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Research of the watercourse confluence based on RSD (by the example of the Sukil river)

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SUMMARY

The work is based on the research of rivers channels processes in river confluences using remote sensing. It presents a method for determining the angles of the confluence of rivers in different geomorphological conditions for example of the Sukil river basin. Determining the influence of tributaries at the main river and sedimentation processes in the confluence zone is the main goal of researching. Also, the riverbeds are typified before and after the confluence, and "a zone of influence" are identified in this area.

Introduction

The watercourse confluence is not only the place where two channels merge to form a single channel; it also includes segments of the channels (downstream and upstream of watercourses) where the changes in the functioning of channel processes take place ("a zone of influence" of watercourse confluence). These changes are due primarily to the increase of water discharge and the amount of river sediments of the main stream and the value of its transport capacity. The confluence site is the basis of erosion for a smaller-scale watercourse, this being important for the functioning of its basin as a whole. The role of river confluences is under investigated, although they determine the functioning of rivers as integral natural systems. An important parameter of river confluence is a junction angle of the watercourse, which is determined by the set of erosion and transport accumulation processes, character of the hydrodynamic flow, geomorphology of the channel and valley, and by a number of other physical and geographical factors. . This study identifies three different angles (α, β and γ) at the confluence of different watercourses in three key sections of the Sukil river and analyzes changes in channel processes and types of channels within the watercourse confluence. The source material is high-resolution GoogleEarthPro pictures from satellites. The results of the study support the possibility of using remote sensing data (RSD) of the Earth to accurately determine the angles of river confluence and to delineate the types of channels and erosion accumulation processes occurring within the watercourse confluence.

Method of investigation

GoogleEarthPro pictures from satellites and SAS Planet software were used to carry out the study. All calculations and recording of information were performed in Microsoft Excel and are provided in Table 1. The research of confluence of the key parts of the Sukil river is based on the work of Woldenberg and Horsfield (Woldenberg, 1983) and the methodology of M.Pereira, B.Barbieiro, and M.Carneiro (Pereira, 2019), according to which a point of the of river junction (p) should be first determined. To achieve this, the flow is straightened by conditional lines, at the intersection of which the point (p) will be located (Figure 1b). After obtaining the point of intersection (p), the coordinates X0, Y0; X1, Y1; X2, and Y2 are determined by drawing guidelines from point (p), reflecting the direction of flow before and after the watercourse confluence. Their length should be four times the width of the channel at point (p) (Figure 1c) (Pereira, 2019, Best, 1987).

a) *b)* *c)*

Figure 1 *Scheme of finding the point of the intersection of channels and the directions of their stretching by the example of the Sukil and Svicha river confluence: (a) river confluence; (b) finding the point of channel intersection; (c) determining the direction of stretching and the length of channels (source: GoogleEarth).*

To determine the angles α, β, γ, the following formulas were used:

$$\alpha = cos^{-1}\frac{(b^2+c^2-A^2)}{(2*b*c)}\beta = cos^{-1}\frac{(a^2+c^2-B^2)}{(2*a*c)}\gamma = cos^{-1}\frac{(a^2+b^2-C^2)}{(2*a*b)} \quad (1)$$

where a, b, c are the distances between points S0, S1, S2 and the point of intersection of channels (p);

A, B, C – the distance between the points S0, S1, and S2 (Figure 2) (Pereira, 2019; Woldenberg, 1983).

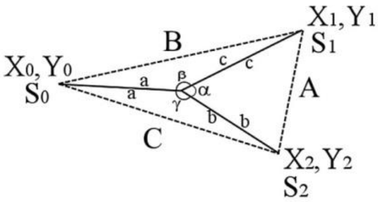

***Figure 2** Scheme for determining the angles of the confluence of watercourses* (Pereira, 2019).

The horizontal distance between points S0, S1, and S2 is calculated according to their known coordinates using the following formula (Pereira, 2019):

$$D_s = \sqrt{(X_1 - X_2)^2 + (Y_1 - Y_2)^2} = \sqrt{\Delta X^2 + \Delta Y^2} \quad (2)$$

Results of investigations

The Sukil river originates in the Ukrainian Carpathians at an altitude of 1040 m above sea level and flows into the Svicha river in the plain at an altitude of 263 m. Thus, there will be a different type of the channel in different parts of the river, ranging from mountain to plain. This allows exploring the confluence of flows with a different nature of the channel processes and different features of physical and geographical factors which determine them.

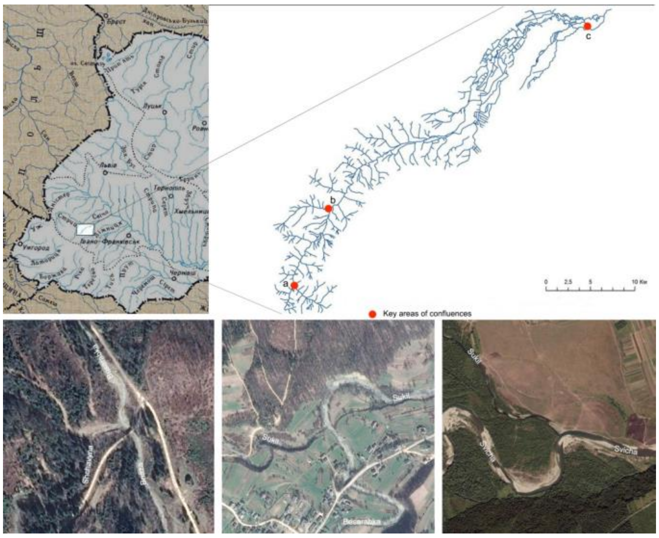

***Figure 3** Location of the Sukil river and the studied confluences: a) Briaza-Shchavyna; b) Sukil-Besarabka; c) Sukil-Svicha (source: GoogleEarth).*

