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The geographical prerequisites for the identification and prevention of dangerous geomorphological processes in the mountain geosystems of the Alpine-Himalayan belt (on the example of the Major Caucasus of Azerbaijan)

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Abstract. Destructive natural phenomena are a serious, sometimes unsolvable, regional and local environmental and socioeconomic problem. This paper presents the results of a comprehensive analysis of materials from long-term geomorphological studies in the mountainous areas on the example of the Major Caucasus of Azerbaijan. The dangerous

geomorphological processes on the example of the Major Caucasus of Azerbaijan were investigated in detail using large-scale maps, satellite imagery and aerial photography. Geomorphological maps were drawn (map of mudflow hazard and map of landslide hazard in the Azerbaijani part of the Major Caucasus). The research determined the dangerous zones where landslides could cover 65–70% of the total area and outlined the zones and regularities of spread of various types of mudflow origination sites. The analysis of the manifestations of most active (with catastrophic consequences) destructive natural processes and the morphotectonic structure of the studied area showed that their occurrence and maximum intensity was confined to the weakest plexuses of mountains – intersections of faults and fractures of various directions and orders. A technique for assessing the eco-geomorphological risk to prevent dangerous natural phenomena was offered. The technique is based on the detection of zones with intensive geomorphological processes, which are often not dangerous separately, but could have catastrophic consequences together. The results obtained during the assessment of the effect of natural and man-caused factors on the stability of montane ecosystems may be used to forecast dangerous natural phenomena and to research geodynamical dangerous geomorphological process not only in Azerbaijan, but also in other regions of the Alpine-Himalayan orogenic belt. The obtained results can be used to plan and perform economic activities, determine and minimize the hazards and risks of occurrence of dangerous natural phenomena, and forecast such phenomena in the future.

Keywords: hazardous geomorphological processes, Alpine-Himalayan montane system, geomorphology, tectonics, dangerous exogenous processes.

Географічні передумови ідентифікації та запобігання небезпечним геоморфологічним процесам у гірських геосистемах Альпійсько-Гімалайського поясу (на прикладі Велико-го Кавказу Азербайджану)

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Анотація. Деструктивні природні явища являють собою серйозну, іноді нездійсненну, регіональну і місцеву екологічну і соціально-економічну проблему. У даній статті на прикладі Велико-го Кавказу Азербайджану представлені результати комплексного аналізу матеріалів багаторічних геоморфологічних досліджень в гірських районах. Небезпечні геоморфологічні процеси на прикладі Велико-го Кавказу Азербайджану були детально вивчені з використанням великомасштабних карт, супутникових знімків і аерофотознімання. Були складені геоморфологічні карти (карта селевої безпеки і карта зсувної безпеки в азербайджанській частині Велико-го Кавказу). В ході дослідження були визначені небезпечні зони, в яких зсуви можуть покривати 65–70% загальної площі, а також окреслені зони і закономірності поширення різних типів місць виникнення селів. Аналіз проявів найбільш активних (з катастрофічними наслідками) руйнівних природних процесів і морфотектонічної будови досліджуваної території показав, що їх виникнення і максимальна інтенсивність обмежувалися найбільш слабкими сплетеннями гір – перетинами розломів різних напрямків. Запропоновано методику оцінки екогеоморфологічного ризику для запобігання небезпечним природним явищам. Методика заснована на виявленні зон з інтенсивними геоморфологічними процесами, які окремо часто не представляють безпеки, але разом можуть мати катастрофічні наслідки. Результати, отримані в ході оцінки впливу природних і техногенних факторів на стійкість гірських екосистем, можуть бути використані

для прогнозування небезпечних природних явищ та дослідження геодинамічно небезпечних геоморфологічних процесів не тільки в Азербайджані, але і в інших регіонах Альпійсько-Гімалайського орогенного пояса. Отримані результати можуть бути використані для планування і здійснення господарської діяльності, визначення і зведення до мінімуму небезпек і ризиків виникнення небезпечних природних явищ та прогнозування таких явищ в майбутньому.

Ключові слова: небезпечні геоморфологічні процеси, Альпійсько-Гімалайський гірська система, геоморфологія, тектоніка, небезпечні екзогенні процеси.

Introduction. Over recent decades have seen a trend of increasingly intensive involvement of mountainous areas in human economic activities, which include mass construction and expansion of settlements, motorways and railroads, pipelines, agricultural and industrial facilities, construction of Olympic facilities, sanatoriums, hotels, holiday centers, etc. This causes intensive degradation of the natural resource potential of mountainous and piedmont territories, which are viewed as a means of achieving economic goals. The geo-systems of such regions lose their stability to external impacts, which increases the probability of dangerous destructive natural phenomena occurring (Alizade and Tarikhazer, 2010, 2015; Gotvansky, 2010; Mazur, 2004; Jansky, 2006; Spengler et al., 2016). Human activity combined with climate change have a direct effect on the formation and development of destructive natural phenomena, such as mudflows, scree, landslides, avalanches, desertification, etc. (Mazur, 2004; Jansky, 2006; Kang et al., 2004; Anakhaev et al., 2016; Lioubimtseva, 2009). These phenomena are especially dangerous for settled territories of mountainous and piedmont regions, since they completely destroy the infrastructure, buildings, and structures and cause deaths and considerable financial loss. Such territories include Central Asian countries, including the Azerbaijan Republic.

