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DISTURBANCE OF FLUVIAL PROCESSES IN THE LOWER RUN OF YABLUNKA RIVER

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The Yablunka, a tributary of the Dniester is a nearly natural river flowing through Carpathians (Western Ukraine). It is 21 km long and its basin area is 84.7 km^2. The river alimentation is mixed with rain domination. Spring floods are often enhanced by rains. The Yablunka's channel is curvy and in some reaches braided. Width of the lower Yablunka channel ranges from 12 to 28 meters. Its floodplain is uneven, two-sided, 40-150 m wide. Low flow water depth ranges from 0.2 to 0.35 m and during floods it reaches up to 2 m. The river bottom is irregular, covered by gravel and pebbles. Within a region of Staryi Sambir town, the Yablunka and the Dniester are partially regulated. Two gravel-pit factories are located in Staryi Sambir and they collect raw materials from the terrace and channels of both rivers.
This paper describes the intensity of fluvial processes within the mouth of the Yablunka. As the bed of the Yablunka is becoming incised, hydrological, cross-sectional and bed granulometry analyses have been performed in the study. A forecast of bed stability was used to describe changes in erosion intensity. These factors were calculated using the values of critical stresses. The process most probably responsible for the incision of the Yablunka riverbed is headward erosion following a lowering of the Dniester channel.

KEY WORDS: bed erosion, gravel extraction, riverbed deformation, bed load transport, river morphology.

1. INTRODUCTION

The Yablunka river basin is situated in the geomorphological district of Upper-Dniester Beskids within the region of External Carpathians (Figure 1). The district's highland relief is characterized by soft forms, sometimes looking like waves with gentle slopes. Mountain ridges are built of Cretaceous flysch. Longitudinal valleys are lined up with soft rocks and sediments of Eocene and Oligocene (Tsys 1962, Hofshtejn 1995, Kravchuk 2005).

Dominant geomorphological processes in the basin are erosion, landslides, horizontal and vertical riverbed deformations.

