Acta Montanistica Slovaca
ISSN 1335-1788
actamont.tuke.sk

Selection of the variant of highway based on the territory susceptibility to landslides – model area D1/R3 highway nearby Oravský Podzámok

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Funding information:
European Union's Horizon 2020 research and innovation programme under grant agreement No 101006661.

Acknowledgement:
This work was supported by the Slovak Research and Development Agency under the Contract no. APVV-21-0099: Effective management of innovation-oriented territorial clusters.

How to cite this article:
Šalkovič, M., Hajduk, J. and Pauditšová, E. (2023) Selection of the variant of highway based on the territory susceptibility to landslides – model area D1/R3 highway nearby Oravský Podzámok. *Acta Montanistica Slovaca*, Volume 28 (2), 424-436

DOI:
https://doi.org/10.46544/AMS.v28i2.13

Abstract

The article focuses on the issue of routing lineside constructions in Slovakia. The chosen section of the planned lineside construction is the future section of the R3 expressway starting at the D1/R3 highway intersection in Hubová up to Oravský Podzámok. The selected road section was investigated based on the built-up model of the territory's susceptibility to landslides. Multivariate statistical analysis was used to determine the susceptibility of the territory to landslides, the success of which was determined based on ROC curves. Four variants were compared, of which two surface and two tunnel variants with the Dolný Kubín tunnel. By comparing the routes of the individual variants that pass through the landslide area, the order of suitability of the highway variants was determined in terms of slope stability. Determining the conflict of interests of line constructions with sites of susceptibility to landslides is very important in the environmental impact assessment process. Prediction of probable negative impacts of construction is one of the basic missions of this process. Missing data, whose acquisition extends the processing time for the project and the funding of associated expenditures, is a common drawback when building prediction models in the field of road construction.

Keywords

crossroad Hubová – Oravský Podzámok; Landslide hazard assessment; Multivariate statistical analysis; GIS

Introduction

In recent years, we have been observing an increase in traffic on roads that were not designed for it. The increase in transit freight traffic, in particular, opens up the issue of routing individual sections of highways and expressways. The very evaluation of the various proposed solution variants represents a complex system of evaluation of input data, aiming to identify the expected impacts in the future.

Evaluating the susceptibility of the constructions to landslides is important from the point of view of several processes:

1. Territorial planning and development: it is crucial to assess the risk of landslides in the early stages of spatial planning and development to ensure that buildings, infrastructure and other structures are built in areas susceptible to landslides minimally;
2. Natural disaster response: after a landslide event, it is crucial to assess the susceptibility of the affected area to future landslides to understand the risk better and to plan the response and recovery efforts.
3. Environmental impact assessments: evaluating susceptibility to landslides is a crucial step in environmental impact assessments of proposed projects, such as mining, dam construction, and road building, to understand the potential impact of the project on the stability of slopes; high-quality predicting the possible impacts to prevent environmental disasters and reduce the economic complexity of constructions.

In all of these processes, the assessment of susceptibility to landslides should be performed by qualified professionals and based on appropriate geotechnical and geological studies, as well as other relevant data sources. Landslide hazard assessment is a scientific process used to evaluate the likelihood and potential impact of landslide events in a specific area. It involves analyzing the physical, geological, and meteorological factors that contribute to landslide occurrences, as well as mapping and modelling potential landslide zones and assessing the potential impacts on infrastructure and human populations. The results of landslide hazard assessments can be used to inform land-use planning and risk management decisions and to prioritize resources for hazard mitigation and response. Effective landslide hazard assessments require interdisciplinary expertise and a comprehensive approach, integrating geology, geotechnical engineering, hydrology, and hazard modelling data. Assessments of landslide susceptibility, which quantify the anticipated sites of future landslides, are frequently used in landslide mitigation (Guzzetti et al. 2006).

The threat, referred to in English and American literature as "hazards ", along with risk, began to be elaborated in American literature based on the interest of insurance companies. Some natural and man-made hazards were listed in California State Standards as early as 1971 (Smith 1985). Varnes (1984) characterizes natural hazard as the probability of occurrence of a potentially dangerous phenomenon at a certain time in a given period. The risk distinguishes between specific and general, while the general risk is characterized as the expected number of victims, or injured, the size of property losses or the interruption of economic activities as a result of a certain phenomenon. Brabb (1984) states that in relation to the threat of landslides, the population in the area is exposed, as well as the vulnerability of the environment and the expected consequences for people and structures if a landslide occurs. In Slovak literature, the mentioned terms began to be used only in the nineties of the 20th century (Drdoš 1992, Minár, Tremboš 1994, 1995, Ondrášik 1994, 1998, Gajdoš, Bánska, Ondrášik 1998, Ondrášik, Gajdoš, Bánska 1999). The later introduction of the mentioned concepts in Slovak literature was connected with the development of landscape ecology in the Central European area and the focus on assessing the potential and carrying capacity of the landscape (Drdoš 1992, Drdoš, Kozová 1992) and the search for environmental limits (Tremboš 1992, Hrnčiarová 1997, 1998 and others). Similarly, in engineering geology, attention was focused on potentials and geobarriers (Matula, Ondrášik 1990). Later in the researched area, we can mention, for example, works by Bednarik & Pauditš (2010), Spinetti et al. (2019), etc. Other authors deal with the neural network method in their works, Yilmaz et al. (2011), Wang et al. (2019), Amato et al. (2021) and so on. There is a large amount of work reflecting on the effects of the weather, which we will mention, for example, Gassner et al. (2015), Antonetti et al. (2022). The authors in Bao et al. (2022) focus on the application of new technologies and the understanding of the analysis of the development of new, particularly digital technologies in landslide risks in their research. They discuss the application of instruments and the usage of various sensors to record the condition and make of the landscape where landslide concerns are kept track of. The use of learning AI technology in landslide research is also mentioned.

The risk of landslides occurring is greatly influenced by the geological structure of a region. A region's stability may be impacted by the type, texture, and structure of the local rock and soil, which could result in landslides. Geological faults can weaken rock masses and make them more susceptible to failure, which is a common cause of landslides. Another important factor is the permeability of rock and soil, while the geological structure of the territory has a significant influence on the occurrence of landslides. Factors such as the presence of faults and the permeability of rock and soil can affect soil stability, leading to the possibility of landslides.

