GEOMORPHOLOGY

ASSESSMENT OF THE DEVELOPMENT OF DANGEROUS EXOGENOUS PROCESSES ON THE HIGHWAYS OF THE KARABAKH AND EASTERN ZANGAZUR ECONOMIC REGIONS (in the case study for "Zafaryolu")

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Abstract

One of the current ecological problems is the development of a methodology for assessing the risks and damage caused by hazardous exogenous processes on road surfaces and the compilation of ecological risk maps. Based on the geomorphological research materials, as well as refe-rences, the geomorphological characteristics of hazardous processes were scrutinized and provided a complete geomorphological description of the area through which the "Zafaryolu" highway passes in the research paper.

In order to determine the general background of the fragmentation of the modern relief on which the "Zafaryolu" highway is being built, a 5-point scale was developed and adopted for assessing morphometric stress, which reflects the degree of horizontal and vertical fragmentation of the area, slope inclination, etc. Analysis of various quantitative indicators of the relief and the compiled synthetic map of morphometric stress makes a way to determine the dependence of the intensity and direction of development of hazardous exogenous processes on the scale and nature of the fragmentation of the relief, as well as a high indicator.

1. Introduction

The cumulative deepening of the ecological crisis in the 21st century, that is, the crisis of the relationship between society and nature, has necessitated radical changes in the development goals and priorities of humanity.

The safety of human life and economic activities, as well as infrastructure facilities, in areas where dangerous natural and natural-anthropogenic processes develop is one of the main socio-ecological problems of our time [9].

The properties of Azerbaijan's transition to sustainable development are primarily related to the need for comprehensive solutions to environmental, economic, and social problems. Despite the fact that some recent improvements have been made in certain environmental indicators in the republic, the ecological situation in the liberated territories of Karabakh and Eastern Zangezur remains critical. The military aggression carried out by the enemy during the 30-year occupation of these lands has led to numerous and various ecological problems, including the deterioration of the ecological and geomorphological con-ditions of the region. As a result, the ecosystem balance has been disrupted. The Azerbaijani government has developed a master plan for the restoration of Karabakh and Eastern Zangezur territories, including Aghdam, Fuzuli, Khojaly, Khojavend, Shusha, Tartar, Jabrayil, Kalbajar, Gubadli, Lachin, Zangilan districts, and the city of Khankendi, for the next 20 years. The list of tasks includes road construction, communication works, commissioning of international airports, power plants, construction of "smart villages", etc.

It is an undeniable fact that the involvement of territories in economic activity, especially in areas where potentially hazardous objects are located, leads to inevitable changes in the environment, accompanied by disruptions to the natural course of processes and intensification of anthropogenic impacts.

Among the most destructive exogenous processes are avalanches, landslides, and upheavals, as well as floods [13].

Failure to take appropriate environmental and engineering measures for economic activity and development of territories leads to the intensification and spread of landslides, which pose a threat to the lives of the population living in settlements, the stability of infrastructure, and the territory as a whole. Preventing dangerous processes is less expensive than eliminating their consequences. The number of accidents and disasters at construction sites is increasing as a result of the failure to calculate the degree of danger and the insufficient development of me-thods for calculating the strength of anti-gravity structures, and the failure to always comply with the requirements of anti-gravity construction standards. This determines the relevance of work on improving methods for calculating hazards associated with exogenous processes and the effectiveness of protecting structures in the areas. One of the main tasks of the emergency ma-nagement methodology is the task of managing emergency monitoring projects [8].

Thus, the challenges regarding preventing dangerous processes and ensuring the stability of areas exposed to active soil displacement are concerning the safety of the population and household facilities. The cases of the numerous hazardous process activities are accompanied by the construction and operation of highways and railways, pipelines, power line supports, residential and other buildings.

Assessing threats at different stages of development in a territory and selecting measures to prevent them requires identifying and taking into account many factors and considering various scenarios for the development of events. These measures include analysis of reserve materials and current observation results, study of physical and mechanical properties of soils, development of models of hazardous processes, selection of calculation schemes, assessment of the probability and frequency of displacement development, pos-sible damage, and analysis of consequences [7].

