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Morphodynamics of the confluence of the Svicha and Sukil rivers

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SUMMARY

With the development of GIS technologies and remote sensing in international research, the study of the morphology and dynamics of the confluence of both large and small rivers is gaining considerable popularity. Confluence nodes are special hydro-geomorphological elements of river systems. Their morphodynamics determines the development of horizontal and vertical deformations of confluent rivers' riverbeds and affects the economy and infrastructure in the region of confluence, especially in mountainous and foothill areas. The purpose of the present study is to assess the morphodynamics of the Sukil-Svicha confluence within the period of 1880-2021 and to reveal its causes and consequences. To achieve this purpose, topographic maps, space photographs, and UAV surveys were used. According to the results of the study, three periods of the morphodynamics of the Sukil-Svicha confluence node were identified: the first one embraces 1880-1984 (maximum horizontal displacements over 3 km); the second one – 1984-2001 (maximum displacements up to 750 m); the third period covers 2001-2021 (stabilization and formation of present junction morphology; maximum displacements – 25-50 m). The main reasons for the riverbed morphodynamics during these periods are analyzed.

Keywords: confluence nodes, morphodynamics, types of riverbeds, functioning, Remote Sensing, Google Earth

Introduction

Research studies of different authors indicate significant morphodynamics of the river confluence nodes, which is mainly determined by horizontal deformations of the larger river. The morphodynamics of nodes is also due to such features of river confluence as water content and structure of water flows, accumulation of alluvium within the riverbed and low floodplain directly where the tributary flows into the main river, morphodynamics of the riverbeds upstream and downstream, and the relief of the floodplain complex. The confluence of rivers is the basis of erosion for smaller order rivers, which is also key to the functioning of river systems in general. Despite numerous publications, there are few studies of morphodynamics of confluence nodes within the foothills including the Ukrainian Carpathians. The present study revealed the morphodynamics of the confluence of the Sukil and Svicha rivers from 1880 to 2021. The source materials included topographic maps of different time periods, high-resolution space images (Google Earth Pro, Landsat 4-7 and Sentinel), and UAV survey results (Bubniak et al., 2020). The research revealed significant morphodynamics of the confluence node of the Sukil and Svicha riverbeds during 1880-2001 and its relative stabilization in 2001-2021 and established the “role” of the Svicha and Sukil rivers in the formation of the morphology of the existing confluence and its spatial displacement.

Methodological Framework

The study of morphodynamics of the river confluences was primarily based on cartographic research methods with the use of GIS technologies. Satellite images Google Earth Pro (2006-2019), multispectral images Landsat 4-7 and Sentinel (1984-2020), and SAS Planet software and were used as well as historical topographic maps of 1880, 1929, 1978 with a scale of 1:25 000 and 1: 50 000. To analyze the morphology of the current state of the confluence node, the results of UAVs were used and field studies of the floodplain-riverbed complex were conducted (Rybak, 2020, Rybak, et al., 2020). The research algorithm consisted of three main stages: 1) analysis of topographic maps and space images to determine the position of the confluence and its spatial shifting; 2) correlation of the results of migration of the river confluence with the water discharge according to the data of hydroposts; 3) aerial photography with the help of UAVs and analysis of its results to establish the features of current functioning of the Sukil-Svich confluence node (Yousuf et al., 2020).

Previous research. The problems of morphology and morphodynamics of the confluence of two rivers have been well covered in international publications. For example, Richards (1980) and Best and Rhoads (2008) indicate that river confluences are key points in river systems which can have a significant impact on horizontal riverbed deformations, transport and sedimentation above and below the confluence. Important issues currently discussed in the scientific literature are as follows: features of the morphology of confluence of the rivers of different order (Parsons et al., 2008), mechanisms of sedimentation, structure and interaction of water flows within confluence nodes under floods (Ali et al., 2019), the dynamics of confluence of small rivers (Biron et al., 1993) including mountain ones (Guillén-Ludeña et al., 2016; and others). However, there were only few studies of the dynamics of river confluence in the foothills, in Ukraine in particular.