Climate change affects the stability of natural and engineered slopes and has implications for landslides. The increase in the occurrence of landslides caused by climatic factors has resulted in several studies dealing with the type, extent, size and direction of changes in stability conditions and the location, frequency, activity and frequency of landslides in response to climate change (Gariano, Guzzetti 2016, Palmer 2020, Pierre-Louis 2022).

In the processes of strategic and spatial planning, there are elements such as bridges, terminals, stations, tunnels and many other engineering objects that are considered critical infrastructure elements. In the processes of strategic and spatial planning, there are elements such as bridges, terminals, stations, tunnels and many other engineering objects are considered critical infrastructure elements for which is important to evaluate the level of security (Fuchs 2015, Plos et al. 2016, Soušek, Dvořák 2009). The R3 expressway from the intersection with the D1 highway to Oravský Podzámok represents a part of the expressway that starts at the Hubová intersection with the D1 highway and continues north through a relatively complex geological area prone to slope movements. In the examined section of the route, four variants were evaluated, the routes of which are shown in Figure 1. All the evaluated variants are at the beginning of the route in the valley of the Komjatná stream.

Passing between the slopes of Ostra (1 067 m) and Kečka (1 159 m), which represent the border between the geomorphological whole of Veľká Fatra and Oravská vrchovina (Mazúr, Lukniš 1978), the assessed variants differ from each other over a length of 2.5 km (in which they are identical). The total length of the routes for the individual variants is variant 1 – 17 779 m, variant 2 – 20 538 m, variant 3 – 22 899 m, and variant 4 – 17 252 m. On the route of option 2, there is the Dolný Kubín tunnel with a length of 300 meters; with option 4, the length of the Dolný Kubín tunnel is up to 4 573 meters.

The article aims to determine the suitability of individual routes of the variants of the expressway solution in the investigated section from the point of view of slope stability. The work creates a model of the territory prone to landslides, categorizes the territory into landslide classes, and then determines the length of the variants of the expressway within the identified landslide classes. Based on the landslide-prone terrain model, a design can be made for the route variant.

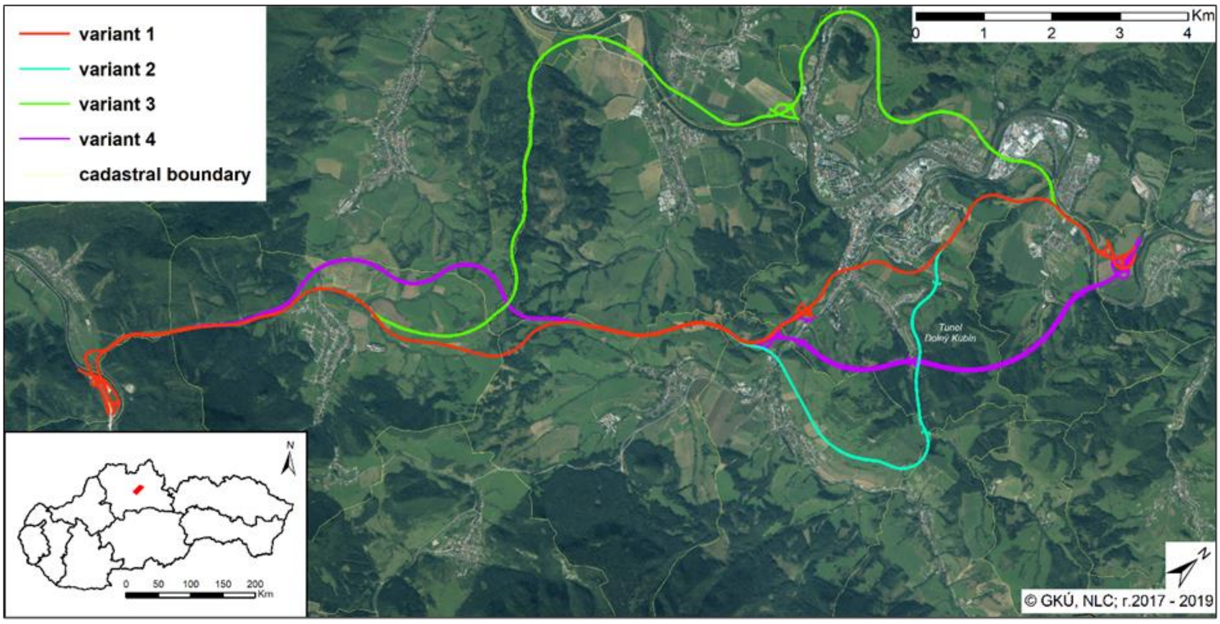

Figure 1. Spatial localization of variant of the solution of the R3 expressway in the section of the intersection Hubová – Oravský Podzámok, which were the subjects of the environmental impact assessment process.

Material and methodology

Using the analysis model from the ArcCatalog menu, a slope model was constructed based on the input DMR, which was divided into nine categories according to altitude in the meaning of work to Matula et al. (1983). The slope raster was divided into nine intervals. The limits of the interval were slope values of 2°, 3°, 5°, 7°, 11°, 17°, 20° and 31°. According to the slope grid, the average slope of the selected location's territory represented a value of 14.1°. Another model used, based on DMR, was the orientation of the relief with respect to the cardinal points, which we divided into eight basic directions. Aspect classes facing towards N (337.5 – 22.5), NE (22.5 – 67.5), E (67.5 – 112.5), SE (112.5 – 157.5), S (157.5 – 202.5), SW (202.5 – 247.5), W (247.5 – 292.5), NW (292.5 – 337.5). Using the DMR raster, a model of the curvature of the relief was built, which tells us about the concavity and convexity of the territory. The model inputs derived from the DMR raster are shown in Figure 2.

