

Ihor Hnativ, Roman Hnativ, Nazariy Honcharuk

IMPACT OF CONSTRUCTION ON EROSION OF SLOPE AREAS IN THE SLAVSKA RIVER BASIN

*Department of Hydraulic and Water Engineering,
Lviv Polytechnic National University,
roman.m.hnativ@lpnu.ua*

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Over the past 25 years, the western regions of Ukraine have been affected by floods and mudflows caused by a complex of factors, the main of which are climate change, rapid snowmelt and intense precipitation, urbanization and deforestation. These hydrological phenomena caused significant material damage and a threat to human life. To prevent them, the construction of hydraulic structures, strengthening of river banks and afforestation, the creation of early warning systems and improvement of the monitoring system were carried out.

The conducted studies show that during the period from 2015 to 2025, significant changes occurred in the structure and condition of the soil cover on the studied slope and in the floodplain of the Slavska River. The identified cracks and vegetation degradation can be considered as the initial phase of the development of potentially dangerous geomorphological processes that require further monitoring.

Keywords: landslides, mudflows, floods, anthropogenic impact, engineering measures, satellite monitoring.

Introduction

Landslides and mudflows are among the most dangerous geological processes in mountainous areas of Ukraine. They are most pronounced in the Carpathians and adjacent foothills, where natural factors (steep slopes, intense precipitation, tectonic features) and anthropogenic impact (deforestation, unauthorized construction, road infrastructure) combine (Shekhunova et al., 2020; Rushchak and Chepurnyi, 2025; Kasiyanchuk and Shtohryn, 2023; Hnativ, Yakhno and Hnativ, 2023). The intensification of these processes creates significant risks for the life of the population, the condition of engineering structures and the natural environment (Shekhunova et al., 2022; Pityulich, 2015; Angnuureng et al., 2023). Over the past two decades, cases of intensification of landslides and the formation of mudflows have been regularly recorded in the western regions of Ukraine. According to the State Emergency Service and the Ukrhydrometeorological Center, during periods of intense rains, the water level in mountain rivers rises by 1–1.5 m, which is accompanied by the formation of dangerous slope runoff (IFRC, 2021; State Water Agency, 2020). In April 2025, collapses of retaining walls, dams, and local landslides were recorded in Transcarpathia, which damaged gas pipelines and roads. Similar cases are recorded almost annually, in particular, in 2021, villages blocked roads in the Khust district (Red Cross Climate Centre, 2024).

Climate change and the increase in the frequency of intense rainfall events, together with deforestation and insufficient development of drainage infrastructure, are increasing the scale and consequences of landslides (Hnativ, Yakhno and Hnativ, 2023; Petronchenko, 2020; Red Cross Climate Centre, 2024; Shekhunova et al., 2020). This indicates the need for a systemic approach to risk management.

At the state level, the issue of landslide hazard was raised in the “Comprehensive Program of Landslide Prevention Measures for 2005–2014”, which provided for monitoring, slope strengthening, construction of retaining structures and control over land use (Pityulich, 2015). However, after the completion of the program, a new similar document of a national scale has not been officially introduced.

Currently, the main implementers of landslide prevention measures remain the State Emergency Service, which carries out warnings to the population and responds to the consequences of natural

phenomena, as well as local authorities, which are limited in funding. The Ministry of Community and Territorial Development, within the framework of decentralization, integrates the issue of hazardous geological processes into spatial planning, but this is still of a point nature (Chepurnyi, Rushchak and Chepurna, 2024; Rushchak and Chepurnyi, 2025).

The purpose of the study is to analyze the causes of floods and mudflows in the western regions of Ukraine over the past 25 years, determine their main consequences for the population and infrastructure, and assess the effectiveness of implemented measures to prevent and mitigate their impact in order to increase the region's resilience to hydrological hazards.

Materials and methods

Floods and mudslides have been one of the main natural hazards in the western regions of Ukraine for many years. The Carpathian regions, namely Ivano-Frankivsk, Chernivtsi, Zakarpattia, Lviv and partly Ternopil regions, are particularly vulnerable. Over the past 25 years, natural disasters have been recorded here repeatedly, the most large-scale of which occurred in 2008, 2010 and 2020 (State Water Agency, 2020; IFRC, 2021). In particular, the 2020 flood is considered one of the most severe in several decades. More than 14 thousand residential buildings were flooded, hundreds of kilometers of roads and dozens of bridges were damaged, and thousands of people had to be evacuated (Petronchenko, 2020; Red Cross Climate Centre, 2024). The floods of 2008, which affected the Dniester and Prut basins, had similar devastating consequences (State Water Agency, 2020).

