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Monitoring of landslides and erosion-accumulation processes in the upper reaches of the Prut River basin (Ukrainian Carpathians)

V. Brusak *(Ivan Franko National University of Lviv)*, ***I. Hnatiak*** *(Ivan Franko National University of Lviv)*, ***I. Brusak*** *(Lviv Polytechnic National University)*

SUMMARY

The upper Prut River basin in Chornogora (southeastern part of the Ukrainian Carpathians) serves as a key site for studying meteorological, geomorphological, hydrological, and landscape processes. Since 2001, geomorphological monitoring has focused on coastal and bottom erosion, erosion on tourist trails, and landslides, scree, and collapses. After the catastrophic flood of July 24–26, 2008, as a result of the reshaping and deepening of the Prut riverbed, landslide processes along the foot of the Ozirny ridge and the banks of the river valley intensified, to a lesser extent, landslides and erosion-accumulation processes intensified after the high flood in June 2020. The appearance, deepening, and expansion of cracks in the soil and vegetation cover, the retreat of the rear wall and the sliding of landslide bodies, and the intensification of scree and erosion processes were observed. Monitoring is carried out at three observation sites, the dimensions of the activated landslides are: upper part – 8.5–10.5 m, lower part – 16.6–43.7 m, length of landslides – 14–48 m, slope exposure – south-west and south-east. During September 2009 – September 2012, the width of cracks in root exposure increased by an average of 7 cm, and the average depth by 0.5 cm. Erosion and accumulation processes depend on the precipitation regime. During September 2011–September 2012, the micro-relief of observation site No. 3 changed the most – a scree slope on the left south-eastern bank of the Prut River, dominated by argillites with layers of siltstones and sandstones. The intensity of surface washout at observation site No. 3 was 8.64 cm/year, and the intensity of accumulation was 9.5 cm/year.

Introduction

The upper reaches of the Prut River basin are located in the southeastern part of the Ukrainian Carpathians and cover the alpine-subalpine and forested middle and low mountain ranges on the northeastern macro-slope of the Chornogora mountain range (Fig. 1). Intensive economic and recreational development of the territory against the dynamic natural factors has intensified recent exogenous geomorphological processes (Yushchenko, Yu. & Yushchenko, O., 2011). They are often caused by Prut River's hydrological regime, with rain floods occurring 5-7 times annually, including the catastrophic July 2008 floods (Kostenyuk, 2009; Melnyk, et al, 2009; Korchemlyuk, Prykhodko & Arkhipova, 2016).

At the upper reaches of the Prut River basin, at the foot of the Ozirny Ridge, lies the Chornohora Geographical Station of Ivan Franko National University of Lviv (CGS LNU), which is a center for comprehensive geographical research. The goal of geomorphological research is to observe the recent exogenous geomorphological processes in the region such as:

- research of seasonal horizontal and vertical transformations and morphometric characteristics of the Prut floodplain-channel complex and control of dangerous coastal and bottom erosion (Melnyk, et al, 2009; Dudych, 2011);
- observation of changes in the morphology and morphometry of ecological trail surfaces, including seasonal dynamics, recreational digression, erosion-accumulation processes, and development of recommendations to regulate micro-relief transformations of tourist routes (Brusak, et al, 2024);
- assessment of the mechanism and dynamics of gravitational processes, including landslides, scree, and rockfalls (Dudych & Gnatiak, 2012; Dudych, 2014).

