UDC 528.92

K. V. BURSHTYNSKA[1], A. V. BABUSHKA[1]*, I. M. BUBNIAK[2], L. V. BABIY[1],
S. K. TRETYAK[1]

[1] Department of Photogrammetry and Geoinformatics, Lviv Polytechnic National University, 12, S. Bandery Str., Lviv, 79013, Ukraine, +38(096)4768773, e-mail: andriy.babushka@gmail.com
[2] Department of Engineering Geodesy, Lviv Polytechnic National University, 12, S. Bandery Str., Lviv, 79013, Ukraine

https://doi.org/10.23939/jgd2019.02.024

INFLUENCE OF GEOLOGICAL STRUCTURES ON THE NATURE OF RIVERBED DISPLACEMENTS FOR THE RIVERS OF THE DNISTER BASIN UPPER PART

Aim of work is to investigate the influence of the Precarpathian bend and the Volynian-Podolian upland for the nature of displacement of the Dnister River tributaries and to determine stability of river channels. The object of this research is the Dnister River and its left and right tributaries. Considering the main factors influencing the nature of the horizontal riverbed displacements caused by both natural and anthropogenic factors, special attention is focused on the geological structures in the area on which Dnister River and its tributaries flow. **Methods.** Applying the software package ArcGIS authors had implemented the monitoring for a 100 year period using various topographical, geological, ground maps, and space images. For monitoring of displacements of the riverbeds of right and left bank tributaries of the Dnister there were used: topographic maps at scales 1:100000 and 1:75000 (Austrian period – 1886, 1910, Polish period –1930, the Soviet period – 1985, 1989); space images Landsat 7 (2000), Landsat 8 (2014) and Sentinel 2 (2016, 2017); and soil map scale 1:200000. It allows declaration about the different nature of the displacements. **Results.** The Dnister River flows on the border of two structures **-** the Precarpathian bend and the Volynian-Podolian upland. The right bank tributaries (Bystrytsia, Limnytsia, Stryi, and others) that begin in the Carpathians, cross the outer and inner boundaries of the Precarpathian bend, and are characterized by riverbed stability in the mountainous part, with multithreading and considerable meandering (especially for the Stryi River) within the Precarpathian bend. Lithological deposits have a significant influence at the mouth of the Stryi River. For these tributaries, according to the results of the study, large horizontal displacements are observed, they extend for: Limnytsia river – 500 m, Bystrytsia river – 580 m, Stryi River – 1200 m. The left bank tributaries, which are located on the Volynian-Podolian upland, include Zolota Lypa, Seret, Zbruch, Smotrych, and Strypa rivers. They are highly sinuos but much more stable in horizontal displacements. The maximum displacements for these rivers are 300–380 m. **Scientific novelty**. Investigation includes the influence of geological structures on the displacements of the left and right bank tributaries of the Dnister River and an analysis of the basic mathematical expressions that are used to evaluate the stability of the riverbeds. **The practical significance.** The results of monitoring riverbed deformation processes have to be considered while solving tasks related to riverbed processes, namely for: development and building of hydraulic engineering facilities, design of power transmission network when crossing rivers, development of gas transmission pipelines, determination of flood hazard zones and consequences of destruction after flash floods or seasonal floods, establishment of boundaries of land conservation areas, management of recreation activities, monitoring of the condition of frontier lands, and establishment of the border along the midstream of rivers.

Key words: monitoring; riverbed displacements; space images; topographic maps; geological structure.

Introduction

It is well known that riverbeds change their plane position and elevation with time. Depending on the type of river, during a period of 50-100 years. Its riverbed can move distances which can significantly exceeds the width of a riverbed, new straits and distributaries can appear, and a riverbed can change its configuration.

Results of monitoring riverbed deformation processes must be considered while solving tasks related to riverbed processes, namely:

- development and building of hydraulic engineering facilities;
- design of power transmission networks when crossing rivers;
- development of gas transmission pipelines;
- determination of flood hazard zones and consequences of destruction after flash floods or seasonal floods;
- establishment of boundaries of land conservation areas;
- management of recreation activities;

– monitoring of the condition of frontier lands and establishment of the border along the midstream of rivers.

Expenses for research of a riverbed and geological environment comprise a few percent of expenses incurred for construction of a facility, but these engineering and geological examinations often determine successful use of the designed facility. Ignoring plane displacements of riverbeds often results in unpredictable consequences. Thus, for example, a displacement of a riverbed can cause emergencies at submerged cross nodes of pipelines. Bank caving causes breakage of pipelines, which in its turn could cause a massive explosion and fire, oil spill, and environmental disruptions. Significant losses to the economy can be caused by erosion of bridge pillars, power transmission line support, etc.

Significant material losses and even human toll during floods are also associated with the riverbed process. Therefore, these processes are reflected in the EU documents (Directive 2000/60/ES), in Poland (ISOK) and in Ukraine (the Resolution of the Cabinet of Ministers of Ukraine, The Water Code of Ukraine).

In the carried research the theoretical aspects of hydrology, in particular mathematical expressions of the interaction of a riverbed stream, erosion processes, and transport and accumulation of sediments were not considered. Although undoubtedly, these factors are the cause of the horizontal and vertical displacements of the Dnister River [Burshtynska, et al., 2016, 2017, 2018] and its tributaries.

The object of the study is the left and right bank tributaries of the second largest river in Ukraine, the Dnister River, in the part of the basin from the riverhead to the canyon part (Zalishchyky town) (Fig. 1).

Fig. 1. General view of the field of research

Despite the general approaches to the study of riverbed processes, each river has its own natural features and undergoes anthropogenic impact, so each river and its basin are explored separately. Such studies are of practical importance, first of all, in relation to hydraulic engineering and land cadastre. In recent decades, the field which is associated with ecological research of riverbeds (that is, the study of changes in the riverbed as a result of anthropogenic actions on the riverbed processes) is rapidly developing.

At the Department of Photogrammetry and Geoinformatics of the Lviv Polytechnic National University, the issues of displacement and change of riverbed configuration of the Dnister and Tysa rivers have been a subject of research since 2010. Among the main works on this subject, it is possible to note [Burshtynska, et al., 2010, 2016; Shevchuk, & Burshtynska, 2011]. It has been established that over the period of 100 years, at some parts of the rivers, the riverbeds have shifted 800–1000 meters. An analysis of maps of quaternary sediments and soils made it possible to conclude alluvial deposits mainly of gravel and sand type, as well as about large-scale, have often incurred significant uncontrolled extraction of these raw materials for producing building materials.

Interesting studies of the changes in the Stryi Riverbed on the base of topographic maps and space images for the period 1896–2006 are given in [Horishnyi, 2014]. The study of the influence of forest cover changes on the territory of the river Pidbuzh (tributary of Dnister River), as well as the peculiarities of the meandering on some sections of the Dnister River are given in [Bayrak, 2016].

The study of the structure and dynamics of the Carpathian riverbeds on the basis of ground survey is in the work [Krzemien, 2006]. The author emphasizes the necessity of dividing the rivers into several parts having a homogeneous morphological structure, as well as performing analysis of changes using cartographic data and aerial images. The conclusion about the significant impact of anthropogenic factors on the change of the bottom of the valley and flow due to regulation of the riverbed, construction of water reservoirs, extraction of gravel and stone, as well as contamination of the valley are made. The non-useful changes of soil erosion and research of drainage degradation are emphasized. It is indicated as a necessity to prohibit extraction of gravel from the rivers, to protect the parts of riverbed which are not destroyed by excessive explication of coastal lands and the channels themselves.

