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Assessment of ecological-geomorphological strength and risk of geosystems of the north-eastern slope of the Great Caucasus (within Azerbaijan)

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ABSTRACT

Problem statement. The increased human pressure on natural geo-complexes is causing the revival of undesirable processes that create an extensive risk for the inhabitants of these regions. Alpine-type orogenic zones, which belong to the northeastern slope of the Greater Caucasus, are distinguished from many geomorphological systems by excessive activity of endo- and exogenous processes. Therefore, at this time, the task of diagnosing and assessing the ecological and geomorphological risk that the population faces in the development of new territories of the region seems to be important.

Analysis of recent research and publications. After analyzing a number of techniques used to assess the landslide and mudflow hazards, the conclusion was made that most of them had their flaws.

Research method. There are a large number of methods for assessing the risk of environmental management and predicting hazardous exodynamic processes. However, in modern conditions, these techniques are not sufficiently reliable. This, in turn, determines the relevance and the need to develop new or modernised methods of strategies for the prevention, protection, and elimination of the consequences of catastrophes and natural disasters.

The purpose of this work is to reveal the geomorphological features and dynamics of the development of the most dangerous and often repeating landslide and mudflow processes based on field geomorphological studies, as well as fund literature, indicate the reasons for their formation and propose measures to combat them.

Research results. The article discusses the results of ecological and geomorphological surveys on the northeastern slope of the Greater Caucasus, dedicated to the assessment of landslide and mudflow risk for the period from 1990 to 2020. To assess them in order to obtain morphometric characteristics (including the down gradient of slopes, the length and shape of slopes, areas of mudflow centers), large-scale (M 1:100000) topographic maps were used, as well as interpretation materials for different-scale and multi-temporal ASP. Based on the interpretation of the ASP within the studied region, in order to clarify the general picture of the dissection of the modern relief of the studied region, a map of morphometric tension was compiled, which includes the degree of vertical dissection of the territory, the down gradient of slopes, etc., and also maps of the risk of landslides and mudflows were compiled according to the degree of danger of landslide and mudflow processes, and the area of their distribution was calculated. Landslide and mudflow risk analysis mainly used high-resolution aerospace imagery (ASI) from CNES / Airbus, Maxar Technologies (GeoEye-1), and medium resolution Sentinel-2A and 2B. Thus visual and semi-automatic interpretation (classification with training) was performed in the ArcGIS environment. As a result, taking into account the morphometric tension, as well as the mudflow and landslide hazards, a map of the morphodynamic tension of the northeastern slope of the Greater Caucasus was compiled, which makes it possible to reveal the modern nature of the manifestation of exodynamic processes, to predict and assess the risk coming from them.

Conclusion. The results of the research will make it possible to use the obtained data for the development of the Program for the safe and sustainable functioning and development for the purpose of recreational and tourist development of the difficult of access mountain geosystems of Azerbaijan.

Keywords*: ecological and geomorphological tension, risk, landslide, mudflow, anthropogenic impact, GIS technologies, interpretation, environmental safety.*

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Problem statement. The development and implementation of a regional policy in the field of guaranteeing environmental reliability are considered a significant component in implementing a stable socio-economic formation of the country and its regions. The immediacy of the task of guaranteeing environmental reliability in Azerbaijan is due not only to the natural specificity of high-mountain ecosystems, which predetermines their increased vulnerability under anthropogenic impact but also to a drastic violation of the ecological situation in most regions of the country. The study of natural geosystems and the specifics of their modifications under the pressure of natural and anthropogenic causes is biased by the need for a scientifically reasoned attitude to resolving regional environmental issues. The mountain geosystems of the Greater Caucasus are characterised by high-altitude zoning of landscapes, a variety of spatial structures, and developmental activity. Mountain ecosystems are extremely prone to climate fluctuations and reckless anthropogenic activities. As a result, high-quality habitats are decreasing, and the ecological situation is deteriorating. The lack of modern technologies for the rational use of natural resources in the mountains, the legislative base that does not work on the ground, the still prevailing opinion about the inexhaustibility of natural resources, and the extremely low ecological culture of human relations with nature have significantly affected the natural complexes of the region. In the past years, the growth of the anthropogenic factor on the natural geo-complexes of the northeastern slope of the Greater Caucasus leads to the activation of exodynamic processes, which pose a huge risk for the inhabitants of these regions. Therefore, by now, the vital task is to analyse and assess the ecological and geomorphological risk, which people encounter when settling these territories.

It is well known that the problem of engineering and environmental geomorphology is the analysis and assessment of the manifesting processes of relief formation and the forms created by them to solve acceptable versions of the location of settlements, agricultural arable lands, infrastructure and economic facilities, other engineering and construction structures, guaranteeing their effective and rational operation, and protection from destructive exodynamic processes (Kononova & Malneva, 2007; Kuzmin, 2014; Corominas et al., 2014; Schlögel et al., 2015).

Analysis of recent research and publications. After analyzing a number of techniques used to assess the landslide hazards (Kononova & Malneva, 2007; Kuzmin, 2014; Corominas et al., 2014; Schlögel et al., 2015), the conclusion was made that most of them had their flaws. Techniques based on probability and statistics methods (geodynamic potential method, regression analysis method) (Lee et al., 2006; Duong et al., 2013), the idea behind which is the determination of the probability of landslide occurrence based on the probability of an impact of landslide-formation factors, are very labor-intensive and require complicated mathematical treatment. The landslide rhythm analysis technique (Seversky et al., 2010), which is based on the detection of the periodicity of landslide occurrence and its relation to precipitation intensity and other meteorological parameters, is complicated by a lack of representative observations and the complexity of treatment of raw data.

It is expedient to indicate the main factors that cause the activation of said processes: geological structure, slope, thickness of potentially landslide-dangerous sediments, landscape, etc. The main criterion that allows regarding this or that factor as a landslide hazard is the shape of distribution of discovered landslides by the information classes of the factor under consideration.

Mudflow phenomena have been investigated from different perspectives: the regional peculiarities of their occurrence or general territorial regularities of their spread; mudflow-forming processes as a result of the impact of water flows with friable debris; specific mudflow-forming factors or certain types of mudflows, etc. (Seversky et al., 2010; Zerkal,2014). Several studies (Budagov, 1993; Akizade, Tarikhazer, 2010; 2015) determined the mapping criteria, optimal scale and legend of maps, depending on the hierarchic level of the investigation of the region and the landscape conditions of the manifestation of the processes.

