, however, in this section, which is not characteristic of other rivers Bystrytsia and Limnytsia (Fig. 15), meandering is observed between the folds of the structure, and then the river sharply turns to the northeast. The tectonic faults of the structures have a clear northeast direction, and the flow of the Stryi coincides with the faults in the transverse direction to the Skole Carpathians and part of the Borislav-Pokutsky Precarpathian Depression zone.

In the Inner part of the Foredeep of the Carpathians, the Stryi River (Fig. 14) exhibits a characteristic braided pattern. In the Outer part of the Foredeep (Bilche-Volytska structure), the river meanders, and in the estuarine part, due to the heterogeneity of the structures and the significant influence of lithological deposits composed of Miocene molasses, layered clays, sandstones, and other deposits, it shows the highest instability among the tributaries, which is visible on the map of quaternary deposits (Fig. 15).

The Limnytsia and Bystrytsia rivers have markedly different characteristics in the Skibo zone and in the Outer Foredeep of the Carpathians. For the Carpathians, straight sections of riverbeds and the absence of meanders and braiding are characteristic. In the Outer zone, meandering and braiding of these rivers are common. In the case of the fold-thrust part of the studied area (Fig. 13), the presence of faults, layers, and folds in the mountainous rocks can direct water flows and influence the direction of river flow. The studied rivers in this area often flow along faults. Also, fractures where the bedrock, as in the case of faults, is fragmented, often determine the direction of rivers. The direction of rivers in the mountainous part coincides with the main directions of fractures. These features of the influence of tectonic peculiarities are also characteristic of the Inner zone of the Foredeep of the Carpathians, where folds and faults are developed. Transverse faults influence the formation of river channels (Fig. 13).

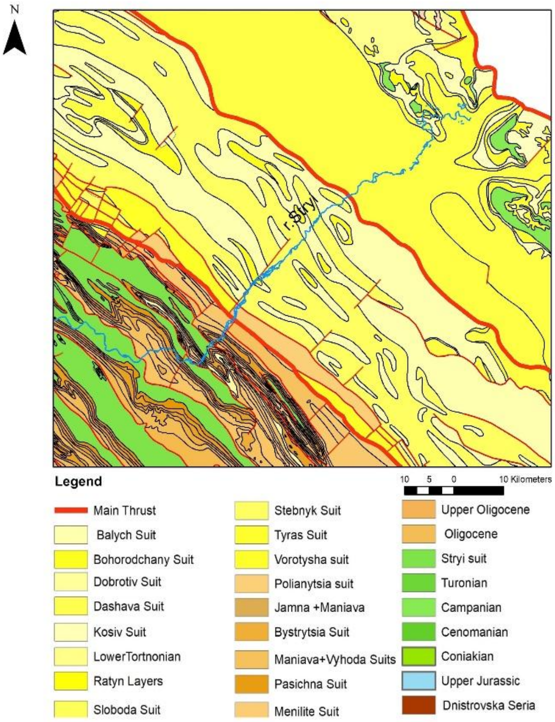

Fig. 14. The Stryi River on Geological Map of the Ukrainian Carpathians and Adjacent Basins

In the Inner zone of the Foredeep of the Carpathians (Boryslav-Pokutian folds), the lithological composition of rocks influences the character of river channels, particularly the occurrence of braiding. Molasse formations are mechanically weaker than flysch formations and are easily eroded. Therefore, in this part of the study area, the appearance of braiding is observed. The Outer zone is composed of softer mountainous rocks, characterized by low relief, which also promotes the development of meandering and braiding. Modern tectonic activity affects the slope of the river and consequently its energy and erosion capacity. Such activity is much more pronounced in the mountainous part and accordingly creates characteristic river valleys. The Outer zone is associated with low tectonic activity. For this part, slight subsidence is characteristic, which influences the formation of river channels.

The climate also affects the character of these rivers. The amount of precipitation affects the water level in the river and its erosion potential.