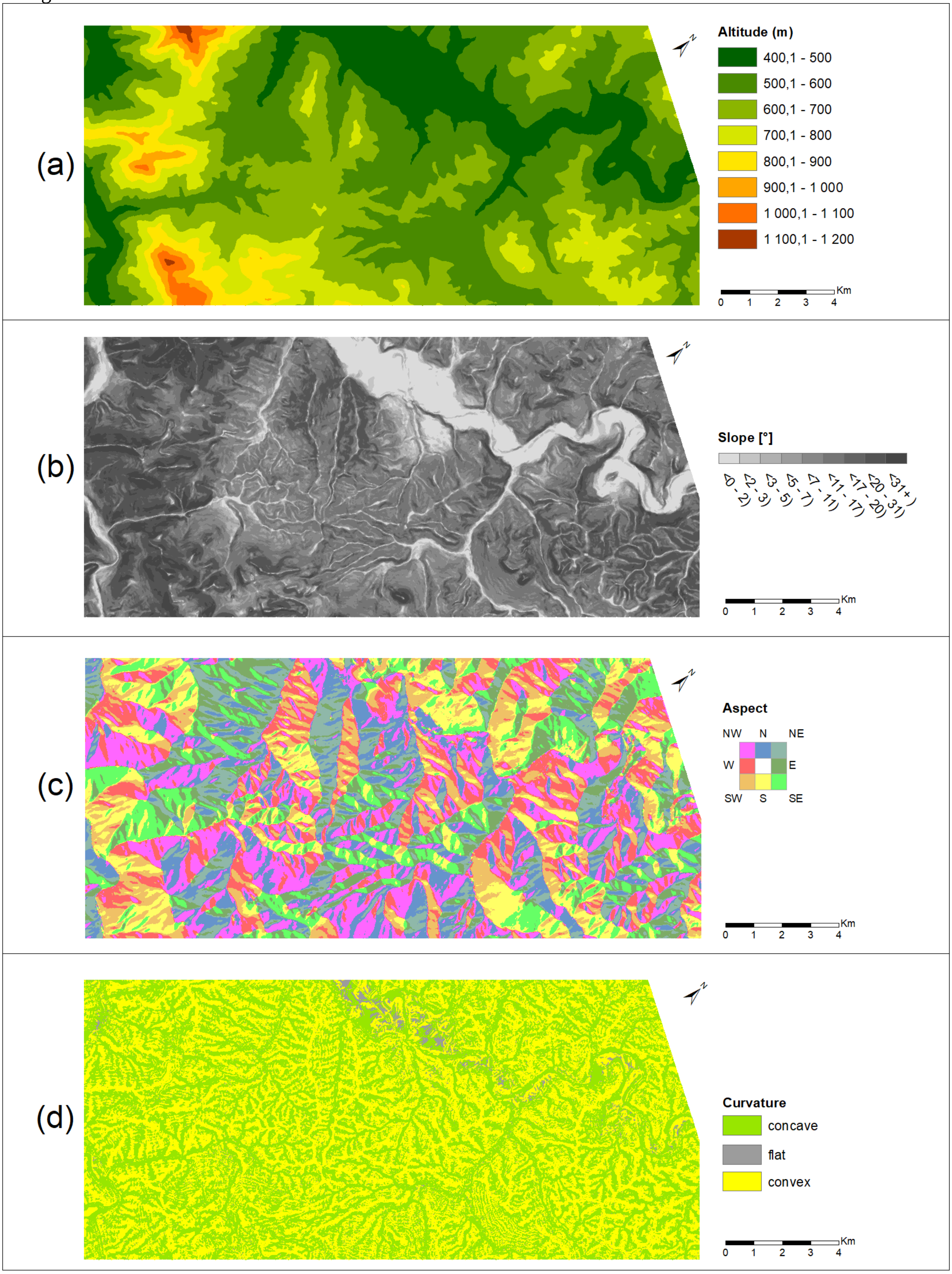

Figure 2. *Landslide causative factor maps: Altitude (a), Slope (b), Aspect (c), Curvature (d)*

The basis for the creation of the map layer representing the geological conditions of the area of interest were the geological maps of South and East Orava by the authors Gross et al. (1994) and Lithofacies segment of the Borov Formation of the Podtatra Group (Orava Paleogene) by the authors Filo, Buček, Siráňová (2009). The processing of this map can be seen in Figure 3. The data source for creating the land cover map layer was the vector ESRI geodatabase Corine Land Cover 2018. Land cover classes found in the investigated location according to the codes: 112 – Discontinuous urban fabric; 121 – Industrial or commercial units; 142 – Sport and leisure facilities; 211 – Non-irrigated arable land; 222 – Fruit trees and berry plantations; 231 – Pastures; 242 – Complex cultivation patterns; 243 – Land principally occupied by agriculture, with significant areas of natural vegetation; 311 – Broad-leaved forest; 312 – Coniferous forest; 313 – Mixed forest; 324 – Transitional woodland-shrub; 333 – Sparsely vegetated areas; 512 – Water bodies.