The causes of these disasters are related to both natural and human factors. Short-term intense precipitation, rapid snowmelt, and geomorphological features of the Carpathians create favorable conditions for the formation of floods and mudflows (Kasiyanchuk and Shtohryn, 2023; Rushchak and Chepurnyi I., 2025). However, their impact is significantly increased by deforestation, chaotic land use, and floodplain development, which reduces the natural ability of territories to retain water and restrain erosion processes (Shekhunova et al., 2020; Shekhunova et al., 2022).

Various measures are used to reduce the damage from such phenomena in the Carpathians. One of the main directions is engineering solutions for the construction of sediment traps, dams and barriers in mountain streams (Petronchenko, 2020; Pityulych, 2015). They help reduce the speed and force of the mudflow, retain rock and soil material, and protect settlements and infrastructure. In many cases, these structures have proven their effectiveness and prevented significant destruction. At the same time, their operation requires large financial costs and constant maintenance, and without proper care they quickly lose their effectiveness (Chepurnyi, Rushchak and Chepurna, 2024; Froude, and Petley, 2018).

A separate direction in the fight against mudflows and floods is Nature-Based Solutions (NBS). These are afforestation of mountain slopes, restoration of protective plantations, regeneration of floodplains and other environmental measures that restore natural protection mechanisms (Siversko-Donetsk BUVR, 2022; Red Cross Climate Centre, 2024). Thanks to this, the soil absorbs water better, surface runoff is reduced and erosion processes are slowed down. Unlike engineering structures, such solutions do not give an instant effect, but provide a stable and long-term result. In addition, they bring additional benefits: they contribute to the preservation of biodiversity, stabilize soils and improve the state of the environment in general (Petronchenko, 2020; Rushchak and Chepurnyi I., 2025).

The study of landslides and mudflows in the Carpathian region was based on open sources and remote monitoring. Satellite images from Google Earth and Sentinel-2 were used for the analysis (Rushchak and Chepurnyi I., 2025). This allowed us to trace changes in riverbeds, coastal zones, and slopes over the past decades. Hydrometeorological data reflecting precipitation intensity, water levels, and snowmelt rate were used to assess natural conditions. They help identify areas where mudflows and landslide activation are most likely (Kasiyanchuk and Shtohryn, 2023; Shekhunova et al., 2020).

Results and discussion

Our analysis showed that landslides and mudflows occur regularly in the Carpathians, especially during heavy rainfall or snowmelt. Steep slopes, areas with damaged coastal strips and areas with sparse vegetation are most at risk. Some river floodplains have been altered by agriculture, grazing or

development, which reduces the natural stability of soils and increases the likelihood of erosion and loss of topsoil (Hnativ I. and Hnativ R., 2025).

The impact of landslides and mudflows on ecosystems and infrastructure is very significant. River banks are destroyed, riverbeds change, the condition of coastal vegetation deteriorates, biodiversity decreases, and residential buildings, roads and small engineering structures are at risk. In local communities, this can lead to temporary loss of access to transport routes, damage to land plots and significant costs for eliminating the consequences of destruction. Comparison of satellite images and analysis of historical data helps to identify critical areas where the risk of further landslides and mudflows is greatest. This allows for preventive measures to be planned and for timely responses to dangerous changes in riverbeds and slope conditions.

In areas where natural engineering measures have been applied, noticeable positive results are observed. Restoration of forest belts, creation of buffer zones and control of riverbeds reduce the speed of mudflows, limit erosion and stabilize soils. Such comprehensive solutions combine natural mechanisms with engineering protection methods and increase the resilience of ecosystems and the safety of the population.

In addition, regular satellite monitoring and spatial analysis allow for tracking changes in river systems in real time. This makes it possible to predict potential hazards, plan restoration of territories, determine priorities for planting plants or strengthening banks, as well as assess the effectiveness of the implemented measures. This approach contributes not only to the protection of infrastructure, but also to the restoration of the natural balance in coastal and mountain ecosystems. This is especially important for preserving biodiversity and improving the quality of water resources (Trofymchuk, Adamenko and Trysnyuk, 2020).

In 2015, satellite images (Fig. 1) recorded the beginning of construction work at the foot of the slope near the highway and the Slavska River bed. Large-scale clearing was carried out to develop the territory, which included partial felling of the forest cover.



Fig. 1. Construction work with clearing of forest cover in the floodplain of the Slavska River between the villages of Volosyanka and Slavska in 2015 (Satellite image from March 2015 using Google Earth Pro)

By 2017, the area of felling in the above-mentioned territory had increased significantly (Fig. 2). As a result, a significant forestless corridor was formed on the slope, which led to the loss of an important stabilizing factor – the root system of trees. It was it that previously performed the function of natural soil reinforcement, reducing the tendency to erosion and preventing the development of dangerous geodynamic processes.

