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ABSTRACT

of the dissertation for the degree of Doctor of Philosophy

**STUDY OF EXODYNAMIC PROCESSES IN THE
TERRITORY OF THE NAKHCHIVAN AUTONOMOUS
REPUBLIC**

Speciality: 5408.01 – Physical geography, and biogeography,
soil geography, geophysics and geochemistry of
landscapes

Field of Science: Geography

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GENERAL CHARACTERISTICS OF THE WORK

Relevance of the topic and degree of development. The territory of the Nakhchivan Autonomous Republic is characterized by a sharply fragmented high-mountainous relief between the folded-faulted ranges of the South Caucasus. The orographic features of the region make it resemble a basin surrounded by high mountains. As a result, humid air currents from the Caspian and Black Seas are unable to enter the area, which in turn causes a dry and harsh continental climate to dominate the region.

The sharp fragmentation of the relief, the complex geological structure of the area (the widespread presence of rocks that have undergone intense dislocation with various lithological compositions starting from the Devonian period), and the modern climatic conditions are interconnected. The impact of the climate manifests itself more in the degree of relief fragmentation, the modern morphosculptures, and the intensity of denudation processes.

As in the rest of the world, in Azerbaijan, including the Nakhchivan Autonomous Republic, the rapid increase in anthropogenic impact on the environment in recent decades, the occurring climate changes, and the intensification of desertification processes have led to a significant change in natural-geographical processes and caused fundamental dynamic changes in natural complexes. In this context, the study and monitoring of the ecological situation of the area, where the mosaic and classification of vegetation cover are changing, and where any disruption could lead to irreversible consequences, is extremely important and relevant.

Although the Nakhchivan Autonomous Republic has been studied in detail from a geological and geomorphological perspective, there are almost no complex research works dedicated to the development characteristics of morphodynamic processes. The existing preliminary research works only cover some slope processes occurring in the area. However, the level of study of these processes is insufficient, and it does not allow obtaining

comprehensive knowledge about natural-destructive processes that pose a threat to the development of mountainous areas for economic purposes. Therefore, considering the relevance of the topic and the eco-geographical features of the area, this research could make important innovations in the study of the region's geological-geomorphological and landscape conditions. Furthermore, this topic is also essential for the conservation of the region's ecosystem and the sustainability of future agricultural projects to be implemented in this area. The study of exodynamic processes is of great importance in terms of developing scientific-practical recommendations to ensure the stability of the region's geosystems and prevent natural disasters.

During the research process, the scientific works of researchers such as M.A.Abasov, B.A.Antonov, M.A.Museyibov, B.A.Budagov, S.Y.Babayev, E.K.Alizade, Q.S.Mammadov, S.Y.Guliyeva, H.A.Khalilov, K.A.Tanriverdiyev, A.S.Safarov, V.A.Guluzadeh, R.S.Abdullayev, N.A.Pashayev, T.N.Kengerli, N.S.Bababeyli and others were utilized. In the development of the theoretical and methodological foundations of various exodynamic processes, the works of R.Shuster, C.Troisi, M.Anderson, C.Gökçeoğlu, A.Üçler, A.Uzun, H.Aksoy, M.Ercanoğlu, D.Benjamin, F.Guzzetti, Y.Okura, S.A.Tarikhazer, I.I.Mardanov, A.Z.Hajiyeva, S.N.Abushova, J.Y.Gasimov and others were employed.

The object and subject of the research. The object of the research is the territory of the Nakhchivan Autonomous Republic, which covers the Middle Arax natural region with a total area of 5,500 km². The subject of the research is the study of the exodynamical processes occurring in this area.

The aim and objectives of the research. The aim of the research is to scientifically analyze and investigate the widely distributed exodynamic processes within the study area individually and on a theoretical basis. To achieve this aim, the following objectives were set and accomplished:

- To analyze the main factors shaping the geomorphological environment and determine their influence on exodynamic

processes;

- To identify the spatial distribution patterns and genetic types of various exodynamic processes and to conduct corresponding regionalization;

- To develop recommendations aimed at improving the ecogeographical conditions of the area;

- To compile regionalization map-schemes using modern methods by enhancing the results of previous research in this field;

- To implement ecogeomorphological regionalization of the area based on morphometric indicators.

Research methods. The unique relief of the area, the diversity of hydrometeorological conditions, and the sharply continental climate have also influenced the methods and approaches of the research, as most of the exodynamical processes observed are located in the difficult-to-reach middle and high mountain belts. Here, studying them with traditional methods is not only challenging and time-consuming but also requires a significant amount of resources. Therefore, to solve the set problem, new cartographic and cartometric (Geographical Information Systems - GIS) approach methods were widely used. To ensure the accuracy of the results, various routes were carried out along river valleys, and field observations and photographs were taken in areas with different hypsometric conditions and relief features. In addition, traditional historical-geographical, mathematical-statistical, comparative, observation, and systematic analysis methods were employed, with references to large-scale topographic maps as well as data from various satellites such as Azersky, Landsat, and Sentinel-1.

Main propositions for defense:

1. The main factors shaping the geomorphological environment and their role in the formation of exodynamic processes;

2. The influence of exodynamic processes on the formation of exogenetic relief forms and landscapes;

3. Measures to combat exodynamic processes and ensuring their effectiveness;

4. Based on the interpretation of aerospace images, a map of the genetic forms of relief shaped by floods, along with their hazard levels, has been compiled;

5. Ecogeomorphological problems caused by exodynamic processes, their assessment, and mapping;

Scientific novelty of the research:

- The morphometric indicators of the relief were analyzed based on various maps (horizontal and vertical fragmentation, hypsometry, slope, and aspect), and the role of these indicators in the development of modern geomorphological hazardous processes was assessed;

- An integrated landslide susceptibility assessment for the Autonomous Republic was carried out using Geographic Information Systems (GIS) and remote sensing data;

- For the first time, an assessment of the landslide and debris flow hazard in the area was conducted;

- For the first time, an ecogeomorphological tension map was created based on morphometric indicators in the ArcGIS program.