In the work [Żelaziński, 2014] the detailed analysis of changes in morphology of Vistula riverbed caused by river regulations is presented. The evolution for the period 1737–1990 was described using maps and other data about changes in the shape of the riverbed of the mountain part of Vistula. The first phase lasted until the middle of the 19th century and was characterized by the influence of the development of arable land and deforestation on the riverbed changes, which led to the increase of erosion and increased falling of erosion products into the riverbed. The second phase began with the intensity of regulatory processes since 1890. Engineering works led to a shortening of the river length, narrowing of the channel, and constructions of dams as a protection against floods. However, based on mathematical calculations it is shown that “the regulation of the mountainous Vistula caused a significant increase in the frequency of catastrophic flood events”. At the same time authors give the reasons of such phenomena.

Large-scale and different in character research on riverbed deformations are carried out in many countries. Thus, the influence of topography, geology, climate, vegetation, and land use on the spatial and temporal change of riverbed processes in the Pacific Northwest is indicated in [Buffington, et al., 2003]. The authors investigated the effect of the types of riverbeds on physical models that can be used to forecast the changes in the morphology of the riverbed.

The relationship between the topography of the Earth's surface and hydrological parameters of a riverbed, including an impact of aboveground and underground water flow, as well as study of morphology and structure of the Amazon River is given in the works [Pirmez, et al., 1995].

Scientists from Great Britain [Friend, & Sinha, 1993] studied the interweaving and sinuosity of singlethread and multithread rivers with determination of interweaving and sinuosity coefficients. It has been found that multithread rivers are more sinuous than singlethread ones.

The study of issues of riverbed processes in the rivers of Western Australia are given in report [Janicke, 2000]. It has revealed the impact of anthropogenic factors onto the transportation of deposits and silting. Attention has been paid to the solution of the problem of rivers degradation and riverbed processes, which is the responsibility of a special Water and Rivers Commission

The study [Guneralp, et al., 2011] analyzes the riverbed migration of the Brazos River in Texas for the period 1910–2010. Author used topographic maps and space images of different years. Not only the migration of the riverbed, but also the meanders, the slope and shape of the riverbed were studied. Riverbed migration zones have been identified that combine historical riverbed displacements with forecasting of future displacements, which is an analytical tool for identifying areas that may be in danger of catastrophic events and floods.

In [Legg, & Olson, 2014] the objects of the study are the rivers of Western Washington, in particular migration of riverbeds. It is indicated that the riverbeds migrate over the floodplain due to the processes of riverbed expansion, changes in the bends, and their frequency.

From reference sources [Obodovskyi, et al., 2005] it is known that every river has its own properties depending on natural and anthropogenic factors. Factors affecting deformation processes of riverbeds are divided into two groups: natural and anthropogenic, which in turn are divided into direct and indirect factors. The classification of the main factors of influence on riverbed displacements is given in the Table 1 [Obodovskyi, 2001].

Analyzing the natural factors in Table 1, it has been established that the geological structure has the dominant influence for the studied region. It directly and indirectly influences other factors (in particular, erosion) under the same influence of the hydro meteorological conditions.

Aim

The aim of work is to investigate the influence of the Precarpathian bend and the Volynian–Podolian upland regarding the nature of displacement of the Dnister River tributaries and to determine stability of river channels. The object of research is the Dnister River and its left and right tributaries. Considering the main factors influencing the nature of the horizontal riverbed displacements, caused by both natural and anthropogenic factors, special attention is focused on the geological structures of the area on which the Dnister River and its tributaries flow.

Table 1

Classification of main factors influencing riverbed displacements [Obodovskyi, 2001]

Riverbed processes				
Natural			Anthropogenic	
Direct		Indirect	Direct	Indirect
Water flow	Landslides and bank erosion	Rainfall regime	Hydro-technical construction	Watershed destruction
Sediment run-off	Soil drifting	Erosion intensity at the watershed	Overregulation of the water flow	Deforestation in the basin
Geological and morphological structure	Surge of the river	Water-blocking capacity of the soil	Streambed and floodplain quarries	Mining for mineral resources at the watershed
	Freeze-up and frozen soil	Vegetation at the watershed	Communications across rivers	Hydro-technical and amelioration measures at the watershed and floodplains
	Vegetation in the river and on the floodplain	Landscape structure of the watershed	Amelioration works in the riverbed	Gravel and stone extraction
			Settlements along riverbanks	

Methods

For monitoring of displacements of the riverbeds of right and left bank tributaries of the Dnister there were used:

– topographic maps at scales 1:100000 and 1:75000 (Austrian period – 1886, 1910, Polish period – 1930, the Soviet period – 1985, 1989);

– space images Landsat 7 (2000), Landsat 8 (2014) and Sentinel 2 (2016, 2017);

– soil map in scale 1:200000.

Workflow of the research is presented in Fig. 2. Visualization and analysis of the configurations of the riverbeds of right and left bank tributaries of the river Dnister River were performed using ArcGIS 10.1 software. Since the given topographic maps were created in different time periods and with different map projections, while the space images are presented in the UTM projection, it is necessary to reduce all data to a universal topographic projection of Mercator UTM.

The studied rivers are located on the two structures of the first order: the platform and the orogene. The platform part includes East European and Western European ones, and the Ukrainian Carpathians belong to orogene. Ukrainian Carpathian foredeep is imposed on these two structures. In the territory of the Western Ukraine there are two platforms distinguished at the front of the Ukrainian Carpathians: old East European and Western European ones. The reason for this dividing is the time of the basement consolidation. The consolidation of the old platform (craton) took place in Prerifean time, while the young ones were in the Riphean and Paleozoic.

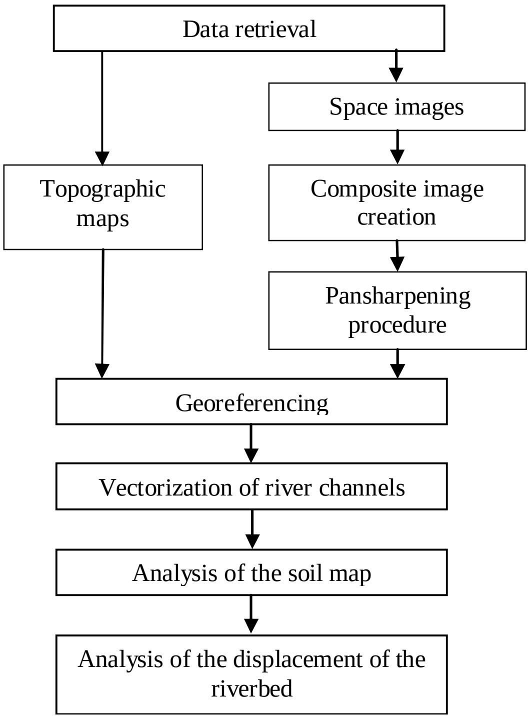

Fig. 2. Technological scheme of investigations

General characteristics of the right and left bank tributaries of the Dnister River

East European platform is composed of crystalline basement and sedimentary cover. Sedimentary cover in the western part of Ukraine forms so called Volyno-Podillia plate. The basement consists of metamorphic, sedimentary-volcanogenic, and intrusive rocks.

Ukrainian Carpathians are orogeny part of the studied region. From tectonic point of view, Carpathians consist of the Inner and Outer Carpathians. The reason for such a division is the time of the final (main) folding. For the Inner Carpathians the main ones were in Cretaceous (65 Ma), and for the Outer ones they were in Cenozoic (11 Ma). These two tectonic regions are separated by a narrow Pieniny zone (Fig. 3).

Ukrainian Carpathians have typical thrust folded structure. The thrusts distinguished here were thrust in the northwest direction. The thickness of the thrusted complex within the Ukrainian Carpathians reaches 12 km. Based on the detailed geological studies, data of drilling, analysis of the relationships of the youngest structures covered by sediments and the youngest thusted and folding, the folding phases were identified in the Carpathians and the Inner zone of the Carpathian foredeep.