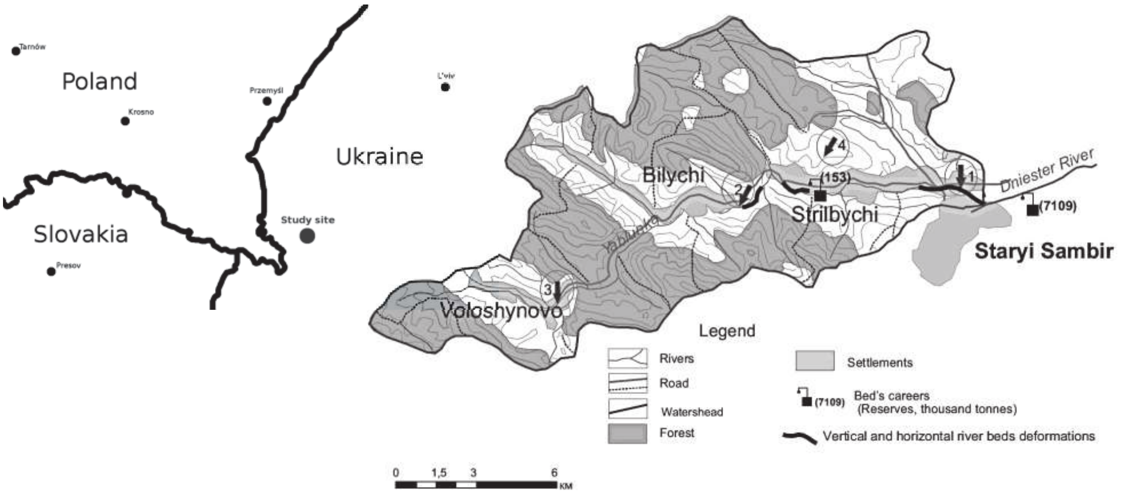

Fig.1 Yablunka River basin and the map of the region

River alimentation is mixed with rain domination. Annual average rainfall equals to 800 mm. Spring floods are often enhanced by rains. Usual spring flood duration is up to 5 days. The highest source elevation is 712 m and in the mouth section it is 330 m a.s.l. The length of the river is 21 km, and its catchment area is 84.7 km^2. The riverbed is braided, deformed, 12-28 m wide. The bottom is uneven, covered with pebbles, and 0.2-0.35 m deep during low water periods. An erosion caused riverbed lowering near Staryi Sambir resulted in cutting down of the Yablunka channel. According to the observations (Pylypovych 1997), the river bottom of the Dniester near the Yablunka junction was cut up to 4.5 m. As a result, the fall of the Yablunka increased from 0.006 to 0.012 ‰ and the channel erosion intensified. Average erosion intensity in the years 1987-1997 was 8-10 cm per year. The incised Yablunka channel is presented in Figs. 2 a) and b).

Fig.2 Yablunka River, a) in cross-section 420 m ,b) cross-section 020 m and the view of the recipient, Dniester River

All settlements are of a valley type and are located along the rivers. This intensifies the risk of morphodynamic processes within the riverside due to developing economic activities. The slopes of the river basin are also affected by intense agricultural works. In eighteenth century arable lands occupied about 32 % of the total area (Skorowidz 1914). By the middle of the twentieth century, the arable area doubled (Strilbychi, Voloshynove). Therefore, 70.5 % of the river bank belt is affected by human activities. It particularly refers to the gravel-pebble fields that are mined in the riverbed quarries for building and commerce purposes. An analysis of topographic maps (1:100 000) showed increasing forestation from 31.2 km^2 in 1940 (36.8 % of the catchment area) to 36.5 km^2 in 2000 (43.0 % of the catchment) (Pylypovych 2006, Mykhnovych 2016). In some villages (Bilych, Stara Sil'), the share of arable decreased in favor of pastures and hay fields.

2. PRESENT STATE REVIEW

The mechanism of bedload transport and bed erosion is continuously under the high interest of researchers. Early measurements focused mostly on stresses acting on the bed during the flow of clean water. Newer research extend the range also to other mechanisms like: bed composition (Bartnik and Strużyński 1999) hydrodynamic balance (Bartnik 2006, Michalik and Książek 2009, Strużyński et al. 2013), transport in formed active layer (Ferreira et al. 2010) sediment supply rates (Sklar and Diertich 2001) or abrasion (Sklar and Dietrich 2004). Investigations performed in Carpathians by Bąk et al. (2011) lead to conclusions that side erosion can be the main supply of river sediment and observed intensive transport rates results with bed incision. Flow dynamics as well as sediment flux and composition influence specific morphologic types of river channels (Church and Jones 1982, Rosgen 1994, Thorne 1997). Different flows appearing in natural rivers can lead to local intensification of bank or bed erosion and these processes create specific hydromorphic zones within the river channel, but not the lowering of the whole reach. When channel types naturally change with the river run the variety of bed forms exist (Buffington and Montgomery 2013). This can only be provided when river has wide enough erosion corridor (Piégay et al. 2005, Wyżga and Zawiejska 2012). Łapuszek (2013) measuring tempo of incision in Karpathian rivers defines the causes of intensive erosion as: rivers straightening, bank stabilization and gravel exploitation. Especially the last one can lead rivers to incision (Wyżga et al. 2010,).

The Yablunka experienced intense riverbed deformations during the last decades. The river system structure was considerably changed between 1940 and 2000. The main causes of the river system structure transformation and intense riverbed deformations include settlement, agricultural and hydrotechnical impact upon the catchment and intensive gravel mining within the river channel and floodplains (Pylypovych 2006, Kovalchuk et al. 2013). Gravel quarries are located in the Yablunka river and the Dniester river downstream of the Yablunka junction (see Fig. 1).