Results

The main purpose of the present study is to assess the change in the position of the confluence of the Sukil and Svicha rivers (hereafter Sukil-Svicha) for the period of 1880-2021 and the role of these rivers in its formation and functioning. The studied junction is located within the Ukrainian Carpathian foredeep, namely the Sambir nappe (Nakapelyukh et al., 2017), which corresponds to the Precarpathian Upland as to its relief. The dynamics of the Svicha riverbed is greater and plays a major role in the dynamics and formation of the confluence, as this river has larger water discharge. According to the Lviv Regional Center for Hydrometeorology, the average annual water consumption of the Svicha in Zarichne (22 m3 / s) is 8 times higher than that of the Sukil River in the village of Tysiv (2.7 m3 / s).

Analysis of different time topographic maps, Google Earth Pro space images and Landsat 4-7 and Sentinel multispectral space images allowed us to establish significant different time migrations of the river junction (Fig.1) and to identify three main periods of dynamics of the Sukil-Svicha confluence on the plan.

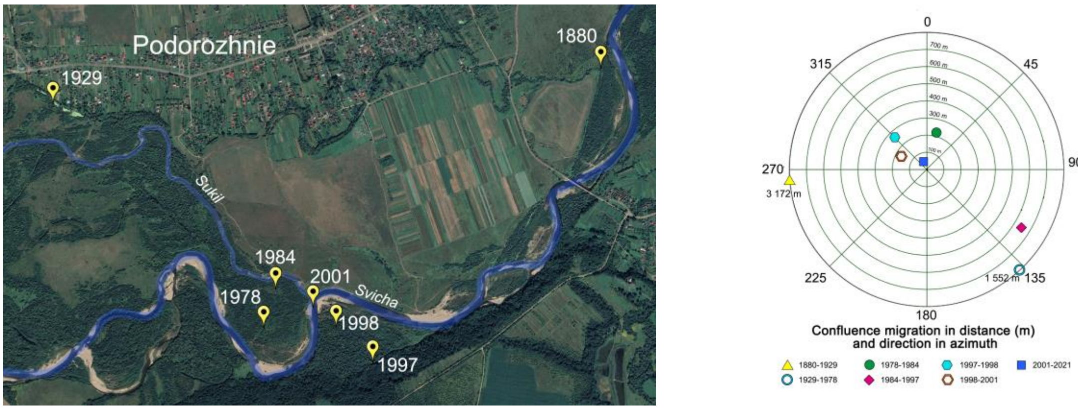

Figure 1 *The position of the river mouth of the Sukil River for the period of 1880-2021 on the Google Earth 2019 space image*

The first period embraces the time from 1880 to 1984 and is characterized by maximum displacements of river junction. Thus, in the study area in 1880, the Sukil-Svicha confluence was located at a distance of 2.8 km to the northeast (Fig. 1; Fig. 2a) as compared to the present one. On the 1929 map, the node is significantly shifted and is located at a distance of 3172 m to the east of its place in 1880 (Fig. 1; Fig. 2a). The main reason for this change is significant horizontal deformations of the Svicha riverbed. In 1880-1929, it had shifted to the north by 250 m, which led to the interception of Sukil's waters by the Svicha and the formation of a new river confluence (Fig. 2a, 2b). Part of the cut Sukil riverbed, of 4 km length, has become an inactive riverbed existing to this day (Fig. 1; Fig. 2b). In 1929-1978, the Svicha river formed a new riverbed within the high floodplain (Fig. 2c), this leading to the displacement of the Sukil mouth to the southeast by 1552 m from the site of the node localization in 1929 and to increasing the length of the Sukil by 1700 m. The main riverbed of the Svicha became a secondary one by connecting the Sukil and Svicha (Fig. 2c).