The rivers in the presented studies cross the Skyba nappe of the Ukrainian Carpathians and the Inner zone of the Carpathian foredeep. The direction of the channels for most of the river is due to tectonic factors, namely, transverse to the Carpathians by regional faults. Although there are exceptions, such as the meanders of the Stryi River in the area of Rybnyk village, which may be due to the composition and mechanical properties of rocks. Also fractures (orientation of cracks, their size) of rocks play an important role in the formation of the river channels.

Pleistocene deposits of the described territory are divided into Lower, Middle and Upper. They consist of a variety of genetic types of rocks – valley moraines, glacial and water-glacial deposits, fluvio-glacial sands. Coarse material is composed mainly of sandstones, siltstones, cornices, quartz and a small admixture of other rocks. The crustaceans are described on the surface of the floodplain and the first floodplain terraces of the rivers (Upper Dnidrist swamps), the ancient valleys of the drainage of thawed glacial waters, less frequently in water bodies and in the holes of the carriages. Their thickness is 2–3 m.

The following right bank tributaries have been analyzed: Stryi (232 km), Limnytsia (122 km), Bystrytsia (17 km), Bystrytsia Nadvirnianska (94 km), and Bystrytsia Solotvynska (82 km)). Right bank tributaries are characterized by flood regime throughout the year.

There were studied 5 main left bank tributaries of the Dnister River: Zolota Lypa (85 km), Strypa (147 km), Seret (242 km), Zbruch (244 km) and Smotrych (169 km). The left tributaries of the Dnister River, which originate at the Volynian-Podolian upland, flow on low banks. Near the Dnister River, they erode solid rock, which makes the banks become steep and tall. Left bank tributaries are meridian rivers entering the Dnister in the deep canyon valley. At higher areas these tributaries pass along steep slopes of valleys with outcrops of ancient rocks. The left bank is characterized by rapid drainage of precipitation and spring precipitation. There are frequent summer rain floods. The flow rate of these tributaries is not large and is from 0.50 to 1.20 m/sec. In the places of riverhead of the left tributaries the valleys are narrow and shallow, and in the lower parts of the flow they become deep. The maximum flow of water per year is during the spring floods. Summer rain floods reach the level of spring floods, but on some areas most of the rivers are regulated and accumulate water in storage ponds and reservoirs.

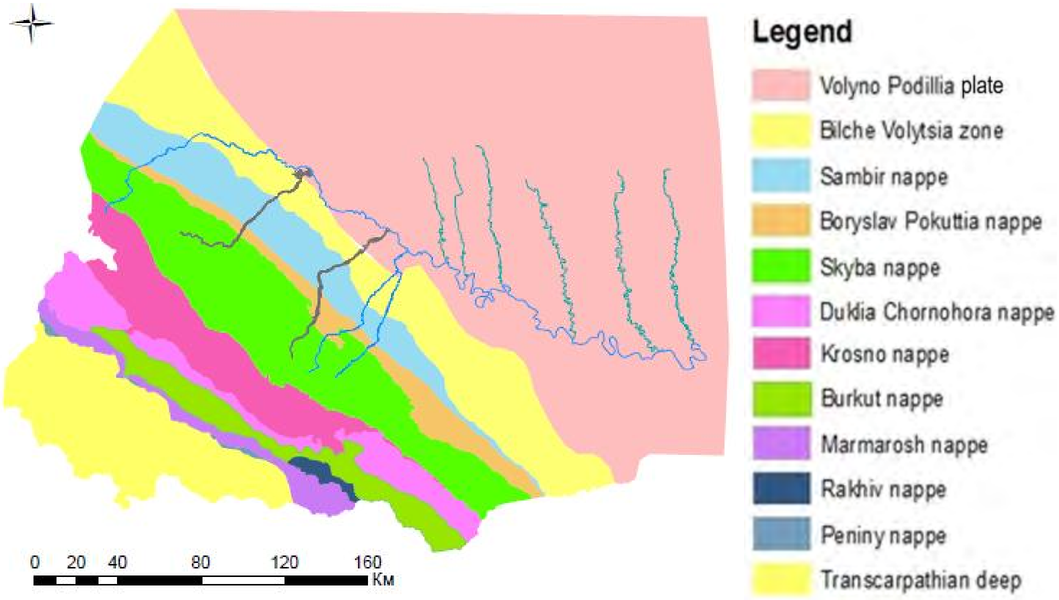

Fig. 3. Overlapping of studied rivers with tectonic structures of the west of Ukraine

Results and discussion

Authors consider such parameters as the nature and displacement values of the riverbeds to divide all studied right bank tributaries of the Dnister River into three main parts and study them separately: mountain, foothill, and plain for the river Stryi, and mountain, mountain with marshy plain, and plain for rivers Bystrytsia and Limnytsia. Left tributaries are divided into 2 parts depending on the nature of the channel: the northern part – hilly, with wider floodplains and southern part has canyon nature.

The task involves studying the horizontal displacements of the right and left tributaries of the Dnister River, determining the areas of maximum displacement, analyzing various mathematical expressions for assessing the stability of the riverbed presented in the specialized literature [Obodovskyi, 2001], and calculating the stability coefficient, taking into account the displacement of the riverbed.

One of the principal characteristics of the rivers is sinuosity coefficient K_l, which is determined from the correlation (Table 2, 3):

$$K_l=L'/L, \qquad (1)$$

where: L' is the length of the riverbed in the area; L is the length of the riverbed between the extreme points measured in a straight line.

Using presented in the special literature classification of rivers according to Sinuosity: relatively straightforward – <1.1, very weakly sinuous – 1.10–1.20, weakly sinuous – 1.21–1.40, moderately sinuous -1.41–1.60, sinuous – 1.61–1.80, strongly sinuous – 1.81–2.00, extremely sinuous – > 2.00 and calculations on the expression (1) we conclude that: the Stryi River belongs to the category of weakly sinuous rivers, the Bystrytsia River with its tributaries belongs to the very weakly sinuous rivers, except the first part (I) of the Bystrytsia Solotvynska tributary, which is relatively straightforward, as well as the Limnytsia River.

Left bank tributaries were divided into 2 parts for calculating the Sinuosity (Fig. 4). The hilly part of these rivers is less sinuous than the canyon. The hilly part of the Zolota Lypa River are classified as relatively straightforward because of the hydrotechnical work carried out in 1930s. The hilly part of the Strypa and Smotrych Rivers are very weakly sinuous, and the Seret and Zbruch Rivers are weakly sinuous. The canyon part of the Zolota Lypa, Strypa, and Seret Rivers is classified as moderately sinuous. The most sinuous is the canyon part of the Zbruch and Smotrych Rivers, which are strongly sinuous, where the large bends of the channel are noted.

Table 2

Sinuosity coefficients for the right bank tributaries

River	Sinuosity coefficients		
	part I	part II	part III
Stryi	1.30	1.20	1.30
Bystrytsia Nadvirnyanska	1.16	1.19	1.11
Bystrytsia Solotvynska	1.03	1.11	–
Limnytsia	1.08	1.07	1.06

Table 3

Sinuosity coefficients for the left bank tributaries

River	Sinuosity coefficients	
	part I	part II
Zolota Lypa	1.00	1.56
Strypa	1.18	1.46
Seret	1.43	1.51
Zbruch	1.36	1.92
Smotrych	1.17	1.92