Research method. There are a large number of methods for assessing the risk of environmental management and predicting hazardous exodynamic processes (Petrascheck, et al. 2003; Seversky, et al., 2010; Zerkal, 2014; Makarov et al., 2014; Anakhaev, 2016; Marchenko, 2017, etc.). However, in modern conditions, these techniques are not sufficiently reliable. This, in turn, determines the relevance and the need to develop new or modernised methods of strategies for the prevention, protection, and elimination of the consequences of catastrophes and natural disasters.

The purpose of this work is to reveal the geomorphological features and dynamics of the development of the most dangerous and often repeating landslide and mudflow processes based on field geomorphological studies, as well as fund literature, indicate the reasons for their formation and propose measures to combat them.

Morphometric analysis was carried out using a digital elevation model (DEM) using the ArcGIS package. The initial data were the results of the Shuttle radar topographic mission (SRTM), calculated to create a high-precision global DEM network. Its root-mean-square error is estimated at a height of about 16 m, and the clarity of the position of the nodes of the three-second grid is about 20 m, while these indicators become higher in the conditions of mountainous terrain. An SRTM image with a resolution of approximately 60 m is useful for implementing morphometric analysis and generating proper GIS maps (Tarikhazer, 2018; Tarikhazer, 2019). Image editing, related to the identification and elimination of minor errors, was performed using the tools of the ArcGIS package and its Spatial Analyst module. The slope map was compiled using the Special Analyst feature and its Surface analysis option. Landslide and mudflow risk analysis mainly used high-resolution aerospace imagery (ASI) from CNES/Airbus, Maxar Technologies (GeoEye-1), and medium resolution Sentinel-2A and 2B. In general, visual and semi-automatic decryption (classification with training) was performed in the ArcGIS environment.

Research results. Within Azerbaijan, an extension of orographic topographical features is inherent for the northeastern slope of the Greater Caucasus, parallel to the Main Caucasian Ridge. Among them, the most massive is the Lateral Ridge, which gives rise to a colossal variety in the distribution of the intensity of water-erosion processes. Between the Lateral and Main Caucasian ridges, there are intramontane basins - Khynalyg, Rustov, Shakhnabad, Khaltan, Gilgilchay, and others. The next one is the massive Gaytar-Goja Ridge dissected by the right tributaries of the Gilgilchay River. The Gusar sloping plain is a foothill part, passing in the east into the Samur-Devechi lowland. Numerous rivers leaving the mountains create alluvial cones, which unite with each other, form a common plume.

A significant area of the northeastern slope of the Greater Caucasus is represented by slopes, the steepness of which exceeds 10-15°, which has set a stamp upon the nature of exodynamic processes. Steep slopes occupy significant sections of river basins (upper and middle). Within high mountains, intensely dissected by erosion and denudation-nival processes, they are characterised by the development of mainly glacial and gravitational exodynamic processes. In the study area, these slopes occupy up to 70% of the total area of the mountainous region, and then, there is a noticeable decrease in the steepness and energy of the relief from the northwest to the southeast. The energy of the relief and the inclines of the slopes are the determining conditions for the speed, nature of the movement, and mass movement of soils on the slopes. Geological-geomorphological and hydrological-climatic conditions within the studied region contribute to the development of a whole set of exodynamic processes. In addition, these conditions are complicated by the fact that in recent decades, the relief of this region has been intensively exposed to anthropogenic impact in order to develop the tourism industry.

The northeastern slope of the Greater Caucasus consists of sedimentary rocks of the Jurassic, Cretaceous, Tertiary, and Quaternary periods (Alizade and Tarihazer, 2010). In the area of the Bazarduzu (4466 m) and Tufandagh (4191 m) mountains, the basins of the Gudyalchay, Gusarchay, and other rivers are represented by limestones, dolomites, clays, clay shales, sandstones, marls, and conglomerates. Tertiary rocks are found in mid-mountain and partly low-mountain belts and are represented by clays, sandstones, pebbles, and loams. In the upper reaches of the Gudyalchay, Gusarchay, Aghchay, Garachay, and Valvalachay rivers, there are found Upper Quaternary excretory material (Alizade, Tarihazer, 2015). The relief of the northeastern slope of the Greater Caucasus is distinguished by significant dissection and is experiencing impressive denudation (Budagov, 1993). Exodynamic processes play a significant role in the formation of the relief. For example, the processes of denudation and erosion are increasing manifold due to the latest tectonic uplifts. The forms of river valleys, terraces, etc. testify to the active newest tectonic uplifts.

Glaciation, physical weathering, erosion, landslides, placers, talus, landslides, mudflows, etc. are among the modern exodynamic relief-forming processes. However, among the dominant exodynamic processes are landslide and mudflow processes, which are one of the main parameters of the negative ecological and geomorphological state of the region under study.

The role of relief energy and slopes in the development of exodynamic processes. Composed mainly of shales, sandstones, marls, and limestones, the slopes of the mountains and ridges of the studied region are distinguished by the development of flat and linear erosion, different drift rates, and accumulation rates. Under other conditions (physical and mechanical properties of soils and their consistency), debris on the slopes of the Main and Side Ridges is in a state of constant movement due to the steepness of the slopes. In the upper reaches of the Gudyalchay, Valvalachay, Gusarchay, and other rivers, the surfaces of watersheds are subject to intense destruction due to significant differences in daily temperatures, an almost absolute absence of vegetation cover, rock fractures, steep slopes of river valleys of more than 45°, etc. The movement of debris here occurs at a high speed, where the removal of weathered material prevails over the rate of accumulation of debris. For this reason, an impressive volume of coarse detrital material is deposited on the slopes of river valleys in the form of placers, talus, and landslides. With intense snowmelt and heavy rainfall, this material is washed off into river valleys, which causes the formation of destructive mudflows. In the presence of large slopes within the highlands, the slopes are mainly covered with a thick cover of colluvium, lithologically represented by shales and sandstones. Frosty weathering on such slopes is so intense that denudation does not always manage to remove all the prepared loose material. The most powerful cover is formed on the watershed, where the slopes are insignificant (up to 5-10°). As it goes down the slope, the thickness of the friable fragmental material increases, which leads to an increase in adhesion between debris and bedrocks and a slowdown in the speed of movement of soil masses along the slope, regardless of the increase in slopes.