Destructive natural phenomena against the backdrop of urbanization, expansion of agricultural lands and industry in mountainous and piedmont regions of Azerbaijan, the sudden occurrence of said phenomena, their unpredictability, and close relation to geological, geomorphological, and other geodynamic processes are a serious, sometimes unsolvable, regional and local environmental and socioeconomic problem, the consequences whereof have a negative effect on the development of the entire country. The most dangerous, common, and destructive ones are landslides and mudflows (Anakhaev et al., 2016; van den Eeckhaut et al., 2007; Petrascheck and Hazard, 2003; Yafiazova, 2009; Seversky et al., 2010; Lee et al., 2008).

In order to solve a series of problems facing mountainous areas, specialists direct their efforts to the detection and anticipation of the causes of spread and development of current destructive natural processes. This will help to solve many practical

and economic problems, prevent dangerous natural phenomena and their consequences caused by a catastrophic transformation of natural geo-systems, and minimize the risk of damage therefrom. Therefore, the development of a technique for assessing the risk to montane systems from adverse natural and man-caused processes (geo-ecological assessment) is a national priority. Such risk assessment methods should take into account multiple natural and man-caused factors, the combination whereof facilitates the development of these dangerous processes and phenomena. The dynamic of these processes and phenomena can be traced in the geo-dynamically active area of the Major Caucasus of Azerbaijan, most of which is part of zones with a high level of general eco-dynamic hazard that are exposed to several intensive dangerous terrain-formation processes and a probability of catastrophic manifestation of some of them. Therefore, studying the regularities in the connection between the endogenous and exogenous components of the terrain, i.e. the comparison of the terrain morphology in mountainous regions to Alpine orogeny in the system, which causes dangerous geodynamic processes, is a relevant task of structural geomorphology and morphostructural analysis. Therefore, the purpose of this research was to investigate the dynamic of these processes and phenomena, which required determining the main factors and trends in the development of terrain.

Methods and materials. Researchers of different countries have developed and continue to develop techniques for preventing landslides, which calculate the risks of occurrence of this or that phenomenon in territories with different natural conditions (Petrascheck and Hazard, 2003; Yafiazova, 2009; Seversky et al., 2010; Lee et al., 2008; Schlögel et al., 2015; Duong et al., 2013; Ardizzone et al., 2002; Baynes et al., 2002; Brardinoni et al., 2003; Corominas et al., 2014; Malamud et al., 2004; Singhroy and Molch, 2004; Abu-Zeid et al., 2003; Inaba, 2003; Mills, 2003; Paramonov, 2005).

After analyzing a number of techniques used to assess the landslide hazards (Seversky et al., 2010; Lee, 2006; Bobrovich, 2008; Schlögel et al., 2015; Duong et al., 2013; Ardizzone et al., 2002; Baynes et al., 2002; Brardinoni et al., 2003; Corominas et al., 2015; Malamud et al., 2004; Singhroy and Molch,

2004), the conclusion was made that most of them had their flaws. Deterministic methods of analysis (Bobrovich, 2008) based on estimated values of stability coefficients often show results that do not correspond to reality due to the lack of initial engineering and geological data. 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 (Yafazova, 2009; Seversky et al., 2010; Bobrovich, 2008; Baynes et al., 2002), 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. Remote sensing techniques are more practical. Such techniques enable determining the morphological indicators of landslide development to draw 1:5000 maps of density and probable occurrence of landslides (Ardizzone et al., 2002; Baynes et al., 2002; Brardinoni et al., 2003; Corominas et al., 2015; Malamud et al., 2004; Singhroy and Molch, 2004).

This research used a technique of landslide susceptibility of the territory (Duong et al., 2013), which is considered more appropriate for the territory of the Major Caucasus of Azerbaijan. 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. The standard deviation of the distribution of discovered landslides by the information classes of the factor under consideration is the basis for determining its weight w_j ; at that, the weights of all (n) assessed factors are normalized so that their sum is 1:

$$w_j = 1 - \frac{\sigma_j}{\sum_{j=1}^n \sigma_j} \quad (1)$$

where σ_j is the standard deviation of the distribution of discovered landslides by the information classes of factor j .

The weights of information classes x_{ij} are normalized as regard to the number of detected landslides so that the sum for each factor is 1:

$$x_{ij} = \frac{\text{number of detected landslides in this information class}}{\text{number of detected landslides in the entire studied territory}} \quad (2)$$

The method for zoning the landslide susceptibility of the territory consists in the following. An integrated index H is calculated for each elementary plot of the studied:

$$H = \sum_{i,j=1}^n w_j x_{ij} \quad (3)$$

where H is the integrated landslide susceptibility index, dimensionless; w_j is the weight of factor j ; x_{ij} is the weight of class i of factor j .

This research uses a comprehensive technique of landslide susceptibility of the territory: structural morphotectonics, seismicity, climate, hydrogeological conditions, exogenous geomorphologic processes that facilitate landslide formation, vegetation, nature of engineering and economic activities in the studied regions, etc. (Gotvansky, 2010).

Researchers in various countries (Abu-Zeid and Furlanis, 2003; Huang, 2003; Inaba, 2003; Mills, 2003), including post-Soviet countries that are exposed to mudflow phenomena (Yafazova, 2009; Seversky et al., 2010; Chernomorets, 2003;), are actively studying said phenomena, with a view to preventing them, minimizing their consequences, and developing means of protection therefrom. 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. (Yafazova, 2009; Seversky et al., 2010).