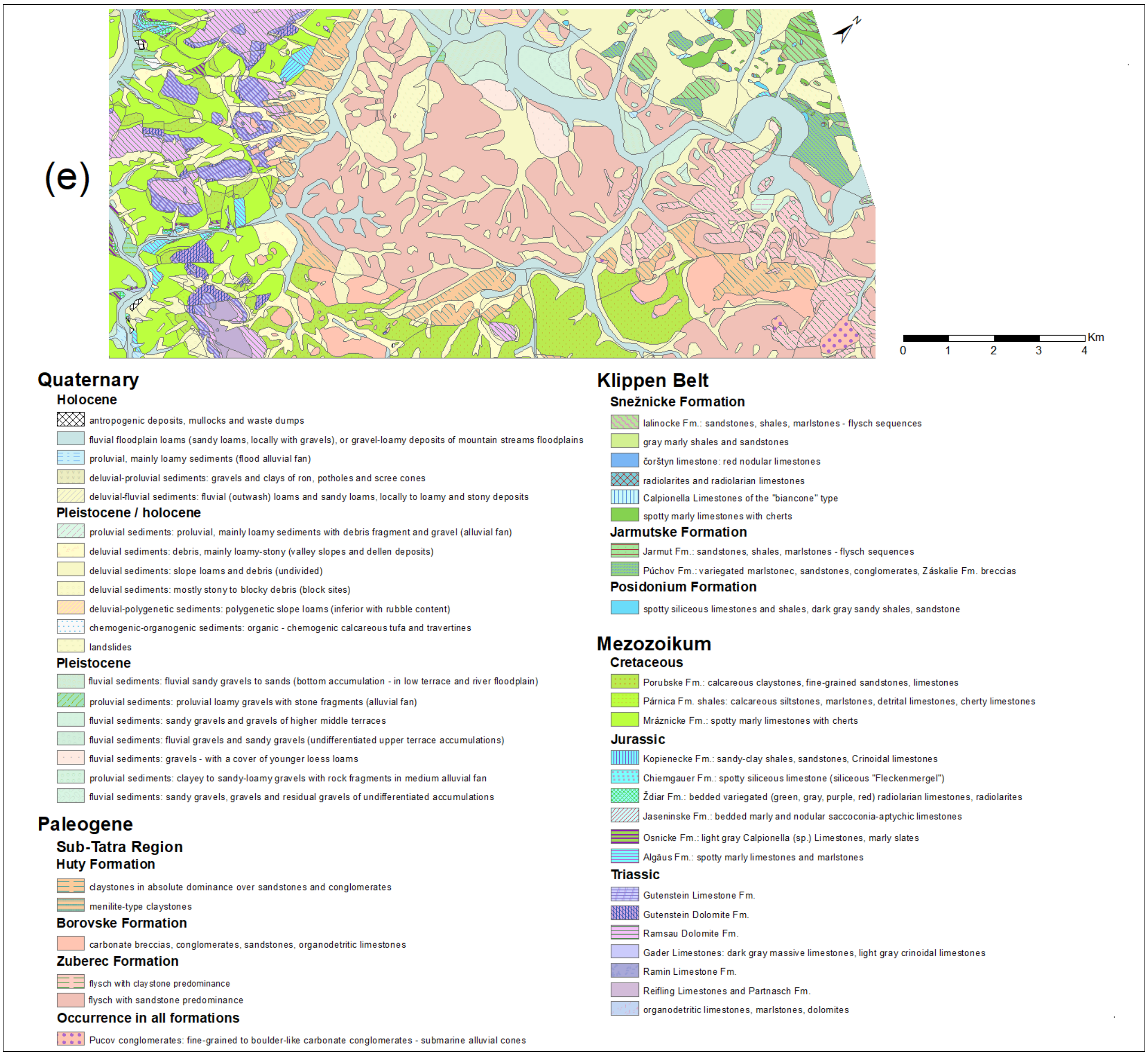

Figure 3. *Landslide causative factor map – Geological structure (e)*

The distance to the stream layer was used as another input to the model. The slope's proximity to the stream course is a crucial element that determines how the landscape evolves in the region and serves as a predictor of landslides and related erosional characteristics. As rivers erode the slope base and saturate the submerged portion of the slope-forming material, they increase the likelihood of landslides occurring (Akgun, Turk 2011). The model was divided into four classes, 0 – 50 m, 50 – 100 m, 100 – 150 m and more than 150 meters from the stream. The last input layer was a raster with the annual total of precipitation for the given territory, where the data from the Atlas of the Slovak Republic were used. The last input layer was a raster with the annual total of precipitation for the given territory, where the data from the Atlas of the Slovak Republic were used. In the studied locality, the average annual precipitation totals in the normal period 1961 – 1991 ranged in four intervals. The value intervals of average annual rainfall totals are 700 – 800 mm, 800 – 900 mm, 900 – 1000 mm and 1000 – 1200 mm. Figure 4 shows the input land cover layers, distance to stream and rainfall.