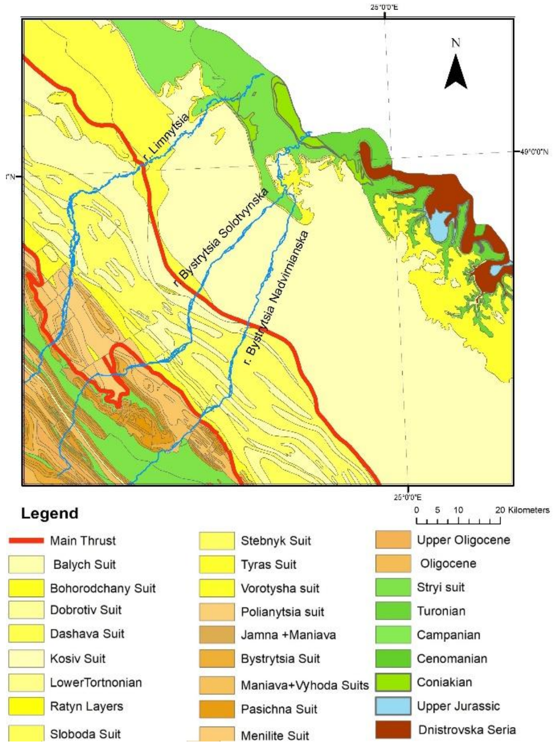

Fig. 15. The map of the main geological structures with the right-bank rivers Limnytsia, Bystrytsia with the tributaries Bystrytsia Nadvirnianska and Bystrytsia Solotvynska.

Originality

The dependence of river processes of the right-bank rivers of the Dniester on the geological and sedimentological structures of the Skole Beskids and the Precarpathian Depression has been established.

Practical significance

The results of monitoring riverbed processes need to be considered when addressing various tasks, including the construction of hydraulic structures, designing power transmission networks when crossing rivers, developing gas pipelines, determining flood zones, assessing the consequences of erosion after floods, land development in floodplains, establishing water protection zones, managing recreational and border areas, and delineating international borders along rivers.

Perspective research directions in the study of river processes include assessing flood risk, addressing ecological issues, developing and implementing various types of projects related to hydraulic engineering, as well as sustainable restoration projects and the implementation of effective measures for the conservation and restoration of river systems and increasing biodiversity in riparian areas.

Conclusions

1. Taking into account the morphology, valley width, manifestation and development of riverbed processes, the rivers Stryi, Bystrytsia, and Limnytsia are divided into three sections: mountainous, pre-mountainous, and plain, with developed accumulative forms.

2. In the mountainous part of the riverbeds of all three rivers, they are single-channel, while in the pre-mountainous part, there is multichannel morphology, which decreases from the 19th to the 21st century with a reduction in the width of multichannel morphology and the number of river channels, which indicates a decrease in flow discharge.

3. For the plain sections of channels with undeveloped accumulative forms, a clear tendency is observed for the type of channels to depend on structural-lithological features.

4. The Stryi River multichannelty coincides with the transverse faults of the Skole Beskids and faults of the Inner zone of the Precarpathian Depression. The multichannelty of the Limnytsia River begins in the Skole Beskids and continues in the Precarpathian Depression, while the multichannelty of the Nadvirnianska and Solotvynska Bystrytsia is typical of the Internal Zone of the Precarpathian Depression.

5. Significant meandering of the Stryi River is observed in the estuarine region, where the geological basis consists of tectonic structures composed of Upper Molasse of the Outer zone of the Kosiv formation.

6. The intertwining of the Limnytsia River is associated with the foundation of the Precarpathian Depression, while the Bystrytsia River is associated with the Outer zone of the Precarpathian Depression of the Kosiv formation.

References

Beighley, R. E., Eggert, K. G., Dunne, T., He Y., Gummadi, V., & Verdin, K. L. (2009). Simulating hydrologic and hydraulic processes throughout the Amazon River. *Hydrological Processes*. No. 23(8) p. 1221–1235. https://doi.org/10.1002/hyp.7252

Biedenharn, D. S., & Copeland, R. R. (2000). Effective Discharge Calculation: *A Practical Guide*. P.60. https://erdc-library.erdc.dren.mil/jspui/bitstream/11681/2042/1/CHETN-VIII-4.pdf

Bubniak I., & Bubniak A. (1997). On the nature of the Stryi Jurassic depression. *Works of the NTSh Vol. 1. Geology, geophysics, chemistry, biochemistry, material science, materials mechanics.* P. 69–72. (in Ukrainian).

Buffington, J. M., Woodsmith, R. D., Booth, D. B., & Montgomery, D. R. (2003). Fluvial processes in Puget Sound rivers and the Pacific Northwest. Restoration of Puget Sound Rivers, 46-78.