The most practical and sufficiently informative technique is aerial photography followed by photogrammetric treatment of aerial photographs of mudflow-hazardous regions with a scale of 1:2000-1:5000 (Chernomorets, 2003; Seversky et al., 2010; Paramonov, 2005). It enables covering the entire studied district; it can also be used when planning the socioeconomic development of regions, outlining "risk zones", distributing resources, planning measures aimed at minimizing damage, making long-term forecasts, and analyzing mudflow phenomena. Several studies (Alizade and 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. It was found that the optimal scale for the detection and anticipation of natural destructive phenomena in the montane geo-systems of the Major Caucasus of

Azerbaijan, as well as local morphogenesis processes, was 1:100000.

Mapping on a 1:100000 scale, by the example of mudflows, allows for additional monitoring of the state of the mudflow origination site, mudflow channel, and impact area of mudflows. This scale enables covering the entire mudflow basin, which allows using it as a basis for modeling the mudflow process along the entire mudflow channel and monitoring the entire mudflow basin comprehensively.

While analyzing the materials, the conclusion was made that much depends on the stability of terrain objects to the impact of both natural and, primarily, man-caused factors. Therefore, in newly developed regions, it is necessary to pay special attention to the detection of zones of risk or intensive geomorphological processes, which are often not dangerous separately, but could have catastrophic consequences together.

The information framework of this research included materials of long-term geomorphological studies in the mountainous regions of the Major Caucasus of Azerbaijan. The dangerous geomorphological processes of the Major Caucasus of Azerbaijan were investigated in detail using large-scale maps, satellite imagery and aerial photography (1986-2018) with the ArcGIS software package (Hydrology, Stial, Analyst, 3D Analyst, etc.). Geomorphological maps were drawn.

The types of dangerous morphogenesis processes (main, accompanying, and secondary) and their intensity index, expressed in percentage of the areal extent of the process in a certain exo-geomorphological region, were compared to those of other processes.

Results. The results of the morphotectonic interpretation of the materials of structural and geomorphological decoding of satellite imagery and aerial photography materials of Major Caucasus and adjacent territories were analyzed to determine the geo-dynamically active borders of morphostructures, their spatial arrangement, and interrelation.

Endodynamic factors

The studied region has a complex morphotectonic structure. It is characterized by extensive overthrust masses, magma and mud volcanos, frequently changing bearing of trend of large morphostructures (Fig.1), active seismotectonic and neotectonic processes, clear differentiation of exogenous processes, etc.

The territory of Azerbaijan is an area of collision of the East European Craton and the Arabian Platform. The current morphotectonic frame of this region was formed by the subduction of the Meso-Tethys oceanic crust under the Anatolian-Iranian Platform (to the Late Cretaceous) and the collision of the Transcaucasian continental crust under the Scythian Platform with the Anatolian-Iranian crust under the Transcaucasian Platform. At that, various morphotectonic processes

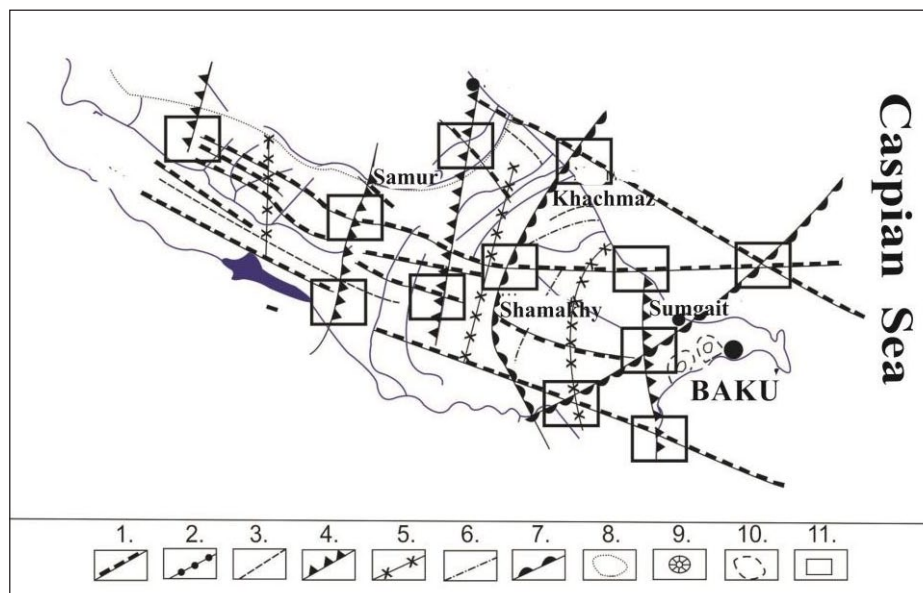


Fig. 1. Schematic map of morphotectonic intensity in Major Caucasus and adjacent territories (Alizade, 2004)

Lineaments that correspond to longitudinal (general-Small-Caucasus) faults (overthrust and upthrust): 1 – Regional deep faults that limit large longitudinal orogenic-block terraces; 2 – Local faults that correspond to the borders of longitudinal orogenic-block morphostructures; 3 – Fractures that determine the details of morphostructures.

Lineaments that correspond to longitudinal (anti-Caucasus) faults (overthrust and upthrust): 4 – Regional deep faults that limit longitudinal megablocks; 5 – Local faults that correspond to the borders of longitudinal block segments; 6 – Fractures; 7 – Large interregional diagonal volcanic centers; 10 – Ring structures (tectonic and volcanic). 11 – Geo-dynamically intense fields.

created a complex area that features the results of rifting and orogeny. Intensive, but differentiated horizontal and resulting vertical tectonic movements created rootless montane structures of the Major Caucasus.