Theoretical and practical significance of the research:

The results of this study create a starting point for further research into natural destructive events such as floods, landslides, and debris flows. At the same time, studying their causes and geographical distribution patterns, as well as zoning them according to the degree of hazard, provides a valuable resource for relevant authorities and can contribute to the development of key strategies for disaster protection. The cartographic materials prepared as a result of the research also have significant practical importance for the creation of a diversified transportation network, ensuring the safety of transportation, and the efficient implementation of landscape planning.

Approval and application. The main propositions of the dissertation have been presented and discussed at several scientific conferences, including: The Conference on Contemporary Issues in Nature and Economic Sciences (Ganja, 2019), Materials of the Republic Scientific Conference dedicated to the 95th Anniversary of the Nakhchivan Autonomous Republic (Nakhchivan, 2019), The

Republic Scientific Conference on Global Climate Change and the Modern Ecosystem of Azerbaijan (Baku, 2024), The International Scientific-Practical Conference on “The Impact of Modern Climate Changes on Natural Complexes and Economic Systems in Azerbaijan” (Baku, 2024), The Collection of Scientific Articles from the XVI International Scientific-Practical Conference “Technological Innovations and Scientific Discoveries” (Ufa, 2024), Forest Ecosystems under Climate Change: Biological Productivity and Remote Monitoring (Kazan, 2024), XIX International Scientific Conference “Development of Science in the XXI Century” (Dortmund, 2025).

The practical and scientific recommendations presented in the dissertation may be useful and relevant for the Ministry of Agriculture, Ministry of Ecology and Natural Resources, Ministry of Emergency Situations, and local government authorities of the Republic of Azerbaijan.

Organization where the dissertation was carried out. The dissertation was conducted at the "Geography" department of the Institute of Natural Resources under the Ministry of Science and Education of the Republic of Azerbaijan.

The total volume of the dissertation, with a mark indicating the volume of the structural sections of the dissertation separately.

The dissertation consists of an introduction, four chapters, conclusions and proposals, as well as a list of used literature, and a total of 180 pages. The work contains 22 figures, 8 tables, 2 graphs and 24 maps, and 260 titles of literature were used. The introduction consists of 8265 conventional characters, Chapter I – 52553 conventional characters, Chapter II – 75227 conventional characters, Chapter III – 53166 conventional characters, Chapter IV – 44413 conventional characters, conclusion – 4115 conventional characters, and proposals – 1806 conventional characters. The part without tables, graphs, figures and literature list has a total volume of 239622 characters.

MAIN CONTENT OF THE RESEARCH

In the “Introduction” section of the dissertation, the relevance of the topic is substantiated, the level of study of the problem is analyzed, theoretical and methodological issues are clarified, the object and subject of the research, as well as its aims and objectives, are defined. The scientific novelty and practical significance of the study are also presented.

The first chapter of the dissertation is entitled **“The Main Factors Shaping the Geomorphological Environment”**. Within the sub-sections of this chapter, the physical-geographical conditions of the study area are analyzed accordingly.

Two orographic units, where exodynamic processes are most extensively developed within the territory of the Nakhchivan Autonomous Republic, are of particular importance. The first and most significant is the Zangazur Range, followed by the Daralayaz Range. Although these mountain ranges form a unified orographic zone, they differ considerably in their morphological structures.

The southern half of the high-mountainous Zangazur Range, with an average elevation reaching approximately 3200 m, is characterized overall by significant deep dissection and steep slopes that create conditions favorable for the gravitational movement of weathering materials. In this area, the slope gradient is distinguished as the highest within the studied region, varying between 10° and 45° or even higher values. Similar to the Zangazur Range, the southeastern extremity of the Dareleyez Range features sharply dissected southern slopes, forming an extensive zone of nearly cliff-like slopes. Moving northwest from the Kukuchay River, the height and corresponding steepness of the slopes gradually decrease, which conditions a reduction in the intensity of debris transport and a more active accumulation of soil-forming deposits. Currently, most of the territory is covered with soil and vegetation, and, including the watershed of the range, it is relatively less dissected. Therefore, exodynamic processes manifest more weakly here compared to the Zangazur Range.

The genetic types, geographical distribution, as well as the

quantitative and qualitative characteristics of natural-destructive processes are directly related to the geological-tectonic structure of the area. From the perspective of geological structure and geotectonic development, the Nakhchivan Autonomous Republic represents one of the most complex and distinctive regions of the Alpine orogenic zone. Although the foundation of the relief was laid during older geological periods within a broad stratigraphic range from the Devonian to the Holocene it was primarily shaped during the neotectonic phase. According to Azizbeyov's (1961) classification, the tectonic structure of the northern part of the study area is defined by the presence of the Sharur-Julfa and Zangazur anticlinoria, as well as the Ordubad synclinorium that separates them¹.

Morphometric indicators of the relief function as indicators of various slope processes occurring in the area. Therefore, as the main morphometric parameters influencing and shaping the ecological environment, relief hypsometry, vertical and horizontal dissection degree, slope gradient, and slope aspect were processed using ArcGIS/ArcMap 10.4 software. As a result, morphometric maps of the area were compiled, and morphometric quantitative indicators were subjected to analysis.

Climate is a factor that determines the directions of geodynamic process development. The location of Nakhchivan in the subtropical belt, as well as in the transition zone to the continental type of this belt, creates conditions for a high number of sunny days throughout the year and, accordingly, a large amount of solar radiation. In the sloping plain along the Aras River, this indicator rises up to 2900 hours. According to P.S.Mirzayev's calculations, the vertical gradient of total radiation in the area increases by 0.8 kcal/cm² for every 100 m of elevation. Therefore, while the amount of radiation in the Aras plains is 150 kcal/cm², this value reaches 160 kcal/cm² in the high mountainous zone.