Thus, the first confluence (Briaza-Shchavyna) is located in the mountainous part at an altitude of 748 m above sea level with coordinates N48 ° 54’46 “E23°35’45”. This is a confluence of two third-order streams according to the Horton-Strahler classification (Figure 3a). According to the character of channel processes, both channels are mountainous. Shchavyna has a relatively straight channel with undeveloped alluvial forms before the confluence, while Briaza is accumulative, branched into channels, with point bars and islands, of 7 to 130 m long. After the confluence, there are also accumulative forms in the combined channel. The branching of the point bars in the area of confluence is clearly recorded in a 2009 satellite picture. Their formation is due to the expansion of the channel in the area of confluence and reduction of the depth and speed of the water flow that have reduced its transport capacity (Best, 2008). The “zone of influence” of the confluence of watercourses in the main channel after the confluence is about 450 m. Further downstream, the channel changes its type, becoming meandering. In the picture of 2016, the channel in the area of the “confluence influence" has already been anthropogenically changed, straightened in particular. The confluence angles (α, β and γ) of the watercourses vary in the range of 86–149 (Table 1).

The second confluence (Sukil-Besarabka) is located within the village of Kozakivka in the intermountain basin and has coordinates N48°59'21"E23°39'12". It is located at an altitude of about 545 m above sea level. The confluence is formed by the streams of the 3rd (Sukil-1 river) and 4th order (Besarabka) (Figure 3b). Downstream the confluence, the river is called Sukil. In accordance with the character of channel processes, Sukil-1 is a mountain river with undeveloped alluvial forms, while Besarabka is a mountain river with developed alluvial forms, in particular point bars. In the "zone of influence" of the confluence (up to 60 m upstream), the Besarabka riverbed is straightening. It is dominated by the transportation of material and protrusion of bedrocks. Instead, in the Sukil-1 channel, there is deep erosion, and the channel is embedded in the section of 460 m long upstream from the confluence. The length of the point bar is 125 m and the maximum width is 8 m. The junctions angles (α, β and γ) of the watercourses vary in the range of 100–151 ° (Table 1).

Table 1 *Junction angles of watercourses within key segments of the Sukil river*

SUKIL-SVICHA confluence							
Coordinates of points		Distance between points (m)		Distance between point *p* and S0; S1; S2 (m)		Angle	
X0	49°09'57,6742"	A=	122,86	a=	78,7	α=	101°38'24"
Y0	24°04'02,0612"						
X1	49°09'58,5724"	B=	137,69	b=	75,83	β=	117°13'48"
Y1	24°03'55,3913"						
X2	49°09'54,6673"	C=	145,73	c=	82,57	γ=	141°07'48"
Y2	24°03'56,5114"						
SUKIL-BESARABKA confluence							
Coordinates of points		Distance between points (m)		Distance between point *p* and S0; S1; S2 (m)		Angle	
X0	48°59'23,4258"	A=	71,89	a=	54,85	α=	100°55'12"
Y0	23°39'11,7678"						
X1	48°59'21,0497"	B=	76,04	b=	53,92	β=	107°55'48"
Y1	23°39'10,8022"						
X2	48°59'20,4209"	C=	105,34	c=	38,42	γ=	151°09'00"
Y2	23°39'14,2132"						
BRIAZA-SHCHAVYNA confluence							
Coordinates of points		Distance between points (м)		Distance between point *p* and S0; S1; S2 (м)		Angle	
X0	48°59'23,4258"	A=	56,51	a=	22,04	α=	123°51'00"
Y0	23°39'11,7678"						
X1	48°59'21,0497"	B=	47,32	b=	19,65	β=	86°43'12"
Y1	23°39'10,8022"						
X2	48°59'20,4209"	C=	40,22	c=	43,16	γ=	149°25'48"
Y2	23°39'14,2132"						

The third confluence is formed by the inflow of the Sukil river into the Svicha (Figure 3c). It is located in the plain within the Pre-Carpathian Depression. Its coordinates are N49°09'57"E24°03'58", and the height above sea level is 263 m. By the character of the channel processes, the Sukil river, like the Svicha, belongs to the plain type. An alluvial fan of the Sukil river has been formed at the confluence within the main channel of the Svicha. It is partially washed away by the water flow of the Svicha. In the "zone of influence" of the confluence, sediments are accumulated in the Sukil riverbed. The delta of filling is formed, according to the classification of R. Chalov (Chalov, 1997). It is developed due to the support of water in the Sukil riverbed by the waters of the Svicha main river. The junction angles (α, β and γ) of the watercourses vary in the range of 101– 141 (Table 1).

According to Table 1, the confluence angles of the rivers Sukil-Svicha and Sukil-Besarabka are closer in magnitude. The magnitudes of the angles of the Briaza-Shchavyna confluence (Table 1), located in the mountainous part of the Carpathians where there is an unknown expansion of the valley near the confluence, are significantly different. The main reasons are the differences in the geological and geomorphological conditions of the formation of watercourses and the character of the river channel processes.

Conclusions

Current geoinformation technologies and RSD facilitate the researching of river systems, in particular of the confluences of different watercourses, which play an important role in their operation. Studies of representative confluences of watercourses of the river Sukil allowed not only determining the junction angles watercourses, but also outlining the "zones of their influence" and the peculiarities of channel processes within them. The obtained results form the basis for a more detailed aerial photography of the studied UAV confluences and for thorough field studies of channel processes, which will be the next stage of our research.

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