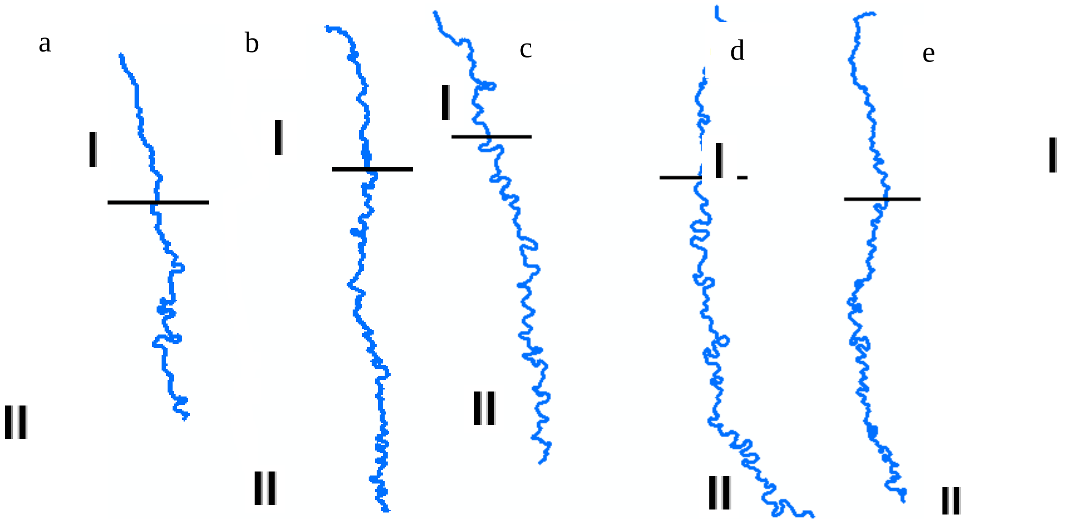

Fig. 4. Five left bank tributaries of the Dnister River divided into 2 parts (I – hilly part, II – canyon part): a – Zolota Lypa; b – Strypa; c – Seret; d – Zbruch; e – Smotrych

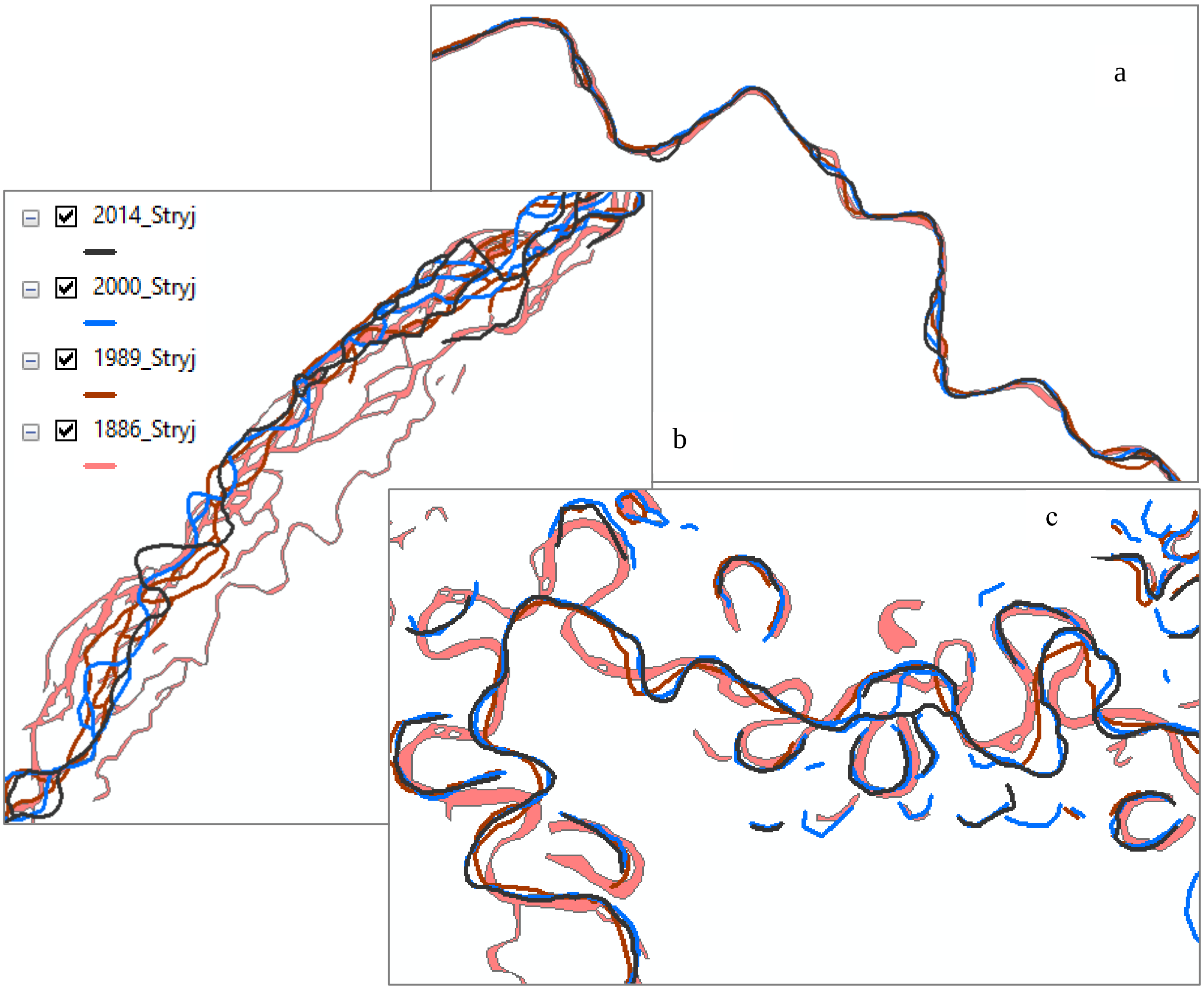

Fig. 5. Right bank tributaries of the Dnister River:
a – the mountain part; b – foothill part; c – plain part

Digitized riverbeds are given in Fig. 5 (Stryi River) which shows the digitized channels for the different time periods (a – the mountain part; b – foothill part; c – plain part).

The mountain part of the Stryi River is characterized by small displacements, maximum is 159 m. In this part of river we chose only 5 points to determine the displacement, as in this part the channels are almost overlapping. The length of the mountain part is 25 km. The foothill part of the Stryi River is characterized by multithreading (Fig. 5b).

Table 4 presents the displacements of the right bank tributary (Stryi River). Other right bank tributaries have similar characteristics of riverbed displacements. Therefore, we do not represent them in separate tables. Table 4 shows displacements for two time periods, since the displacements of riverbed between 2000 and 2014 is slightly different. The maximum displacements of all tributaries are given in Table 10.

Table 4

Displacements of the Stryi River

Part of river	Point №	Riverbed displacements (m)	
		1886–1989	1989–2014
I	1	90	105
	2	155	–155
	3	**–160**	50
	4	–	145
	5	30	**160**
III	1	**1150**	135
	2	765	–15
	3	–325	–55
	4	–645	15
	5	500	–165
	6	165	**270**
	7	–360	–250
	8	–195	–165

We represent the number of threads and the measured distance between the outermost threads (Table 5). In 1886 the maximum width of multithreading is up to 1500 m, the river is divided into 3–4 threads. In almost 100 years (on the map of 1989), the width between the outermost threads is reduced to 500 m, but significant interlacement of the channel is observed which we can also be seen in the space image (2000). In the space image (2016), the riverbed of Stryi River in this area is single thread. In the foothill section, we consider displacements as the differences between the width of multithreading. The length of this part is 50 km. On the plain part, the largest displacements are found, reaching a magnitude of 1150 m. The length of the plain part of the Stryi River is 18 km. On the Austrian map, there are observed 20 former riverbeds and 12 islands, but over time this number has decreased and on the 2014 space image there were 12 former riverbeds and 2 islands. Actually, on the foothills and plain areas, the reason for changing the character of the riverbed is the significant influence of anthropogenic factors, in particular, the extracting of gravel and sand materials [Rudko, & Petryshyn, 2014].

Table 5

Multithreading widths and number of threads between outermost threads of Stryi River 1886, 1989, 2000, 2014.