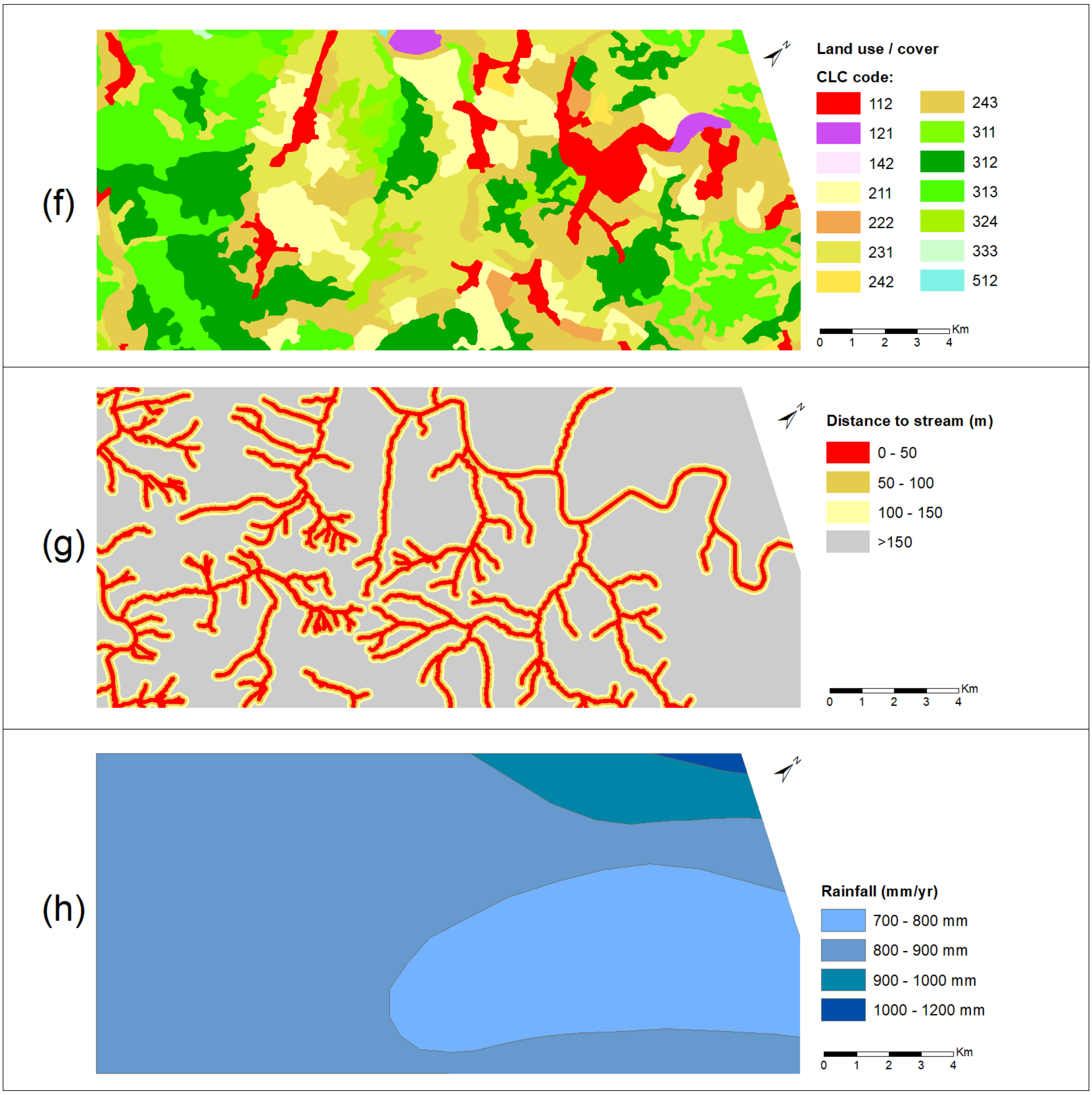

Figure 4. *Landslide causative factor maps (a) Altitude, (b) Slope, (c) Aspect (d) Curvature (e) Lithology, (f) Land use / cover (g) Rainfall and (h) Distance to stream*

Multivariate statistical analysis was the chosen method for determining the land's susceptibility to landslides. According to Aleotti and Chowdhury (1999), there are two main categories of statistical methods for landslide risk assessment: qualitative and quantitative methods. One of the quantitative methods is multivariate statistical analysis (Baeza, Corominas 2001, Santacana et al. 2003, Pauditš 2006, Clerici et al. 2006 and Shen et al. 2012). The input data were reclassified grids: elevations, slope inclinations, orientation of slopes with respect to the cardinal points, geological structure, land cover and slope deformations. By combining the input raster layers, each of which was divided into certain classes, a new map layer formed by almost homogeneous units called "unique conditional units" (UCU) was created. The principle of multivariate statistical analysis, according to Pauditš (2006), can be seen in Figure 5. The subsequent zonal statistics, for which a raster layer of slope deformations was used, where the values "0" and "1" represent the presence of a landslide, resulted in a raster of average values taking on a value from 0 to 1.

Using the relation of Clerici (2002), which defines the "P" value represented by the share of two-fifths of the total area of landslides to the total area without a landslide, the resulting "P" value represents the probability of occurrence of landslides. The raster map layer created after the implementation of zonal statistics and the application of the mathematical relationship, according to Clerici (2002), was classified into 5 classes of susceptibility of the territory to landslides, from very low to very high degree of susceptibility of the territory to landslides. To check the correctness of the achieved results of the modeled layer, verification using the ROC curve (ROC – Receiver Operating Characteristic) was used, which compares the truth or false of the assertion of the presence of landslides in individual classes.

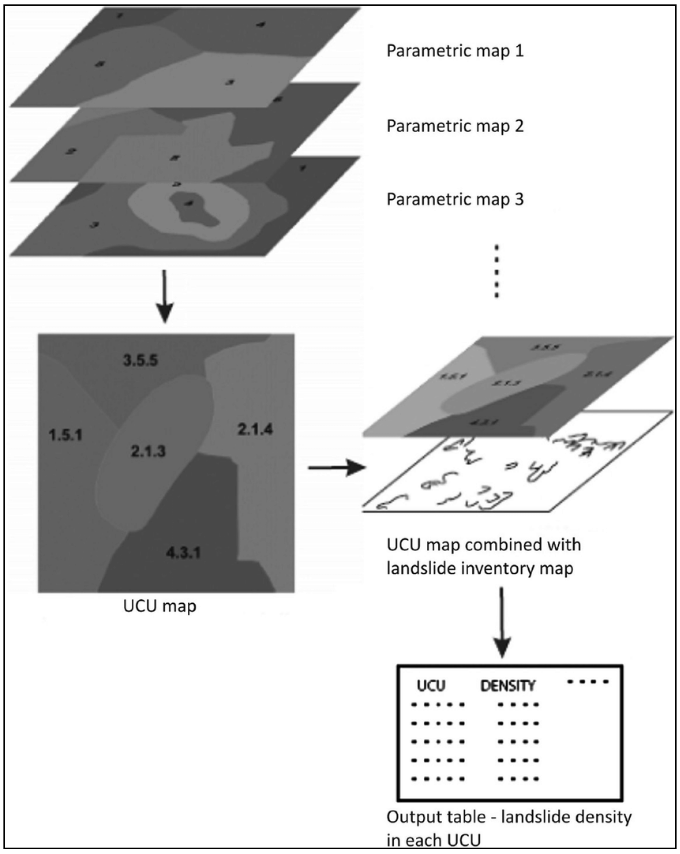

Figure 5. Principle of multivariate statistical analysis (Pauditš, 2006)

Results and discussion

The accuracy of the modelled land layer prone to landslides verified using the ROC curve method (Figure 6) was 90.8%, which we consider a very good success rate. While according to Bednarik et al. (2014) state that the closer the area value is to 1 (or 100%), the more accurate the model will be. In order to determine the length of the variants of the R3 expressway passing through individual stages of the land prone to landslides, we took into account only the surface parts of each variant. The tunnel part of the sections was not included in the total length of the individual variants. According to the claim that the model is only as accurate as the accurate input data, it should be noted that the input was the slope deformation layer from 2010.