3. GOAL AND METHODOLOGY

The aim of this study was to determine the extent of boundary stress exceedance in the Yablunka bottom and the effects of this exceedance on the shape of cross-section profiles at the mouth section of the river. The simulation outcomes were verified against an on-site inspection that took place in 2016, an analysis of changes in the catchment management and data on sediment harvesting from the Yablunka and the Dniester beds.

The study aim was approached by taking a series of 21 specific photographs of the river substrate cover depicting its bottom at a mean area of 0.16 m^2. The photographs were then used to develop granulometric curves of the cover. Direct measurements covered dimensions "a" and "b". Dimension "c" was worked out after determining the predominant grain shape based on a grain sphericity index (Wadell 1932)

$$\Phi = \left(\frac{bc}{a^2}\right)^{1/3} \tag{1}$$

Data based on grain size and shape factor (SF)

$$SF = \frac{c}{\sqrt{ab}}. \tag{2}$$

The weight of each grain was calculated using an equation experimentally developed for this project

$$M_i = abc\rho(0.7ln(SF) + 0.10845)[\text{kg}], \tag{3}$$

where: a, b and c – grain dimensions [m], ρ – sediment mass 2650 [kg/m^3].

Granulometric composition of the bedload was determined by adding up the fractions together with the smaller ones. The curve parameters were calculated using the equation shown below:

arithmetic mean $d_m = \frac{\Sigma(fd_i)}{100}[\text{m}]$, (4)

geometric mean $d_{mg} = exp\frac{\Sigma(flnd_i)}{100}$ [m]. (5)

Standard deviation of the curve was defined graphically from the granulometric curve that was used for determination of the degree of the bed armoring

$$\delta_g = \sqrt{\frac{d_{84,13\%}}{d_{15,87\%}}} \approx \sqrt{\frac{d_{84\%}}{d_{16\%}}} \tag{6}$$

(Simons i Sentürk 1992), and determination of the degree of the sediment sorting

$$\delta_g{}' = exp\sqrt{\frac{\Sigma f(lnd_i - lnd_{mg})^2}{100}} \tag{7}$$

(Blott i Pye 2001).

The cross sections were measured by the leveling method, and the slope of the lower Yablunka section was determined by numerical modeling of the terrain. Bankfull discharge was established based on on-site inspection and an analysis of local maxima of changes in water table width increment by means of Riley's method (BI - bench index)

$$BI = \left(\frac{B_i - B_{i+1}}{h_i - h_{i+1}}\right) \tag{8}$$

where: B_i, B_{i+1} – width of water surface, h_i, h_{i+1} – water depth (Radecki-Pawlik 2011).

The Yablunka channel capacity was estimated using Chezy equation implemented into "konsum" software. Special attention was paid to the analysis of bankfull discharge within $Q_{10\%}$ and $Q_{25\%}$ flows indicated by Pickup and Warner (Strużyński et al. 2013). The cover stability was determined based on diameter $d_{90\%}$, as suggested by Bray (2002). A river bottom remains stable until its cover is removed. The bottom stability forecast was provided using an approach proposed by Bartnik and Strużyński (1999). It is based on a stochastic method of determining the conditions for grain movement developed by Gessler (1970) and an original software called Armour available at: http://kiw.ur.krakow.pl/~loczek/software_AS.html. Stability of the Yablunka bed cover was assessed for probable flows calculated from Punzet equation for Carpathian formula (Punzet 1978). Once the cover is removed, mass transportation begins. Excessive armoring usually indicates not enough sediment in the channel. It should also be mentioned that bottom erosion should not occur at medium flows. For this reason, the simulation was carried out up to $Q_{10\%}$ flow.

4. RESULTS

The values of calculated flows are presented in Table 1. Numbers in gray cells indicate bankfull discharges range proposed by Pickup and Warner (Radecki-Pawlik 2011).

