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MONITORING OF THE RIVERBED OF RIVER DNIESTER USING GIS TECHNOLOGIES

MONITORINGKORYTA RZEKI DNIESTR Z WYKORZYSTANIEM TECHNOLOGII GIS

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ABSTRACT: The paper analyses the causes of riverbeds shifts and meandering of Dniester. Among such reasons are mostly climatic, geographical and anthropogenic factors, such as frequent floods semi-stable rocks and soils, deforestation and removal of gravel and sand material from the river bed. The research is carried out on the lowland of the Dniester along the 100 km section over the 100 years period. Topographic maps (1910, 1923, 1976 years), and satellite images from Landsat 5 (1986) Landsat 7 (2000) Sentinel (2017) and special soil maps was taken as initial information. The Dniester meandering research shows significant correlation in horizontal riverbed movements for the periods from 1910 till 1986 and from 1984 till 2017. Correlation rate variate within the limits 0.97 – 0.99 respectively that corresponds to the almost full dependence in the riverbed displacement configuration. Beside that the maximum horizontal deviations can reached up to 800 meters. In addition, it was revealed that sediment processes caused significant increase in the area of the river islands from 1910 to 1976 by 2.4 times, and from 1976 to 2017 the island areas somewhat reduced. Nearly the largest island River channel is divided into two branches. Sinuosity coefficient is 2.3 over the test site. The analysis of soil maps shows prevailing bleached soils and loamy on alluvial deposits soils in areas with highest sinuosity coefficient.

1. INTRODUCTION

Riverbed is the longest part the river where the different dynamical processes occurs. These processes are sensitive to weather conditions changes, dynamics and environmental indicators and anthropogenic loads (Hooke, 1984; Obodovsky, 2001). For a period of 30-50 years the river can change position by a distance equals to its width, or new river branch may appears. The main factors caused such dynamic are climatic, geographical and anthropogenic factors, such as frequent floods semi-stable rocks and soils, deforestation and removal of gravel and sand material from the river bed (Mahmood *et al.* 2015; Hooke, 2006; Shevchuk and Burshtynska, 2011). In addition, the increase in of seasonal rainfall amount, repeatability of abnormal seasons caused not only the water level increasing in the mainstream, but also river braches extension, flooding of oxbows and backwaters, changing of the main stream position, banks caving and growth of alluvium deposits. The riverbed changes affects to the natural and cultural landscapes and the human activity. From the other hand, human activities, including mining and construction works in the valley of the river also causes the riverbeds changes.

The permanent monitoring of water objects plays the significant role in solution of applied problems and is necessary to carry out in the view of frequent floods occurrence in Ukraine and their negative impact on anthropogenic systems (Obodovsky *et al.*, 2005; Hamar and Sárkány-Kiss, 1999).

Such observations are based on the use of Earth remote sensing and GIS-technologies, which makes it possible to carry out regular monitoring of the condition of territories, ensures a wide range of visibility, frequency, acquisition and processing of real-time information. Besides that, the use of Earth remote sensing and GIS-technologies offers new possibilities for providing real-time forecast of possible flood zones, preliminary assessment of the scale of floods, geographical objects modeling, determining best places for building protective structures and controlling coastal territories (Burshtynska *et al.*, 2016).

Detailed development of riverbeds monitoring methods and investigations of meandering processes is very important in relation to the spatial changes of designated water areas. The comparison of existing cartographic information and data originated from monitoring to the satellite information allows predict flood events. Modern GIS help in modeling and prediction of flood zones also as in preparation of thematic maps.

Hydrological and morphological analysis based on different information, which involves a combination and analysis of current and past riverbed configurations is the main efficient method for riverbed changes forecasting (Galay, 1983; Morisawa, 1985).

Major stream-bed forming factors are floods and freshets, lithological structure and hydrogeology, neotectonic motions, earthquakes, rockfalls, flora and fauna on the territory of the basin, accumulation and erosion of sediments on flood plains.

Some authors (Hooke, 2006; Obodovsky, 2001) believed that meandering caused by Coriolis acceleration, presence of random obstacles, entropy concentration, structural turbulence, cross-circulation, variations in stream dynamic axis.