Burshtynska K., Shevchuk V., Tretyak S., & Vekliuk V. (2016). Monitoring of the riverbeds of rivers Dniester and Tisza of the Carpathian region. [*XXIII ISPRS Congress, Commission VII. 12–19 July 2016, Prague, Czech Republic*]. Vol. XLI-B7

p. 177–182. https://doi.org/10.5194/isprs-archives-XLI-B7-177-2016.

Burshtynska, K., Zayats, I., Halochkin, M., Bakula, K., & Babiy, L. (2023). The Influence of the Main Factors on the Accuracy of Hydrological Modelling of Flooded Lands. *Water (Switzerland)*, 15(18), 3303, ISSN 20734441, https://doi.org/10.3390/w15183303

Burshtynska, Kh. V., Kokhan, S. S., Babushka, A. V., Bubniak, I. M., & Shevchuk, V. M. (2021). Long term hydrological and environmental monitoring of the Stryi River using remote sensing data and GIS technologies. *Journal Geology, Geography Geoecology,* 30(2), 215–230. https://doi.org/10.15421/112119.

Burshtynska, K. V., Babushka, A. V., Bubniak, I. M., Babiy, L. V., Tretyak, S. K. (2019). Influence of geological structures on the nature of riverbed displacements for the rivers of the Dnister basin upper part. *Geodynamics*. 2019, 2 (27), p. 24-38. https://doi.org/10.23939/jgd2019.02.024

Burshtynska, K., Kokhan, S., Pfeifer, N., Halochkin, M., & Zayats, I. (2023). Hydrological Modeling for Determining Flooded Land from Unmanned Aerial Vehicle Images – Case Study at the Dniester River. *Remote Sensing*, *15*(4), 1071. https://doi.org/10.3390/rs15041071

Dubis L., Kuzio N. (2016). Types of the riverbed of the Nadvirnianska Bystretsia River. *Problems of geomorphology and paleogeography of the Ukrainian Carpathians and adjacent territories.* 1, 261-274. (in Ukrainian). http://nbuv.gov.ua/UJRN/prgeomorpal_2016_1_24.

Fryirs, K. A. and Brierley, G. J. (2013) Geomorphic Analysis of River Systems: An Approach to Reading the Landscape. *Wiley-Blackwell, Hoboken*. P. 345.

Grenfell, M. C., Nicholas, A. P., & Aalto, R. (2014). Mediative adjustment of river dynamics: The role of chute channels in tropical sand-bed meandering rivers. *Sedimentary Geology*. No.301 p. 93–106. https://doi.org/10.1016/j.sedgeo.2013.06.007

Hintov, O. B., Bubniak, I. N., Vikhot, Yu. M., Murovska, A. V., & Nakapeliukh, M. V. (2011). Evolution of the stress-strain state and dynamics of the Skibovy layer of the Ukrainian Carpathians. *Geophysical Journal.* Vol. 33, No. 5. P. 17-34. (in Ukrainian). https://journals.uran.ua/geofizicheskiy/article/view/116847

Hooke, J. M. (2006). Hydromorphological adjustment in meandering river systems and the role of flood events. *Sediment dynamics and the Hydromorphology of fluvial systems*. (Proceedings of a symposium held in Dundee. UK. July 2006). IAHS Publ. No. 306. p. 127–135. https://iahs.info/uploads/dms/13542.20-127-135-10-306-Hooke.pdf

Horishny, P. (2014). Horizontal deformations of the lower streambed of the Stryi River in 1896–2006. *Problems of geomorphology and paleogeography of the Ukrainian Carpathians and adjacent territories.* P. 68-74. (in Ukrainian).

ISOK (Informatyczny System Osiony Kraju przed nadzwyczajnymi zagroïeniami). http://www.gugik.gov.pl/projekty/isok

Janicke, S. (2000). Stream channel processes: Fluvial geomorphology. East Perth, W.A. *Water & Rivers Commission Ser. River restoration*. Report. No. 6 p. 1–12.

Kokhan, S., Dorozhynskyy, O., Burshtynska, K., Vostokov, A., & Drozdivskyi, O. (2020). Improved approach to the development of the crop monitoring system based on the use of multi-source spatial data. Journal of Ecological Engineering, 21(7).