The period of active weathering in the highlands is 160-180 days a year, i.e. when the surface of the slopes is bare and exposed to atmospheric processes (Budagov, 1993). Even before the appearance and after the snow cover has disappeared from the slopes, their surface (40-60 days a year) remains in a frozen state for some time, and the soils are inactive. With the onset of the warm period, the frozen soil thaws and begins to move intensively down the slope. In general, the period of active weathering and the period of intensive rolling of the clastic mass down the slope within the high mountains with large slopes take no more than 120-140 days a year. This leads to a positive balance of clastic mass on the slopes of the mountains, regardless of the high relief energy and the prevalence of significant slopes.

The movement of soil masses proceeds on the slopes of the Lateral Ridge in slightly different conditions, which is composed mainly of chalk limestones on a synclinal structure and abruptly drops to the north and south. The steepest, almost sheer slopes are characteristic of the river basins of Gusarchay, Gudyalchay, Babachay, and Valvalachay, cutting across the strike of the Lateral Ridge. Weathering processes on steep slopes of these valleys spread along the entire length of the slope, reaching 1000-1200 m and more, and ensure the predominance of removal over input, thereby creating a negative balance of clastic material. An impressive volume of debris is carried off the slopes, falling directly into the channel and being carried out by rivers. Sediment runoff can serve as evidence of an increase in drift from the slopes of these rivers, which varies along the length of the river. For example, in the Khinalig point, located before the cutting down of the Gudyalchay River in the Lateral Ridge, the total sediment runoff, carried from the slopes of the Dividing Mountain Range is 68 thousand tons, and in the area of the Kupchal village, located after the river leaves the Lateral Range, - 1023 thousand tons (Eyyubova, 1982). In this case, large drifts of slopes play a significant role in the formation of slopes and landforms - mainly accumulative (fan cones, placers, and talus).

It should be noted that total land runoff and sinking are the results of a complex of factors, contributing to weathering and denudation. Of this complex, the degree of vertical dissection and the slopes should be especially distinguished (Fig. 1, 2).

In the highlands, where the relief energy exceeds

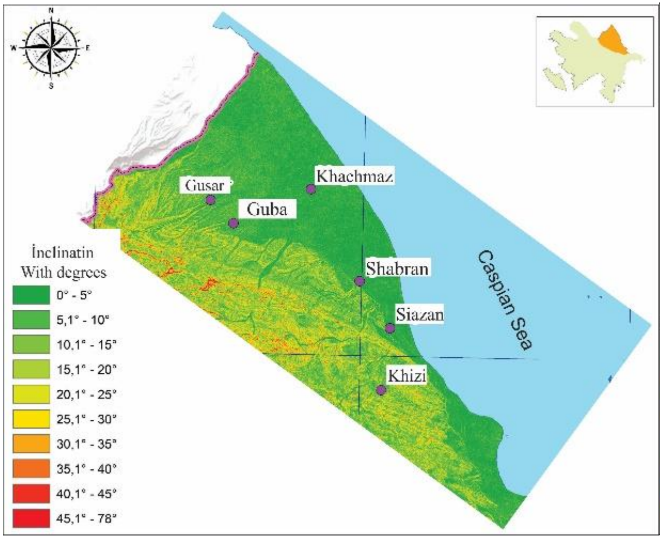

Fig. 1. The map of tilt angles

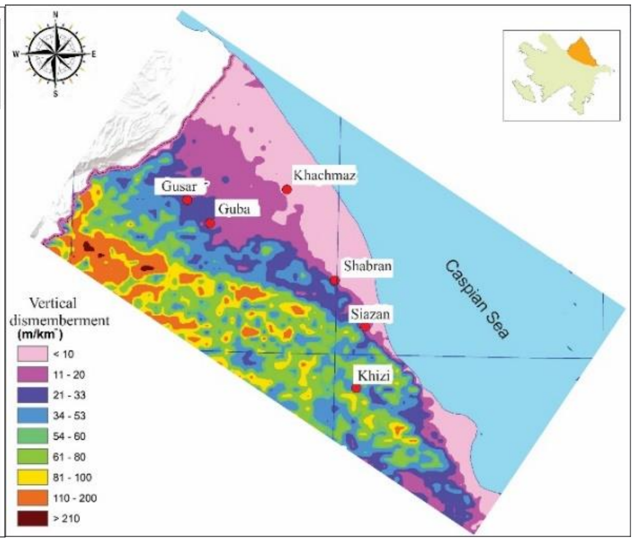

Fig. 2. The map of vertical partition

1000 m, and the slopes are more than 30-40°, the limit of the washout intensity is more than 1 mm/year, while it decreases to 0.10-0.5 mm/year in the low mountains. The presence of a dense river network within an intensely dissected and largely barren territory is the most effective factor in the process of general washout and especially the removal of friable material. It should also be noted that the greatest erosion from the surface is observed in the middle mountain zone, apparently associated with the denudation features of bedrocks and the influence of climatic factors on their destruction.

With the rise in the Quaternary time (0.5 million years) of the mountainous part by 400 m and a denudation meter, covering a period of 1000 years, the rate of uplift is on average 0.8 mm/year. In the high-mountain and partly mid-mountain parts of this territory, the denudation rate is 1 mm/year, and for the entire mountainous part - 0.5 mm/year (Budagov, 1993). The difference between uplift (0.8 mm/year) and washout (0.5 mm/year) is 0.3 mm/year, i.e. the washout layer is less than the amplitude of the intense uplift of the entire mountainous part of the Greater Caucasus and its predominance over the washout in the Pliocene-Quaternary. This feature plays a significant role in the intensity of the general dissection of the relief, and the latter is due to the significant steepness of the slopes and the energy of the relief. Therefore, a map of morphometric intensity was compiled to diagnose a single background of the dissection of the modern topography of the region under study (Fig. 3), which includes the degree of vertical fragmentation of the territory, the steepness of slopes, etc.

Thus, the analysis of various quantitative indicators of the relief of the studied region and the compiled map of morphometric tension makes it possible to reveal the dependence of the type, intensity, and direction of development of modern exodynamic processes also by the magnitudes and nature of the relief dissection, the high indicator of which is morphometric measurements (Tarikhazer, 2020). The obtained factual data of morphometric intensity also make it possible to quantitatively characterise the exodynamic processes within the studied mountainous region.

Landslide processes. Landslides were formed in almost all vertical belts of the studied region but they are most often observed in the middle mountain belt (Table 1).