Meandering is following by destruction of river beds, banks and bottoms. In some cases meanders can approach so close to each other so the earthen bridge between them falling down. This formed a new, shorter river path with greater slope and flow speed. As a consequence flow will accumulate alluvial deposits and bayou will appear at the ends of the abandoned meander (Grenfell, 2013; Zolezzi, *et al.*, 2012).

2. MATERIAL AND METHODS

A part of Dniester River flowing throughout low- and high lands on Ivano-Frankivsk, Ternopil and Chernivtsi regions has been chosen as a research object. The location of investigation area is depicted on Fig.1.

The main goal of research is to investigate planar shifts of Dniester riverbed based on combined approach with used topographic maps and satellite images. Such approach allows carrying out monitoring for the period more than 100 years together with analysis of factors causes riverbed displacements based on soil maps. The objectives of the study also include determination sinuosity river channels, islands areas, river bayous and the correlation between them for a different time periods.

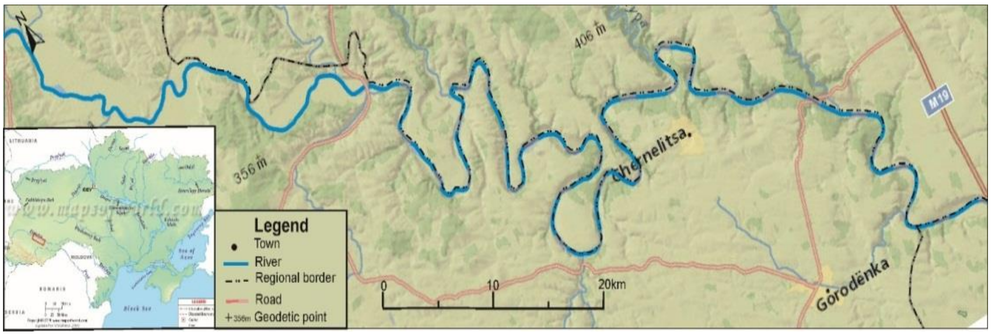

Fig. 1. Investigation area

The following initial data was used for investigation of meandering processes and riverbed deformations taking place over the 100 km between towns Halych and Zalishchyky: 1. Topographic maps in scale 1:100000 (1910, 1923, 1976); 2. Satellite images Landsat 5 (1986), Landsat 7 (2000) and Sentinel-2 (2017); 3. Soil map in scale 1:200000.

The technological scheme of investigations is presented on Fig.2.

Visualization and analysis of planar Dniester's riverbed variations has been done using ArcGIS software (Nath *et al.*, 2013; Pan, 2013).

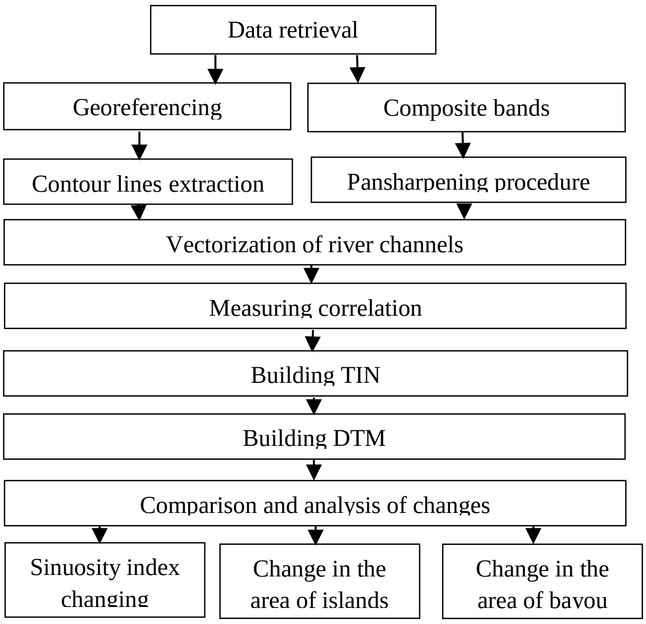

Fig. 2. Technological scheme of investigations

Georeferencing of topographic raster maps was done with use of 10 points coordinates of which determined from the kilometer grid. Map (1910) with absent kilometer grid was georeferenced using coordinates transformation of easily identifying points (bridges, road intersections, geodetic control points) on existing georeferenced maps. Polynomial of second order was chosen to achieve better accuracy which not exceeds 15 meters on the intrinsic convergence. Afterwards all georeferenced raster maps were transformed to WGS-84 ellipsoid in which satellite images was given. Fig.3. shows digitized fragments of Dniester riverbeds on topographical maps: a) for the 1910 year, b) for the 1923 year, c) for the 1976 year within research region.