Depending on the available data, a qualitative and quantitative assessment of the hazard of exogenous processes is carried out. The main difficulty is the presence of uncertainty: spatial variability of soil properties, the subjective nature of the interpretation of the results, and the intensity of the temporal influence of the factor that causes the activation of their displacement [9].

The study of the dynamics of exogenous processes is inextricably linked to the analysis of the stresses in the rocks composing slopes. The nature of the stress distribution in rock masses must also be taken into account when charac-terizing their strength and deformation properties. In recent research, it was revealed that the re-lationship between stress and displacement de-pends on the geological properties of the rocks [14]. The works of numerous foreign researchers [1; 2; 4; 15; 16; 17] in this field are of great interest.

The aim of the work is to study the development of exogenous processes in the area where the “Zafaryolu” highway passes, and to assess their danger.

2. Methods

The processes that cause the activation of gravitational processes can be determined by various methods (soil properties, terrain explo-ration, inspection of sections of highways, or underground mining). Geomorphological changes are detected based on soil survey data, geological maps, aerial photography data interpretation, or remote sensing. Physical changes are recorded through seismographs, displacement devices, and temperature sensors [18].

The initial stage of determining gravitational processes on highways involves reconnaissance of the area. Topographic maps describe the boundaries of the soil in detail. Significant changes in soil conditions can be determined based on the analysis of topographic maps. Geological-geomorphological maps of various scales are widely distributed, which enable us to determine the geological characteristics of the subsoil. Climatic data and historical observations of hazardous exogenous processes in the region can provide relevant information about the damage during torrential rainfall events. The main purpose of field studies is to update previously obtained data, establish criteria for subsequent observations, and record the size or other manifestations of processes.

When studying hazardous exogenous processses, special attention is paid to the rocks composing the slope, the properties of which are the most important factor in their formation. The study of the geological properties of rocks is of great interest for assessing slope stability and predicting hazardous processes. The stress-strain state of rocks involved in the gravitational process changes when exposed to stress for a long time. The main indicators of the mechanical properties of rocks include deformation and strength properties.

When analyzing hazardous exogenous processes on road surfaces, high-resolution satellite images (HR) and digital terrain models (DRTM) from CNES/Airbus, Maxar Technologies (Geo-

Eye-1), and medium-resolution Sentinel-2A and 2B were mainly used. Moreover, visual and semi-automatic decoding (classification with tra-ining) was performed in the ArcGIS en-vironment.

To assess the danger of gravitational processes on the highways passing through the Karabakh and Eastern Zangezur regions, we propose a cartographic modeling method using GIS technologies. During the study, the ArcGIS software package (Hydrology, Statial, Analyst, 3D Analyst, etc.) was applied, and digital morphometric maps (slope inclination, slope steepness, vertical and horizontal fragmentation, etc.) at a scale of 1:100,000 were compiled. A morphometric stress map was compiled based on the data from the morphometric maps. Based on their analysis, areas of gravitational processes with potential geomorphological hazards were identified in the area where the "Zafar" highway passes.

3. Analysis and discussion

Ongoing construction work in the territories of Karabakh and Eastern Zangezur, which returned to the control of the Republic of Azerbaijan during the Second Karabakh War, represents the restoration of territories recently liberated from occupation by Azerbaijan. For this purpose, the Azerbaijani government has prepared the "Great Return" state program.

The construction of 19 highways with a length of 2,241 km is ongoing.

In Karabakh and Eastern Zangezur regions, most roads are limited to watersheds or flattened sections of slopes, where it is particularly easy to disrupt the balance of slope processes. Dangerous factors in the development of gravitational processes are the shearing of the slope above the road, the instability of the slope along which the road passes, the increase in dynamic loads on the ground, and the irregular flow of precipitation on most roads [12].