Analysis of the 2020 images (Fig. 3) indicates the appearance of linear deformations of the slope surface, namely cracks and local subsidence, which are interpreted as initial manifestations of landslide processes. The presence of such morphological signs confirms the activation of landslide hazard, which may pose a threat to transport infrastructure, hydrographic network and adjacent residential development.

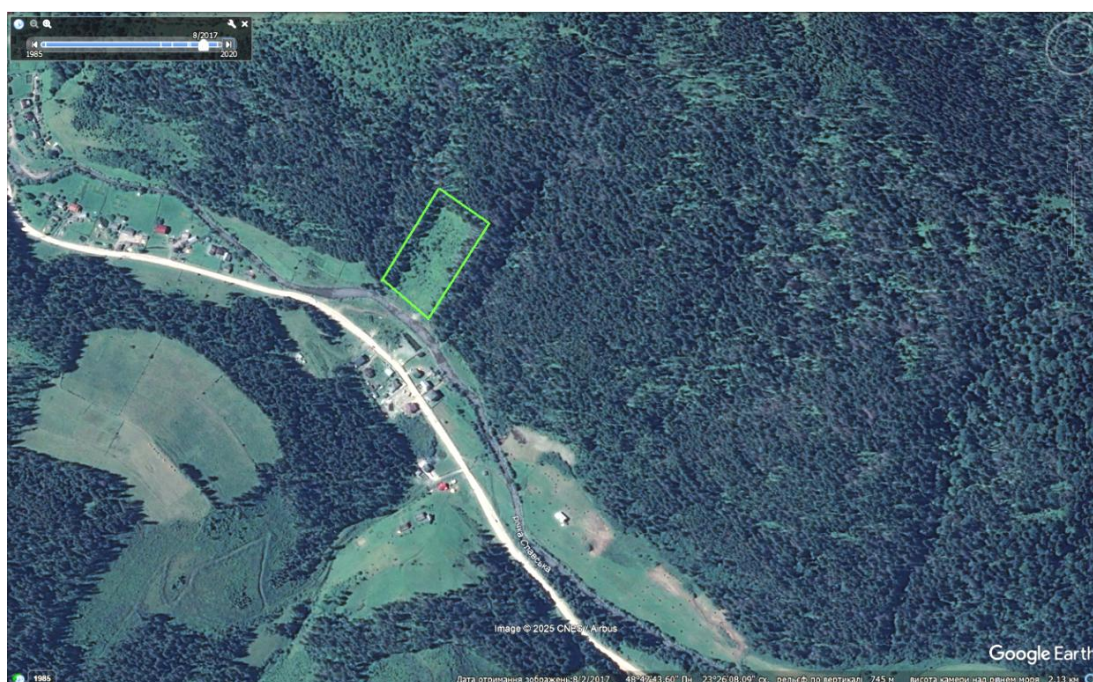


Fig. 2. Growth of the area of felling in the territory between the villages of Volosyanka and Slavsko in 2017 (Satellite image from August 2017 using Google Earth Pro)