Due to the heating and cooling of bare rocks with high heat capacity, the meso- and microclimate of the area creates temperature

¹ Azizbekov, Sh.A. Geology of the Nakhchivan ASSR. –Moscow, – 1961, – 502 p.

conditions and amplitudes different from the surrounding environment during various periods of the year. For this reason, on south-facing slopes, temperatures rise up to 43-45°C during the warm season, while during the cold season severe temperature fluctuations are observed, reaching -30 to -33°C, which differ from the surrounding environment. Analysis of the conducted research materials shows that from 1961 to 2022, the trend of average annual air temperature across all stations of the autonomous republic, despite fluctuations in individual years, generally progresses along a certain linear trajectory. All these thermal changes condition the intensity of weathering processes of mountain rocks.

Overall, areas up to 1250 meters in the autonomous republic are characterized as arid zones. The maximum amount of precipitation is recorded at absolute elevations of approximately 2700-3000 meters, where the annual amount totals only 580-600 mm. Similar to temperature, there are trends in the long-term variations of atmospheric precipitation. Compared to the period 1981-2010, the average long-term precipitation amount at the Sharur station slightly increased (by 3%) during 2011-2023, while at other stations in the region it was observed to decrease by 0.4-15%. Precipitation amounts at Bichanak (14%) and Shahbuz (15%) decreased with more chaotic indicators.

Another significant factor playing a major role in the development of various geodynamic processes on slopes is the hydrographic network. There are more than 400 rivers of varying lengths within the natural region. Additionally, there are intermittent streams in the area that become active mainly during periods of intense torrential rainfall.

Vegetation, considered the main component against the development of slope processes, is poorly developed in the autonomous republic. In accordance with the continental climatic conditions, xerophytic plant formations dominate here, comprising 70% of the vegetation cover. Areas up to 1600 m in elevation are characterized as primary centers of intensive desertification processes. In geocomplexes subjected to severe

desertification, the vegetation cover formed by plant groups is less than 10%. In the mountainous zone, due to the washing away and transportation of fine particles, it is very rare to encounter soil types in which all genetic horizons are fully developed in the profile.

The second chapter of the dissertation is devoted to **“The Development of Exodynamic Processes and Exogenetic Landforms”**. In a relief characterized by complex morphotectonic structure and contrasting altitudinal zonation, the regular manifestation of exodynamic processes and their spatial and temporal impact on the ecological environment have led to the consistent development and distribution of exogenously formed relief features (morphosculptures)².

As a result of climatic variation along vertical belts, the following genetic relief forms and the relief-forming processes that create them are widespread in the area: in the high-mountain zone, alongside ancient glaciers and modern nivation and fluvio-glacial processes, intensive physical (frost) weathering, intensive gravitational processes on steep slopes with corresponding lithological composition and climatic conditions, and their associated forms prevail; in the mid-mountain areas, intensive denudation dominates, accompanied by landslide processes due to the somewhat shallow groundwater level and a decrease in slope steepness compared to the high-mountain zone; in the low-mountain and foothill zones, arid-denudation forms have developed. Unlike these, fluvial processes resulting from the activity of running waters are observed across all landscape belts, with their related ancient and modern relief forms distributed from the plains to the high mountains.

As in other mountainous zones, in the studied area river valleys formed under the influence of hydrodynamic processes are widespread as the main erosion feature. The activity of rivers

² Quluzade, V.A., Abdullayev, R.S. The Impact of Exodynamic Processes on the Ecological Conditions in the Mountainous Geosystem of the Nakhchivan Autonomous Republic // Proceedings of the Azerbaijan National Academy of Sciences, Earth Sciences Series. – Baku: – 2014. No. 3–4, – pp. 74–79.

intensifies especially on steep slopes with poorly developed soil and vegetation cover, which accelerates degradation processes in their catchment basins.

The rivers of the autonomous republic transport approximately 80,000 tons of solid sediment annually, with 40-42% of this load attributed to five rivers (Nakhchivanchay, Jahrichay, Alinjachay, Gilanchay, and Vanadchay). The mechanical composition of riverbed sediments and bank deposits varies significantly. For instance, the average diameter of sediments in Genzachay (near Genza village) ranges from 12 to 45 mm; in Ordubadchay (near Nüsüs village) from 9 to 35 mm; in Aylischay (near Aylis village) from 12 to 41 mm; and in Alinjachay (near Khanaqa village) from 6.2 to 34 mm. Overall, based on sediment size, rivers in the eastern part of the autonomous republic differ markedly from those in the western part. During flood events, these quantities fluctuate sharply, and the diameter of individual stones transported by floods can reach up to 2 meters³.

In the territory of the Nakhchivan Autonomous Republic, the large magnitude of relief declivity and high slope gradients, the intensity of linear erosion, frequent seismic shocks, as well as the impact of various anthropogenic factors create favorable conditions for the activation and development of landslide processes. Field investigations and other methods and approaches indicate that landslides are developing on the slopes of all major watercourses. For the first time, an inventory landslide map of the Nakhchivan Autonomous Republic was compiled by our team (figure 1). On the map, landslides have been classified into three main categories considering their activity and the natural factors influencing them. Simultaneously, their morphogenetic types, driving forces, moisture conditions of landslide slopes, and other relevant aspects have been studied in detail.

³ Bababayli, N.S., Gurbanov, G.H. On River Sediment Transport in the Rivers of the Nakhchivan Autonomous Republic // Scientific Works of the Nakhchivan Branch of the National Academy of Sciences of Azerbaijan. – Nakhchivan, – 2019. No. 2, – pp. 296–300.