The differentiation of compressions within the studied region caused the formation of imbricated and brachiform morphostructures, while the intensive formation of multiple disjunctive and folded dislocations caused the encroachment of surface rock plates on one another, which resulted in the formation of large surface overthrust masses, olistostromes, olistoliths, etc., which radically changed the morphology of this region's terrain (Alizade, 2004; Alizade and Tarikhazer, 2010, 2015).

Fault tectonics plays a major role in the enhanced tangential compression and extension of geoblocks during the formation of the current terrain of the Major Caucasus of Azerbaijan. The mountain terrain is especially complex and mosaic at the intersections of faults and fractures of various directions and orders. Large block morphostructures and their internal differentiation in fracture areas creates a complex and dynamic horizontal and vertical differentiation of the territory. This is seen from the fact that the intensive exogenous processes in these regions are almost always confined to weakened and endogenously fractured parts of the Earth's crust, i.e. zones of fractures, and are caused by block tectonics and limited to them (Alizade and Tarikhazer, 2010, 2015; Tarikhazer, 2006; Tarikhazer, 2010; Tarikhazer, 2013). It was found that virtually all large river valleys in orogenic regions are confined to complex and multi-order grids of lineaments – fractures.

In Azerbaijan, the most geo-dynamically active and dangerous geo-systems are those of the Major Caucasus, which is a large and complex mega anticlinorium, comprised mostly of Mesozoic, Paleogene, and Neogene sediment rocks and Quaternary sediments along river valleys, intermountain basins, and flat surfaces of rangelines.

In the Major Caucasus, endodynamically active ranges alternate with massive plateaus, large intermountain and intramontane basins, and high-mountain glaciers. The mountainous terrain is heavily affected by old and new erosion, which formed a dense network of multiple deep and narrow river valleys and rifts running in different directions. In general, the Major Caucasus is a highly mobile geotectonic area and one of the main seismically active belts on the Earth. The total range of new elevations in the Major Caucasus of Azerbaijan near the mountains of Bazadyzy, Shahdagh, and Tufandag over the Pliocene-Quaternary period exceeds 3600 m.

Despite the diversity of the structural zones that constitute the joint elevation, together they form a regularly arranged divergent horst-anticlinal structure, which is divided into a series of longitudinal block segments by large longitudinal lineaments. Eastern Caucasus, located to the east of the Transcaucasian longitudinal elevation, is divided from the periclinal submersion zone – the Southeastern Caucasus – by the large Western Caspian deep joint.

Exodynamic factors

The geological structure in combination with endodynamic processes that occur in the studied territory are one of the main factors that cause exodynamic processes. It is worth noting that the intensity of these processes largely depends on the geotectonic activity of separate blocks and disjunctive faults. For instance, most river valleys, large cliffs, and edges of terrain terraces are confined to the heterogenic multi-order grid of fractures.

The territory of Azerbaijan that is located in the geo-dynamically active zone is characterized by a high potential probability of occurrence of dangerous endo- and exo-geomorphologic processes. In the mountain regions of the Major Caucasus of Azerbaijan, these processes are primarily caused by intensive neotectonic and differentiated neotectonic movements, typical for the new Alpine-Himalayan orogenic belt, peculiarities of the morphological structure (distinct longitudinal and altitudinal zonation of morphostructures), climate, surface runoff, etc. An indirect but equally important effect on the intensity of development and stabilization of processes comes from vegetation – its floristic composition and plant cover. The lithological factor also has a significant impact. Man-caused processes have a dual effect: stabilizing at the local level (for instance, in case of forestation of hillslopes), but destabilizing during the development of regions (Gotvansky, 2010; Mazur, 2004; Jansky, 2006; Spengler et al., 2016; Kang et al., 2004; Lioubimtseva, 2009; Kuzmin, 2014).

For instance, mudflows, etc. are not subject to the latter. In general, most active catastrophic exogenous processes in the studied area are confined to steeper hillslopes of the Major Caucasus.

The most dangerous exo-geomorphological processes are dominant mostly in high-mountain zones – absolute altitude of 2200 m and higher. These include avalanches, landslides, rockslides, mudflows, etc.

Avalanches are intensive in the Central Caucasus, but in the eastern part of the Major Caucasus, this intensity decreases. The origination sites of avalanches are cirques, narrow erosion cuts, etc. The