Po-int №	1886		1989		2000		2014	
	Width, m	Number	Width, m	Number	Width, m	Number	Width, m	Number
1	1520	4	445	3	450	2	0	1
2	665	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

In the mountain part the length is 13 km for Bystrytsia Nadvirnyanska and 34 km for Bystrytsia Solotvynska. The measurements are made on the points with maximum displacements, which are: for Bystrytsia Nadvirnyanska – 170 m, Bystrytsia Solotvynska – 270 m. The second part of Bystrytsia Nadvirnyanska is characterized by the fact that the riverbed of 1886 is single thread, but on the rest of the data (1989, 2000 and 2014) it is observed the multithreading and interlacement of the riverbed on some area (Fig. 6a). The largest distance between threads is 756 m (2016). The riverbed is divided into 2 threads. This part is swamped. The length of this part is 19 km. In the second part, the difference between the width of multithreading considered as displacements. On the bend near the city of Ivano-Frankivsk, two tributaries (Bystrytsia Solotvynska and Bystrytsia Nadvirnianska) merge into one river Bystrytsia. On the plain part, the maximum width of multithreading is 500–700 m. The channel in all time periods is divided into 2–3 threads with significant braiding. The maximum displacement values in both tributaries of the Bystrytsia River in this part are more than 700–1000 m at different points comparing riverbeds on the map of 1886 and the satellite image of 2016. The complex nature of the riverbed with significant braiding does not allow determining the displacements for specific time periods.

The length of mountain part of the riverbed of the Limnytsia is 21 km. In this part of the Limnytsia River, displacements are not noticeable. Only one point with displacement, which reaches 250 m, is recorded. The second part is characterized by a considerable multithreading of rivers (Fig. 6b); the channel is divided into 3 threads. The width between the threads reaches 1000–1300 m (1910). The length of this part is 29 km. In this part also it is impossible to measure displacements due to multithreading. In the third part, the river bed also has multithreading, but it is significantly reduced in this area. The width of multithreading here is maximum 604 m on the map of 1910, and in other years (1989, 2000 and 2016) it is 250 m and 200 m. The riverbed is divided into 2 threads. The length of this part of the river is 35 km. Here, there were measured the largest displacement, the maximum is 490 m for the period 1910–1989. And at other measured points displacements are 200–300 m (1910–1989). The riverbed has significant sinuosity and bending.

The measurements of displacements of the left bank tributaries were carried out in most of the characteristic bends. Their number is indicated in Tables 6 and 7. The Zolota Lypa River has a length of 85 km, maximum displacement of the riverbed is 385 m (Table 6). In the marshy plain in the upper reaches of the river a drainage sewer was established. The length of the Seret River is 240 km, maximum displacement of the riverbed is 270 m. The Zbruch River is the largest left tributary of the Dnister River. It has a length of 250 km, and maximum displacement is 340 m. Strypa is a river that has a length of 145 km. Its riverbed in the upper reaches is regulated by reservoirs. The maximum displacement is 250 m. And from the analysis of the river, one can see the places where the river has shifted considerably due to the reclamation work, since the channel is regulated at a great distance (500–550 m). The Smotrych River has a length of 170 km. The uniqueness of the river is a canyon near the city of Kamyanets-Podilsky. During the study, it was noted that before, in Austrian times this canyon did not exist. Maximum displacement is 315 m.

Tables 6 and 7 show the displacements of the left bank tributaries.

In addition to riverbed displacements riverbed stability was analyzed on the basis of the mathematical expressions proposed by various authors.

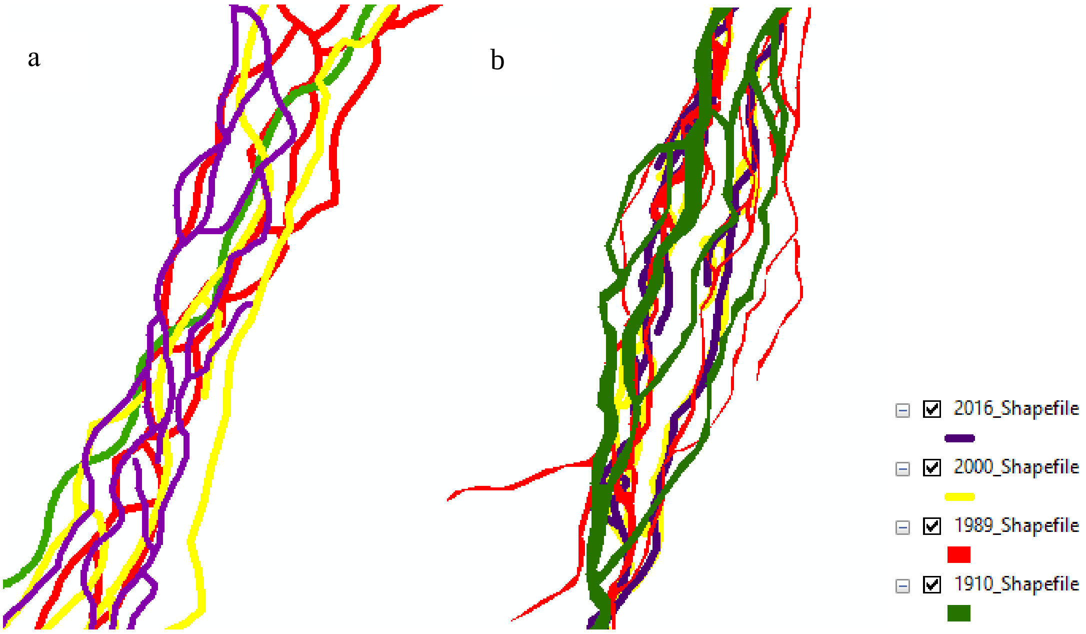

Fig. 6. The nature of the second part of the rivers:
a – Bystrytsia; b – Limnytsia

Table 6

Displacements of the left bank tributaries (Zolota Lypa and Zbruch)

Point №	Part of the river	Zolota Lypa riverbed Displacements, m			Part of the river	Zbruch riverbed Displacements, m		
		1910–1930	1930–1985	1985–2017		1910–1930	1930–1985	1985–2017
1	I	30	–	55	I	–160	–	65
2		70	–30	385		310	–	–75
3		–220	35	–		–320	–	85
6	II	–250	20	35		–300	–	–
7		235	50	–50		–160	–180	70
8		225	–80	–		–280	–60	60
9		220	–65	55		–200	–140	–
10		–185	20	–80	II	215	–	50
11		–280	95	–		230	–	–
12		300	–	25		–340	95	–

Table 7

Displacements of the left bank tributaries (Seret, Strypa, and Smotrych Rivers)

Point №	Part of the river	Strypa riverbed displacements, m			Seret riverbed Displacements, m			Part of the river	Smotrych riverbed Displacements, m		
		1910–1930	1930–1985	1985–2017	1910–1930	1930–1985	1985–2017		1910–1930	1930–1985	1985–2017
1	**I**	–95	–60	30	–55	–145	–	**I**	150	85	–
2		30	–155	60	–120	–40	25		–190	145	–
3		160	–30	30	45	75	65		–20	165	40
4		40	90	30	–125	20	–		105	70	50
5		–	75	30	–185	–	–		200	–40	40
6		–40	–	**–145**	–95	–70	70		265	–35	–
7		–	130	80	–120	–30	**150**		85	**190**	–
8		–95	–40	–20	–90	–105	105		110	115	–20
9		35	25	60	–155	55	–		–70	130	–
10		65	–65	105	–160	–	–35		–150	–130	–40
11	**II**	85	90	–	–110	160	40		–240	–	50
12		125	50	–30	–230	160	–		–150	–	30
13		**250**	15	15	–125	**185**	–	**II**	–170	–40	–
14		–35	115	–15	–150	–	40		–280	–30	–
15		210	–85	–	–240	105	–		–235	–	45
17		130	50	–	–200	40	–15		–250	45	–25
18		175	–	60	–230	–	–		170	80	**–80**
19		135	**175**	–	**–270**	60	–		**–315**	55	–25

As for measurements that characterize the stability of the riverbed, two approaches are described in the special literature. According to the first approach, the coefficient of stability of the riverbed is determined at certain areas of insignificant length, where it is planned to conduct hydrotechnical works and where the river has the same characteristics [Heeren, et al., 2012; Simon, & Klimetz, 2008]. The second approach determinates indicators of stability based on the morphometric characteristics of large sections of the river using appropriate mathematical expressions [Chalov, & Makkaveev, 1986; Krylenko, et al., 2005]. In this paper, stability was determined on the basis of the second approach.