Predicting the development of landslides, avalanches, and debris flows is one of the key points when choosing a location for a transport artery. According to the observations, during the design and construction of roads, little attention is paid to protecting them from gravitational pro-cesses developed on the slope above the road. Slope processes develop both on the slope above and below the road line. Therefore, it is necessary, first of all, to develop and implement protective measures against hazards for road facilities in areas with high gravity hazards and gravity risks.

In this research work, the "Zafaryolu" in terms of the development of dangerous gravitational processes was considered.

The "Zafaryolu" takes its beginning from the Hajigabul-Minjivan-Zangezur corridor highway and extends to the city of Shusha. This road was built through the territories of the liberated Fuzuli, Khojavend, Khojaly and Shusha districts. The highway will cover more than 20 settlements in the districts, including the cities of Fuzuli and Shusha (Fig. 1). This road was named "Zafaryolu" by the President of Azerbaijan in order to perpetuate the memory of the road used during the liberation of the city of Shusha from occupation. The 103 km long road belongs to the second technical category and has two lanes. In order to obtain the width of the road specified in the pro-ject, rocks were blasted and moved aside during the construction of the road in areas with difficult terrain. In order to ensure drainage along the road, circular pipes, rectangular drainage systems and 3 automobile bridges with lengths of 33, 99, 75 m were constructed at sections of 0.6, 26 and 57 km (Fig. 2).

Figure 1. "Zafaryolu" before construction

Figure 2. "Zafaryolu" after construction

The area through which "Zafaryolu" passes tec-tonically corresponds to the Goycha-Karabakh and Miskhana-Gafan tectonic zones, which consist of Jurassic, Cretaceous, Paleogene, Neogene, and Quarternary rocks. Morphostructures composed of denudation-resistant rocks are widespread due to their origin. Such morphostructures include numerous monoclinal ridges on the southwestern slope of the Karabakh Range within the Zamzur anticlinorium. The structures expressed in the relief include the development zone of the northeastern wing of the Gafan anticlinorium. From the southeast, the Goycha-Ka-rabakh and Miskhana-Gafan zones are limited by the Lower Aras transverse tectonic fault.

The Karabakh anticlinorium corresponds to the watershed of the ridge in the area between the Mount Alagaya and Mount Uchtugh and in the area of the Big Kirs Mount. As a result, in the watershed of the Karabakh range, horst uplift occurred in the last tectonic stage, the maximum value of which coincides with the Kirkhgiz and Boyuk Kirs mountain ranges. In the watershed zone, the slopes of the Karabakh Range above 1800-2000 m are complicated by gravitational (avalanche, landslide, etc.) relief forms. This structure of the slope is due to the presence of a deep fault and generally coincides with the emergence of Middle and Upper Jurassic rocks to the surface. Regional bending can be observed in the slope structure along the fault line [10]. Below the fold line of this slope, a wide strip of planation surfaces (probably Miocene) with heights varying between 1600-2200 m due to the differen-tiation of recent tectonic movements can be observed [10]. The relief surfaces reveal elements of the ancient river network in the form of valleys on ancient alluvium and are inclined both to the northeast, in accordance with the flow direction of the modern river network, and to the southeast, in accordance with the direction of ancient (Miocene) river systems. Hypso-metrically, at the same level as these alignment surfaces is the structural surface of the synclinal plateau - the Shusha plateau, formed of Upper Jurassic lime-stones, deeply cut by the valleys of the Gargar-chay tributaries. The highest point of the Shusha Plateau is 1600 m, and the lowest point is 1300 m. This high mountain plateau is surrounded by deep faults that descend to the Khalfalichay and Dashaltychay rivers.

The lithology of the rocks composing the modern relief plays a major role in its plasticity. High-density chalk limestones form monoclinal ridges. Intrusive rocks play an important role in the plasticity of the relief. Because they are resistant to denudation, they form positive relief forms. The relief is also cha-racterized by the presence of intermountain depress-sions. For example, the Sirik depression is located on the southern slope of the southeastern end of the Karabakh ridge, south of the Ziyarat peak. The surface of the depression is smoothed, inclined in direction, and dissected by a network of ravines and gullies.