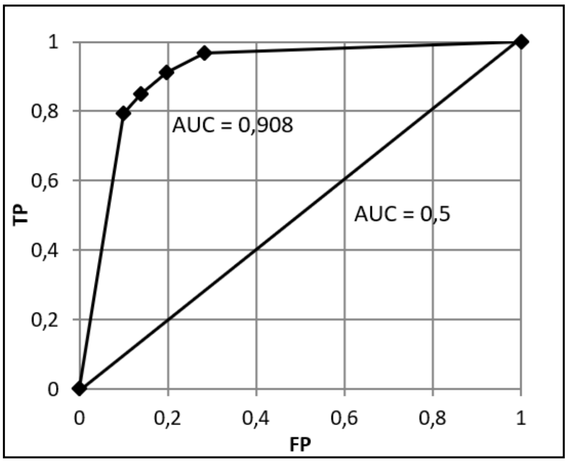

Figure 6. ROC curve for a multivariate statistical model of landslide susceptibility

The non-tunnel variant 1 passes through fourteen landslide areas in its entire route section. Variant 2 is based on variant 1, while both are identical from the beginning to about 10 km; unlike variant 1, variant 2 is a tunnel, and its route is led through 22 landslide areas. The portals of the Dolný Kubín tunnel are located in landslide areas for variant 2. The longest route, variant 3, is a surface variant that leads through 24 landslide areas. The last investigated variant 4 is a tunnel variant that passes through 16 landslide areas, and the northern and southern portals of the Dolný Kubín tunnel are located in a stable area without the presence of landslides (Figure 7).

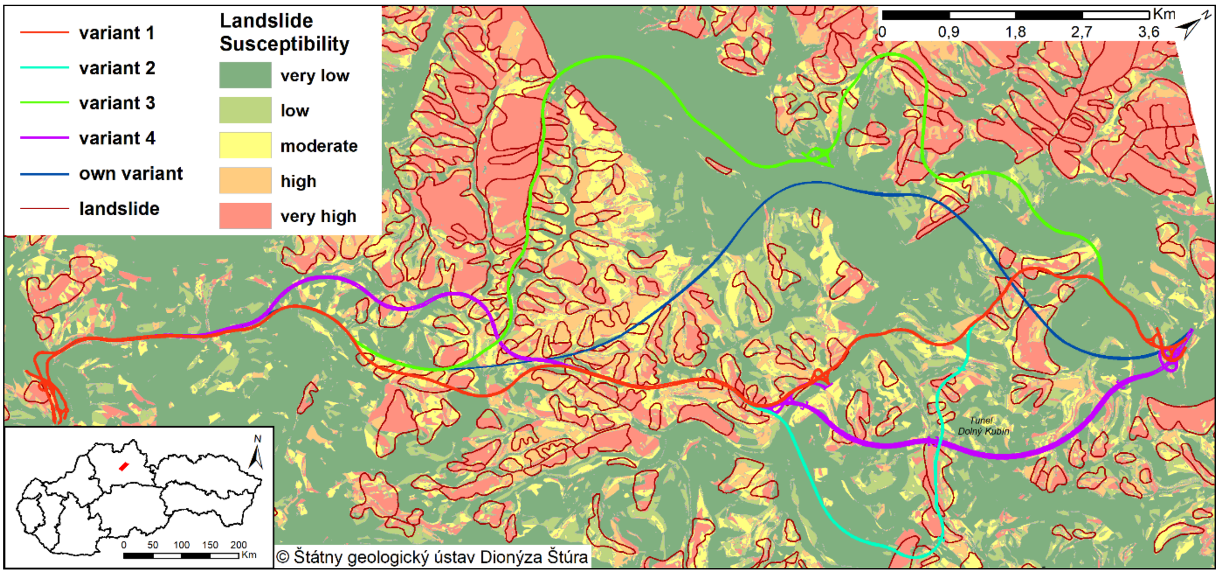

Figure 7. Landslide susceptibility model in the section of the R3 Hubová – Oravský Podzámok expressway

The share of the lengths of the surface parts of all variants of the R3 Hubová – Oravský Podzámok expressway routed in territories with individually determined degrees of susceptibility to landslides was statistically compared and evaluated (Table 1, Figure 8). As the most suitable variant of the expressway solution, i.e. the one whose shortest route is located in territories with higher degrees of susceptibility to landslides, surface variant 1 emerged. The lengths of the surface parts of the individual variants in the lowest degree with a very low degree of susceptibility of the territory to landslides are variant 1 – 7 878 m, variant 2 – 10 912 m, variant 3 – 11 590 m, variant 4 – 7 320 m. The lengths of the surface parts of the variants in the low degree of landslide susceptibility are as follows: variant 1 – 2 275 m, variant 2 – 2 238 m, variant 3 – 2 846 m, variant 4 – 2 628 m. In the medium degree of landslide susceptibility, the surface parts of the variants have a length of variant 1 – 3 135 m, variant 2 – 2 279 m, variant 3 – 2 872 m, variant 4 – 2 605 m. In the high degree of susceptibility of the territory to landslides, the lengths of the surface parts of the variants are as follows: variant 1 – 2 221 m, variant 2 – 1 338 m, variant 3 – 2 085 m, variant 4 – 1 937 m. In the highest, very high degree of susceptibility of the territory to landslides, the lengths of the surface parts of the variants are variant 1 – 2 271 m, variant 2 – 3 771 m, variant 3 – 3 507 m, variant 4 – 2 762 m. The actual proposed variant in terms of lengths in the individual sliding stages represents the following lengths: very low stage 10 820 m, low stage 2 766 m, medium stage 2 153 m, high stage 1 014 m and very high stage 1 117 m.