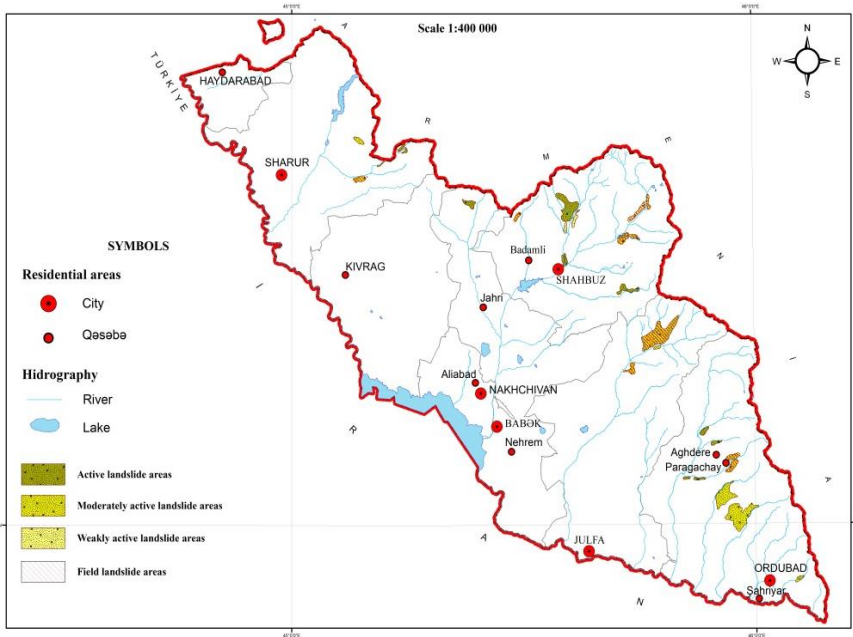


Figure 1. Geographical Distribution of Landslides in the Nakhchivan Autonomous Republic

One of the widely distributed exodynamic processes in the area is landslides. Analysis of large-scale satellite images shows that landslides in the territory of the Autonomous Republic extend both from north to south and from southeast to northwest. The first group of landslides stretches along the tectonic fault line in the first river valleys, while the second is located in the lower part of the middle mountain zone. In the visible spectrum, between wavelengths of 780 nm and 420 nm, landslides are primarily distinguished by their shadows and tonal contrasts. Typically, vegetation does not grow on landslide materials, and the slopes on which they occur are characterized by sharply steep appearances.

The geographic distribution, types, causative factors, main chemical composition, and physical properties of landslide materials have been studied using both traditional and modern remote sensing methods. Specifically, the mass of individual landslide materials and their geomorphological characteristics vary significantly from the low

mountains to the high mountains, and from the northwest to the southeast. The largest landslides are widely distributed in isolated laccoliths and surface dike outcrops in the middle mountain zone. Large landslide masses attract particular attention in the area located in the eastern part of the low mountainous zone of the Autonomous Republic, where a sharply continental climate prevails.

In some cases, talus deposits that do not significantly differ from landslides in terms of their formation mechanisms accumulate at the bases of steep and inclined slopes, creating distinctive morphological forms. Compared to other regions of Azerbaijan, this process is markedly pronounced across almost all altitudinal zones of the Autonomous Republic on the slopes of river valleys, mountainous plateaus, and also on the slopes of depressions. The main reason for this is the widespread presence of favorable geological, geographical, and especially climatic conditions throughout the area, which facilitate erosion and the development of its various types.

The area is composed of rocks with varying properties and, consequently, is subjected to differing degrees of physical weathering. Observations indicate that these processes are more intense in crystalline coarse-grained rocks compared to homogeneous fine-grained rocks. In certain locations, such as the central part of the Zangazur Range, particularly on the slopes of the Kapichiq (3904 m), Gemigaya (3726 m), and Gazangoldag (3829 m) peaks, the color of the rocks (dark gray) plays a significant role in the initiation and intensity of weathering⁴. Therefore, the foothills of these mountains, and sometimes even the slopes of the hills, are covered by numerous rock fragments and various colluvial materials. This is because weathering processes on these slopes are so intense that denudation does not always manage to remove all the produced material. Similar colluvial slopes are also evident on the steep and sharply dissected slopes of the Yaglidere (3825 m), Ayichingil (3707 m), Demirlidag (3368 m), and Esshekmejdani (2862 m) ridges.

⁴ Gurbanov, G.H, Mardanov, İ.İ, Gurbanov, A.K. Characteristic of the scree formation process and influence on the development of floods in Nakchivan Autonomous Republic. // Journal of Geology, Geography and Geocology. – 2024. 33(2), – 263-273. doi:10.15421/112424

In general, the rocky-colluvial zone formed on individual peaks in Zangazur covers an altitude range of approximately 2900-3400 meters. Unlike the lower belts, the colluvial deposits here consist of coarser particles. The size of the materials is also influenced by the type and chemical composition of the rocks that compose them. While the diameter of individual debris materials can reach 0.5-2 meters, the size of andesitic rocks does not exceed 10-50 cm. This also applies to clayey schists.

According to calculations by S.Y.Guliyeva, approximately 20 thousand hectares of the area, which exceeds 97.56 thousand hectares with an absolute altitude over 2000 meters, are covered by rock fragments, rubble, and colluvial materials⁵.

Despite the accumulation of a considerable amount of colluvial material in the upper section of the high mountain zone, these materials practically do not participate in the formation of debris flows. However, in the middle and low mountain belts, these materials act as catalysts for debris flows. Such a hazard exists in all river basins of the Autonomous Republic. Nevertheless, the lower slope gradient of the northwestern part compared to the southeastern slopes significantly reduces this risk. In the Ordubadchay basin alone, the volume of colluvial-debris material transported during a single debris flow event exceeds 1-1.5 million cubic meters.

In order to assess the impact of the dynamics of high-mountain ecosystems on ecological balance within the study area, changes occurring in mountain glaciers were also investigated. Analyses based on satellite imagery indicate that currently, in the high-mountain regions of the Zangazur-Daralayaz range, perennial firn and snow patches are found only around the Kapichiq peak. The area and number of preserved snow patches significantly depend on the volume of solid atmospheric precipitation received in different years. Interpretation of orthophotos from three separate years revealed that these areas were 1.98 km² in 2018, 0.82 km² in 2020, and 0.04 km² in 2023.