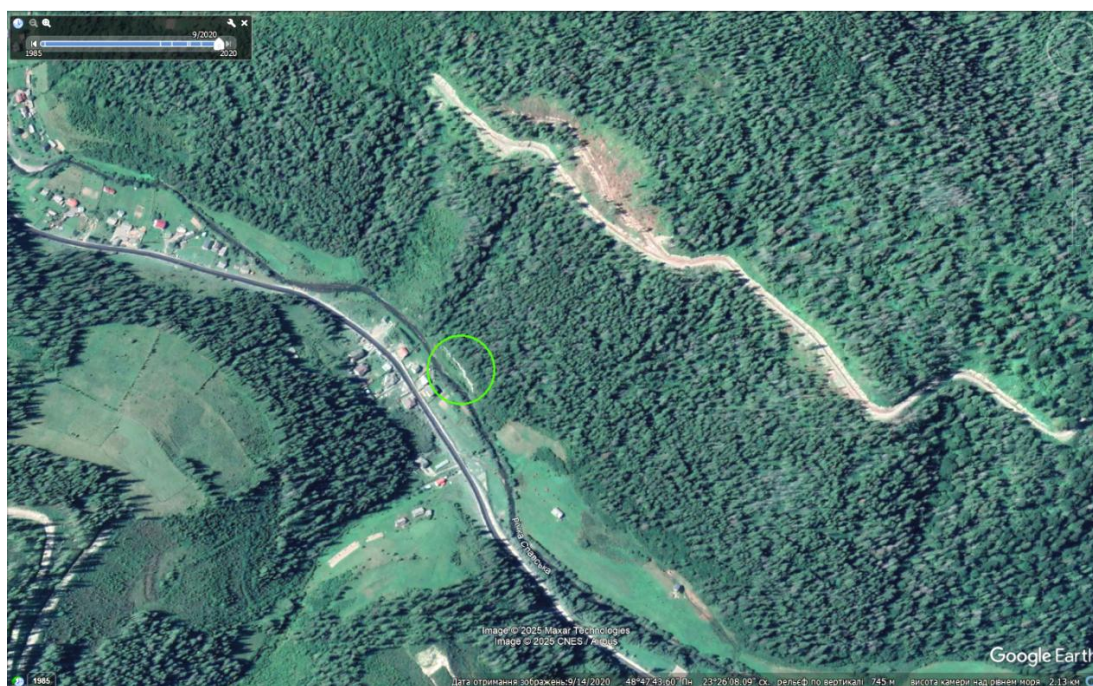


Fig. 3. Linear deformations of the studied area in 2020 (Satellite image from September 2020 using Google Earth Pro)

Thus, the combination of anthropogenic factors (solid felling, construction works) and natural conditions (steepness of the slope, proximity to the riverbed) significantly increased the level of landslide hazard in the studied area.

The scientific literature and practice of natural risk management emphasize the need for a multi-level system of landslide prevention. Short-term measures include drainage and surface water diversion, temporary strengthening of slopes and limitation of loads in risk zones. Such solutions minimize the likelihood of sudden landslide activation in an emergency situation.

The long-term strategy for combating landslides in the Carpathian region should be based on a complex of engineering and nature-based measures. Among the engineering solutions, the most effective are the construction of retaining walls, gabion structures, sediment traps and mudflow barriers in mountain streams. An important direction is the reclamation of territories by restoring forest cover, since the root system of trees plays the role of natural reinforcement of slopes and significantly reduces the likelihood of their destruction.

Analysis of Sentinel-2 L2A satellite data for 2015 and 2025, performed for the territory of the foot of the slope within the studied area, demonstrated significant changes in the state of soil and vegetation cover. The results obtained allow us to identify the initial signs of the development of destructive geomorphological processes that may be associated with landslide activity.

In the images of 2015, the slope surface was characterized by relative stability (Fig. 4). The vegetation cover had a continuous structure without pronounced breaks, and spectral indices, in particular NDVI and NDWI, indicated a sufficient level of moisture and the absence of signs of degradation. NDVI values remained high, which confirms active vegetation, while NDWI did not record local overmoistened zones. This indicates a balanced state of the slope ecosystem and the absence of signs of crack development or active landslide processes (Fig. 5).

However, the analysis of images for 2025 revealed a number of changes that may indicate the activation of geodynamic processes (Fig. 6). Linear spectral anomalies are observed within the foot of the slope, which have the character of narrow bands with reduced reflectivity in the visible and near infrared ranges. Such features are interpreted as soil cracks that arose as a result of stress-deformation processes in the thickness of slope deposits.

