Landslide25_12

Determining the Impact of Anthropogenic Activity on Landslide Hazard Formation Using Remote Sensing Data

L. Yelistratova *(State Institution "Scientific Centre for aerospace research of the Earth of the Institute of Geological Sciences of the National Academy of Sciences of Ukraine")*, ****A. Apostolov*** *(State Institution "Scientific Centre for aerospace research of the Earth of the Institute of Geological Sciences of the National Academy of Sciences of Ukraine")*, ***A. Khodorovskyi*** *(State Institution "Scientific Centre for aerospace research of the Earth of the Institute of Geological Sciences of the National Academy of Sciences of Ukraine")*, ***A. Khyzhniak*** *(State Institution "Scientific Centre for aerospace research of the Earth of the Institute of Geological Sciences of the National Academy of Sciences of Ukraine")*

SUMMARY

This study presents the results of an investigation into the impact of anthropogenic activities on the evolution of landslide processes, based on remote sensing (RS) data. The analysis is based on the Landslide Hazard Intensity Index (ER), calculated from a digital elevation model (DEM) obtained from Shuttle satellite data with a 30-meter resolution. The city of Kryvyi Rih and its surroundings (total area: 5697 km²) were selected as the test site due to intense mining-related land use. ER values within the study area range from 0 to 100, with zones exceeding a value of 7 classified as landslide-prone. Results show that areas associated with industrial activities, such as mining and waste dumps, exhibit significantly higher ER values – 10 to 12 times above the average – and greater elevation differences (up to 469 m) compared to natural terrain. The constructed ER-based map effectively identifies zones with varying degrees of landslide susceptibility, allowing detailed spatial differentiation. This research confirms that RS-based monitoring, in combination with the ER index, provides a valuable tool for the timely detection of hazardous areas and for assessing the impact of various human activities on landslide initiation and intensification.

Introduction

Under current conditions, the number of landslides in developed lowland areas has increased significantly due to the consequences of anthropogenic activities carried out without consideration of local geomorphological and geological factors. As a result, there is undercutting of slopes, overloading, and destabilization of deposits on the slopes. Additionally, this is driven by the expansion of existing settlements and the construction of new ones with a chaotic layout of buildings; the development of linear infrastructure such as roads, power lines, and water supply and sewage networks; deforestation and removal of shrubs on watersheds and slopes; excessive irrigation of agricultural lands; and intensive mining, which causes hydrodynamic impacts on reservoir-bearing strata, etc.

The danger of landslides lies in the dynamic impact of moving rock masses, which leads to the destruction of structures and facilities located on or within the landslide-affected area. As a result of landslide movement, roads, residential buildings, and industrial facilities are destroyed; pipelines, telephone and power lines are damaged; and river channels may become blocked, etc. Therefore, landslides in developed areas often lead to emergencies involving significant material losses and even human casualties.

Since the issue of landslide hazard is widely recognized, the anthropogenic causes of its occurrence have been extensively addressed in numerous scientific studies (Jaboyedoff et al., 2016). The influence of human activity on landslide occurrence in southwestern India was examined using spatial models (Jones et al., 2021). The assessment of the impact of anthropogenic activity and climate change on landslide susceptibility in the Himalayan region is presented in the work (Tyagi et al., 2024). The effect of human activity on the development of landslide susceptibility in the Three Gorges area, which frequently experiences severe landslide disasters and intensive human activity, is discussed (Li, Wang, & Mao, 2020). Authors (Dewi et al., 2019) conducted a landslide risk assessment focusing on the impact of human activities on an agricultural watershed. The physical and anthropogenic factors associated with landslide activity in Northern Peloponnese, Greece, are presented in the study (Skilodimou et al., 2018). The relationship between human activity and the hazard of landslides and debris flows triggered by rainfall in Central China is analyzed (Sun et al., 2021). In research (Zhang et al., 2012) presented a case study of repeated failures on a steep slope resulting from multi-stage excavation.

In Ukraine, the area occupied by mines, quarries, and especially mining waste dumps is increasing significantly each year, which is accompanied by a corresponding rise in landslides. Anthropogenic and technogenic pressures on the natural environment in Ukraine exceed those of developed countries by several times (Verkhovna Rada of Ukraine, 2019).