A horizontal river displacement also was detected using satellite images Landsat 5 (1986), Landsat 7 (2000) and Sentinel-2 (2017).

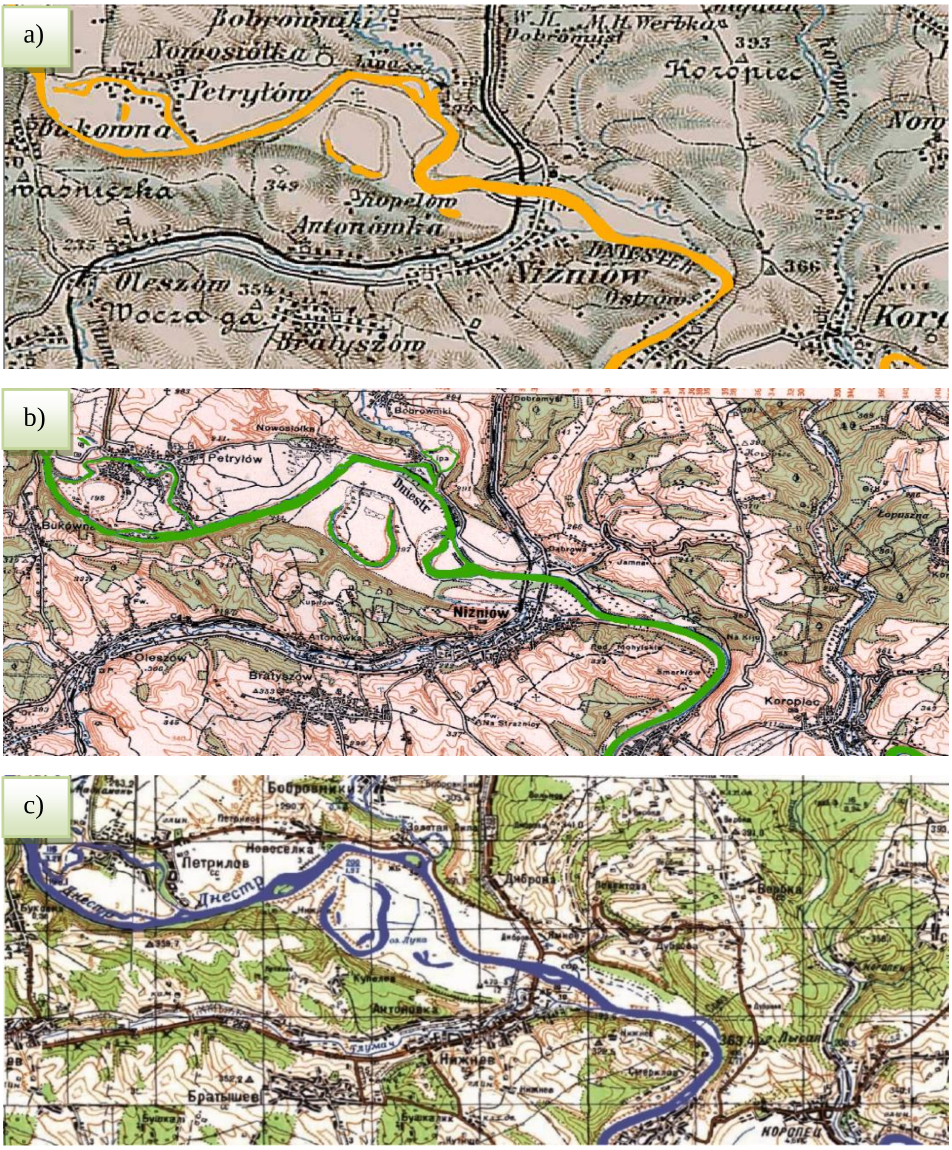

Fig. 3. Topographic maps fragments for: a) 1910, b) 1923, c) 1976

Effective interpretation of remote sensing data depends on spectral properties of objects on the Earth surface. NDWI (Normalized Difference Water Index) indexes are using to distinguish water surfaces from vegetation:

$$NDWI = \frac{Rgreen - Rnir}{Rgreen + Rnir} \quad (1)$$

Fragment of NDWI image obtained from Sentinel-2 with digitized riverbed is presented on Fig. 4.