Following the interpretation of satellite images, a field survey

⁵ Guliyeva, S.Y. Desertification in Arid and Semiarid Mountain Geosystems. – Baku, – 2011. – 178 p.

was conducted on August 28-29, 2024, during which the number and dimensions of snow patches were precisely determined. During the field research, approximately 10 snow patches were observed in the area, which cannot be classified as small glaciers. Only near the source of the Nasirvaz river is there a glacier area of approximately 2.36 hectares. As a result of global warming, while the nival zone is shifting upward, the expansion of alpine and subalpine meadows is not occurring or proceeds very slowly in many locations. In other words, while landscape degradation is intensifying, its recovery is proceeding at a very slow pace. This, in turn, leads to an increase in the volume of debris flows.

The soils of the Nakhchivan Autonomous Republic belong to the category of the most severely eroded soils in Azerbaijan. Formed under various climatic conditions, 70% of these soils are affected by water erosion, 3.7% by wind erosion, and 3.2% by irrigation erosion, or are prone to such erosion⁶. Additionally, due to the rapidly increasing impacts of global warming, a significant portion of the region's fertile soils is shifting from higher quality groups to lower quality groups.

Research conducted by Kh.M.Mustafayev shows that under the influence of a single heavy rainfall event, 200-300 m³ of soil is washed away per hectare from mountain slopes. Such transfer processes, occurring under arid climatic conditions, are most pronounced between the Paragachay and Kilitchay rivers. As a result, not only is the valuable topsoil layer lost, but the underlying soft soil-forming parent rocks are also eroded and disintegrated, leading to the formation of extensive surface, linear rills and gullies.

Although the erosion process does not cause social losses, the direct and indirect damage it inflicts on the economy particularly the agricultural sector can, in many cases, be comparable to the losses caused by dangerous exodynamic events.

In the territory of the Autonomous Republic, typical karst landscapes are distributed in much more limited areas compared to other exogenically formed relief features. The main reason for this is

⁶ Hajiyev, S.A. Problems of soil environment protection in the Nakhchivan Autonomous Republic / S.A.Hajiyev, G.R.Mirzali-Agatagi. – Baku: Teacher, – 2021. – 164 p.

that the lithological-petrographic composition of the rocks mainly consists of volcanic rocks. However, karst cavities have formed in Mesozoic and Paleozoic carbonate rocks distributed in the Dərəleyez Range and to its west. At the same time, in the high-mountain and mid-mountain parts of the Zangazur Range (between the Nakhchivanchay and Ayrichay rivers), karst cavities and caves measuring 10-30 m³ are encountered in Upper Cretaceous limestones. Particularly, the occurrence of large-scale landslides here increases the likelihood of the presence of karst cavities. For example, the landslide event that occurred on June 24-25, 2024, in the Zangazur Range (near Göygöl) directly resulted from the collapse of karst cavities. The main indicators of this event were wells formed on the earth's surface and funnel-shaped landslide depressions.

The third chapter of the dissertation is dedicated to **“Measures to Combat Exodynamical Processes”**. From the above analyses, it can be concluded that the study of exodynamic processes and the development of measures to combat them in the Autonomous Republic are highly relevant both scientifically and practically. Although natural factors initiate exodynamic processes, human improper economic activities have played a significant role in their development and acceleration.

In practice, the measures most commonly used to combat slope processes can be grouped as follows:

- Reducing the driving forces
- Protective measures
- Increasing protective-frictional forces

The effective implementation of such measures not only ensures the weakening of landslide activity but also prevents other potential geodynamic risks (such as floods and erosion) and facilitates the sustainable use of natural resources.

Terracing of slopes holds an important place among control measures and is widely applied in many countries. Channel-graded terraces are technically and economically more advantageous; therefore, their application is appropriate in the mountainous zone of the Nakhchivan Autonomous Republic.

In the Autonomous Republic, particularly in areas where large landslide zones exist west of Kuku village, near the village of Gyzył

Kyshlak, at the confluence of the Gomur river with Nakhchivan river, northeast of the confluence of Dibsuy with Nakhchivan, as well as around Havush village numerous studies we have conducted suggest that if surface drainage systems were constructed in these areas, the soil moisture content would decrease and damages could be minimized. Therefore, drainage measures are of great importance for damage mitigation.

Regarding the types of drainage structures, the most economical and widely used are ditches and channels⁷.

Road complexes represent one of the fundamentally altered landscape types and play an important role in the anthropogenic transformation of natural landscapes. The construction and operation of various roads, especially automobile and railways, adversely affect individual components of the landscape and natural territorial complexes as a whole. In mountainous areas, road construction primarily leads to fragmentation of vegetation complexes, disruption of the lithological base of the landscape including soil and substrate, and disturbance of the ecological balance of the area. Therefore, during road construction, the external appearance and shape of the relief, slope steepness, visibility, vertical and horizontal fragmentation of the surface, as well as soil and rock properties, must be examined from geological and geophysical perspectives and expert opinions obtained prior to commencing work. Otherwise, after the road is put into operation, certain sections may experience subsidence, landslides, avalanches, debris flows, and other processes. For example, during the construction of the Axura-Havush, Unus-Pazmari, Jahri-Payiz-Buzgov, and Kolany-Bichenek automobile roads, frequent landslides and slope failures have occurred in some sections due to neglecting natural conditions. Simultaneously, floodwaters forming on mountain slopes damage the asphalt surface and cause large gullies on the roadbed. In 2024 alone, five landslide events were recorded on these roads.

From this perspective, considering the impact of natural disasters on automobile roads, high-risk zones must be identified and preventive

⁷ Benjamin, D.H. A Design Method for Landslide Surface Water Drainage Control // Environmental & Engineering Geoscience, Vol. XXIII, No. – 4, November 2017, – pp. 275-289.

measures implemented in these areas. Thus, the scientific research conducted focused not only on calculating the damage inflicted on this sector but primarily investigated the types, spatial distribution, and intensity of natural disaster events (table 1.).