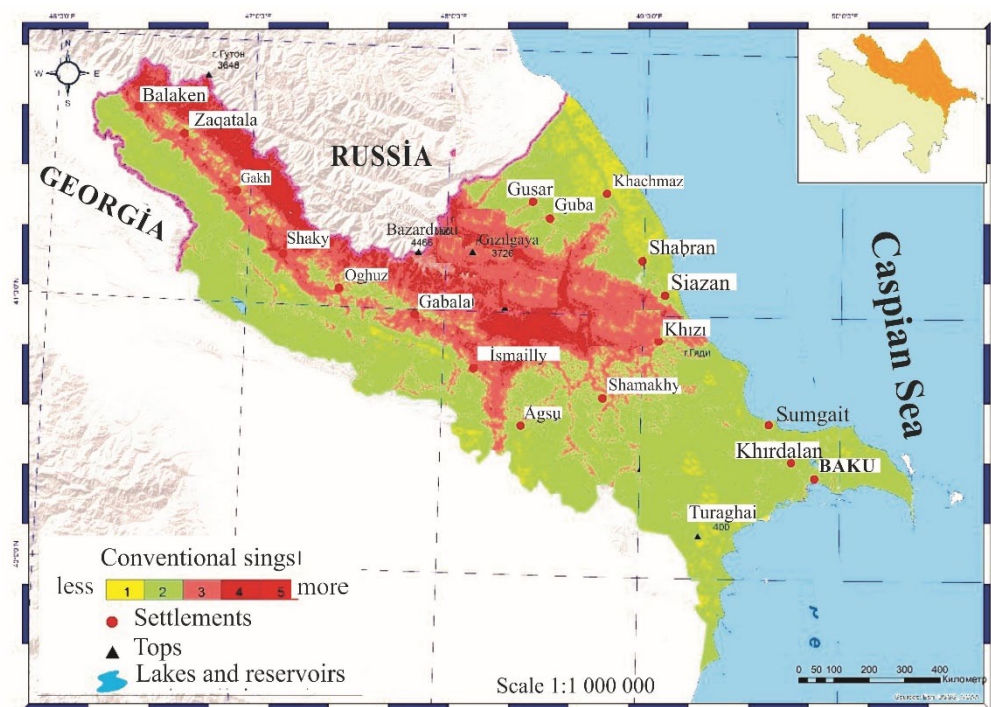


Fig. 2. Map of landslide hazard in the territory of Major Caucasus (in points) (compiled by Tarikhazer, 2018).

- 5 points – highly intensive territories with active landslide processes (landslide occurrence probable in 65-70% of the territory);
 4 points – intensive territories with active landslide processes (landslide occurrence probable in 50-65% of the territory);
 3 points – moderately intensive territories with intensive landslide processes (landslide occurrence probable in 30-50% of the territory);
 2 points – territories with relatively weak landslide processes;
 1 point – territories without landslide processes.

latter are often exposed to channeled avalanches, which are encountered most frequently and are very devastating. Their speed reaches dozens of meters per second, their pressure on a fixed obstacle ranges from dozens to more than a hundred tons per square meter. Avalanches mostly occur at altitudes of 2500-3000 m and higher. The consequences of snow avalanches, which destroy slopes, carry friable debris along avalanche channels, and deposit it at the foothills in the form of avalanche cones, are often found near Bazardyzy Mountain, Shahdag Mountain, Gyzylgaya Mountain, Tufandag Mountain, etc. On the slopes of the Main and Flanking Caucasus ranges, avalanches occur suddenly, destroy buildings, roads, and may cause death.

Dangerous gravitational processes that occur at all altitudes of terrain in Azerbaijan's mountains include landslides, rockslides, and screes.

High ranges, deep valleys, current tectonic mobility, and frequent earthquakes – all this is typical for the Major Caucasus. It creates a considerable potential for gravitational movements of large masses downhill. Ancient landslides are also frequent.

The results obtained during the research were used to draw a schematic map of landslide hazard in the territory of Major Caucasus (Fig. 2). The

parameters of landslide occurrence include the level of landslide activity, seismic activity of the area, man-caused effect, level of vegetation degradation, erosion stratification, lithological composition of constituent rocks, and landslide dynamics.

Landslides are frequently encountered within the Gusar inclined plain, where they occur in both loose and primary deposits and are mostly confined to valley sides. Their spatial development is associated with the outcroppings of Tertiary deposits in the basins of Velvelichay River, Gudiyalchay River, Garachay River, Agchay River, and Chagajugchay River.

In the Major Caucasus, landslides occur at virtually all altitudes, but mostly in medium-altitude mountains. On the southern slope of the Main Caucasus Range, between rivers Mazymchay and Goychay, landslides occur at altitudes from 1300 m to 3000 m. Here they occur in clay-marl rock masses and are caused, alongside other factors, by active faults and cleavage of rocks. Landslides primarily occur on side branches, which are characterized by steep slopes and clay composition, where significant humidification causes genetic types of landslides, such as tectonic-gravitational block slides, tearing, and mudflows (Yafiazova, 2009; Seversky et al., 2010; Lee et al., 2008; Schlögel et al., 2015; Duong, 2013).

In the high-mountain area of the southern slope of the Major Caucasus, landslides occur at the springhead of Shinchay River, on the slopes of some side branches near the Gdym mountain pass, on the slopes of Kazhal Mountain, Gotur Mountain, Peygyambyarbulag Mountain, and



Fig. 3. Landslip processes in Laza village on Major Caucasus

other mountains. In this case, tectonic faults play the major role in the development of landslide processes. Landslides also occur on the northern and southern slopes of the Flanking Range, on the southern slope of the Main Caucasus Range, in the basins of Gusarchay River, Gudiyalchay River, and Velvelichay River, and along the upper reaches of Garachay River, Jimichay River, etc. (Fig. 3, 4).

Rock-falls occupy a lot of space in the mountainous territory of Azerbaijan. They mostly occur in the high-mountain and medium-mountain areas of the Major Caucasus, especially on the slopes of the Flanking Range with its steep step-shaped slopes and the southern slope of the Main Caucasus Range, in the valleys of Velvelichay River, Gilgilchay River, Tugchay River, Sumqayit River, Kurmukchay River, Kishchay River, Talachay River, Belokanchay River, and others. Large rock-falls occur in the foothills of the Shahdag, Gyzylgaya, Buduq, Girdag, and other plateaus. Rock-falls cover the Gusarchay River bed between Shahdag Mountain and Gyzylgaya Mountain (Tarikhazer, 2010; Alizade and Tarikhazer, 2010, 2015).