They are mainly located on the slopes of lateral spurs, characterised by steepness and clay deposits, where, in the context of excessive moisture, the following genetic type of landslides are formed - landslides-flows, landslides-landfalls, and block tectonic-gravity landslides. In the formation of landslides, their systematic confinement to the slopes of the erosion-structural mountains of the Main Caucasian ridge and the northern exposures of the Lateral ridge is noted. This is determined by the layering of rocks composing these slopes, mainly of limestone and clay facies. Landslides are predominantly specific for the river basins of Garachay, Aghchay, Valvalachay, Gilgilchay, Atachay, and Jimichay. In the modern relief, the most characteristic and most pronounced landslides are the Erfin, Atuch (in the basin of the Valvalachay River), Bakhishli, Khalaj (in the basin of the Atachay River), Gunchal (in the basin of the Gilgilchay River), and others. Landslides are widespread on the Gizilgayin Plateau, which occupies a part of the Lateral Ridge, located between the valleys of the Gudyalchay and Gusarchay Rivers. The plateau on the surface is formed by massive dolomitised limestones, collected by Lower Cretaceous carbonate and terrigenous deposits. On the western slope of the Gizilgayin Plateau, the density of limestone strata reaches 600–700 m, on the southern slope – 500-550 m, and the northern slope – 600-650 m.

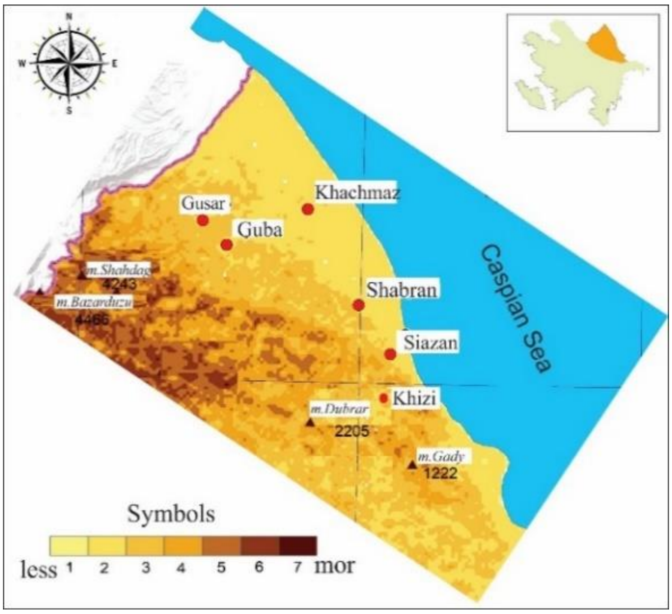

Fig. 3. The map of morphometric tension

The slopes of this plateau in the east and west form the canyon boards of the river valley zones of Gudyalchay and Gusarchay. The steepness of slopes developed in limestones exceeds 40-45˚. On all slopes of the Gizilgayin Plateau, landslides and avalanches are numerous. On the eastern and western and eastern slopes, due to their steepness (50-60˚ and more), their deposits collapse into the river channels of Gudyalchay and Gusarchay, thereby to a large extent narrow them down. The material of landslides and landfalls is perfectly preserved on the southeastern, southern, and, slightly, northern sides of the plateau.

In the course of the work, a comparative analysis of landslide processes was carried out according to the works of B.A. Budagov (1993), with the results of our data based on the interpretation of colour ASI of 1996, 2000-2020 scale 1: 60,000 and field research. In the work of B.A. Budagov (1993), the area of landslides on the territory of the northeastern slope of the Greater Caucasus is 1972 km^2; however, now it reaches 8299 km^2. It was found that today the area of landslides in the Guba region is over 200 hectares, in the Gusar region - over 100 hectares, etc. Considering that these exodynamic processes caused a huge threat to the development of mountainous areas of the studied region, zoning was carried out according to a 4-point system of this region in terms of the degree of landslide risk. At the same time, the data on landslide formation were detailed, coming laden with the morphometric specifics of the relief (horizontal and vertical dissection, steepness of slopes, exposure of slopes, and hypsometry), landscape-high-altitude zones, seismic activity of the region, the lithological composition of the constituent rocks, amount of atmospheric precipitation, and hydrological conditions (Fig. 4).

Table 1

Dates of beginnings of the most threatening landslide processes on the northeastern slope of the Greater Caucasus for 2000-2020

#	Date of beginnings	Place of beginnings	Causes beginnings of landslide	Landslide consequences
1	*2*	*3*	*4*	*5*
1.	April 2000	Guba region	shower	Subsidence phenomena on 6, 7, 8 km of the Guba-Gachresh road
2.	April 2001	Altiagaj village, Khizi region	//-//	A landslide developed in the eastern part of the of Altiagaj village at an altitude of 1130-1500 m
3.	April 2002	Adjakhur village, Gusar region	//-//	Several residential buildings are under threat
4.	May 1, 2002	Najafkend village, Gusar region	//-//	Cracks were found on 24 houses. Part of the Gilakh highway was destroyed
5.	May 10, 2003	Gelenkhur village, Gusar region	Laying a drinking and irrigation channel	School destroyed
6.	May 2003	Boyuk Murug village, Gusar region	shower	The landslide is developed in the northern part of the Boyuk Murug village. Rural school is under threat
7.	April-May 2003	Zeyva village, Shavran region	//-//	Rural road destroyed
8.	April-May 2004	Khizi village, Khizi region	Water from melted snow	Khizi-Bakhyshli highway destroyed in 5 places
9.	April-May 2004	Khizi village, Khizi region	Rains	Landslide activation in the southwestern part of the Khizi village
10.	October 2005	Firik village, Guba region	//-//	The landslide developed here for the first time in 1991. In October 2005, it became active again. 3 residential buildings are under threat of destruction
11.	May 2008	Sedan village, Siyazan region	shower	Landslide activation near water pipeline
12.	July 10, 2008	Ganarchay village, Gusar region	//-//	4 houses were completely destroyed, cracks were revealed in 22 houses. Residents of 15 houses were evacuated
13.	March 15, 2009	Urva village, Gusar region	shower and earthquake 4 points	7 houses were damaged
14.	June 8, 2009	Dellekli village, Guba region (on the bank of the Gudialchay river)	shower	A ravine 500 m long and 30 m high was formed. Part of the rural cemetery and coastal agricultural plots were destroyed
15.	October 12, 2009	Gudurgan and Sudur villages, Gusar region	//-//	The bridge across the Sudur-Gusar road was damaged. Interrupted traffic
16.	February 24, 2010	On the 29th km of the Guba-Khinalig road	Thaw	The road is blocked
17.	March 2, 2010	Urva village, Gusar region	shower	Cracks appeared in 2 residential buildings
18.	April 3, 2010	Urva village, Gusar region	//-//	The soil shifted on 2,7 m. Cracks appeared in 15 houses
19.	April 5, 2010	Gilyazi village, Guba region	//-//	1 house was completely destroyed, 5 houses are in disrepair. Residents evacuated
20.	April 28-29, 2010	Chichi village, Guba region	//-//	Damaged 10 houses and a school building
21.	April 29, 2010	Gilyazi village, Guba region	//-//	A 150-meter highway was destroyed. 29 houses were damaged. Residents evacuated
22.	May 2, 2010	On 32 km of the Guba-Gonagkend road	//-//	Road communication with 34 high-mountainous villages blocked
23.	May 3, 2010	Kyusnat village, Guba region	//-//	Landslide activation. 1 residential building is under threat
24.	May 7, 2010	Achakhur-Boyukmurug automobile road of Gusar region	//-//	Communication with 7 villages interrupted