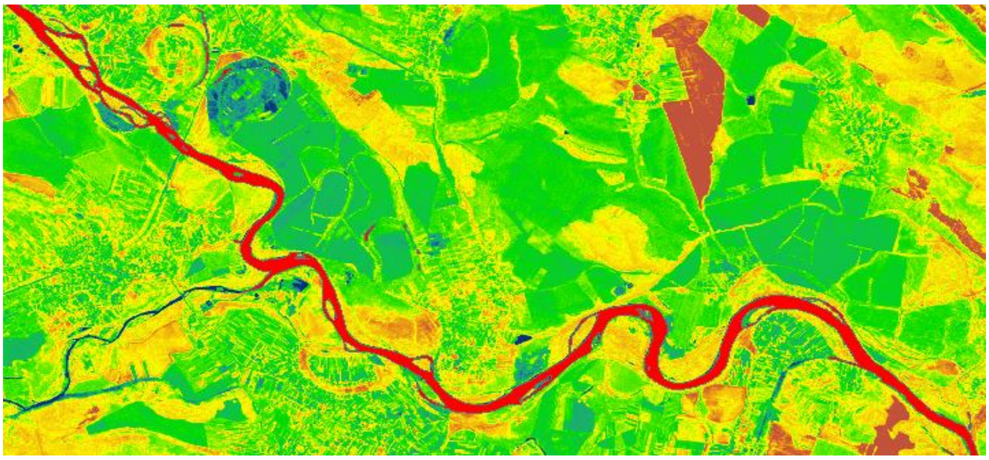

Fig. 4. Fragment of the satellite image obtained from Sentinel-2 with digitized riverbed.

Sinuosity of the river is characterized by coefficient:

$$K_i = L_i' / L , \quad (2)$$

where L'_i – length of the river section along riverbed, L – length of the straight line connecting endpoints of river section.

3. RESULTS

Position of digitized riverbed on topographical maps and satellite images was divided on 5 sections and magnified fragments of riverbed images where maximum changes occurred are presented on Fig.5.

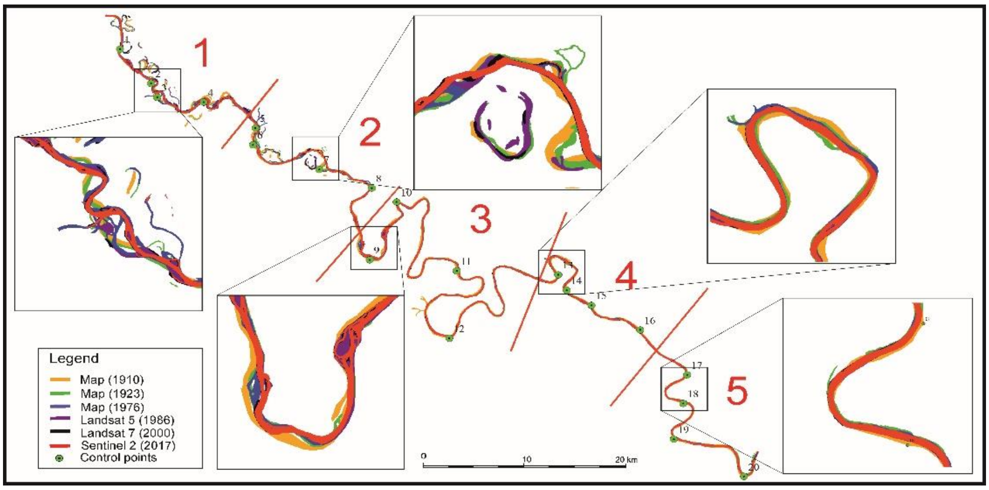

Fig. 5. Common view of Dniester riverbed digitized on topographical maps and satellite images at different epochs.

Map fragment (1910) shows significant river meandering, characterizing by considerable deviations from the mean position which indicates great sinuosity (Tab. 1). A significant area of bayous means major changes in river position during past years. Main characteristics changes related to river meandering are presented in Table 1.