Rock-falls that participate in mudflow formation occur within the high-mountain areas of basins of Kurmukchay River, Gusarchay River, Tikanlychay River, Velvelichay River and others (Fig. 5).

The slopes of trough valleys and cirques within the watershed of the northern slope of the Main Caucasian Range are unstable and exposed to rock-

falls and landslides. Large rock-fall and landslide masses are typical for the slopes of trough valleys of Tufan, Kurve, Garanlyg, and others.

In the Major Caucasus, landslide slopes are typically encountered in the high-mountain parts of valleys of Gusarchay River, Gudiyalchay River, Velvelichay River, and Jimichay River, as well



Fig. 4. Landslide processes in Sudur village on Major Caucasus

as in parts that cut into the synclinal plateau of the Shahdag-Gyzylgaya rock mass. In the Shahdag, Gyzylgaya, and Buduq high synclinal plateaus, the denudation part of landslide slopes is confined to cliffs and overhangs of gravitational and tectonic origin, and zones of altitudinal movement of certain limestone blocks along fault lines. The height of cliffs ranges from several dozens of meters to 500–600 m. The accumulative part of slopes occupies a similarly large area and frames the foothills of northern and southern slopes 6–8 km wide. Certain large limestone rocks several hundred m³ in volume move for 12–13 km. These deposits often fill the beds of longitudinal valleys (upper reaches of Gusarchay River) and accumulate at the foothills of the opposite slope. Vast deluvial deposits with an undulating and hummocky terrain were created by the rock-fall and landslide material at the southern wall of Shahdag and Gyzylgaya mountains — at the left edge of the Shakhnabadchay River valley, Ateshgah area, and the left edge of the Tskhoamush valley (left tributary of Gudiyalchay River), Guzuntakhta-Kechaldag area on the northern slope of Shahdag Mountain, and the Mykhtekian-Dyaligay area at the northern edge of the Gyzylgaya and Buduq plateaus (Tarikhazer, 2006, 2010, 2013).

Mudflows are common in the territory of Azerbaijan. In terms of solid particles (silt, crushed stone, rocks) in the flow, mudflows are divided into structural (mud-and-stone), stone, and mud.



Fig. 5. Mudflow material in channel of river Velvelichay

In the Major Caucasus, mudflow processes are encountered in all landscape and geomorphological zones – from low-mountain areas to high-mountain ones. Many highly populated settlements located in the basins of mudflow rivers are constantly exposed to the threat of mudflows. Mudflows are extremely devastating due to their hydrodynamic properties. They flow in waves, disable hydraulic facilities, destroy bridges, roads, and settlements, cause huge economic damage, and are often accompanied by human losses. For instance, a mudflow (Kishchay River basin) damaged the town of Shaki and caused human losses in 1997. Villages and cities exposed to the mudflow hazard are located near places where rivers run into piedmont areas – Balakan, Zaqatala, Shaki, Qakh, Oghuz, Gabala, Shabran, and others. Devastating mudflows occurred in the basins of Kurmukchay River (2002), Girdimanchay River (2011), Agsuchay River (2013), and others (Fig. 6).

Mudflow rivers in the Major Caucasus include Kishchay River (its largest mudflow tributary is Damarchik River), Shinchay River (including its tributaries – Shikhgaflan River and Babachay River), Kurmukchay River (including its tributaries – Bulanygsu River, Agbulaq River, Khamamchay River, Kunakhaysu, Agsuchay), Gumbash, Lyakit, Zeyzid, Gamzalicha Qatexchay, Talachay, Mukhakhchay, Mazymchay, Damiraparanchay, Dashagyl, Tikanlychay, Goychay, Gusarchay River, Velvelichay River, Gudiyalchay River, Atachay River, Devechichay River, upper reaches of the Sumgait River, and many others. Mudflow rivers in southeastern Caucasus include Tugchay River, Takhtakerpu River, Dzheyrankechmez River, and others. Other areas exposed to mudflows are the blind creeks and gullies in the Adjinour-Djeyranchol piedmont area, Gobustan, and others.

Discussion. The research discovered an intensifying occurrence of destructive natural phenomena in the

studied mountainous regions of the Major Caucasus of Azerbaijan, which is caused by an increasing effect of endo- and exogenous factors. Montane ecosystems, especially in Central Asian regions, are incredibly fragile and require an understanding of the entire complex of interconnected factors and processes that cause this fragility (Alizade and Tarikhazer, 2010, 2015; Gotvansky, 2010). The analysis of the factors that affect the development of dangerous natural phenomena found that besides commonly known causes that were described by other researchers (Budagov, 1993), an important role is played by the geomorphological factor, in particular, their confinement to the weakest plexuses of mountains – intersections of faults and fractures of various directions and orders.

Due to the complex interaction of natural and man-caused factors that cause the development of dangerous geodynamic processes in mountainous regions, it is very difficult to determine the specific role that each of these processes plays. Therefore, these processes should be considered in combination when forecasting the risk of occurrence of dangerous natural phenomena. This approach, which takes into consideration the entire set of factors, was taken to draw the schematic maps of landslide and mudflow hazard areas.