The coefficient of sinuosity can be one of the indicators of stability, only for areas with a small width of flood plain.

The formulas used to assess the stability do not include such parameter as the width of the floodplain, which is associated with the occurrence of flood phenomena. The width of the floodplain is measured for each part of the studied rivers on Quaternary maps using 50–70 points every 3–4 km. It is suggested to show the coefficient of stability of the riverbed, as the ratio of the width of the floodplain to the width of the riverbed:

$$K = \frac{k \cdot B'}{B}, \qquad (2)$$

where k is erosion coefficient, B' is the width of the floodplain, determined based on the maps of quaternary deposits at scales 1:50000.

Table 8

The criterion of stability for the right bank and left bank tributaries of the Dnister River [Burshtynska, Kh. et al., 2018]

Characteristics of stability	Coefficients of stability	
	Right-bank	Left-bank
Stable	1–4	1–10
Relatively stable	4–10	10–20
Relatively unstable	10–20	20–40
Unstable	>20	>40

The criterion of stability is shown in Table 8. Table 9 shows the main morphometric characteristics of mentioned three parts of the riverbeds of each right bank tributary of the Dnister River, and the Table 10 shows the parameters of the stability of the riverbed calculated by the expressions given in the first column [Krylenko, et al., 2005]. Table 11 shows the main morphometric characteristics of the riverbeds of each left bank tributary of the Dnister River and Table 12 shows the riverbed stability calculation. Stability is estimated on the basis of calculated coefficients with their comparison done according to the stability criteria. The criteria of stability are presented by the authors on the results of analysis of different types of rivers [Obodovskyi, 2001; Krylenko, et al., 2005]. In [Krylenko, et al., 2005], it is indicated that the displacements of riverbeds can be considered as the stability criterion. The stability analysis in our study was performed on the basis of comparison of the determined stability coefficients and horizontal displacements separately for right bank (Tables 9, 10) and left bank tributaries (Tables 11, 12).

Table 9

Main morphometric characteristics of three parts of the right bank tributaries of the Dnister River

Morphometric parameters	Stryi River			River Bystrytsia with tributary Nadvirnyanska			River Bystrytsia with tributary Solotvynska		Limnytsia river		
	I	II	III	I	II	III	I	II	I	II	III
Length *l*, km	25	50	18	12	19	39	33	38	21	29	35
River incidence ΔH, m	70	90	8	134	163	160	339	193	287	191	98
Slope of water surface I, m/km	2,8	1.8	0.44	11.1	8.5	4.1	10.2	5	13.6	6.58	2.8
Average width of riverbed *B*, m	40	50	50	10	20	32	10	25	22	40	50
Depth of river **h**, m	0.5	0.8	1.0	0.5	1.5	2	0.5	1	0.5	1.0	1.5
Average diameter of alluvium **d**, mm	50	10	1	50	10	1	50	2	50	10	2
Width of floodplain *B´*, m	265	1025	1477	98	420	900	97	800	200	1002	1500

Table 10

Calculated riverbed stability coefficients (right bank tributaries of the Dnister River)

	Expressions	Criteria of stability	Stryi River			River Bystrytsia with tributary Nadvirnyanska			River Bystrytsia with tributary Solotvynska		Limnytsia River		
			I	II	III	I	II	III	I	II	I	II	III
1	$L = d/I$	2 – <50	17.8	5.5	2.2	4.5	1.1	0.2	4.9	0.4	3.6	1.5	0.7
2	$L_o = (d/I) \cdot (B/h) \cdot A$, (*A* – coefficient of erosion (0,03))	2 – <50	42.7	10.3	3.3	2.7	0.4	0.1	2.9	0.3	4.7	1.8	0.7
3	$K_s = 1000\ (d/B \cdot I)$	6 – >100	446	111	45.4	450	58.8	7.6	490	16	167	38	14.2
4	$\Psi = d/h \cdot I$	1–15	35.7	6.9	2.2	9	0.8	0.1	9.8	0.4	7.3	1.5	0.5
5	$G = (\sqrt{B})/h$	18–1	12.6	8.8	7	6.3	3	2.8	6.3	5	9.3	6.3	4.7
6	$K_u = \sqrt{(B \cdot d/h)}$	5–40	63.2	25	7	31.6	11.5	4	31.6	7	46.9	20	8
7	$K_r = (d \cdot B)/(h \cdot I)$	30–1500	1428	347	113	90	15.7	4	98	10	161.7	60.7	23.8
8	$\boldsymbol{K = B'/B}$	**100 – 1**	**6.6**	**20.5**	**29.5**	**9.8**	**21**	**28**	**9.7**	**32**	**9**	**25**	**30**
	Maximum displacements, m		250–570	–	900–1100	50–100	–	300–550	150–250	280–570	70–250	–	300–500

Table 11

Main morphometric parameters of the above two sections of the left bank tributaries of the Dnister River

Morphometric parameters	Zolota Lypa		Strypa		Seret		Zbruch		Smotrych	
	I	II	I	II	I	II	I	II	I	II
Length *l*, km	23	48	23	80	30	107	30	100	45	85
River incidence ΔH, m	14	55	7	128	19	119	43	106	56	61
Slope of water surface I, m/km	0.6	1.14	0.3	1.6	0.6	1.1	1.43	1.06	1.2	0.71
Average width of riverbed, *B*, m	15	17	18	18	22	50	32	39	16	26
Depth of river **h**, m	1	1.5	1	1	1.5	1.5	1.5	1.5	1.5	1.5
Average diameter of alluvium *d*, mm	20	20	20	20	20	20	20	20	20	20
Width of floodplain *B´*, m	32	15	19	9	12	7	16	7	25	10

Table 12

Calculated riverbed stability coefficients (left bank tributaries of the Dnister River)

Expressions	Criteria of stability	Zolota Lypa		Strypa		Seret		Zbruch		Smotrych	
		I	II	I	II	I	II	I	II	I	II
1. $L = d/I$	2 – <50	33.3	17.5	66.6	12.5	33.3	18.1	13.9	18.8	16.6	28.1
2. $L_o = (d/I) \cdot (B/h) \cdot A$, ($A$ – coefficient of erosion (0,03))	2 – <50	14.9	5.9	35.9	6.7	14.6	18.1	8.8	14.6	5.3	14.6
3. $K_s = 1000^* (d/B \cdot I)$	6 – >100	2222	1031	3703	694	1515	363	437	483	1041	1083
4. $\Psi = d/h \cdot I$	1–15	33.3	11.7	66.6	12.5	22.2	12.1	9.3	12.5	11.1	18.7
5. $G = (\sqrt{B})/h$	18–1	3.8	2.7	4.2	4.2	3.1	4.7	3.7	4.1	2.6	3.4
6. $K_u = \sqrt{(B \cdot d/h)}$	5–40	17.3	15	19	19	17	25.8	20.6	22.8	14.6	18.6
7. $K_r = (d \cdot B)/(h \cdot I)$	30–1500	500	198	151	225	488	606	298	490	177	488
8. $K = k \cdot B'/B$	**100–1**	**32**	**15**	**19**	**9**	**12**	**7**	**16**	**7**	**25**	**10**
Maximum displacements, m		200–380	200–300	170–250	100–150	200–270	100–150	200–340	200–320	200–320	150–270

The analysis of the table relating to the stability of the right bank rivers allows us to conclude about correlation of the determined coefficients with the displacements of the riverbeds, excepting the expression 5 (Table 10). In expression 3 (Table 10), the stability value for the foothill part of the Stryi River is not correlated with displacements.