The area through which "Zafaryolu" passes is characterized by the development of avalanches of gravitational-tectonic origin that occur during seismic activity. The low mountain belt of the Karabakh range is characterized by the weakest manifestation of the mentioned processes. Avalan-ches correspond to mo-noclinal ranges and ridges. The surface of these monoclinal ridges and ranges is covered with layers of sedimentary and volcanogenic-sedimentary rocks. Avalanches occur relatively frequently in the mid-mountain and high mountain belts of the Karabakh range, which is due to the monoclinal structure of the orographic relief elements. They are located ma-inly on the southwestern steep slopes of the ranges, which are complicated by tectonic faults. However, in some places they are also observed in the bare areas of the northern and northeastern slopes of the range, as well as in the Khalfalichay valley. Large rock avalanches occur along the edges of lava flows and covers - in mountainous areas such as Kirkhgyz, Boyuk Gyzlar, etc.

The aggregate materials are also characteristic of the study area. The aggregate materials are divided into creamy and gravel aggregates according to their granulometry. Creamy aggregate materials are located in the high mountain belt - on the slopes of the Khachinchay valley, while gravel aggregate materials are mainly located in the middle and low mountain belts, in the di-rection of the river's flow.

In this place, landslide processes are weaklier ma-nifested. This is primarily explained by favorable climatic and geological conditions, i.e. relatively low amounts of atmospheric precipitation, low volumes of clayey sediments, flat-lying mountain rocks in large areas, etc. The lowland belt of the Karabakh range is characterized by very weak manifestations of land-slides. In this place, landslides developed mainly in thick, overlying clayey sediments. Landslides in the middle mountain belt of the Karabakh range also developed mainly on the slopes of river valleys that cut through clayey sediments that fill and cover intramountain depressions. Landslides are obser-ved

in the bedrock of the Khalfalichay, Kha-chinchay, and other rivers' basins.

The occurrence of landslides in the central part of the Karabakh range is related to the ophiolite belt. The widespread serpentinites and serpentinized rocks in this area are characterized by strong cleavage, intensive fracturing, and very poor denudation resistance [5]. When favorable conditions arise, individual layers and masses of these rocks are subject to displacement along fault planes and tectonic slip planes.

The morphometric characteristics of the relief are of great importance for numerous natural phenomena and processes [3; 6; 11]. Morpho-metric indicators of relief, which are important characteristics in ecological and geomorpho-logical studies, include the following:

1) absolute height,
2) slope inclination,
3) exposition of slopes,
4) vertical and horizontal fragmentation of the relief.

For example, the amount of precipitation and solar radiation and atmospheric pressure depend on the absolute altitude of the area. The inclination and orientation of slopes determine the direction of surface runoff volume. Therefore, morphometric indicators de-termine the deve-lopment trend of exogenous processes. Linear objects (roads) are most affected by the angles of inclination and the length of slopes. Relief affects the operation of various facilities; unfavorable relief worsens the ecological condition of the area and in-creases the risk of industrial accidents.

All this suggests that morphometric maps serve as the main basis for ecological and geomorphological studies.

Morphometric analyses are conducted based on geoinformation technologies. For example, after analyzing the distribution of elevations using a digital elevation model (DEM), a hypsometric map is created that visually depicts elevation gradients.

To study the impact of morphometric indicators on the formation of dangerous exogenous processes, the hypsometric, slope, elevation, and vertical fragmen-tation indicators of the relief of the area through which the "Zafaryolu" highway passes were analyzed (Fig. 3, 4, 5, 6).