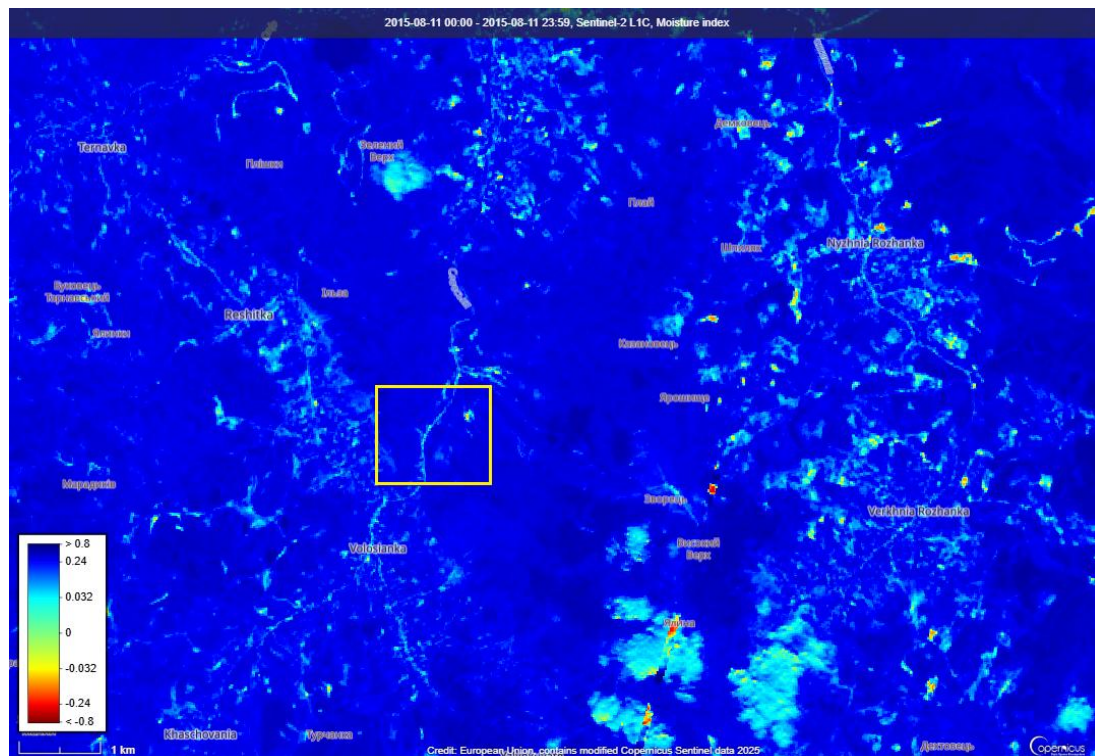


Fig. 4. Relative stability of the study area between the villages of Volosyanka and Slavsko in 2015 (Sentinel-2 L2A satellite image for August 2015)

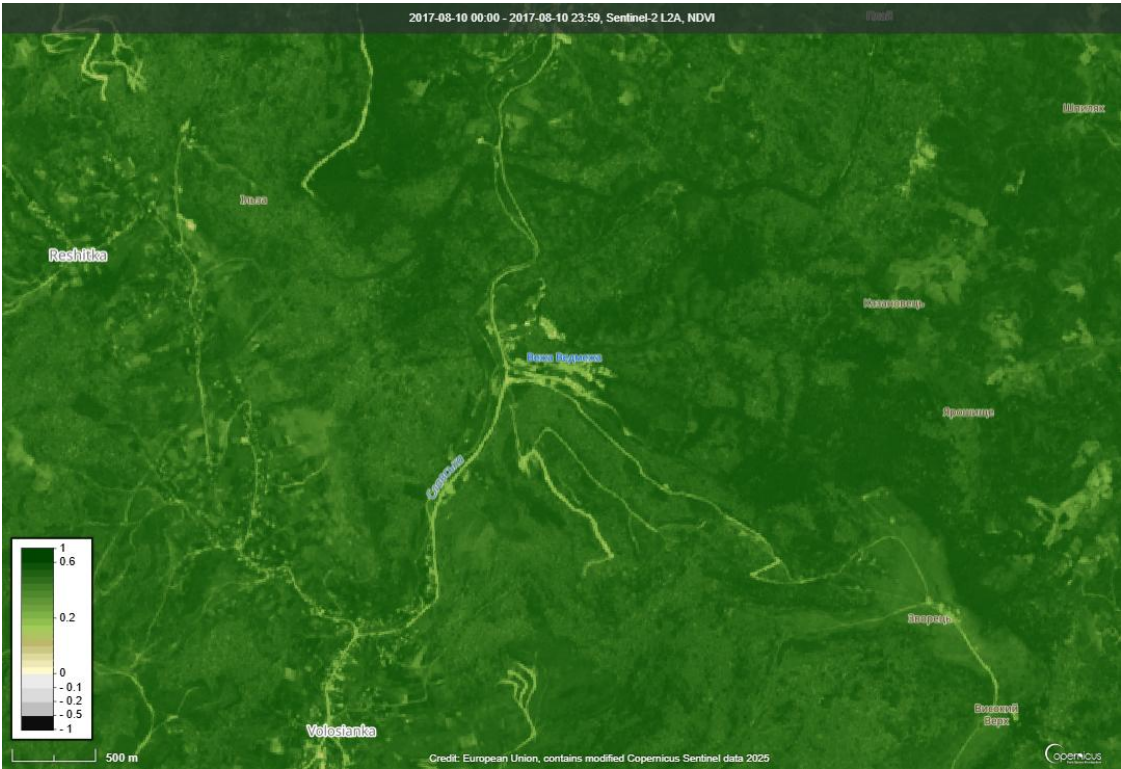


Fig. 5. NDWI vegetation cover for August 2017 between the villages of Volosyanka and Slavsko