It is also worth noting that besides the geomorphological factors, which are the main cause of dangerous natural phenomena, climatic factors also play a significant role. In most cases, they serve as the catalyst of these phenomena and a factor that can upset the natural balance. Considering the fact that in the last decades, the average annual precipitation, evaporation, and surface runoff levels have increased in the high latitudes of the northern hemisphere due to earlier snowmelt caused by global warming (Lioubimtseva, 2009), this factor could not be ignored.

The technique of landslide susceptibility of

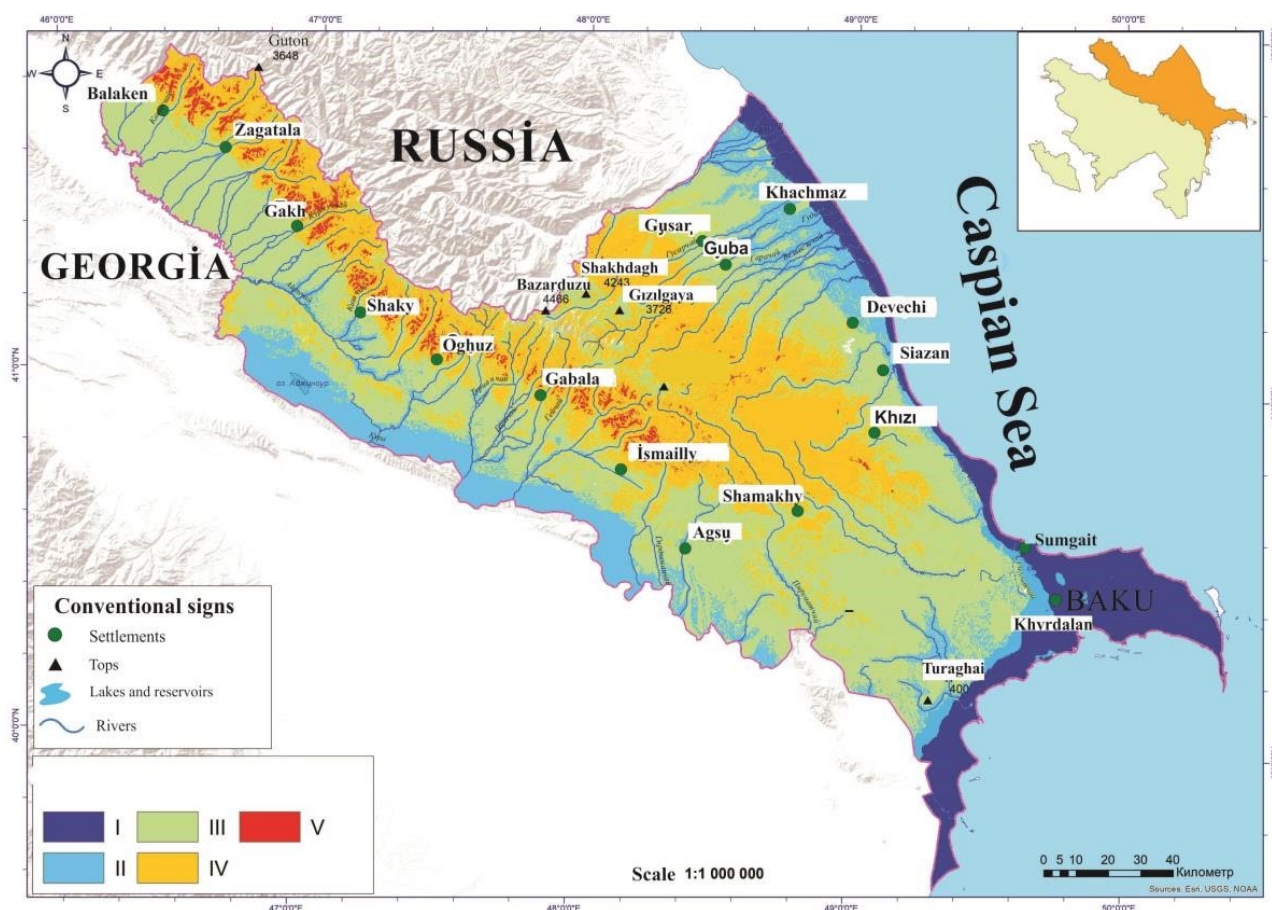


Fig. 6. Map of mudflow hazard in the Azerbaijani part of the Major Caucasus (compiled by Tarikhazer, 2018).

Territories, where there are no mudflow processes - I point.

Territories with potential mudflow hazard - II points.

Territories with a weak mudflow hazard (once in 5-10 years is possible 1 strong mudflow) - III points.

Territories with an average mudflow hazard (once in 3-5 years is possible 1 strong mudflow) - IV points.

Territories with high mudflow hazard (once in 2-3 years is possible 1 strong mudflow) - V points

the territory enabled taking into account not only the geomorphological and climatic factors, but also a number of other factors that participate in the occurrence, development, and manifestation of dangerous natural phenomena, such as the intensity of the studied phenomenon, the seismic activity of the area, manmade influence, erosion stratification, lithological composition of rocks, and the dynamic of the process.