For left bank tributaries the divergence between stability calculated by the expressions and the values of displacements was noted for most values of stability for the hilly parts of the rivers Zolota Lypa, Seret, Zbruch, and Smotrych. However, we must note that actually in hilly parts of the river some hydrotechnical works had been carried out. Calculations of riverbed stability coefficients by the expression 7 (Table 12) show inconsistence for the rivers Zolota Lypa, Seret, Zbruch in their second (II) part related to stable structures.

The proposed expression 8 (Tables 10, 12) for the assessment of stability, which takes into account the width of the floodplain of the river, shows correlation for the right bank as well as left-bank tributaries.

Such factors as intensive development of the Earth requires remote sensing methods for obtaining information on hydrographic objects, the use of historical topographic maps, as well as special maps, in particular maps of soils and quaternary deposits with the processing of all types of input data with the help of geographic information systems open up new possibilities for monitoring of riverbeds. Actually, this comprehensive approach is proposed and implemented to determine the changes in the riverbed of the Dnister, second largest river in Ukraine and its left-bank and right-bank tributaries.

At present there are no effective studies of this river, which is important for the nature use. There are few works related to some tributaries of the Dnister (most often to Stryi River). They consider extraction of stone and gravel or deforestation in some areas, which causes a change in the hydrological regime of the rivers.

In our own studies of the Dnister Riverbed, specified in the references, we focused on determination of horizontal displacements of the river for more than a hundred years, which occurred in different historical periods. This stressing of the historical periods makes sense, since cartographic data were created in various map projections with different technological capabilities. The data processing with their referencing to one cartographic projection WGS84 made it possible to determine the displacement of riverbeds.

Partly in previous studies [Burshtynska, et al., 2017] we have considered the problem of sand migration, formation of islands of and their changes under the influence of hydrological regime.

As a positive factor of this study, we consider the detection of clear influence of geological structures on the character of changes in the left bank and right bank tributaries of the Dnister. For almost the same hydro meteorological regime of the right and left bank rivers, a completely different character and magnitude of displacements are noted. Therefore the conclusion is made about the dominant influence of geological structures: the Ukrainian Carpathians, the Volyno-Podillia plate and the Precarpathian bend.

Finally, detailed analysis of the river stability, as one of the dominant characteristics is carried out. To determine stability, various authors gave various mathematical expressions, guided by ground observations and research of rivers in different hydrological regimes. The authors Makkaveev and others have also established the criteria by which the rivers can be introduced into a certain category.

In the literature [Chalov, & Makkaveev, 1986; Obodovskyi, 2001] it is emphasized that the strictly horizontal displacement can serve as criteria of stability. In this study, we had analyzed the values of stability for different river parts and their correlation with the criteria proposed by the authors, as well as the determined displacements. It is established that not all expressions are reliable for different parts of the rivers allocated on the basis of their nature and displacement values. At the same time, authors proposed the expression of stability coefficient on the basis of determining the width of the floodplain, which is correlated with the horizontal displacement of the riverbed, since the floodplain itself is an indicator of a change in the riverbed during flood phenomena.

Conclusions

1. The methods of studying horizontal displacements of hydrographic objects based on the use of space images and topographic maps of different periods, as well as maps of quaternary sediments and soils, has been worked out. In particular, horizontal displacements and the influence of geological structures on the riverbed processes of right bank and left bank tributaries of the Dnister River have been investigated.

2. The right bank tributaries of the Dnister River pass through the Skyba nappe of the Ukrainian Carpathians, the Inner zone of the Precarpathian bend. These rivers have single thread riverbeds in the mountainous part and change into multithread in the foothill part with significant meandering and horizontal displacements in the plain part of the tributaries. Left bank tributaries of the Dnister River cross Volynian-Podolian upland. They are characterized by significant sinuosity, single thread, and three times smaller horizontal displacements. The direction of the channels, in many cases, is controlled by tectonic elements – fractures and fissures. In the outer zone of the Precarpathian bend, the direction of the channels is often induced by lithological features, which is especially characteristic of the Stryi River.

3. The analysis of the right bank tributaries indicates that the horizontal displacements depend on the conditions of the channel flow. By the nature of their displacements, they are divided into 3 parts. Stryi: on the mountain, foothill and plain, and Limnytsia and Bystrytsia on: mountain, hilly with marshy plain and plain. The Stryi River is characterized by sinuosity, multithreading and significant displacements in the plain part. Limnytsia and Bystrytsia are also characterized by multithreading, but relatively less than the Stryi River. Maximum displacement of the riverbeds: Stryi River – 1200 m, Limnytsia – 490 m, Bystrytsia – 580 m.

4. The left bank tributaries of the Dnister River have been analyzed. They are divided depending on the sinuosity on 2 parts: hilly and canyon. The nature of the displacement of the left-bank tributaries differs from the nature of the right bank tributaries. They are characterized by significant sinuosity and at the same time have fewer displacements. Maximum displacement is 340 m (Zbruch River) and 380 m (Zolota Lypa) at some points.

5. The second parts of the right bank tributaries are characterized by multithreading and braiding, the width of multithreading according to the maps of 1886–1910 is from 600 m to 1500 m; according to the maps of 1989 the width of multithreading has narrowed to 500 m; in 2000–2014 the channels become single thread, with the exception of one part of the Bystrytsia River.

6. In the literature, the sinuosity is often correlated with the stability of the riverbed. From the analysis of the character of the left bank rivers, which are highly sinuous in their structure, especially in the canyon section, the horizontal displacements are smaller in comparison with right bank tributaries, that is, geological structures significantly affect the stability of rivers.

7. From the analyzed expressions, which are used to assess the stability of the right bank and left-bank tributaries of the Dnister River, belonging to different types of geological structures, it is expedient to apply expressions 6 and 8 (Tables 10, 12).

8. These studies can be applied at organizations engaged in the design of hydraulic structures on the rivers, as well as in enterprises of the land cadastre for adjusting the boundaries of protected lands in the contiguous territories.

References

Bayrak, H. (2016). Changes in the small-riverbeds in the context of the changes in the forestness of their pools (for example, Pidbuz River of the Starosambir district). *Problems of geomorphology and paleogeography of the Ukrainian Carpathians and adjacent territories*, 1, 18–31.

Buffington, J., Woodsmith, R., Booth, D. & Montgomery, D. (2003). Fluvial Processes in Puget Sound Rivers and the Pacific Northwest. In *Restoration of Puget Sound Rivers*, 46–78.

Burshtynska, Kh., Malanii, O., & Shevchuk, V. (2010). Monitoring of deformation flows of the rivers channels. *Suchasni dosiahnennia heodezychnoi nauky ta vyrobnytstva: Zbirnyk naukovykh prats Zakhidnoho heodezychnoho tovarystva UTHK, I (19)*, 216–226 (in Ukrainian).

Burshtynska, Kh., Halochkin, M., Tretyak S. & Zayac I. (2017). Monitoring of the riverbed of river Dnister of the Carpathian Region using GIS technologies. *Archiwum Fotogrametrii, Kartografii i Teledetekcji, 29*, 25–36. doi:10.14681/afkit.2017.002.

Burshtynska, Kh., Shevchuk, V., Babushka, A., Tretyak, S. & Halochkin, M. (2018, September). Research of the morphology of river Dnister using remote sensing and cartographic data. *25th Anniversary Conference Geographic Information Systems Conference and Exhibition "GIS ODYSSEY 2018". Conference proceedings*, 64–72.

Burshtynska, Kh., Shevchuk, V., Tretyak, S. & Vekliuk, V. (2016). Monitoring of the riverbeds of rivers Dnister and Tisza of the Carpathian region. *XXIII ISPRS Congress, Commission VII (Volume XLI-B7)*, 177–182. doi:10.5194/isprs-archives-XLI-B7-177-2016

Chalov, R. & Makkaveev, N. (1986). Channel processes. M.: MHU, 264 s.