Table 1.

The roads with a high risk of floods, landslides, and mudflows

District	Flood risk	Rockfall and landslide risk
Ordubad	Channab-Duylun, Yukhari Aylis-Ashaghi Aylis, Diza-Vanand, Dasta-Khanagha, Gilanchay-Bash Diza-Aza, Bilav-Behrud, Unus-Kalaki-Dimis, Ganza-Anabad, Nusnus-Yukhari Andamic, Tivi-Bilav, Ordubad-Kotam, Ganza-Ordubad	Bilav-Bist-Alahli-Khurs-Nurgut, Paragachay-Aghdara-Tivi-Nasirvaz, Ustupu-Mazra, Unus-Pazmari, Pazmari-Urmis, Ashaghi Andamic-Ganza
Julfa	Jamaldin-Arazin, Arazin-Gizilca, Abraqunus-Kirna, Bananiyar-Goydara, Gazanchi-Milakh, Arafsa-Laketag-Boyahmad	Arafsa-Laketag-Boyahmad, Milakh-Teyvaz
Shahbuz	Salasuz-Dayagli, Garababa-Ayrinj, Shahbuz-Badamli, Shahbuz-Nursu, Shahbuz-Shahbuzkand, Kulus-Kechili, Shahbuz-Gizil Gishlag-Kuku, Bichanak-Ashaghi Gishlag	Kulus-Kechili, Badamli-Shada, Badamli-Guney Gishlag, Guney Gishlag-Gizil Gishlag, Gizil Gishlag-Kuku, Ashaghi Gishlag-Yukhari Gishlag, Kolani-Bichanak.
Babek	Ashaghi Buzgov-Yukhari Buzgov, Jahri-Gulshanabad, Karimbayli-Kultepa, Zeynalddin-Sirab, Zeynalddin-Gahab	Jahri-Payiz, Payiz-Ashaghi Buzgov, Ashaghi Buzgov-Yukhari Buzgov-Garmachatag
Kangarli	Garabaglar-Chalkhangala, Aliabad-Chalkhangala	Garabaglar-Chalkhangala
Sharur	Diza-Akhura-Havush, Diza-Yukhari Yayji	Diza-Ashaghi Yayji, Ashaghi Yayji-Yukhari Yayji, Gumushlu-Shahbulag, Akhura-Havush, Akhura-Billava-Tananem.
Sadarak	Damirchi-Gunnüt, Damirchi-Garaghaj	Damirchi-Gunnüt.

(This table was compiled using data from S.Y.Bababayev (1999), the

Atlas of Emergency Situations of the Nakhchivan Autonomous Republic (2017), N.A.Pashayev (2018), as well as ground observations, multispectral satellite imagery, and large-scale topographic maps).

Within the system of comprehensive measures aimed at improving the ecogeographical conditions, phytomeliorative interventions hold a special place. Anthropogenic impacts on the existing landscapes in the area are not only observed in the alpine zone of the high mountains characterized by steep rocky and inaccessible terrains. Other areas, which are used as pastures, have undergone significant changes and modifications. To analyze this factor, the dynamics of vegetation cover in the study area were monitored, and satellite images from Landsat 5 (June 1990) and Landsat 8 and 9 (August 2013 and 2024) were processed. During the image processing, data from bands 3 and 4 of Landsat 5, and bands 4 and 5 of Landsat 8 and 9 were utilized⁸. By comparing the processing results of satellite images from all three periods, changes in vegetation cover in the area were identified (table 2.).

Table 2.
Dynamics of Vegetation Index Distribution in the Research Area

NDVI	Area		
	10.06.1990	8.08.2013	24.08.2024
	km ²	km ²	km ²
< 0	2010,5	47,2	53,1
0 - 0,1	2504,4	1817,3	1761,6
0,1 - 0,2	499,1	2470,8	2873,5
0,2 - 0,3	252,8	758,4	496,6
0,3 - 0,4	174,6	349,4	267,7
0,4 - 0,5	57,7	73,5	63,3
0,5 - 0,6	17,4	5,2	6,0
0,6 <	5,3	-	-
Total area	5521,8	5521,8	5521,8

Note: Compiled based on Landsat 5, 8, and 9 satellite data.

⁸ <https://earthexplorer.usgs.gov>

As shown in the table, the areal extent of some indices has increased over the years, while others have decreased. From the perspective of analyzing exodynamic processes, the most notable change is observed in the areas with an index of 0.5-0.6 (densely vegetated). Specifically, the areas covered by dense vegetation decreased approximately 4.4 times, from 22.7 km² to 5.2 km² over a period of 13 years. In 2024, however, this area increased by 0.8 km² compared to 2013, reaching 6 km². These changes in vegetation indicate the necessity of paying greater attention to environmental protection and implementing special measures in the autonomous republic.

Human economic activities, on the one hand, contribute to the deterioration of soil quality and the development of erosion processes. On the other hand, when agro-industrial practices are properly observed, this process can not only be completely halted but also the fertility of eroded soils can be restored, enabling an increase in the productivity of agricultural crops in the fields.

Among phytomeliorative measures, the most effective is the planting of forests and shrubs on steep and erosion-prone slopes. The correct selection of plant species to be used for planting trees and shrubs is very important. In this case, plants should be chosen from low-growing, drought-resistant genera that have low requirements for soil fertility. Several researchers, such as I.S. Safarov and S.Y. Guliyeva, note that planting almond, pistachio, and walnut on dry slopes in the autonomous republic yields greater benefits. However, in our opinion, the most effective is the planting of rosehip, dogwood, juniper, almond, buckthorn, hawthorn, and other trees and shrubs. This is because the distribution of these plants across different altitudinal zones indicates their high adaptability to ecological conditions. Otherwise, the resources and labor invested will be in vain.