Table 1

Probable discharges (with smaller) calculated for Yablunka's outlet

p [%]	0.01	0.1	0.2	0.5	1	2	3	4	5	10	20	25	30	40	50
Q [m^3/s]	275	211	192	164.8	144.3	123.3	110.7	101.7	94.7	72.6	50.1	42.9	37.2	29.1	24.9

The grains covering the Yablunka bottom are of low sphericity, angular, and rounded. Average sphericity of all grains was 0.57 and shape factor equaled 0.40. Bottom cover parameters were as follows: d_5=0.02, d_{16}=0.04, d_{50}=0.08, d_{84}=0.13, d_{90}=0.14, d_{95}=0.15 [m]. Sieve curve was very well sorted (δ'_g = 1.25). There was some fine material located in the bed cover (δ_g = 1.88), so the bed may be described as moderately armored.

Bankfull discharge determined for both sections of the Yablunka in the years 1985, 1987 and 1997 is displayed in Table 2.

Table 2

Cross-section capacity change within 10 years

cross-section	H [m a.s.l.]	h [m]	Q [m^3/s]	$Q_{\%}$ range	$h_{Q25\%}$ [m]	$h_{Q10\%}$ [m]
21m 1987	331.41	0.51	44.2	25	0.48	0.71
21m 1997	331.54	1.35	421.0	>0.01	0.39	0.51
420m 1985	336.74	1.11	405.0	>0.01	0.38	0.48
420m 1997	336.10	1.17	336.0	>0.01	0.55	0.69

Data in Tables 2 and 3 clearly indicate that between 1980s and 1990s the lower course of the Yablunka was strongly transformed. While at its mouth, the river still had a layer of bed material in 1987, it was transformed into an incised bed ten years later. Armored layer existed until $Q_{10\%}$, which indicated a very low supply of the bed material to the reach. The river is already engineered and does not flood its valley any more. Bed elevation was lowered by about 70 cm in the entire reach. On site inspection carried out in 2016 revealed that the incision reached the level of the recipient, i.e. the Dniester and was stabilized. Gravel exploitation from the Dniester (7 109 000 t/year) exceeded natural transportation in this river. However, backward erosion could also be slower in the Yablunka (153 000 t/year), if the gravel pit exploitation would be stopped. In natural flow conditions, bed armoring is maintained at $\delta_g = 1.30$. This value is reached for the discharge and water depth shown in Table 3.

Table 3

Bed armoring analysis and bed elevation change

cross-section	max armour Q [m^3/s]	max armour h [m]	max armour range Q%	bed elevation [m a.s.l.]
21m 1987	44.54	0.57	25-10	330.90
21m 1997	72.00	0.51	10	330.19
420m 1985	70.00	0.46	10	335.63
420m 1997	71.70	0.67	10	334.93

There are still some sources of transported material when the sorting fluvial processes did not produce strong armoring. At present, this is probably mostly due to the side erosion.

5. CONCLUSIONS

The Yablunka experienced intensive erosion processes that caused the river incision. There are still some sources of eroded material, however, standard deviation $\delta_g = 1.88$ is close to armored bed indicated with a value of 1.3. As reported by other researchers armoring indicates low rates of sediment supply.

The Yablunka used to be a very active braided river. The current chaotic gravel exploitation should be stopped not only in the Yablunka but also in the Dniester due to the headward erosion entering to the Yablunka outlet section.

The present condition of the river cannot be amended probably but as long as its banks are partially regulated the process could be slowed down. The mouth of the Yablunka should be protected by a check dam that would limit the material transported to the Dniester during floods.

Another reason of the Yablunka bed lowering is increased afforestation reported by other researchers of Carpathian region. In the Yablunka basin, the forest area expanded from 32% in eighteenth century to 36.8% in 1940 and 43% in 2000. The forests may reduce the debris supply and stabilize the outflow during small floods.

As long as there is no explicit information on the current river dynamics, the next measurement sessions are expected to provide a more precise description of the tendencies for fluvial processes in the Yablunka river.

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