This study aims to investigate the impact of anthropogenic activity on landslide processes using remote sensing (RS) data.

Method and/or Theory

The study is based on the calculated Landslide Hazard Intensity Index (ER), which was developed using data from the Shuttle satellite's digital elevation model (DEM) with a spatial resolution of 30 meters. The methodology for calculating the ER index is detailed in the research (Apostolov et al., 2021; Yelistratova et al., 2021 and Apostolov et al., 2024). The calculation of the ER index simultaneously considers both the vertical and horizontal components of the terrain, thereby enhancing its reliability and accuracy. Higher values of the index correspond to areas that are potentially prone to erosion and landslides.

The input data for the study included a digital elevation model (DEM) from the Shuttle satellite and a 1:100,000 scale topographic map of the study area.

Results

The study area was selected as a test site to assess the potential of using RS data and the ER index for evaluating landslide hazards. The research focused on the city of Kryvyi Rih and its surroundings, with the test site coordinates ranging from 47°27′13.76" N to 48°20′54.99" N in latitude and from 32°55′56.57" E to 34°14′40.60" E in longitude, covering a total area of 5697 km². This area was chosen due to the high level of anthropogenic pressure on the natural environment, primarily caused by the operations of mining and processing enterprises, the presence of mines, and urban expansion.

The ER index values within the study area range from 0 to 100. Based on the analysis of ground-based data, areas with an index value greater than 7 are classified as landslide-prone zones (Figure 1).