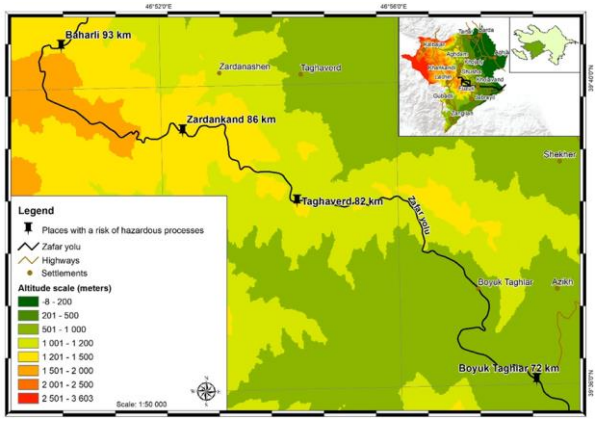

Figure 3. Hypsometric map of "Zafaryolu"

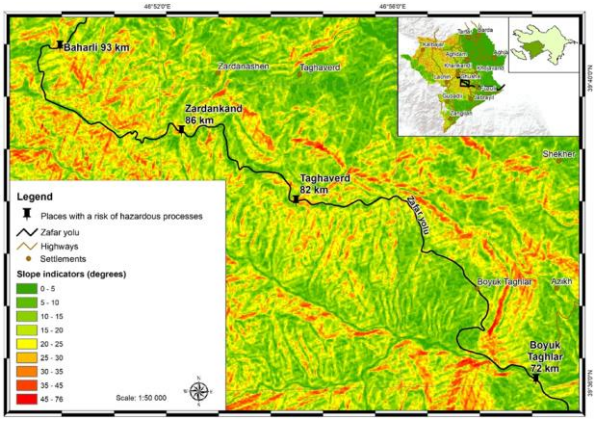

Figure 4. Slope inclination map of the "Zafaryolu"

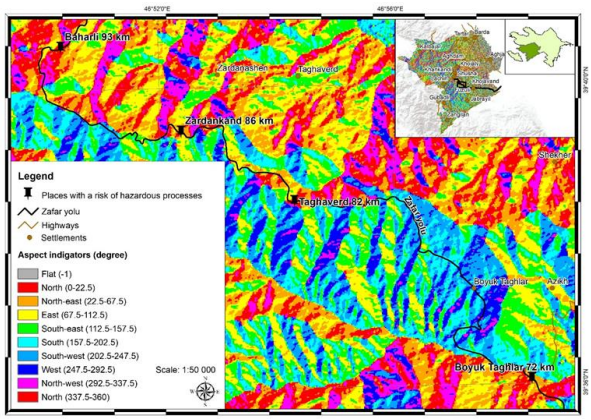

Figure 5. Exposition map of the"Zafaryolu"

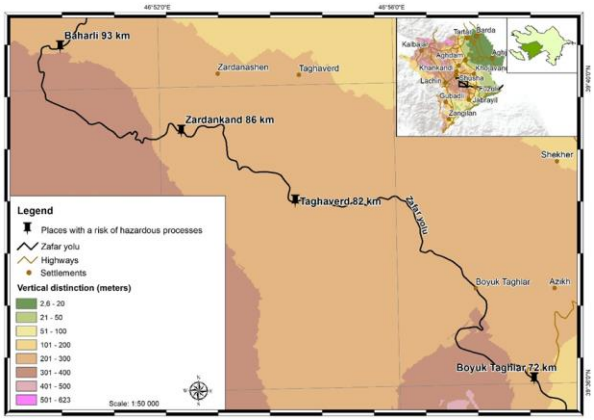

Figure 6. Vertical fragmentation map of "Zafaryolu"