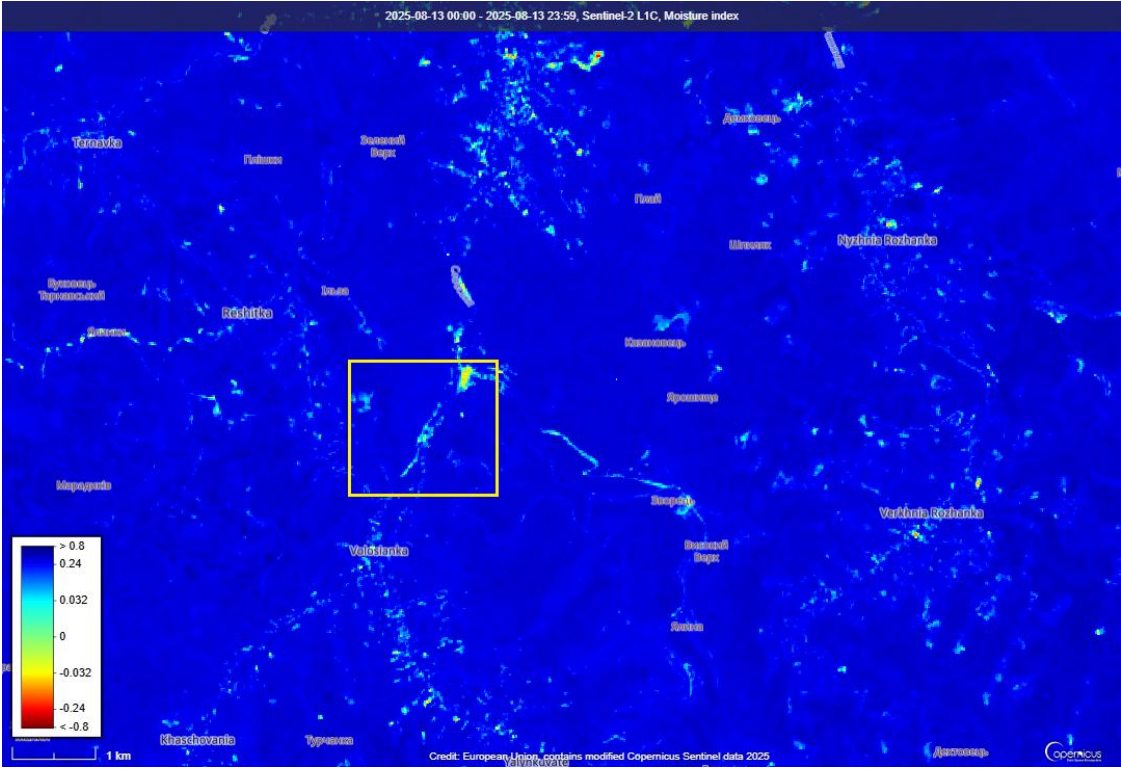


Fig. 6. Sentinel-2 L2A satellite image for August 2025 between the villages of Volosyanka and Slavsko

Additionally, a decrease in NDVI values was recorded, indicating degradation of vegetation cover within the fault zone. This may be the result of disruption of the plant root system due to mechanical changes in the soil. At the same time, a local increase in NDWI indicators was detected, which is explained by the accumulation of moisture in newly formed cracks. The penetration of water into soil fractures creates favorable conditions for further intensification of landslide processes, as internal friction decreases and the mobility of the soil layer increases (Fig. 7).