Table 1 continuation

1	2	3	4	5
25.	May 10, 2010	Sekhyub village, Guba region	//-//	Damaged 2 houses
26.	May 10, 2010	Uchgun village, Guba region	//-//	Damaged 6 houses
27.	May 18, 2010	Guba region	//-//	10 houses and a school building were damaged. Revealed cracks that caused the exit of groundwater
28.	May 25, 2010	Elik village, Guba region	//-//	Cracks were found in 30 houses, 1 house in disrepair
29.	September 20, 2010	Urva village, Gusar region	//-//	Cracks were found in 15 houses. Several rooms of 2 families separated from the house and collapsed into a 15 m ravine. The auxiliary buildings of 4 household plots saged. There are cracks in the rural school
30.	April 26, 2011	Elik village, Guba region	//-//	5 houses were destroyed. More than 10 houses are in disrepair. The building of the branch of the Elik Rural Library has fallen into disrepair
31.	May 30, 2011	Gilyazi village, Guba region	//-//	20 houses were damaged. 29 houses are in disrepair. Hollows and meter cracks formed. Rural road destroyed
32.	May 30, 2011	Afurdja village, Guba region	//-//	20 houses were destroyed. 5 houses are in disrepair
33.	June 6, 2011	Haput village, Guba region	//-//	7 houses in disrepair. Cracks appeared in 13 houses. Residents evacuated
34.	June 6, 2011	Budug village, Guba region	//-//	Part of the rural cemetery destroyed
35.	April 4, 2016	Amirkhanly village, Shabran region	Heavy rain	The road between the Amirkhanly and Gazbabaly villages was destroyed. In Amirkhanly village 1 residential building destroyed
36.	April 18, 2016	Chaman village, Siyazan region	Rains	Numerous cracks appeared in 2 houses
37.	May 21, 2016	Kuzun village, Gusar region	//-//	Road traffic blocked
38.	June 7, 2016	Gryzdagna village, Guba region	//-//	The landslide spread to the bed of Gudialchay river. As a result of the landslide, about 60 trees fell
39.	October 26, 2016	Urva village, Gusar region	//-//	Residents of 15 houses were evacuated
40.	November 30, 2016	On the 11th km of the Altyagadzh highway of the Khizi region	//-//	traffic locked
41.	April 6, 2017	Gazbabaly village, Shabran region	//-//	5 residential buildings completely destroyed
42.	April 11, 2019	At 36 km of the Guba-Khinalig highway	//-//	Interrupted communication with 6 settlements
43.	June 24, 2020	Guba-Khinalig highway	//-//	As a result of a landslide, a six-meter section of the recently repaired road was destroyed, and cracks formed in some parts of the road

Regions with a high degree of landslide risk include territories with an area of 545.80 km^2 (6.6%), where the likelihood of a landslide scale reaches 65-70% of the total area. Such dangerous areas are mid-mountain and low-mountain zones of the northeastern slope of the Greater Caucasus, river basins of Atachay, Gilgilchay, Valvalachay, etc. Regions with a moderate degree of landslide risk include territories with an area of 3295.72 km^2 (39.8%), where the probability of landslide scale reaches 50-65% of the total area.

Over the past few years, landslide processes have increased extremely in the high-mountainous zone within the subalpine and alpine geo-complexes. The reason was a sharp increase in anthropogenic pressure (overgrazing). Active deforestation in the mid-mountain zone also led to the revival of landslides. Therefore, these areas were assigned to zones with the intense manifestation of landslide processes, the scale of which can reach 50-65%. In the regions with a low degree of landslide risk, the area of which makes 3699.62 km^2 (44.56%), the probability of the scale of landslides is 30-50% of the territory. Territories, where landslide processes do not occur, have an area of 758.03 km^2 (9.13%).

Mudflow processes. Mudflow processes are developed on the northeastern slope of the Greater Caucasus in all landscape-geomorphological zones - from the low mountains to the high-mountain zone (Table 2).