Table 1. Main characteristics changes related to river meandering

Year	**1910**	**1923**	**1976**	**1986**	**2000**	**2017**
Sinuosity K	2.28	2.29	2.33	2.28	2.33	2.33
Squares of bayous, (km²)	2.44	1.08	1.22	1.03	0.45	0.10
Squares of islands, (km²)	0.96	0.10	2.45	2.11	1.81	1.69

On the map fragment 1910 we noticed diking systems, indicating presence of hydrotechnical melioration works aimed to prevent riverbed changing. No considerable horizontal displacement of riverbed was noticed at this time, but there were significant increasing islands and decreasing bayous areas. Maximum riverbed shift reached up to 560 meters and average shift consists nearly 80 meters what is significant for relatively short period of time.

Bayou is a part of ancient riverbed in the shape of loop or hook and its appearing is closely related to meandering process. Squares of bayous on the investigation area are presented in Table 1. Areas of islands grows more than 2 times compared to 1923.

Maximum displacement measurements of river in its selection were implemented. Measurements carried out in selected characteristic points are given in Table 2.

Table 2. Maximum shifts of riverbed (m)

Fragment	*№ points*	*1910-1923*	*1910-1976*	*1910-2017*
1	1	179	182	146
	2	**108**	**577**	**629**
	3	**30**	**700**	**659**
	4	183	256	491
2	5	352	233	273
	6	338	189	174
	7	**221**	**904**	**849**
	8	105	135	145
3	9	364	399	402
	10	155	135	146
	11	204	243	219
	12	168	214	225
4	13	64	176	155
	14	138	143	155
	15	101	215	180
	16	133	84	97
5	17	124	132	97
	18	191	105	122
	19	204	175	181
	20	231	164	141

Maximum riverbeds shifts of the researches periods are marked bold in Table 2. Variations of bayous and islands size are presented in Fig. 6.

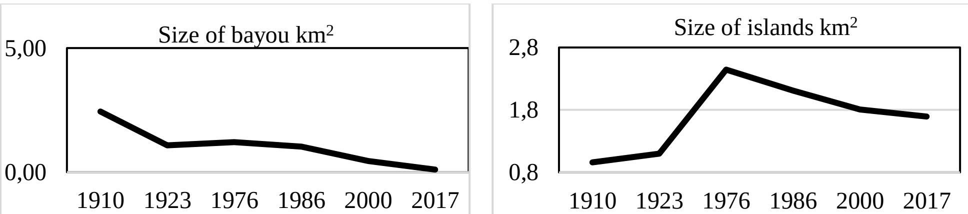

Fig. 6. Variation of bayous and islands size for the period from 1910 till 2017.

Analysis of Fig.6. shows constant decreasing of bayous size. It means that for the last 100 years Dniester riverbed has not been significantly changed and has relatively constant meandering mode. The dramatic growth of the islands area in 1976 caused by increasing river hands count, as a consequence of irrigation and drainage works.

Calculation of correlation relationship starts with drawing a line that will be considered a reference datum. This line is an axis of riverbed determined as mean values of coordinates after its turn to axis. The next step is building perpendiculars at equal segments, in our case they constitute 300 meters. In Figure 7 you can see a fragment in the stream bed of the Dniester River showing a reference datum and perpendiculars drawn off it.

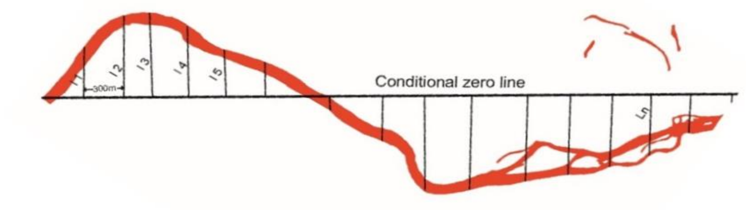

Fig. 7. Position of conditional "zero line" and perpendiculars

Determination of Δl is possible after computation of perpendiculars lengths:

$$\Delta l_i = l_i - M \ , \tag{3}$$

where l_i – deviation distance; M – average deviation.