This chapter is titled “**Ecogeomorphological Zoning of the Area**”. In this chapter, zoning maps of exodynamic processes widely distributed across the territory of the autonomous republic have been developed, and zones with different risk levels have been identified on these maps.

A semi-quantitative approach based on expert knowledge the Weighted Overlay Method was applied for mapping landslide susceptibility (figure 2.). This model can also be interpreted as a multi-layer and multi-criteria assessment. It is obtained by overlaying multiple raster layers with weights assigned both between layers and within each layer based on expert judgment. The resulting output is visualized, and suitable and unsuitable areas within the studied region are identified.

During the model implementation, initially, the values in the input rasters are reclassified into a common evaluation scale, a suitability or similar composite scale. Each input raster cell value is then multiplied by the raster cardinality and added to the cell values obtained to create output rasters. In the third stage, each raster layer is weighted according to its importance or expert-determined impact percentage, considering the landslide component. The sum of assigned weights is evaluated to equal 100%. Finally, the generated raster-based result is transferred to slope units in proportion to the raster weight percentage within each slope unit.

Parameters influencing landslides, such as slope gradient, aspect, elevation, terrain curvature, proximity to river-valley networks, proximity to roads, NDVI, proximity to fault lines, and precipitation, were used to determine the risk zones⁹.

As seen from the map, areas with very high and high landslide susceptibility include the Nakhchivanchay valley and its tributaries, particularly the Kukuchay basin, as well as the middle reaches of the Axurachay, Alinjachay, and Gilanchaay rivers extending up to the watershed of the Dərəleyez and Zangazur mountain ranges. The mid-mountainous areas, especially the middle reaches of Nakhchivanchay, Alinjachay, Qaradərəchay, and Gilanchaay, the upper reaches of Bagirsagdərəchay, Yayji, and Jahrichay rivers, the entire basins of Dyulunchay, Vanandchay, Aylischay, and Ganzachay, as well as the slopes of

⁹ Gurbanov, G.H. Analysis of landslide susceptibility in the Middle Araz Basin (Nakhchivan) using GIS. – *Baltica* 38 (1), – 2025. – pp. 1-14. Vilnius. ISSN 0067-3064.

elevations such as Gulustan, Ilanlidag, Nehechir, and others, demonstrate moderate landslide susceptibility. Low and very low landslide susceptibility is observed in the gently sloping plains along the Aras River, the wide smooth bottom relief of intermontane depressions, and the central parts of leveling surfaces. In these areas, where the slope sharply decreases, small-scale and localized landslides occur rarely, mostly following heavy torrential rains and as a result of human economic activity.

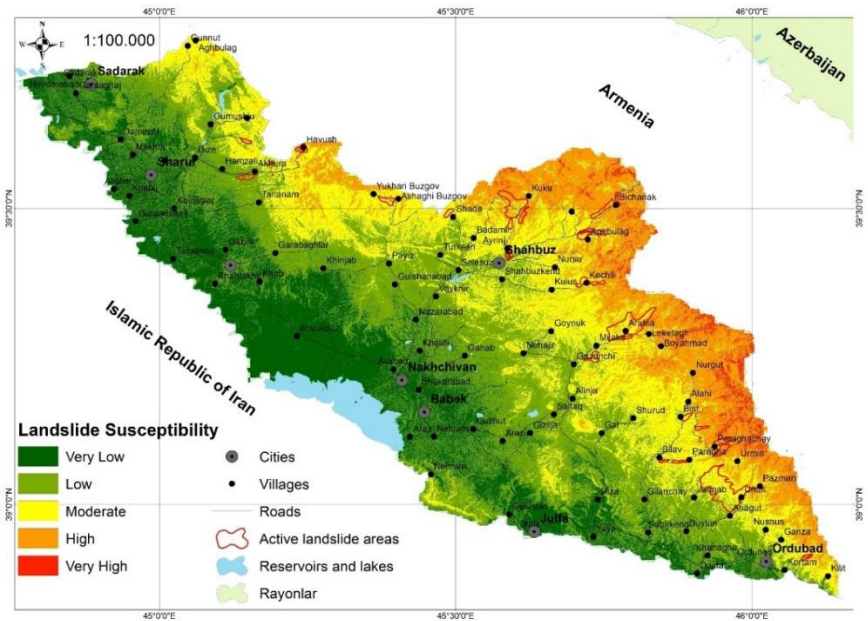


Figure 2. Landslide Susceptibility Map of the Middle Araz Basin

The study and mapping of landslide sites using traditional methods not only pose logistical challenges but also require significant time and financial resources. Therefore, based on the opinions of various researchers, it is possible to rapidly and effectively identify potential risk areas using Digital Elevation Model (DEM) maps. A critical factor here is the resolution of the DEM map to be obtained, since high resolution ensures that the

terrain slope closely reflects reality. In this study, a DEM map with a 12.5-meter resolution covering the research area was acquired using the ArcGIS software. To identify potential hazard sources based on GIS technology, the following formula was used.

$$\alpha = 55 * RES^{-0,075} ,^{10}$$

α (degrees): slope angle for potential risk areas;

RES: resolution of the digital elevation model.

According to the formula, the critical slope was determined to be 45.5° for the DEM map with a resolution of 12.5 m. Based on the obtained results, areas with slopes of 45.5° and above are considered potential zones for landslide occurrence.

To verify whether each point on the map corresponded to potential landslide sites, the KML file was added to Google Earth in 3D format, and detailed observations were conducted accordingly. During field research, the accuracy of the potential landslide sites marked on the map was confirmed, and some points that appeared as potential hazard sources on the map but currently had no landslide probability (mainly in the forested area of the Batabat region) were removed from the map.

In the second phase of the study, using Google Earth imagery and ground observations, wide areas with slopes less than 45.5° but where landslides had been observed were easily distinguished and added to the map. As a result, for the first time, a map-scheme showing areas extensively affected by landslides and colluvial deposits was developed for the territory of the Nakhchivan Autonomous Republic (figure 3.). According to statistical calculations, the total area of these sediment-accumulating sites amounts to 689.8 km².