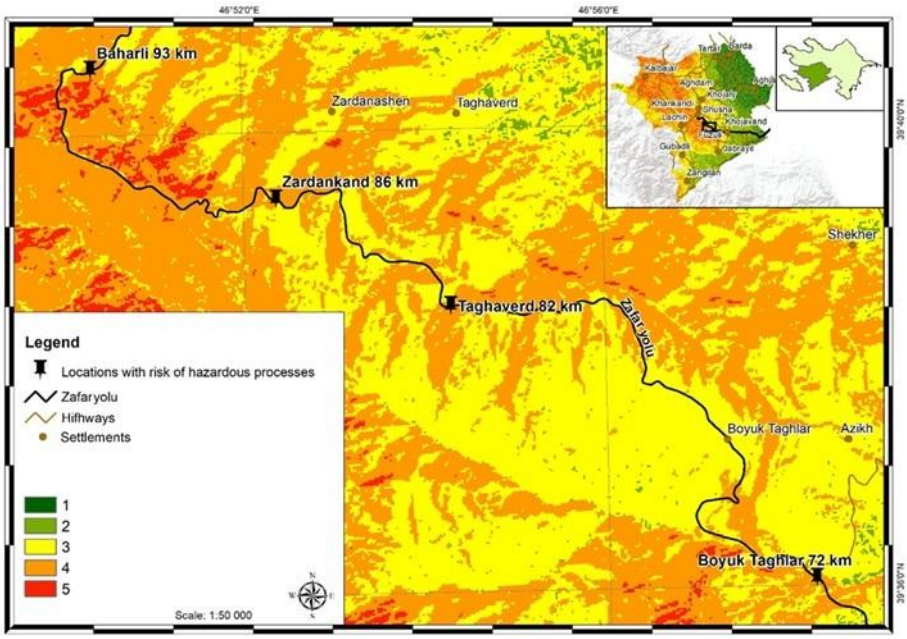

Figure 7. Morphometric stress map of "Zafaryolu"

Table 1

Morphometric stress rating scale

Vertical fragmentation (m)	Slope inclination (^{0})	Rating (points)
>1000	>40°	V
500-1000	30°-40°	IV
200-500	20°-30°	III
100-200	10°-20°	II
0-100	<10°	I

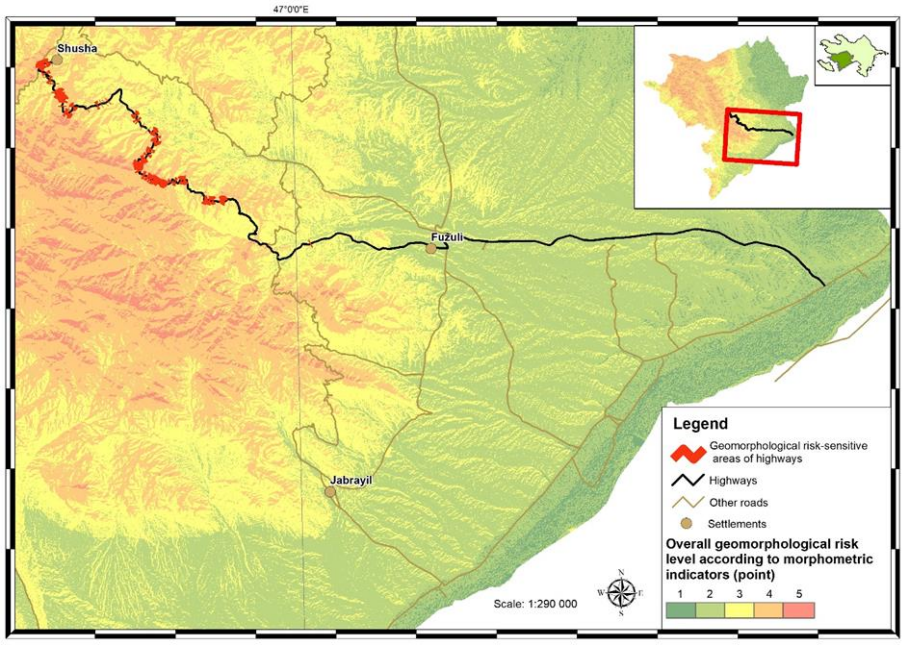

Figure 8. Parts of the "Zafaryolu" which are sensitive to geomorphological risks and hazards

A 5-point scale (degree of vertical fragmentation of the territory, slope inclination, etc.) was developed and adopted to determine the general background of the fragmentation of the modern relief and to assess the morphometric stress in the area where the "Zafaryolu" highway passes through (Fig. 7), (Table 1).