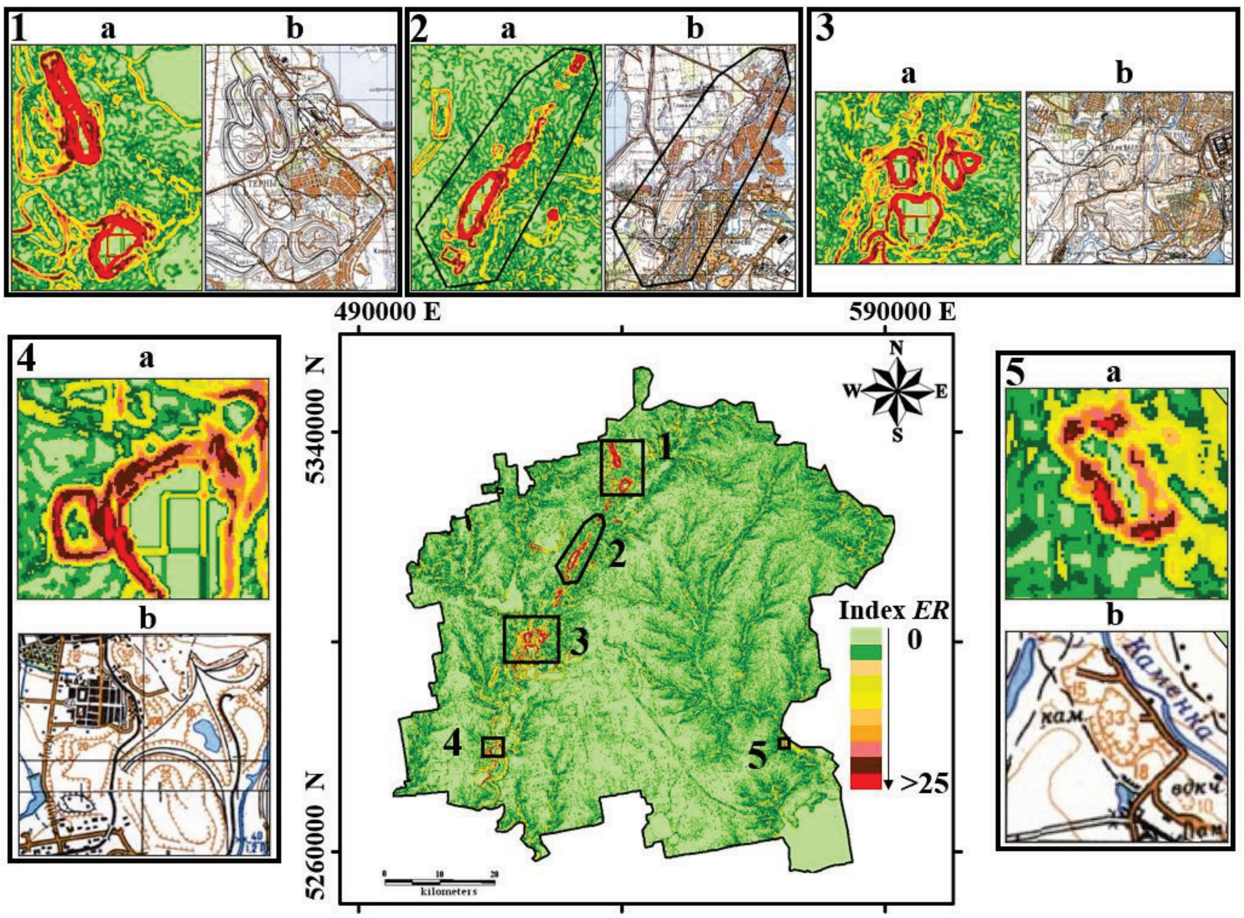

Figure 1 *Assessment of the study area by degree of landslide hazard using the ER index. 1)–5) Areas with the highest landslide hazard values correspond to zones of anthropogenic activity (1) Northern, 2) Central 3) Southern, 4) Ingulets Mining and Processing Plants, 5) stone quarry). a) area according to ER index data, b) area according to topographic maps of scale 1:100,000*

It is clear that the higher the index value, the more likely it is for landslides to develop. This enables the ranking of the territory according to the degree of landslide susceptibility. Based on the calculated ER index, the area of potentially landslide-prone zones within the study region is 98.96 km², which represents 1.74% of the total study area. Zones with the highest landslide hazard cover between 15.85 and 32.3 km², or 0.27% to 0.57%.

Based on the analysis of the spatial distribution map of ER index values (Figure 1), it was established that the entire study area can be confidently divided into two zones. Low index values characterize one zone, while high and maximum values dominate the other zones. The area with low index values occupies the majority of the territory and can be considered the natural background that existed before human intervention. Only isolated, small-scale zones with an increased probability of landslide occurrence are observed here. However, such areas are almost always present in any region and are typically associated with river valleys, particularly sections where there is a significant elevation difference in the modern relief. The formation of these zones has undoubtedly been influenced by modern displacements along fault zones.

A completely different pattern is observed in the area with high ER index values. First of all, this area is significantly smaller in size and stretches as a relatively narrow band in a north–northeast direction, clearly coinciding with the zone of mines and quarries that develop iron ore deposits—from Pivnichnyi Mining and Processing Plant (PivnGZK) in the north to Inhulets Mining and Processing Plant (InGZK) in the south. Within this band, numerous mining waste dumps are located, formed during the exploitation of the deposits. On the ER index map (Figure 1), it is evident that nearly all of these dumps are characterized by elevated and maximum index values. Additionally, the analyzed map clearly highlights quarry benches as areas with the highest index values. This is consistent with the concept of the index, as benches are zones with an increased likelihood of rock sliding, collapse, or failure. At the same time, certain features, such as pit bottoms and dump tops, appear as localized zones with the lowest index values. For the selected areas 1-5, which correspond to industrial production (Northern, Central, Southern, Ingulets Mining and Processing Plants and a stone quarry), the number of landslide-hazardous areas was calculated according to the ER index and their percentage within the areas, which is from 18.5% to 28.1%, which is 10-12 times more than the ER values for the entire studied area. Anthropogenic load on the areas leads to the fact that the height difference (from the maximum values in the dumps to the minimum in the quarries) is 389-469 m. At the same time, the height difference in the area with no active anthropogenic load is 180 m, which is 2.1-2.6 times less. Thus, anthropogenic activity significantly enhances the occurrence of landslides and land degradation processes.

The presented findings indicate that the constructed map effectively reflects areas with varying degrees of landslide hazard. Moreover, the wide range of numerical index values allows for a detailed differentiation of the study area according to the degree of landslide hazard.

Conclusions

The use of accumulated remote sensing data enables landslide hazard assessments to be conducted in monitoring mode, which significantly enhances the informational value of such studies. This approach does not replace traditional ground-based methods for studying landslide formation processes, but rather complements them, allowing timely attention to be directed toward the most hazardous areas. Thus, the use of the ER index enables the evaluation of the impact of various types of anthropogenic activities, such as road construction, quarrying, and other forms of development, on the initiation and intensification of landslide processes.