When all Δl are computed we can estimate variation, covariance and correlation coefficient. For variation computation we use following equation:

$$D = \frac{\sum_{i=1}^{n} \Delta l_i^2}{n-1} \ , \tag{4}$$

where n – measurements count.

Covariance is a measure of the joint variability of two random variables and can be expressed in the following form:

$$K_{j-k} = \frac{\sum_{i=1}^{n} \Delta l_j \cdot \Delta l_k}{n-1} \ , \tag{5}$$

where j, k – years of investigation.

When variance and covariance are known then correlation coefficient can be computed from the following equation:

$$r_{j-k} = \frac{K_{j-k}}{\sqrt{D_j} \cdot \sqrt{D_k}} \tag{6}$$

Results of calculations:
D_1 = 866309 ; D_2 = 768213; D_3 = 786477
K_{1-2} = 788205; K_{2-3} = 772446
r_{1-2} = 0,96; r_{2-3} = 0.99

Correlation coefficients make 0.96 for 1910-1986 period and 0.99 for 1986-2017 period, which testifies to almost total dependence of shift configurations.

The determined correlation coefficients refer only to the position of main stream beds in different periods, without considering oxbow lakes, created in between. The general look of the stream bed testifies to a significant meandering of the river in the lowland part of the terrain. It should be noted that the stream bed on fragments 3, 4 and 5 has not really changed over a 100-year period due to the specifics of terrain and soil structure.

Digital Terrain Model (DTM) was constructed based on topographic map of scale 1: 100000 for a visual study of the riverbed displacement causes. Fragment of satellite image overlaid on DTM is presented on Fig.8. Soil map overlaid on DTM was used for detailed study of the dependences between riverbed shifts and soil types (Fig. 9).

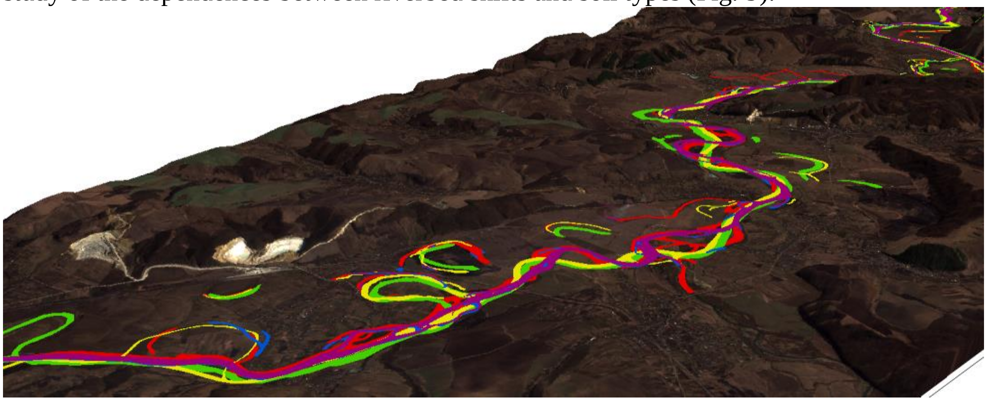

Fig. 8. First section of riverbed and satellite image overlaid on DTM.