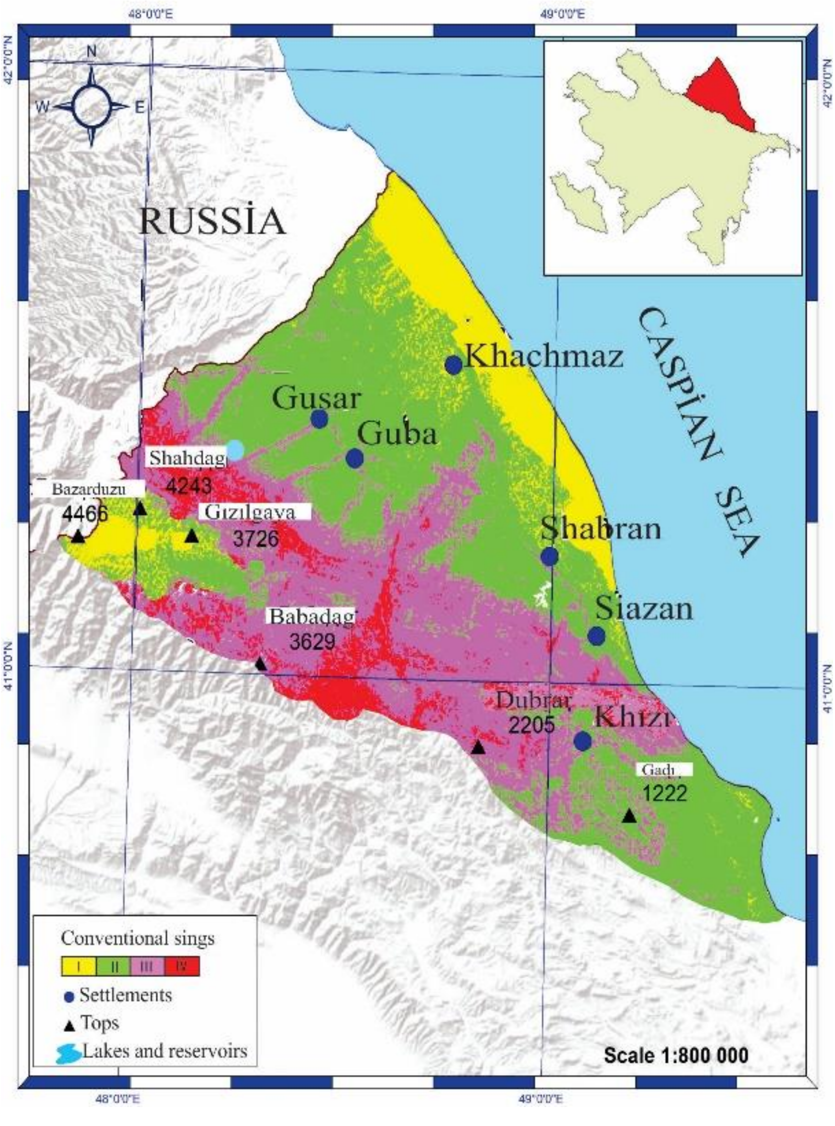

Fig. 4. The map of landslide hazard.
1. Areas where landslide processes do not occur - I point;
2. Areas with a low degree of landslide risk
(probability of landslide expansion by 30-50% of the territory) - II point;
3. Areas with a moderate degree of landslide risk
(the probability of landslide expansion by 50-65% of the territory) - III point;
4. Areas with a high degree of landslide risk
(probability of landslide expansion by 65-70% of the territory) - IV point

Table 2

Dates of the passage of the most dangerous mudflows on the northeastern slope of the Greater Caucasus for 2000-2020

#	River	Date of passage of the mudflow	Mudflow consequences
1	*2*	*3*	*4*
1.	Devechichay	July 14, 2000	The bridge across the Devechi-Guba road was destroyed
2.	Gilgilchay	May 23, 2003	3 people perished
3.	Gudialchay	July 07-08, 2008	Material damage was inflicted on houses and social facilities in the city of Khachmaz
4.	Gudialchay	March 04, 2008	24 houses were damaged. 1 person perished
5.	Devechichay	April 17,2009	5 bridges was dmaged, perished livestock in Chichi and Zeyva villages
6.	Gilgilchay	July 09, 2009	1 person perished
7.	Gudialchay	July 19, 2009	Damaged 4 social facilities and houses in Tyulyakaran, Guba region
8.	Gusarchay	September 17, 2009	More than 100 houses in Neredzhan village of Khachmaz region were damaged
9.	Gilgilchay	July 17, 2012	The road connecting the Chukhurazami village with Shabran city were damaged
10.	Gudialchay	April 23, 2013	Mudflows blocked a section of road of the Baku-state border with Russia near the Vladimirovka village. The movement of vehicles on the highway is limited
11.	Gudialchay	August 29, 2013	About 10 houses in Alekseevka village of Guba district was destroyed. Damage was caused to more than 100 houses located on the Vagif str. in Krasnaya Sloboda village
12.	Gudialchay	September 12, 2013	A bridge was destroyed in the Guba region, several houses were damaged in the Tuler village, livestock perished
13.	Gudialchay	October 31, 2014	36 km and 38 km of the Guba-Khinalig highway of the Guba region are washed out
14.	Gusarchay	September 16, 2015	The mudflow was destroyed 3 houses in the Gusar city and 1 house in the Chilegir village. Flooded 60 houses. In the Tuler village destroyed the bridge
15.	Gudialchay	April 17, 2016	A bridge in the Guba region was destroyed
16.	Gusarchay	May 19-20, 2016	The road in the Kuzun village of Gusar district was destroyed
17.	Gudialchay	May 20, 2016	The bridge in the Tuler village of Guba region was destroyed
18.	Gusarchay	June 25, 2016	Damage was caused to more than 20 houses and sown areas in the Kuzun village. Livestock perished. Bridge destroyed
19.	Lazachay	September 01, 2016	53 people from Laza village evacuated. The Guba-Khinalig road partially and the bridge on this road on 29 km were destroyed. Traffic on the road was interrupted. Mudflows also caused damage to residential buildings in the Utug village of the same region, the electricity supply to this settlement is cut off
20.	Gudialchay	September 01-02, 2016	Damage was caused to about 10 villages of the Guba region. The mudflow washed away the pylons of power lines in the Krasnaya Sloboda village. A section of the Guba-Khinalig road was destroyed. The mudflow destroyed almost 30 telecommunication poles, as a result communication with 20 settlements of the region was interrupted. The greatest damage was inflicted to automatic telephone exchange operating in villages in the direction of Gonagkent-Sokhub, Kupchal-Gechresh, Zargova-Chichi and Khinalig
21.	Lazachay	June 04, 2019	Mudflow caused damage to agricultural land of Laza village of Gusar district
22.	Garachay	June 30, 2019	Basements and courtyards of residential buildings in Guba region flooded
23.	Jagadukchay	May 07, 2020	Mudflows destroyed the bridge over the Jagadzhukchay river in the Khanagakh village of Guba region
24.	Velvelichay	May 11, 2020	2 cars of "Niva" and "UAZ" brands were carried away by the mudflow. The drivers are saved
25.	Shabranchay	May 12, 2020	The bridge over the Shabranchay river in the Chaigishlig village was destroyed.
26.	Gudialchay	June 13, 2020	A mudflow destroyed a 56 km section of the Guba-Khinalig highway. Serious damage was inflicted on residential buildings, private households and road infrastructure in Bostankesh and Gala Khudat villages
27.	Garachay	July 16, 2020	Mudflow damaged road infrastructure and farms in Birinji Nyugedi, Ikinji Nyugedi, Khanegah, Erfi, Gayadaly, Budug, Sokhyub and Galahudat villages. The bridge on the Garachay river destroyed. The mudflow damaged the roads, flooded the gardens and orchards of local residents
28.	Garachay	August 04, 2020	Mudflow damaged several private houses and a recreation center in the Gurbanfendi village. 40 sheep were perished, the mudflow washed away poultry