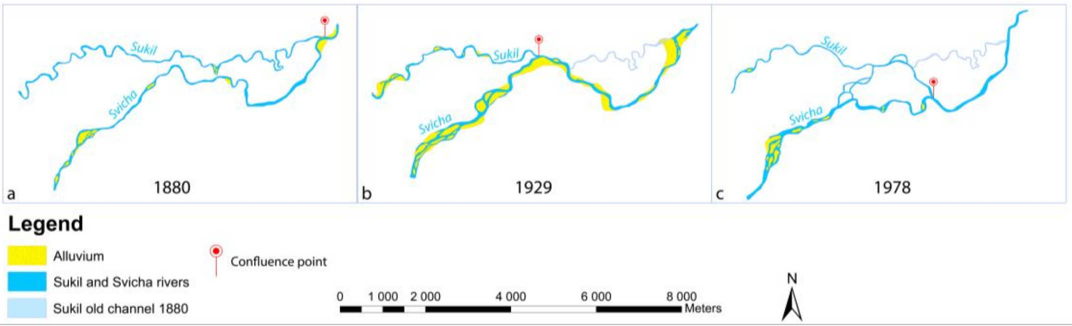

Figure 2 *Confluence of Sukil and Svicha river in 1880 (a), 1929 (b), 1978 (c)*

The second period (1984-2001) is also marked by the displacements of the Sukil-Svicha confluence, although they are much smaller as compared to the first period. The largest change in the morphology of the junction was recorded in 1991-2001 (Fig. 3). Its maximum displacement of 750 m occurred in 1993-1994 and was connected with a breakthrough in the neck of the Svicha meander. It should be noted that during 1989-1990 no displacements of the river junction were detected, although the maximum water discharge at the hydropost in Zarichne was 515 m^3/s in 1989. A similar situation can be observed in 1997-1998, when the maximum water consumption of 834 m^3 was recorded, and the node displaced only by 280 m.

The third period (2001-2021) is characterized by the stabilization of the Svicha-Sukil confluence (Fig.3). Its maximum shifting was 25-50 m. During this period, there were a number of catastrophic floods, in particular in 2007, 2008, 2010 and 2020. Thus, water discharge during the flood in July 2008, according to the hydrological post in Zarichne on the Svicha river, exceeded the average annual value by 57 times, which is the highest indicator for the entire period of observations at this hydropost. It is important that on the images of 2008 made before and after the flood, there are almost no changes in the morphology of the Svicha and Sukil riverbeds, either within the confluence node or in the riverbeds of these rivers upstream (Fig. 4). There are two main reasons for the stabilization of the riverbeds and river confluence. The first is related to the change of hydrological parameters of the flow during catastrophic floods and the deviation of the axis of the main flow from the top of meanders to the center of the riverbed which resulted in slight lateral erosion (Massimo Rinaldi et al., 2008; and others). The second reason is the local manifestation of deep erosion in its riverbed. The latter is evidenced by the data of the hydropost in Zarichne. Thus, during the period of 1982-2008, the bottom of the Svicha riverbed was deepened by 3.4 m including 1.6 m in 2008 (Shevchuk, Kozytsky et al., 2016). The deepening of the riverbed at the hydropost in Zarichne, which is located about 2 km below the Sukil-Svicha confluence, probably, contributed to the development of regressive deep erosion which accordingly stabilized the development of horizontal riverbed deformations within the confluence. The increase in deep erosion of the Svicha riverbed is also indicated by the increase in deep erosion in the Sukil riverbed (at its section t from the confluence and 120 m upstream), which was established based on UAV survey results and field research. Comparative analysis of the images made in 2008 and 2021 allowed detecting significant horizontal shifting of the Svicha riverbed upstream from the confluence of the Sukil (Fig. 3). During this period, the maximum horizontal deformations in this section are up to 220 m, the meanders become more omega-shaped and the meandering belt width of the Svicha riverbed has increased (Fig.3). Another trend is the observed downstream of the Svicha riverbed from the mouth of the Sukil. Here, the Svicha riverbed straightens and its tortuosity decreases (Fig.3). A significant difference in the manifestation of horizontal deformations of the Svicha riverbed before and after the Sukil inflow can also be treated as an indirect evidence of local manifestation of deep erosion in the Svicha riverbed in the section beginning at the Sukil mouth and downstream the Svicha river.