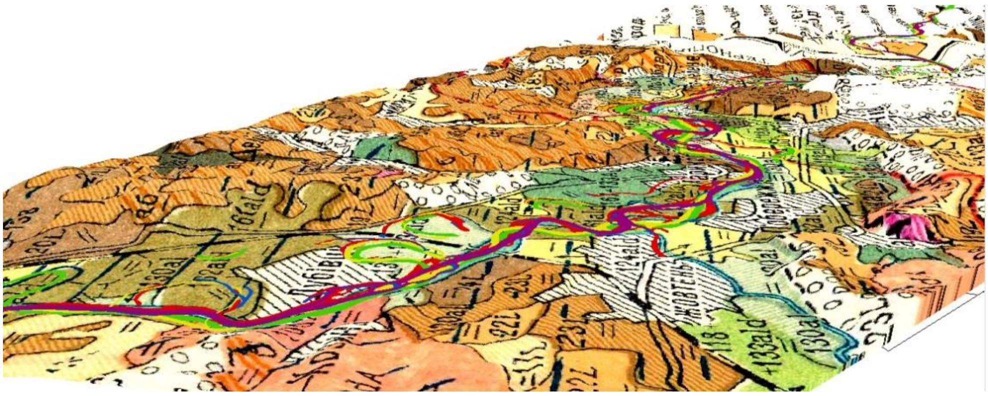

Fig. 9. First section of riverbed and soil map overlaid on DTM

Based on the analysis of the soil map in places of maximum meandering (fragments 1,2) and tortuosity it has been established that major types of soils causing significant changes in the stream locations are podzolized soils and mud on alluvial sediments. Fragments 3, 4 and 5 demonstrate a large variety of soils, with predominantly loess soil on the modern alluvium and diluvium.

4. CONCLUSIONS

1) A complex approach to the research of hydrographic objects is based on the use of satellite images, topographic maps, and soil maps considering the type of terrain.
2) The study of riverbed shifts, conducted according to satellite images of the satellites Landsat 5 (1986), Landsat 7 (2000), Sentinel-2 (2017) and topographic maps of scale

1: 100 000 (1910, 1923, 1976) certifies about significant shifts of their riverbeds, especially during the transition from a mountainous to the lowland part, which reach 800 m. The monitoring has been conducted on the 100 km part of river.

3) The section under research has a high tortuosity coefficient, a great number of meanders and oxbow lakes. A significant displacement of riverbeds in the lowland section and an almost stable stream bed in the hilly one was revealed.
4) Hydro-technical works conducted in the 20-80s of the XX century significantly reduced the tortuosity and meandering as compared to the natural character of the stream bed shown in a map dated 1910.
5) A research of correlation relationship testifies to an almost total dependence of configuration of the main stream bed shift, without regard to oxbow lakes. In a hilly section of the terrain shifts are insignificant and have not exceeded the width of the stream bed over a 100-year period.
6) Based on the analysis of the soil map in places of maximum meandering and tortuosity it has been established that major types of soils causing significant changes in the stream locations are sod loam and mud soils on the alluvium for the lowland sections, and podzolized gley soils – for the hilly ones.

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MONITORING KORYTA RZEKI DNIESTR Z WYKORZYSTANIEM TECHNOLOGII GIS

SŁOWA KLUCZOWE: monitoring, procesy koryt rzecznych, powodzie, meandrowanie rzek, zdjęcia satelitarne, mapy topograficzne

Streszczenie

Za główne przyczyny przemieszczenia się i meandrowania koryta rzek uznaje się zjawiska klimatyczne, a także czynniki geograficzne i antropogeniczne. Częste powodzie, określone rodzaje skał i gruntów, wylesienia i wymywanie żwiru i piasku z łożyska powodują przemieszczenie rzeki. Prezentowane badania przemieszczeń dotyczą równinnej części rzeki Dniestr. Analiza została przeprowadzona na odcinku rzeki długości około 100 km i dotyczy okresu minionych 100 lat. Do badań wykorzystano mapy topograficzne z lat 1910, 1923, 1976 i zdjęcia satelitarne z satelity Landsat 5 (1986), Landsat 7 (2000) i Sentinel (2017), a także mapy gruntów. Z badań meandrowania rzeki Dniestr w okresach 1910-1986 i 1984-2017 określono związki korelacyjne między przemieszczeniami sytuacyjnymi, które wyrażone w formie współczynnika korelacji wynoszą odpowiednio 0.99 i 0.97, co świadczy o prawie całkowitym związku kształtów łożysk. Jednocześnie wyjaśniono że maksymalne przemieszczenia łożyska rzeki na odcinkach 1 i 2 wynoszą blisko 800 m, a na odcinku 5 do 100 m. Wyjaśniono, że zwiększenie niesionych osadów spowodowało w latach od 1910 do 1976 znaczny wzrost powierzchni wysp (około 2,4 razy), a w latach od 1976 do 2017 powierzchnia wysp zmniejszyła się, jednak w miejscu największej wyspy koryto podzieliło się na dwa rękawy.Ogółem krętość koryta na badanym fragmencie wynosi 2.3, co świadczy o tym że koryto jest meandrujące. Analiza mapy gruntów w miejscach maksymalnego meandrowania wskazuje, że głównymi typami gruntów są gleby łąkowe bielicowe i oglejone na złożach naniesionych.

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