Table 1. The share (%) of the length of the routes of the variants of the R3 expressway in the section of the intersection D1 Hubová – Oravský Podzámok run through the territory classified according to the degree of susceptibility to landslides

LandslideSusceptibility	Variants				
	V1	**V2**	**V3**	**V4**	**Own**
very low	44.31	53.13	50.61	42.43	60.55
low	12.79	10.90	12.43	15.24	15.48
moderate	17.63	11.10	12.54	15.10	12.05
high	12.49	6.52	9.10	11.23	5.68
very high	12.77	18.36	15.31	16.01	6.25

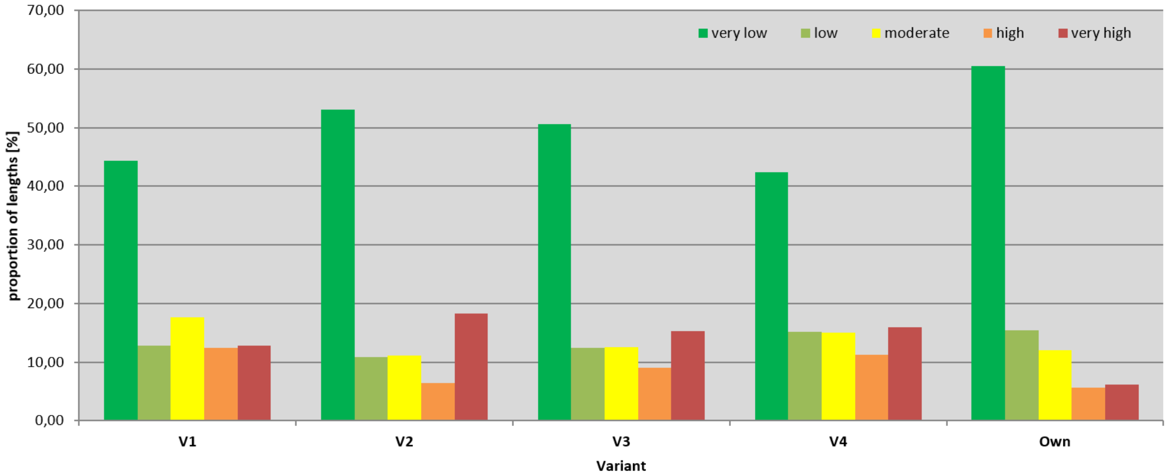

Figure 8. The share of the surface parts of the variants of the solution of the R3 expressway in the section of the intersection D1 Hubová – Oravský Podzámok routed in the territories according to the degrees of susceptibility to landslides

The Dolný Kubín tunnel, which is planned for two variants, V2 and V4, would be excavated in the territory of different geological structures. The detailed geological structure at the tunnel site for the planned variants V2 and V4 can be found in Table 2. In variant 2, the tunnel part contains the most rocks: carbonate breccias, conglomerates, sandstones, organodetritic limestones. The share of this rock structure is up to 69.1%, which represents almost 11 000 m^2. Rocks are another significant geological unit in terms of size: claystones in absolute dominance over sandstones and conglomerates, which represents a share of approx. 20%. The tunnel part of variant 4 consists mainly of Paleogene rocks of Eocene to Eocene – Oligocene age in three formations (Porubske, Huty and Zuberec). The geological structure in the variant 4 tunnel route has three dominant rock types. A third of the entire length of the tunnel is represented by rocks: flysch with sandstone predominance (32.0%), another third is carbonate breccias, conglomerates, sandstones, organodetritic limestones (32.0%) and the third is represented by rocks: claystones in absolute dominance over sandstones and conglomerates (30.2%). The portals of the tunnel are founded in flysch rocks, which alternate with quartet sediments.

Table 2. Geological structure of the Dolný Kubín tunnel

Tunnel "Dolný Kubín" – Variant 2

Succession	Geological Periode	Geological Epoch	Geological Stage	Description	Area [m^2]	%
Križňan Nappe	Cretaceous	-	Albian - Cenomanian	Porubske Fm.: calcareous claystones, fine-grained sandstones, limestones	220	1,4
Sub-Tatra region	Paleogene	Eocene	Priabonian	Huty Fm.: claystones in absolute dominance over sandstones and conglomerates	3164	19,9
Sub-Tatra region	Paleogene	Eocene - Oligocene	Priabonian - Rupelian	Zuberec Fm.: flysch with sandstone predominance	202	1,3
Sub-Tatra region	Paleogene	Eocene	Priabonian	Borovske Fm.: carbonate breccias, conglomerates, sandstones, organodetritic limestones	10999	69,1
Sub-Tatra region	Paleogene	-	-	Zuberec Fm.: flysch with claystone predominance	111	0,7
-	Quaternary	Quaternary	-	deluvial sediments: slope loams and debris (undivided)	43	0,3
-	Quaternary	Pleistocene	Mindel	fluvial sediments: sandy gravels, gravels and residual gravels of undifferentiated accumulations	1187	7,5

Tunnel "Dolný Kubín" – Variant 4

Succession	Geological Periode	Geological Epoch	Geological Stage	Description	Area [m^2]	%
Križňan Nappe	Cretaceous	-	Albian - Cenomanian	Porubske Fm.: calcareous claystones, fine-grained sandstones, limestones	220	1,7
Sub-Tatra region	Paleogene	Eocene	Priabonian	Huty Fm.: claystones in absolute dominance over sandstones and conglomerates	3823	30,2
Sub-Tatra region	Paleogene	Eocene - Oligocene	Priabonian - Rupelian	Zuberec Fm.: flysch with sandstone predominance	4057	32,0
Sub-Tatra region	Paleogene	Eocene	Priabonian	Borovske Fm.: carbonate breccias, conglomerates, sandstones, organodetritic limestones	4053	32,0
-	Quaternary	Quaternary	-	deluvial sediments: slope loams and debris (undivided)	519	4,1

The environmental impact assessment report (Dopravoprojekt a.s. 2010) evaluated 4 variants. From the point of view of the established expected impacts on the rock environment, mineral resources, geodynamic phenomena and geomorphological conditions, variant 1 and variant 4 are mentioned as suitable route solutions. Variant 4 was chosen as the most optimal variant in the environmental impact assessment process (in accordance with Act no. 24/2006 Coll.). Both assessed according to the landslide susceptibility model, the tunnel variants are more prone to landslides in their surface parts than the other two surface variants. The design of the own optimal variant in the length of 17 560 meters was based on the basis of the model of the land's susceptibility to landslides and the conditions so that the variant does not interfere with residential development and the beginning and end of the section are identical to the assessed variants. By proposing our own variant, we minimized the routing of the route in the risk levels of the territory's susceptibility to landslides.