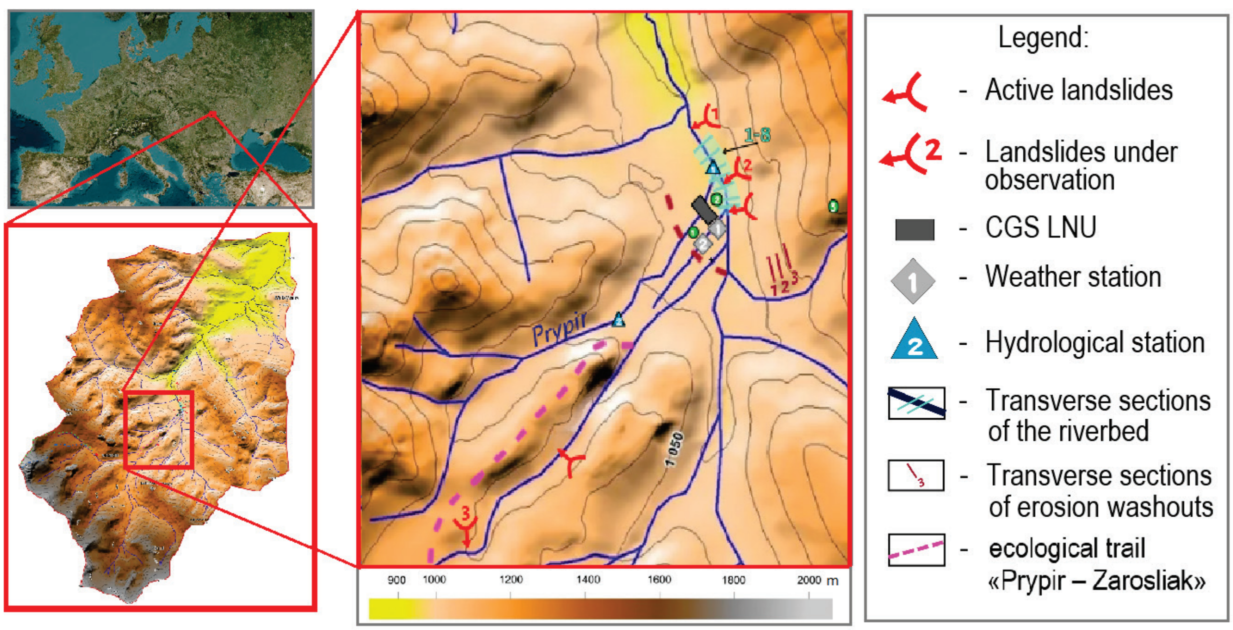

Figure 1 *Location of landslides subject to monitoring in the upper reaches of the Prut basin.*

Methods

Monitoring of recent exogenous geomorphological processes has been conducted since 2001 at 8 cross-sections of the Prut River within the CGS LNU; at 6 cross-sections of the meteorological station trail No.2 of the CGS LNU, in summer at 10 control cross-sections of the ecological trail «Prypir – Zaroslyak», at 3 cross-sections on trail «Ozirny Ridge», at 14 cross-sections within ecological trail "Zaroslyak – Hoverla"; on 2 landslide areas and 1 scree-landslide area (see Fig. 1). The main monitoring characteristics are:

- width of elements of the floodplain-channel complex of the Prut River and deepening or accumulation in the river channel;
- change in the forms and configuration of active landslides and scree slopes, cracks propagation in the soil and vegetation cover, formation of landslide breakaway walls andvelocity of retreat of scree slopes, amount of erosion or accumulation on landslide bodies;
- morphometric characteristics of tourist trail surfaces, formation and increase of erosional microforms of relief on trails, maximum depth of gullies.

Research on erosional microforms of relief is conducted by repeated levelling of typical transverse and longitudinal profiles in spring and autumn (May, September) and after heavy rains; by observing spiked and plate-shaped benchmarks on landslide bodies; instrumental measurement and photographic recording of morphometric parameters and morphological features of microforms of relief. Monitoring of landslide processes, accumulation, and erosion on landslide bodies began in 2009 at three sites.

Results

There are many stabilized landslides on the slopes of the Ozirny Ridge. After the catastrophic flood at the end of July 2008 (Melnyk, et al, 2009), landslide processes along the bottom of the ridge intensified as a result of the reshaping and deepening of the Prut River bed. To a lesser extent, landslides were observed as a result of a much smaller flood at the end of June 2020.

Observation site (OS) No. 1. Landslide on the slope of the Ozirny Ridge. Altitude above sea level: 994 m. Length of the upper part: 10.5 m; length of the lower part: 43.7 m. Slope exposure – south-west. The rocks at the base of the landslide belong to the Probynianska Formation (P^2 pr, Upper Eocene) and are represented by thin-layered rhythmic sandy-clayey gray-green flysch with layers of coarse-grained sandstone. The upper part of the landslide slope is characterized by a large number of transverse and longitudinal cracks (33, of which 10 were measured and shown on Table 1.