Acknowledgements

This project has received funding from the European Union’s Framework Programme for Research and Innovation Horizon Europe – the Framework Programme for Research and Innovation (2021-2027), Grant Agreement No. ID 101086250.

References

Apostolov, A. A., Yelistratova, L. A., Romanciuc, I. F., and Zakharchuk, I. (2021). Identifying potential landslide areas by employing the erosion relief index and meteorological criteria in Ukraine. Rev. Roum. Géogr./Rom. Journ. Geogr., 65(2), 125–141. http://www.rjgeo.ro/issues/revue%20roumaine%2065_2/apostolov%20et%20al..pdf

Apostolov, A., Yelistratova, L., Hodorovsky, A., and Tymchyshyn, M. (2024). Land cover degradation challenges in Ukraine: natural drivers and processes. 24th International Multidisciplinary Scientific GeoConference SGEM 2024. 29 Jun - 8 Jul, 2024, 24(2.1) https://doi.org/10.5593/sgem2024/2.1/s10.32

Dewi, H. N., Suryatmojo, H., Ngadisih, N., and Satriagasa, M. C. (2019). Landslide risk assessment: human activities influence on an agriculture catchment. IOP Conference Series Earth and Environmental Science, 361(1), 012033. https://doi.org/10.1088/1755-1315/361/1/012033

Jaboyedoff, M., Michoud M., Derron, M.-H., Voumard, J., Leibundgut, G., Sudmeier-Rieux, K., Nadim, F. and Leroi, E. (2016). Human-induced landslides: toward the analysis of an-thropogenic changes of the slope environment. In: Avresa S., Cascini L., Picarelli L. and Scavia C. (Eds.). Landslides and Engineering Slopes – Experiences, Theory and practices. CRCPress, 217-232. https://doi.org/10.1201/9781315375007-12

Jones, S., Kasthurba, A. K., Bhagyanathan, A., and Binoy, B. V. (2021). Impact of anthropogenic activities on landslide occurrences in southwest India: An investigation using spatial models. Journal of Earth System Science, 130(70). https://doi.org/10.1007/s12040-021-01566-6

Li, Y., Wang, X., and Mao, H. (2020). Influence of human activity on landslide susceptibility development in the Three Gorges area. Natural Hazards, 104(3), 2115–2151. https://doi.org/10.1007/s11069-020-04264-6

Skilodimou, H. D., Bathrellos, G. D., Koskeridou, E., Soukis, K., and Rozos, D. (2018). Physical and Anthropogenic Factors Related to Landslide Activity in the Northern Peloponnese, Greece. Land, 7(3), 85. https://doi.org/10.3390/land7030085

Sun, L., Ma, B., Pei, L., Zhang, X., and Zhou, J. L. (2021). The relationship of human activities and rainfall-induced landslide and debris flow hazards in Central China. Natural Hazards, 107(1), 147–169. https://doi.org/10.1007/s11069-021-04577-0 .

Tyagi, A., Gupta, N., Tiwari, R. K., James, N., and Chavan, S. R. (2025). Determining the impact of anthropogenic activities and climate change on landslide susceptibility for the Himalayan region. Natural Hazards. 121, 5239–5265. https://doi.org/10.1007/s11069-024-07011-3

Verkhovna Rada of Ukraine. (2019). *On the Basic Principles (Strategy) of the State Environmental Policy of Ukraine for the Period Until 2020: Law of Ukraine No. 2697-VIII of February 28, 2019*. https://zakon.rada.gov.ua/laws/show/2818-17#Text

Yelistratova L. A., Apostolov A. A., Romanciuc I. F., Orlenko T. A., and Tymchyshyn M. A. (2021). Application of remote sensing data for detection the landslides areas in Ukraine. Third EAGE Workshop on assessment of landslide hazards and impact on communities 2021, 20-23 September 2021, Odesa, Ukraine, 2021, 1 – 5. https://doi.org/10.3997/2214-4609.20215K1017

Zhang, F., Liu, G., Chen, W., Liang, S., Chen, R., and Han, W. (2012). Human-induced landslide on a high cut slope: a case of repeated failures due to multi-excavation. Journal of Rock Mechanics and Geotechnical Engineering, 4(4), 367–374. https://doi.org/10.3724/sp.j.1235.2012.00367