The effect of human activities on the occurrence and development of dangerous geomorphological phenomena was proven once again. It was found that deforestation, overgrazing, and steep slopes in the mountainous regions of Major Caucasus in Azerbaijan created prerequisites for the occurrence of mudflows with scree, landslide, and rock-fall materials. Similar to other mountainous regions of Central Asia, excessive manmade influence triggers dangerous destructive natural phenomena (Kang et al., 2004; Anakhaev et al., 2016; Liubimtseva, 2009). The consequences of various manmade influences are

especially dangerous in regions that are undergoing intensive development. In areas with minimum natural process intensity, which are territories with increased risk, even the smallest intrusion might have catastrophic consequences (Seversky et al., 2010).

Presently, mountainous regions of Azerbaijan are exposed to active human activities: construction of tourist and recreation facilities, roads, canals and other line structures, deforestation, etc. All this can increase the amount of catastrophic consequences for the infrastructure and the population. Therefore, a top-priority task that can help to prevent economic and human loss is the organization of monitoring, with a view to collecting information and data that could allow detecting and anticipating destructive natural phenomena in Alpine-Himalayan montane geosystems.

Conclusion. The obtained results allow analyzing in detail the factors that facilitate the occurrence of dangerous natural phenomena in the mountainous regions of the Major Caucasus of Azerbaijan. Similar

to all orogenic zones, these areas are characterized by an increasing rate of dangerous destructive natural phenomena, which is caused by an increased effect of both natural and man-caused factors. The analysis of the manifestations of most active (with catastrophic consequences) destructive natural processes and the morphotectonic structure of the studied area showed that their occurrence and maximum intensity was confined to the weakest plexuses of mountains – intersections of faults and fractures of various directions and orders.

The analysis of large-scale maps, satellite images, and aerial photographs of the territory of Azerbaijan made from 1986 to 2018 determined the main geomorphological processes in specific regions of the country and their main causes. In such areas as the Shahdagh-Gyzylgaya rock mass, the Main Watershed Range, the Gonagkend-Khaltan intramontane basins, and others, the main geomorphological processes are earthquakes, landslides, scree, rock-falls, and snow avalanches; in the Gusar inclined plain – landslides, rock-falls, scree, and erosion processes; in the Samur-Devechi depression – eoliation and abrasion; in the Absheron Peninsula – earthquakes, landslides, gullies, arroyos, eoliation, and abrasion.

Due to the complex interaction of natural and man-caused factors that cause the development of dangerous geodynamic processes in mountainous regions, it is very difficult to determine the specific role that each of these processes plays. Therefore, these processes were considered in combination when predicting the risk of occurrence of dangerous natural phenomena. This approach took into consideration the entire set of factors, such as the intensity of the studied phenomenon, the seismic activity of the area, manmade influence, erosion stratification, lithological composition of rocks, and the dynamic of the process. Obtained data were used to draw the schematic maps of landslide and mudflow hazard areas and to outline the areas where they are most likely to occur.

The studied region was zoned in terms of landslide hazards according to a five-point system. The most intensive geosystems included territories where landslides could cover 65–70% of the total area. Such territories include medium-mountain and low-mountain zones of the Major Caucasus, the basins of Velvelichay River, Girdimanchay River, Gilgilchay River, Atachay River, Pirsatchay River, etc. The research found that the main factor that caused the emergence of new mudflow origination sites was favorable lithological conditions that facilitate denudation and exposure of slopes.

The most intensive landslide processes (with up to catastrophic consequences) in the Major Caucasus

occur in the low- and medium-mountain areas (basins of Sumgait River, Gusarchay, Gudiyalchay River, Devechichay River, Gilgilchay River, Atachay River, Kishchay River, Damiraparanchay River, Girdimanchay River, Shinchay River, etc.). Here, they are confined to argillaceous outcroppings of various age: in covering deposits, Jurassic, Cretaceous, and Tertiary clay and slate, as well as in Paleogene, Neogene, and Quaternary deposits.

Obtained results were also used to draw the schematic maps of mudflow hazard areas and to outline the most vulnerable areas with prerequisites for the occurrence of mudflows with scree, landslide, and rock-fall materials. These areas are mostly confined to nival-subnival, mountain-meadow, and, partly, mountain-forest landscape belts. They include scree, rock-fall, and landslide areas with alluvial cones of friable debris, accumulated in the foothills of southern and southwestern steep slopes and cliffs. Active mudflow origination sites in the nival-subnival belt are developed in the area of Akhvay Mountain (springhead of Bulanygsu River), Garagay Mountain (springhead of Shinchay River), and others; in the mountain-meadow belt, they are developed in the area of Garaguzey Mountain (springhead of Gaynarchay River), Kishchay River basin, etc.; in the mountain-forest belt, they are developed in the area of Kish village (Kishchay River basin), Shinchay River basin, the northern slope of Yarpuzbassar Mountain near Ilisu village, etc. Their main causes are the geomorphological structure and lithological composition of rocks, deforestation, overgrazing, and manmade influence.

The step-by-step method used to assess the effect of factors on the stability of montane geosystems provides for more accurate a detection of morphodynamic stress within separate montane geosystems and allows forecasting the development of dangerous geodynamic processes.

The scientific and methodological approach and the results obtained during the assessment of the effect of natural and man-caused factors on the stability of montane geosystems by the example of the Major Caucasus of Azerbaijan may be used to study geo-dynamically dangerous geomorphological processes in other regions of the Alpine-Himalayan orogenic belt, especially in France, Austria, Italy, Balkan countries, Switzerland, Georgia, Tajikistan, Kyrgyzstan, and other countries.

The obtained results can be used to plan and perform economic activities, determine and minimize the hazards and risks of occurrence of dangerous natural phenomena, and forecast such phenomena in the future.

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