Table 1

Crack parameters on the landslide of the OS No.1. (Dudych & Gnatiak, 2012 with additions)

No. of cracks	Width (cm) (September 2009)	Width (cm) (September 2012)	Width 2012-2009 **%**	Depth (cm) (September 2009)	Depth (cm) (September 2012)	Depth 2012-2009 **%**	Cross sectional area (cm^2) (September 2009)	Cross sectional area (cm^2) (September 2012)	Cross sectional area 2012-2009 (%)
2	46	53	**115**	10	8	**80**	460	424	**92**
5	66	74	**112**	9	8	**89**	594	592	**100**
8	95	100	**105**	7	11	**157**	665	1100	**165**
12	69	75	**109**	10	5	**50**	690	375	**54**
17	58	65	**112**	11	9	**82**	638	585	**92**
22	82	89	**109**	10	14	**140**	820	1246	**152**
23	33	37	**112**	8	13	**163**	264	481	**182**
30	30	35	**117**	6	4	**67**	180	140	**78**
31	33	47	**142**	8	5	**63**	264	235	**89**
33	35	42	**120**	6	3	**50**	210	126	**60**
min	30	35	**105**	6	3	**50**	180	126	**54**
max	95	100	**142**	11	14	**163**	820	1246	**182**
avg	54,7	61,7	**115**	8,5	8	**94**	478,5	530	**106**

Between September 2009 and September 2012, the cracks widened by an average of 15%, their depths decreased by 6%, and their cross-sectional areas increased by 6%. At the same time, as of 2012, a decrease in the depth of individual cracks was observed due to an increase in width and crumbling of fine soil, while the depth of cracks located near the breakaway wall increased, indicating a slow downward slide of the landslide body. In the years following the sliding of individual parts of the landslide body, approximately the same increase in the width of new cracks was observed.

Observation site No.2. Landslide opposite the teaching building of CGS LNU (Fig. 2). Altitude above sea level: 987 m. Length of the upper part of the landslide: 8.5 m; length of the lower part: 20.5 m. Slope exposure – south-west. The landslide is composed of deposits of the Probynianska Formation P^2 pr (Upper Eocene). Gravitational processes intensified here after the catastrophic flood of 2008: there was a 0.8–1 m water incision in the Prut riverbed with exposure of bedrock and erosion of the right-bank landslide slope. Before the flood in 2008, this slope was relatively stable and covered with vegetation.