Kovalchuk, I. P. (2003). Hydrological-geomorphological processes in the Carpathian region of Ukraine. *Works of the Shevchenko Scientific Society. XII: Environmental collection. Environmental problems of the Carpathian region*, 101-125. (in Ukrainian). http://dspace.nbuv.gov.ua/handle/123456789/73587

Kravchuk Ya. S. (1999). Geomorphology of Precarpathia. *Mercator*. P. 188. (in Ukrainian).

Krzemien, K. (2006). Badania struktury i dynamiki koryt rzek karpackich. *Infrastruktura i ekologia terenyw wiejskich, Komisja Technicznej Infrastruktury Wsi PAN*, Krakyw. Vol 4(1). p. 131–142. https://agro.icm.edu.pl/agro/element/bwmeta1.element.agro-ca1b887a-5e43-4e47-b27a-0bda7cbf223a

Miller, J., Germanoski, D., Waltman, K., Tausch, R., & Chambers, J. (2001). Influence of late Holocene hillslope processes and landforms on modern channel dynamics in upland watersheds of central Nevada. Geomorphology, 38(3-4), 373-391. https://doi.org/10.1016/S0169-555X(00)00106-9

Morris, A., & Kokhan, S. (2007). Classification of Remotely Sensed Data. Geographic Uncertainty in Environmental Security. *NATO Science for Peace and Security Series C: Environmental Security. Springer, Dordrecht.* https://doi.org/10.1007/978-1-4020-6438-8_14

Nakapelyukh, M., Bubniak, I., Bubniak, A., Jonckheere, R., & Ratschbacher, L. (2018). Cenozoic structural evolution, thermal history, and erosion of the Ukrainian Carpathians fold-thrust belt. *Tectonophysics*, 722, p.197-209. https://doi.org/10.1016/j.tecto.2017.11.009

Obodovsky O. H. (2001). Hydrological and ecological assessment of channel processes (on the example of rivers of Ukraine). K.: Nika-Center. P. 274. (in Ukrainian).

Ostrowski P., Falkowski T., & Utratna-Ïukowska M. (2021). The effect of geological channel structures on floodplain morphodynamics of lowland rivers: A case study from the Bug River, Poland'' https://doi.org/10.1016/j.catena.2021.105209.

Pramanik, M. K. (2016). Morphometric Characteristics and Water Resource Management of Tista River Basin Using Remote Sensing and GIS Techniques. *Journal of Hydrogeology & Hydrologic Engineering*. 5:1. https://doi.org/10.4172/2325-9647.1000131

Rudko, H. I., & Petryshyn, V. Y. (2014). Characteristics of boulder-gravel-sandstone deposits in the Lviv region and their impact on the ecological state of the local environment. *Mineral Resources of Ukraine,* 1, 39-47. (in Ukrainian). http://nbuv.gov.ua/UJRN/Mru_2014_1_15

Shulyarenko, I. P. (1998). Assessment of horizontal channel deformations and stability of small and medium rivers within the Dnieper basin (within Ukraine). *PhD thesis in geographical sciences: 11.00.07. Taras Shevchenko National University of Kyiv.* P. 178. (in Ukrainian).

Starkel, L., Michczynska, D., Gкbica, P., Kiss, T., Panin, A., & Persoiu, I. (2015). Climatic fluctuations reflected in the evolution of fluvial systems of Central-Eastern Europe (60–8 ka cal BP). *Quaternary International*. 388. https://doi.org/10.1016/j.quaint. 2015.04.017.

Tretyak, S. K. (2018). Monitoring of planned displacements of the channels of the right-bank tributaries of the Dniester River. *Current achievements of geodetic science and production,* II(36), 77-86. (in Ukrainian). https://ena.lpnu.ua:8443/server/api/core/bitstreams/02bbe8ad-007c-41e4-95ef-505dc1dbb8d9/content

Volosetsky, B. I., Shpyrnal, T. H. (2013). Study of the transfer of gravel-pebble masses in the channel of the Stryi River based on geodetic monitoring data. *Geodesy, cartography, and aerial photography.* 77, 115-121. (in Ukrainian). https://science.lpnu.ua/istcgcap/all-volumes-and-issues/volume-77-2013/research-about-gravel-and-pebble-mass-transfer

Watson, A. J., & Basher, L. R. (2006). Stream bank erosion: A review of processes of bank failure, measurement and assessment techniques, and modeling approaches. Landcare ICM. *Report Monitoring of horizontal displacements and changes of the riverine area of the Dniester River.* 15 No. 2005-2006/01. **Ошибка! Недопустимый объект гиперссылки.**

Wierzbicki, G., Ostrowski, P., Falkowski, T., & Mazgajski, M. (2018). Geological setting control of flood dynamics in lowland rivers (Poland). *The Science of the total environment*. 636. 367-382. https://doi.org/10.1016/j.scitotenv.2018.04.250.