Gudiyangada et al. (2019) map the terrain's susceptibility to landslides in Austria using the geon method with optimization based on the Dempster-Shafer theory. Altitude, slope, aspect, land cover, precipitation, distance to drainage, distance to faults, distance to highways, and lithology were the nine input criteria they used for all of Austria. We used more information on the relief's curvature in comparison to their study. However, we are missing the values for the separations between faults and the pathways they used. It is highly convenient to know and have pertinent and in-depth data that would be relevant for entering the model to simulate slope stability more accurately. The lithology, slope, land cover (using CLC2012), slope curvature, distance from rivers, and distance from highways were utilized as input data to the model in the work of the authors Milevski and Dragievi (2018), who analyzed the susceptibility of the region to landslides in Macedonia. They left out altitude, aspect, and rainfall, unlike us. The use of new and accurate technologies will help in the future in more accurate and detailed modelling of landslide areas, authors Buša et al. (2019) in their work, they state that the application of data layers that take into account the activity of slope deformations based on PS InSAR reflection points and accurate height digital models obtained by aerial lidar will significantly contribute to the accuracy of the methods used in the future. In their work, they used multivariate and bivariate statistical analysis, which they used to evaluate the landslide hazard in the Košice basin (Western Carpathians). When using multivariate statistical analysis, the findings of their study in the Košice basin reveal that up to 45.23% of the area is in the 4th and 5th degree of landslide hazard. These numbers are much higher when utilizing bivariate statistical analysis and account for 56.85% of the share in the fourth and fifth degrees of sliding hazard. These numbers for the fourth and fifth degrees of susceptibility are lower in comparison to our territory, which does not encompass the full geomorphological area (4th degree: 9.5% and fifth-degree: 17.8%). In the study, Solheim et al. (2022) discuss how to reduce the risk of landslides in Norway through a close collaboration between research, business, and government agencies. Public-private partnerships, as well as cross-sectoral and union collaboration, are required, according to the authors. During the initial planning stage, it would be appropriate to implement similar solutions in our region. From there, it would be appropriate to follow a consistent course until the project was finished.

The predicted impacts of the road on the rock environment represent only one of the many criteria assessed. Predictive models of the suitability of locating projects in the country, such as expressways, must be subjected to adequate weighting of individual evaluation criteria or apply multi-level assessment. The authors Klimeš and Blahůt (2012), in their analysis of the risks of landslides and their application in regional planning using the example of the highlands of the Outer Western Carpathians in the Czech Republic, define the danger of landslides using landslide susceptibility maps based on information about the reactivation of landslides and recurring periods of precipitation. They point to the fact that no legally binding regulations would force the planners to use this information when creating proposals for individual routes of lineside constructions.

In the case of linear barrier constructions such as expressways, the key criteria are those that mediate the assessment of the prediction of project impacts on geodynamic processes, hydrological conditions, elements of nature and landscape protection (including protected areas belonging to the European system of protected areas Natura 2000), territorial system of ecological stability including animal migration routes (Pauditšová 2008).

In Slovakia, there are no tools for preparing project documentation that would be directed by designers in such a way that unsuitable natural conditions are compulsorily accepted when locating the constructions in the landscape. The localization of critical infrastructure should be fundamentally designed already at the level of strategic planning. Feasibility studies should necessarily include predictive modelling. The absence of mandatory high-quality landscape planning and development of a landscape study is a long-term problem of territorial planning in Slovakia. These problems are not solved even by Act No. 200/2022 Coll. on territorial planning and its implementing decrees.

Building a spatial planning information system with relevant data (under Act No. 200/2022 Coll.) is a good step, but it does not automatically solve the prediction of the suitability of the territory for specific projects. Syntheses of landscape planning represent demanding processes requiring knowledge from many scientific fields.

After the mandatory acceptance of the outputs of landscape planning, only selected construction variants supported by arguments, including linear constructions, would be input into the process of assessing the impacts of the projects on the environment. Such a procedure would also increase the efficiency of the environmental impact assessment process of the projects.

Conclusion

The compiled model of the territory's susceptibility to landslides proved to be a suitable tool for analyzing the suitability of expressway solution variants from the point of view of slope stability. The proposed variants on the section of the R3 expressway from the intersection with the D1 highway in the Hubová location to Oravský Podzámok were evaluated. By subjecting the individual routes of the variants to the constructed landslide susceptibility model, the lengths of the sections in individual degrees of landslide susceptibility were determined. Of the four evaluated variants, variant 1 has the smallest length. In our work, we also dealt with the design of our own optimal variant. The variant for the solution was designed most optimally so as to avoid unstable slopes as much as possible and was not conducted in a protected area and in locations with minimal interference in the built-up area of settlements. The input to the model should be the most detailed and up-to-date data, which will increase the detail and especially the up-to-dateness of the model. The resulting model is only as accurate as the data used in the input. Under the current legislative conditions, we recommend using the following steps when assessing the effects of lineside constructions on the environment:

1. expert assessment (e.g., the Delphi method), the result of which would be the selection of the assumed most sensitive environmental parameters with respect to the assessed project
2. detailed assessment of expected impacts, e.g., evaluation of road variants from the point of view of landslide hazard and creation of prediction models.

The ideal procedure would include the development of a landscape study containing an analysis of all risks related to the biotic and abiotic features of the landscape (e.g. susceptibility to landslides, flood threat, the occurrence of sensitive areas from the point of view of nature protection, etc.).

The landscape study would represent the basic output of landscape planning and would be compulsorily accepted in the documents of spatial planning at individual hierarchical levels. Road building in landslide-prone areas might be subject to a number of restrictions and risks, such as:

1. Road building in landslide-prone locations can increase the danger of landslides occurring close to the road, which can result in environmental and traffic concerns.
2. Cost: Building roads in landslide-prone areas can be expensive since stabilizing measures like retaining walls and diversion channels are required.
3. Technical challenges: Because of the unstable terrain, building roads in landslide-prone locations can be technically difficult. The ability to build roads may be constrained by challenging terrain or a steep slope inclination.
4. Environmental harm: The biodiversity and local ecosystems may be negatively impacted by road development in landslide-prone locations. Deforestation, altered water flows, or environmental pollution can endanger some regions.
5. Road safety regulations may be stricter in landslide-prone locations to reduce the danger of accidents and property damage. This can entail restricting traffic's speed or adding extra security to protect traffic safety.

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