Mudflows are mainly of rain origin, and the amount and mode of precipitation play a special role in the formation and occurrence of catastrophic mudflow processes (Makhmudov, 2008). On the northeastern slope of the Greater Caucasus, mudflows are often repeated in the river basins of Gilgilchay, Atachay, Shabranchay, Davachichay, etc. Traces of mudstone mudflows in the form of mudflows and mud masses are well preserved in the wide floodplains of the rivers of Gilgilchay and Atachay. The confinement of mudstone mudflows to the indicated river basins is undoubtedly associated with the widespread development of landslides and landslide-mudflows in the catchments of these rivers. In the arid-low-mountain zone, the formation and passage of mudflows and the flat vague forms of solidified mudflow created by them are mainly observed. There are frequent cases of solidification of mud and mudflow mass at the bottom of ravines and gullies, due to their "enrichment" with muddy-clay intrusions with short showers, the waters of which are one of the main driving factors. The centres of formation of mudflows are mainly confined to vast erosional catchments and landslide-mudflows. Mudflow centres of the erosion funnel type are specific for the high-mountainous parts of the river basins of Gudyalchay, Jimichay, Babachay, and Gusarchay. Mudflow centres of such basins as Gilgilchay, Atachay, Tughchay, Shabranchay, and Takhtakorpuchay are confined to landslide and landslide-mudflows. In this respect, the river basin of Atachay is especially characteristic. Here, the centres of the occurrence of mudflows, in general, are the Bakhishli landslide massif, into the body of which a channel is cut at a distance of 6-8 km, from the village of Bakhishli to the village of Khalanj. Sections of the Valvalachay River valley between the village of Gonagkend and the village of Afurja can be referred to similar foci.

A zoning map was compiled according to the degree of mudflow risk on a 5-point scale (Fig. 5), based on the interpretation of the ASI within the northeastern slope of the Greater Caucasus according to the degree of hazard of mudflow processes (the amount of material carried out, the erosional effect of the flow on the valley, taking into account mudflows of tributaries and the basin as a whole, as well as by the prevailing types and classes of mudflows, and geomorphological conditions of formation, occurrence, and passage of mudflows, and statistical data on past mudflows) and based on the actual and possible damage to the population from mudflows.

The area of the territory, where mudflows are not

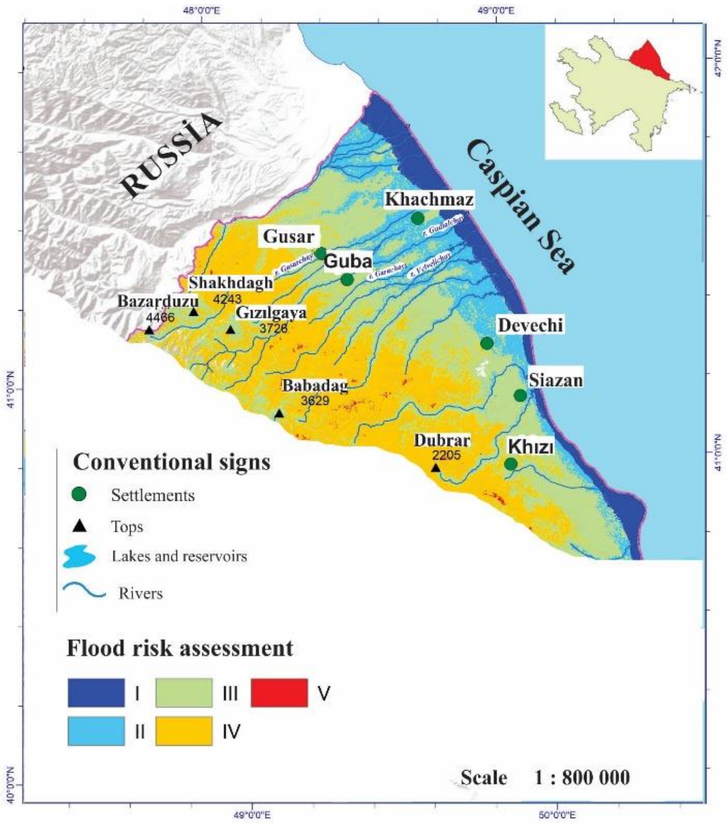

Fig. 5. The map of mudflow hazard.
1. Territories, where there are no mudflow processes - I point.
2. Territories with potential mudflow hazard - II points.
3. Territories with a weak mudflow hazard (once in 5-10 years is possible 1 strong mudflow) - III points.
4. Territories with an average mudflow hazard (once in 3-5 years is possible 1 strong mudflow) - IV points.
5. Territories with high mudflow hazard (once in 2-3 years is possible 1 strong mudflow) - V points

observed, is 683.914 km^2 (8.27%), while the area of the territory with potential mudflow risk is 1457.117 km^2 (17.56%). The area of the territory with low mudflow risk is 3097.842 km^2 (37, 33%), an area with an average mudflow risk - 3037.503 km^2 (36.63%), and an area with a high mudflow risk - 15.506 km^2 (0.21%).

Thus, a map of the morphodynamic tension of the northeastern slope of the Greater Caucasus (Fig. 6) was compiled, as a result of a detailed analysis of numerous data and available material that was identified during expeditionary conditions and on the basis of decoding the ASI, as well as taking into account the morphometric tension, mudflow and landslide hazard. This will reveal the current orientation of the manifestation of exodynamic processes, predict and weigh the risk coming from them, which take on all the significant acuteness and relevance in the region under study from year to year (Tarikhazer, 2019; Tarikhazer, 2020).