Zolezzi, G., Luchi, R., & Tubino, M. (2012). Modeling morphodynamic processes in meandering rivers with spatial width variations. *Reviews of Geophysics.* Vol. 50. RG4005. https://doi.org/10.1029/2012RG000392.

Христина БУРШТИНСЬКА[1], Ігор БУБНЯК[2], Ірина ЗАЯЦЬ[1], Софія БЛАЖКО[3], Назар ГРИЦЬКІВ[1]

[1] Кафедра фотограмметрії та геоінформатики, Національний університет «Львівська політехніка», вул. С. Бандери, 12, Львів, 79013, Україна, ел. пошта: khrystyna.v.burshtynska@lpnu.ua, iryna.v.dolynska@lpnu.ua, nazar.z.hrytskiv@lpnu.ua
[2] Кафедра інженерної геодезії, Національний університет «Львівська політехніка», вул. С. Бандери, 12, Львів, 79013, Україна, ел. пошта: ihor.m.bubniak@lpnu.ua
[3] Служба статистики у Кракові, вул. Казімежа Віки, 3, Краків, Польща, ел. пошта: sofiia.k.tretiak@lpnu.ua

ВПЛИВ ГЕОЛОГІЧНИХ СТРУКТУР НА ХАРАКТЕР РУСЕЛ ПРАВОБЕРЕЖНИХ ПРИТОК РІЧКИ ДНІСТЕР

В запропонованому дослідженні поставлено завдання визначити вплив геологічних структур на характер русел найбільших правобережних приток річки Дністер Стрия, Бистриці і Лімниці. З цією метою здійснено районування річки за морфометричними та гідрологічними характеристиками. Виділено три частини: гірську, передгірську і рівнинну, які кардинально відрізняються характеристиками русел, їхніми змінами в часі та деформаційними процесами. Мета роботи. На підставі дистанційних методів отримання зображень різної розрізнювальної здатності, використання різночасових історичних карт та спеціальних карт дослідити характер русел правобережних приток Дністра: Стрия, Лімниці і Бистриці від витоків до гирлової частини при впадінні в річку Дністер залежно від геологічних та структурно-літологічних особливостей поверхні. Основними методами дослідження є перетворення різних матеріалів дистанційного зондування, історичних та спеціальних карт з метою дослідження специфічних явищ руслових процесів. Методика включає підготовку вхідних матеріалів: історичних топографічних карт; геологічних карт; космічних знімків; прив’язку карт та знімків; опрацювання космічних знімків; векторизацію русел; аналіз русел річок залежно від геологічних структур. Результати. Враховуючи особливості морфології, ширину долини, проявлення і розвиток руслових процесів, річки Стрий, Бистрицю, Лімницю розділено на три ділянки: гірську; передгірську та рівнинну з розвиненими акумулятивними формами. В гірській частині русла всіх трьох річок однорукавні, в передгірській частині простежується багаторукавність, яка зменшується при переході з 19ст до 21ст щодо ширини багаторукавності і кількості рукавів, що свідчить про зменшення модуля стоку. Для рівнинних ділянок русел з нерозвиненими акумулятивними формами простежуються чітка тенденція до залежності типу русла від структурно-літологічних особливостей. Оригінальність. Встановлено залежність руслових процесів правобережних річка Дністер з геологічними та седиментологічними структурами Скибових Карпат та Передкарпатського прогину. Практична значущість. Результати моніторингу руслових процесів необхідно враховувати при вирішенні низки завдань, а саме: будівництві гідротехнічних споруд, проєктуванні мереж електропередач на перетині з річками, розвитку газопроводів, визначенні зон затоплення, визначенні наслідків руйнування після повеней, освоюванні заплавних земель, встановленні меж водоохоронних зон, управлінні рекреаційними та прикордонними землями та встановленні міждержавного кордону вздовж річок.

Ключові слова: руслові процеси, правобережні притоки, річка Дністер, геологічні та седиментологічні структури, космічні знімки, Скибові Карпати, Передкарпатський прогин, багаторукавність.

Received 26.02.2024