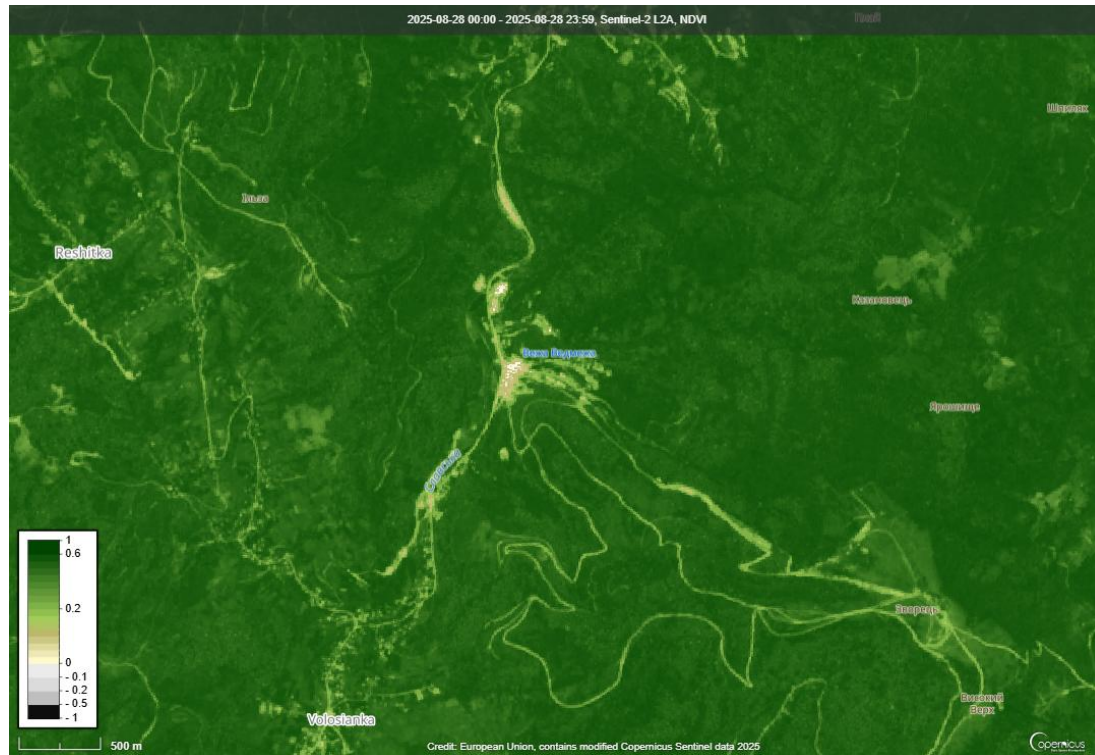


Fig. 7. NDWI vegetation cover for 08.2025 between the villages of Volosyanka and Slavsko

The results obtained confirm the high intensity of the development of exogenous processes in the mountainous regions of Ukraine, as well as the need for further monitoring studies to identify other potentially dangerous areas in this territory.

Conclusions

Thus, the experience of recent decades shows that effective counteraction to floods and mudflows in the Carpathians is possible only if two approaches are combined - engineering and nature-based. Only comprehensive risk management, which includes technical structures, ecological restoration and modern forecasting systems, can significantly reduce the vulnerability of the region and increase the level of safety of local communities. The results obtained confirm that significant changes have occurred in the structure and condition of the soil cover on the studied slope during the period from 2015 to 2025. The identified cracks and vegetation degradation can be considered as the initial phase of the development of potentially dangerous geomorphological processes that require further monitoring and consideration in landslide hazard forecasts.

References

Shekhunova S. B., Aleksieienkova M. V., Kril T. V., Stadnichenko S. M. and Siumar N. P. (2020). Natural and man-induced landslides. Second EAGE Workshop on Assessment of Landslide Hazards and impact on communities, Sep. 2020, Vol. 2020, pp. 1–6. <https://doi.org/10.3997/2214-4609.202055018>

Rushchak V. and Chepurnyi I. (2025). Assessment of Forest Cover Dynamics in Landslide-Prone Areas of the Ukrainian Carpathians using Remote Sensing Data. 18th International Conference Monitoring of Geological Processes and Ecological Condition of the Environment, Apr 2025, Vol. 2025, pp. 1–5. <https://www.earthdoc.org/content/papers/10.3997/2214-4609.2025510172>

Kasiyanchuk D., Shtohryn L. (2023). Assessment of landslide hazard risks on the example of the land cadastre of Kosiv district. *ISTCGCAP*, Vol. 98, No. 98, 50–62. <https://doi.org/10.23939/istcgcap2023.98.050>

Hnativ Roman, Yakhno Oleh, Hnativ Ihor (2023). Formation of the Surface Runoff of the Rivers of the Carpathian Region during the Urbanization of Slope Areas. *Journal of Ecological Engineering*, 24(5), 249–255. <https://doi.org/10.12911/22998993/161765>

Shekhunova S. B., Siumar N. P., Lobasov O. P., Stadnichenko S. M. (2022). Analysis of spatial patterns of landslide formation with gis tools (Zakarpatska oblast). *Ukrainian Geographical Journal*, No. 3, 11–20. <https://doi.org/10.15407/ugz2022.03.011> (in Ukrainian).

Pitiulych M. M. (2015). Mountainous territories of the Ukrainian Carpathians: current state and development prospects: monograph / State Institution “Institute of Regional Studies named after M. I. Dolishnyi, NAS of Ukraine”. Uzhgorod: Hrazhda, 320 p. <https://ird.gov.ua/ird01/p106108.php> (in Ukrainian).

Angnuureng Bapentire Donatus, Adade Richard, Chuku Ernest Obeng, Dzantor Selorm, Brempong Emmanuel Kwadzo, Mattah Precious Agbeko Dzorgbe (2023). Effects of coastal protection structures in controlling erosion and livelihoods *Heliyon*, 9(10) : e20633 <https://doi.org/10.1016/j.heliyon.2023.e20633>

International Federation of Red Cross and Red Crescent Societies (IFRC) (2021). Ukraine: Floods – Final report (Mar 2021). Ukraine Floods: Final Report – DREF operation n° MDRUA010 – Ukraine / ReliefWeb <https://reliefweb.int/report/ukraine/ukraine-floods-final-report-dref-operation-n-mdrua010>

State Agency of Water Resources of Ukraine (2020). Floods of 2008, 2010 and 2020 – consequences and damages. <https://davr.gov.ua/news/pavodki-2008-2010-ta-2020-rokiv--naslidki-ta-zbitki> (in Ukrainian).