Friend, P. & Sinha, R. (1993). Braiding and meandering parameters. *Geological Society London. Special Publications, 75*(1), 105-111.

Guneralp, I. (2011). Channel avulsion processes on the lower Brazos river, Texas/Guneralp I., Billy U. Hales, Anthony M. Filippi. *TWDB Final Report*, *904830968*, 88.

Heeren, D. M., Mittelstet, A. R., Fox, G. A., Storm, D. E., Al-Madhhachi, A. T., Midgley, T. L., ... & Tejral, R. D. (2012). Using rapid geomorphic assessments to assess streambank stability in Oklahoma Ozark streams. *Transactions of the ASABE*, *55*(3), 957–968.

Horishnyi, P. (2014). Horizontal deformations of the lower course of the river Stryi River in 1896-2006]. *Problems of geomorphology and paleogeography of the Ukrainian Carpathians and adjacent territories,* 68–74. Retrieved from http://nbuv.gov.ua/UJRN/prgeomorpal_2014_2014_10.

Janicke, S. (2000). *Stream channel processes*. Fluvial Geomorphology. Water & Rivers Commission Report, 6, 1–12.

Krylenko, Y., Dzahanyia, E. & Krylenko, V. (2005). Estimation of the stability of the rocks of mountain rivers]. *Ekotekhnolohyia,* 22s. Retrieved from https://www.proza.ru/2011/07/06/225

Krzemień, K. (2006). Badania struktury I dynamiki koryt rzek Karpackich. *Infrastruktura i ekologia terenow wiejskich,* 4/1, 131–142.

Legg, N. & Olson, P. (2014). *Channel Migration Processes and Patterns in Western Washington: A Synthesis for Floodplain Management and Restoration*. Ecology Publication, 36 p. Retrieved from https://fortress.wa.gov/ecy/publications/SummaryPages/1406028.html

Obodovskyi, O. (2001). Hydrological and ecological assessment of river processes (on the example of the rivers of Ukraine), *Nika-Tsentr*, 274 s. (in Ukrainian).

Obodovskyi, O., Onyshchuk, V., Yaroshevych, O. (2005). Analysis of channel processes and recommendations for managing the floodplain complex in the foothill plain section of the Tisza River. *Hidrolohiia, hidrokhimiia i hidroekolohiia. Nauk. Zbirnyk, Tom 7,* 69–88 (in Ukrainian).

Pirmez, C., & Flood, R. D. (1995). In R. D. Flood, D. J. W. Piper, A. Klaus, & L. C. Peterson (Eds.), Morphology and structure of Amazon channel (Vol. 155) (pp. 23–45). Proceedings of the ODP, scientific results, College Station, TX: Ocean Drilling Program.

Rudko, H., & Petryshyn, V. (2014). Characteristics of deposits of boulder-gravel-sandy rocks in the Lviv region and their impact on the ecological state of the environment. *Mineralni resursy Ukrainy,* 2014. *1*, 39–47 (in Ukrainian).

Shevchuk, V. & Burshtynska, Kh. (2011). Method of monitoring the rivers in urban areas. *Heodeziia, kartohrafiia i aerofotoznimannia, 75,* 73–82 (in Ukrainian).

Simon, A., & Klimetz, L. (2008). Magnitude, Frequency, and Duration Relations for Suspended Sediment in Stable (“Reference”) Southeastern Streams 1. *JAWRA Journal of the American Water Resources Association, 44*(5), 1270–1283.

Żelaziński, J. (2014). Identyfikacja i opis zmian morfologii koryta Wisły wywołanych obwałowaniem i regulacją wraz z oceną ich wpływu na ryzyko powodziowe. Załącznik 1. *Projekt: Rewitalizacja, ochrona bioróżnorodności i wykorzystanie walorów starorzeczy Wisły, zatrzymanie degradacji doliny górnej Wisły jako korytarza ekologicznego, 26 p.*

Х. В. БУРШТИНСЬКА[1], А. В. БАБУШКА[1]*, І. М. БУБНЯК[2], Л. В. БАБІЙ[1], С. К. ТРЕТЯК[1]

[1] Кафедра фотограмметрії та геоінформатики, Національний університет “Львівська політехніка”,
вул. С. Бандери, 12, Львів, 79013, Україна, +38(096)4768773, e-mail andriy.babushka@gmail.com
[2] Кафедра інженерної геодезії, Національний університет “Львівська політехніка”, вул. С. Бандери, 12, Львів, 79013, Україна.

ВПЛИВ ГЕОЛОГІЧНИХ СТРУКТУР НА ХАРАКТЕР ЗМІЩЕНЬ РУСЕЛ РІК ВЕРХНЬОЇ ЧАСТИНИ БАСЕЙНУ ДНІСТРА

Мета роботи – дослідити вплив Передкарпатського прогину та Волино-Подільської височини на характер зміщень приток Дністра та визначення стійкості їх русел. Об’єктом цього дослідження є річка Дністер та її ліві й праві притоки. Розглядаючи основні чинники, що впливають на природу горизонтальних зміщень русла, спричинених як природними, так і антропогенними чинниками, особливу увагу автори приділили геологічним структурам у районі, де протікає річка Дністер та її притоки. **Методи.** Застосовуючи програмний пакет ArcGIS, автори виконали моніторинг протягом 100 років, використовуючи різні топографічні, геологічні, ґрунтові карти та космічні зображення. Для моніторингу зміщень русел річок правобережно-лівобережних приток Дністра використано: топографічні карти в масштабах 1:100000 та 1:75000 (австрійський період – 1886 р., 1910 р., польський період – 1930 р., радянський період – 1985 р., 1989 р.); космічні зображення Landsat 7 (2000 р.), Landsat 8 (2014 р.) та Sentinel 2 (2016 р., 2017 р.); і ґрунтову карту масштабу 1: 200000. Це дає підстави говорити про різний характер зміщень. **Результати.** Річка Дністер протікає на кордоні двох структур – Передкарпатського прогину та Волино-Подільської височини. Правобережні притоки (Бистриця, Лімниця, Стрий тощо), які починаються в Карпатах, перетинають зовнішні та внутрішні межі Передкарпатського прогину і характеризуються стійкістю русла річки в гірській частині, багаторічним і значним меандруванням (особливо для р. Стрий) у межах Прикарпаття. Літологічні родовища істотно впливають у гирлі річки Стрий. Для цих приток, за результатами дослідження, спостерігаються великі горизонтальні зміщення, вони поширюються на: річку Лімниця – 500 м, річку Бистриця – 580 м, річку Стрий – 1200 м. До лівобережних приток, розташованих на Волино-Подільській височині, належать річки Золота Липа, Серет, Збруч, Смотрич та Стрипа. Вони сильно звивисті, але набагато стійкіші в горизонтальних зміщеннях. Максимальні зміщення для цих річок – 300–380 м. **Наукова новизна.** Дослідження охоплює вплив геологічних структур на зміщення ліво-правобережних приток річки Дністер та аналіз основних математичних виразів, які використовують для оцінки стійкості русел річок. **Практичне значення.** Результати моніторингу процесів деформації русла повинні враховуватися під час вирішення завдань, пов’язаних з русловими процесами річки, а саме: розроблення та будівництва гідротехнічних споруд, проєктування мереж електропередачі на перетині річок, розвиток газопроводів, визначення небезпечних зон затоплення, визначення наслідків руйнування після спалахів або сезонних повеней, встановлення меж природоохоронних зон, управління відпочинковою діяльністю, моніторинг стану прикордонних земель та встановлення кордону вздовж річок.

Ключові слова: моніторинг; зміщення русла річки; космічні зображення; топографічні карти; геологічна будова.

Received 05.09.2019