According to the analyses conducted, 13 areas with high geomorphological risks and hazards

were identified along the “Zafaryolu” route (Fig. 8).

Thus, the analysis of various quantitative indicators of the relief and the compiled synthetic map of morphometric stress make it possible to determine the dependence of the intensity and direction of development of dangerous gravitational processes on the scale of relief fragmentation and the nature of morphometric indicators.

4. Conclusion

Based on the morphometric indicators of the relief (horizontal and vertical fragmentation, hypsometry, inclination and exposition), a geomorphological risk assessment was conducted in the Karabakh and Eastern Zangezur territories, and areas where dangerous geomorphological processes (seismic dislocation, avalanche, aggregation, landslide, flood, etc.) affect the road and transport infrastructure were identified, and a corresponding map was compiled. According to calculations, a total of 10.6 km (9.73%) of the "Zafaryolu" (103 km) are areas with high geomorphological risks and hazards.

The operation of such a complex and important facility as a highway requires the development of projects for engineering protection against dangerous geological and geomorphological processes. These projects should be based on the study and assessment of the modern engineering-geological and geomorphological conditions of the studied area, the characteristics of the history of slope development and the possibility of the development of dangerous processes in them, factors related to modern geodynamics (composition, thickness, conditions of formation of rocks, their dislocation and fracture, hydrogeological properties, etc.), the development of forecasts for changes in the stability of the geological environment during the operation of facilities based on calculations and modeling, and the development of appropriate protective measures.

It is essential to develop site-specific, detailed engineering projects to ensure comprehensive geotechnical protection of individual structures within areas undergoing highway construction. These engineering interventions may encompass slope grading and terracing; the design and implementation of surface drainage networks, including both open-channel and subsurface systems; as well as the construction of substantial retaining structures and stabilization measures for mountainous slopes susceptible to landslides and avalanches.

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QARABAĞ VƏ ŞƏRQİ ZƏNGƏZUR İQTİSADİ RAYONLARININ YOLLARINDA TƏHLÜKƏLİ EKZOGEN PROSESLƏRİN İNKİŞAFININ QİYMƏTLƏNDİRİLMƏSİ (“Zəfəryolu” timsalında)

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Xülasə. Mövcud elmi problemlərdən biri yol səthlərində təhlükəli ekzogen proseslərdən görünən risk və ziyanın qiymətləndirilməsi metodologiyasının işlənib hazırlanması və ekoloji risk xəritələrinin tərtib edilməsidir. Məqalədə geomorfoloji tədqiqatlarının materiallarına, eləcə də istinad ədəbiyyatına əsaslanaraq təhlükəli proseslərin geomorfoloji xüsusiyyətləri araşdırılır, “Zəfəryolu”nun keçdiyi ərazinin geomorfoloji təsviri verilir.

“Zəfəryolu” avtomobil yolunun salındığı relyefin müasir parçalanmasının ümumi fonunu müəyyən etmək üçün ərazinin üfüqi və şaquli parçalanma dərəcəsini, yamacın meyilliyini və s. özündə əks etdirən morfometrik gərginliyin qiymətləndirilməsi üçün 5 ballıq şkala hazırlanmış və qəbul edilmişdir. Relyefin müxtəlif kəmiyyət göstəricilərinin təhlili və morfometrik gərginliyin tərtib olunmuş sintetik xəritəsi təhlükəli ekzogen proseslərin intensivliyi və inkişaf istiqamətinin həm də relyefin parçalanmasının miqyasından və xarakterindən asılılığını, yüksək göstəricisini müəyyən etməyə imkan verir.

Açar sözlər: ekoloji böhran, təhlükə, dağıdıcı ekzogen proseslər, davamlı inkişaf, avtomobil yolu, qiymətləndirmə, CİS texnologiyası.