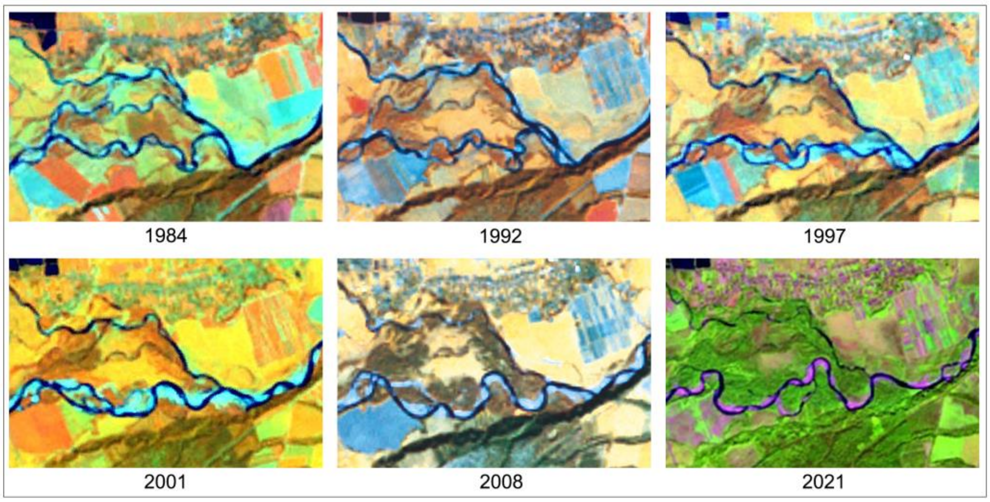

Figure 3 *Multispectral satellite images show periods of activity (1978-2001) and the period of stabilization of the Sukil-Svicha confluence*

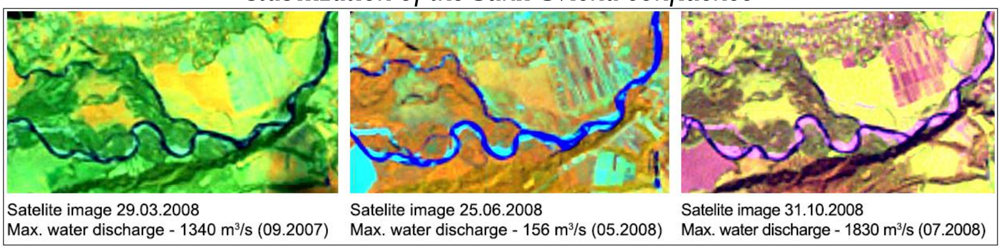

Figure 4 *Multispectral satellite images show the absence of any shifting of riverbed and confluence after a high flood*

Conclusions

From 1880 to 2021, three main periods were distinguished in the morphodynamics of the Sukil-Svicha river confluence. The first period (1880-1984) is characterized by maximum displacements of the confluence node in the plan. The largest riverbed displacement constitutes more than 3 km. The second period (1984-2001) is characterized by significant although much smaller horizontal shifting of the river junction (up to 750 m). The third period (2001-2021) is a stage of the formation of present morphology of the confluence node marked by its stabilization. During this period, the displacements of the node are insignificant constituting 30-40 m. The main reason for the vivid morphodynamics of the Sukil-Svich confluence node in the first and second periods is the dynamics of the Svicha riverbed. Probable reasons for the stabilization of the studied confluence in the third period are as follows: change of the water flow axis from top of meanders to the center of the riverbed during catastrophic floods and local deep erosion in the Svicha riverbed which manifested itself downstream from the inflow of the Sukil.

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