Red Cross Climate Centre (RCCC) (2024). Climate fact sheet. Country profile: Ukraine. https://www.climatecentre.org/wp-content/uploads/RCCC-Country-profiles-Ukraine_2024_final.pdf

Petronchenko O. V. (2020). Assessment and forecasting of flood risks in river basins. *Ecological Safety and Nature Management*, No. 1 (33), 18–41. <http://jnas.nbuv.gov.ua/article/UJRN-0001138318> (in Ukrainian).

Chepurnyi I., Rushchak V. and Chepurna T. (2024). Spatial Analysis of the Relationship between the Distribution of Landslide Areas and Forest Cover. International Conference of Young Professionals “GeoTerrace-2024”, Oct. 2024, Vol. 017, 1–5. <https://doi.org/10.3997/2214-4609.2024510017>

Froude, M., & Petley, D. (2018). Global fatal landslide occurrence 2004 to 2016. *Natural Hazards and Earth System Sciences Discussions*, 1–44. <https://doi.org/10.5194/nhess-2018-49>

Seversko-Donetsk Basin Water Resources Management (2022). Nature-based solutions in water management: successful examples and ways of implementation. <https://sdbuvr.gov.ua/news/pryrodooriyentovani-rishennya-u-vodnomu-hospodarstvi-vdali-prykłady-ta-shlyakhy-vprovadzhennya> (in Ukrainian).

Kazachenko Ludmila, Kazachenko Vladyslav, Zhidkova Tetyana (2021). Gis technologies and 3D simulation in mapping manifestation of exogenic processes in renewable territories. *ISTCGCAP*, Vol. 94, No. 94, 29–34. <https://doi.org/10.23939/istcgcap2021.94.029>

Hnativ I. R., Hnativ R. M. (2025). Development of channel processes and mudflows on mountain rivers of the Prykarpattia. *SWorld Journal*, No. 29, Part 2, 13–19. <https://doi.org/10.30888/2663-5712.2025-29-02-013>

Trofymchuk O., Adamenko O., Trysnyuk V. (2020). Geoinformation technologies for environmental protection of the nature reserve fund. Ivano-Frankivsk – Kyiv: Suprun V. P. 340 p. <https://uterra.org.ua/articles/geoinformatsiini-tekhnologii-zakhystu-dovkillia-pryrodo-zapovidnoho-fondu.pdf> (in Ukrainian).

І. Р. Гнатів, Р. М. Гнатів, Н. В. Гончарук
Національний університет “Львівська політехніка”,
кафедра гідротехніки та водної інженерії

ВПЛИВ БУДІВНИЦТВА НА ЕРОЗІЮ СХИЛОВИХ ТЕРИТОРІЙ В БАСЕЙНІ РІЧКИ СЛАВСЬКА

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За останніх 25 років західні регіони України неодноразово зазнавали паводків та селевих потоків, спричинених комплексом факторів, серед яких інтенсивні опади, швидке танення снігу в Карпатах, зміни клімату, урбанізація та вирубування лісів. Ці гідрологічні явища створювали значні проблеми для місцевого населення та інфраструктури, спричиняючи підтоплення населених пунктів, руйнування доріг і мостів, втрату майна та загрозу життю людей. Їхні наслідки – великі економічні збитки, перебої із електропостачанням і водопостачанням, а також масова евакуація населення. Для подолання цих проблем реалізовано низку заходів: будівництво дамб та водозливних споруд, укріплення берегів річок, заліснення, створення систем раннього попередження та удосконалення гідрометеорологічного моніторингу. На ділянках, де застосовували природо-інженерні заходи, а саме відновлення лісових смуг, створення буферних зон і контроль русел річок, зменшено швидкість селевих потоків, обмежено ерозію і стабілізовано ґрунти. Саме комплексне поєднання природних механізмів із інженерними методами захисту найефективніше підвищує стійкість екосистем і безпеку населення. Регулярний супутниковий моніторинг і просторовий аналіз забезпечують можливість прогнозувати потенційні небезпеки і планувати відновлення територій, визначати пріоритети для насадження рослин чи зміцнення берегів, а також оцінювати ефективність впроваджених заходів.

Результати досліджень свідчать, що за 2015–2025 р. відбулися істотні зміни у структурі та стані ґрунтового покриву на досліджуваному схилі та в заплаві річки Славська. Виявлені тріщини та деградацію рослинності можна розглядати як початкову фазу розвитку потенційно небезпечних геоморфологічних процесів, що потребують подальшого моніторингу та врахування у прогнозах зсувонебезпечності.

Ключові слова: зсуви, селеві потоки, паводки, антропогенний вплив, інженерні заходи, супутниковий моніторинг.