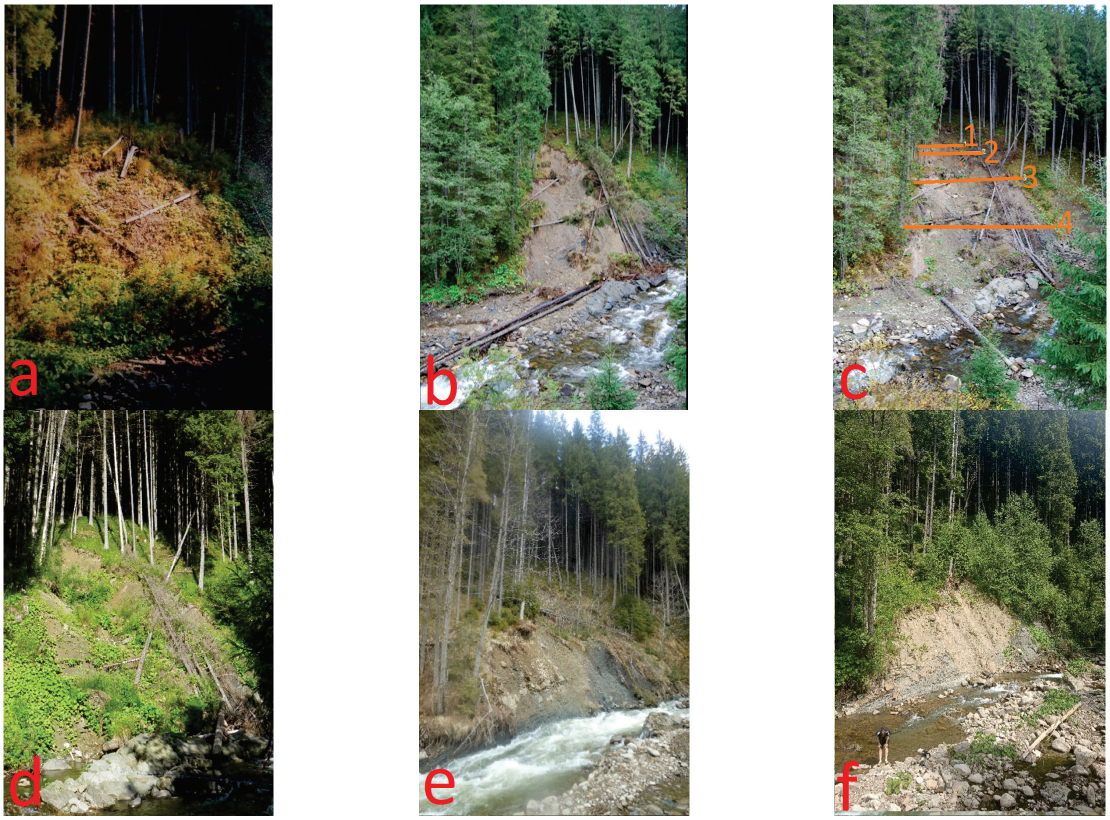

Figure 2 *Landslide at observation site No.2: June 2007 (a), September 2008 (b), September 2009 (c), July 2011 (d), April 2022 (e), June 2025 (f).*

Observation site No. 3 Landslide and scree on the left bank of the Prut River near the first bridge of the CGS LNU –Zarosiak road. Altitude above sea level: 1,090 m. Length of the upper part of the scree: 9.9 m; length of the lower part: 16.6 m. Exposure – south-east. The scree is represented by the Yalivets Formation K^2jl^2 (upper chalk) and consists of thin-bedded greenish-gray argillites, siltstones, and sandstones. Analysis of cartographic data and field studies shows that as a result of economic intervention (construction of a road and bridge), the Prut River channel, which flowed to the right in the 1950s and 1960s, changed its direction. As a result, the riverbed changed to a direction perpendicular to the slope, which led to the intensive development of landslide processes on it.

The upper reaches of the Prut River basin receive a lot of precipitation, often in the form of heavy rain, which directly affects surface runoff and accumulation on the slopes of activated landslides. From September 2011 to September 2012, the upper Prut River basin received 1115 mm of precipitation. In autumn 2011, 10% of micro-relief changes occurred, with soil erosion ranging from 0.46 cm at OS No. 1 to 0.89 cm at OS No. 3. Accumulation was highest at OS No. 3 (0.94 cm) and lowest at OS No. 1 (0.52 cm) (Dudych, Gnatiak, 2012). During winter (December–February), 307 mm of precipitation (27.5%) was recorded, with snowmelt causing fluctuations that did not expose the soil. The maximum soil erosion was recorded at OS No. 3 (0.92 cm), and the minimum at OS No. 2 (0.62 cm). The highest accumulation rates were observed at OS No. 3 (0.96 cm), and the lowest at OS No. 1 (0.72 cm). Spring (March–May) contributed 284 mm (25.5%), with maximum erosion at OS No. 3 (1.5 cm) and minimum at OS No. 1 (0.1 cm); sediment accumulation followed similar patterns. During the summer period (June–September 2012), 406 mm of precipitation fell (36.4%). Most of the rainfall was torrential, so erosion and accumulation processes reached their maximum development in the summer (60% of changes). The maximum values of surface runoff were recorded at OS No. 3 (1.16 cm), and the minimum values were recorded at OS No. 1 (0.21 cm). The highest accumulation rates were recorded at OS No. 3 (1.18 cm), and the lowest at OS No. 1 (0.34 cm).

Conclusions

The intensification of landslides, rockfalls, scree, and erosion-accumulation processes in the upper reaches of the basin depends on the amount and pattern of precipitation, the flood hydrological regime, and the characteristics of the geological and geomorphological structure. Gravitational processes intensified after the catastrophic flood in July 2008 and the high flood in June 2020. Erosion and accumulation processes on landslide and scree slopes are highly dependent on precipitation patterns. During the period of detailed research (September 2011 – September 2012), the observation site No. 3 – scree on the left bank of the Prut River where argillites dominate, which contributes to the formation of larger thicker layer of loose sediments. The intensity of surface washout at this OS was 8.64 cm/year, and the intensity of accumulation was 9.5 cm/year.

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