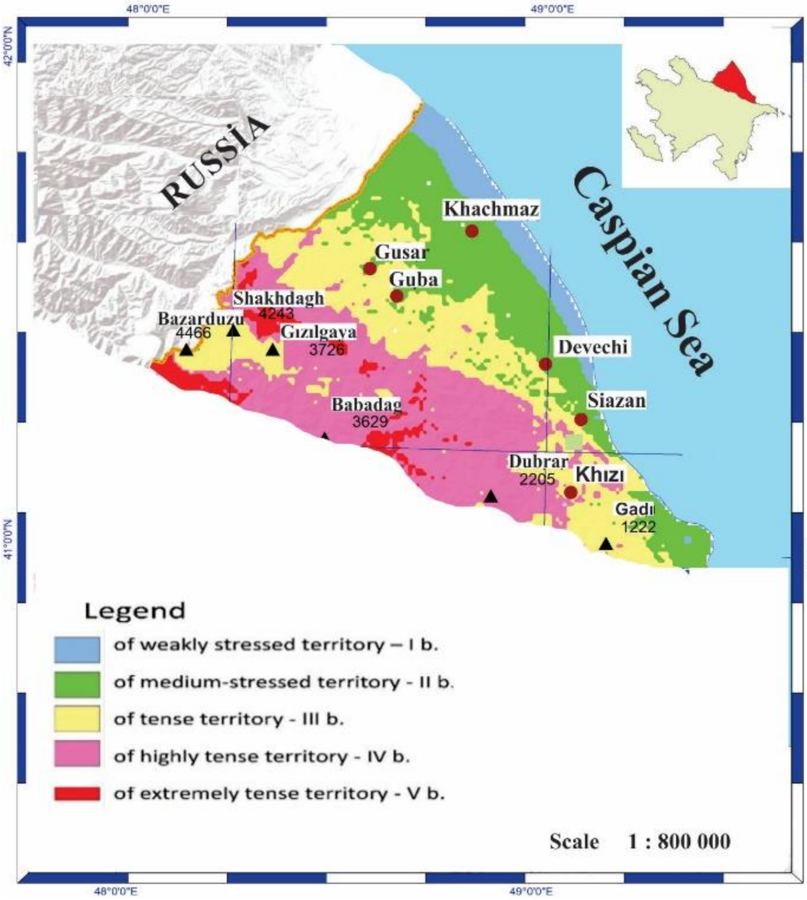

Fig. 6. The map of morphodynamic tension

Analysis of the map helps to detect areas with significant tension of the modern relief, which cause the development of such dangerous morphodynamic phenomena as mudflows, landslides, etc. The strengthening of morphodynamic processes demonstrates a real impact on the stability of mountain geosystems and complicates their anthropogenic settlement. In this context, special attention is paid to the high-altitude and mid-mountain zones of the Gusarchay-Valvalachay and Shahdag junctions of morphostructures. The experience of conducting a comprehensive study, in order to determine the specific geomorphological features of the mechanism of functioning of geosystems, made it possible to identify the general ecological and geomorphological situation and to establish the degree of anthropogenic loads on the internal structure of unstable geo-complexes in mountainous regions.

The area of a weakly stressed territory (I b.) is 344 km^2, the area of a moderately stressed territory (II b.) - 1566 km^2, the area of a stressed territory (III b.) - 2652 km^2, while the area of a highly stressed territory (IV b.) makes 3095 km^2. The area of an extremely tense territory (V b.) is 642 km^2.

Conclusion. On the basis of complex data and using a scoring system, an assessment of the ecological and geomorphological tension and natural risk of geosystems within the northeastern slope of the Greater Caucasus was carried out, which contributes to clearly and thoroughly developing the landscape-reclamation and engineering-geomorphological methods to increase efficiency or maintain the ecological geomorphological environment of the region. In addition, one of the most important problems of ensuring sustainable and safe development of the territory of the studied region is risk management from exodynamic processes. The transition of the region to the assessment and control of risks, as a unified system that guarantees the reliability of the functioning of mountain geosystems, the population, and the economy should ensure a decrease in the growth in the number of consequences from exodynamic processes. Risk management of exodynamic processes is a series of consistently solved tasks, each of which pursues its own goals and end results. The control system of exodynamic processes is considered to include the following: assessing their potential risk; control of anthropogenic factors capable of activating exodynamic processes; emergency response and elimination of consequences in case of their activation; carrying out individual protective measures at facilities in the zone of their development; monitoring the state of protective structures; assessment of damage from them, etc. According to the study, this problem could be solved by using GIS technologies and creating a system of cartographic models.

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Оцінка еколого-геоморфологічної напруженості і ризику геосистем північно-східного схилу Великого Кавказу (у межах Азербайджану)

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Посилення людського пресингу на природні геокомплекси спричиняє пожвавлення небажаних процесів, що створюють великий ризик для мешканців цих регіонів. З багатьох геоморфологічних систем надмірною активністю ендо- та екзогенних процесів виділяються альпінотипні орогенні зони, до яких належить північно-східний схил Великого Кавказу. Тому на даний час важливим є завдання діагностики та оцінки еколого-геоморфологічного ризику, з яким стикається населення при освоєнні нових територій регіону.

У статті розглянуто результати виконання еколого-геоморфологічних досліджень на північно-східному схилі Великого Кавказу, присвячених оцінці зсувного та селевого ризику за період з 1990 по 2020 роки. Для їх оцінки з метою отримання морфометричних характеристик (у тому числі про ухили схилів, довжини та форми схилів, площ селевих вогнищ), використані великомасштабні (М 1:100000) топографічні карти, а також матеріали інтерпретації різномаштабних та різночасних АКС.

На основі дешифрування АКС у межах досліджуваного регіону для з'ясування загальної картини розчленованості сучасного рельєфу досліджуваного регіону складено карту морфометричної напруженості, куди укладено ступінь вертикальної розчленованості території, ухил схилів та ін., а також за ступенем небезпеки зсувних та селевих процесів склад, та проведено підрахунки площ їх розповсюдження. При проведенні аналізу зсувного та селевого ризику в основному використовувалися аерокосмічні знімки (АКС) високої роздільної здатності CNES/Airbus, Maxar Technologies (GeoEye-1), та середньої роздільної здатності Sentinel-2A і 2B. Т.ч. було проведено візуальне та напівавтоматичне дешифрування (класифікація з навчанням) у середовищі ArcGIS. Через війну, з урахуванням морфометричної напруженості, і навіть селе- і зсувонебезпеки складено карта морфодинамічної напруженості північно-східного схилу Великого Кавказу, що дозволяє розкрити сучасний характер прояви екзодинамічних процесів, передбачити і оцінити ризик, що від них. Результати досліджень дозволять використовувати отримані дані для розробки Програми безпечного та сталого функціонування та освоєння з метою рекреаційно-туристичного розвитку важкодоступних гірських геосистем Азербайджану.

***Ключові слова**: еколого-геоморфологічна напруженість, ризик, зсув, сіль, антропогенний вплив, ГІС-технології, дешифрування, екологічна безпека*

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