¹⁰ Troisi, C., Berger, F., Dorren, L. Protection de la viabilité alpine. PROVIALP project report. – 2008.

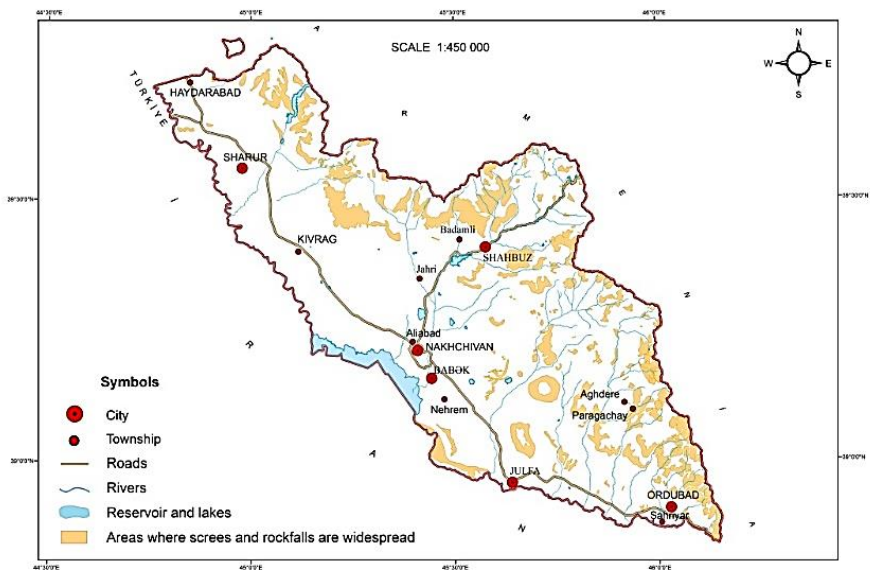


Figure 3. Areas where screes and rockfalls are widespread

The majority of natural disasters in the territory of the Autonomous Republic, specifically 26%, are related to destructive floods that have occurred in various years¹¹. Therefore, based on aerospace imagery and by illustrating the genetic forms of relief shaped by floods, a map at a scale of 1:100,000 was compiled (figure 4.). The map distinguishes five zones differing in terms of flood hazard¹².

1. Zone with no observed floods. This zone covers the parts of the Zangazur and Daralayaz mountain ranges above 3000 meters. Although well-developed exaration and glacial accumulation are widespread here, they do not generate flood processes within the zone.

2. Zone of weakly active structural floods. This zone includes the

¹¹ Atlas of Emergency Situations of the Nakhchivan Autonomous Republic. – Nakhchivan, – 2016. – 247 p.

¹² Bababeyli, N.S., Gurbanov, G.H., Hajiyeva, G.S. Study of the Geomorphological Characteristics of Flood Basins in the Nakhchivan Autonomous Republic // Scientific Works of Nakhchivan University, – Nakhchivan: – 2019. №3, – pp. 227-235.

middle and upper sections of the high mountains, approximately from 2100 to 2900 meters above sea level.

3. Zone of moderately active floods. This zone covers areas between approximately 1700 and 2100 meters above sea level. Floods in the river basins of this zone usually occur during the warm season as a result of heavy rains and snowmelt.

4. Zone of highly active floods. This zone covers the Aras lowland. Unlike the previous zone, floods here have turbulent flow.

5. Zone of destructive, highly active floods. This zone is located above the highly active zone in the low foothill belt. Poor vegetation cover, abundance of collapse-derived debris, strong flows coming from higher elevations, as well as the absence of natural barriers against floods, cause catastrophic and extremely powerful flows in this area.

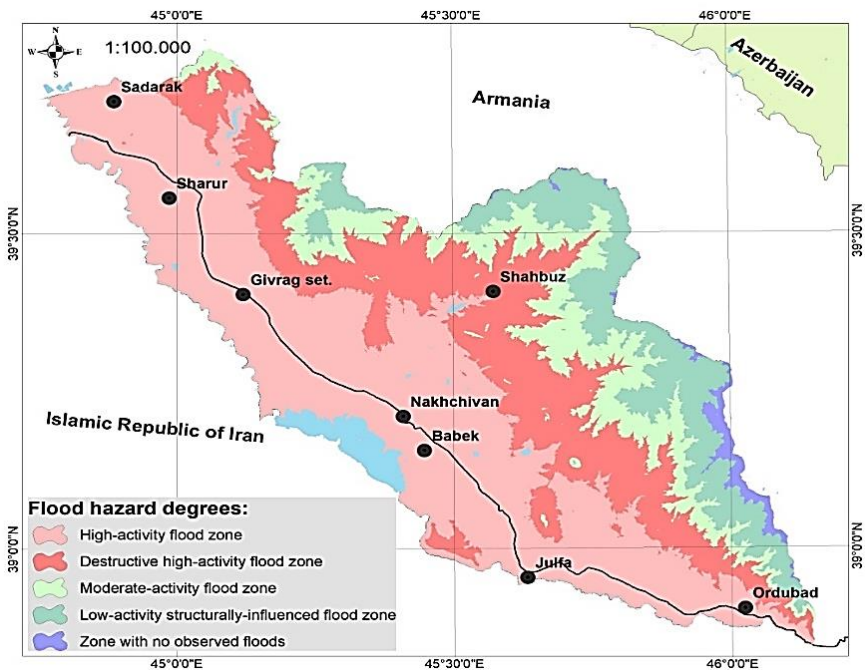


Figure 4. Zoning Based on Flood Hazard

For the purpose of assessing the eco-geomorphological stress of the area, slope inclination and aspect, as well as vertical and horizontal fragmentation maps, were jointly analyzed and compared in ArcGIS software. The areas ranging from the lowest to the highest values of these parameters were overlaid accordingly, and a stress map was produced (figure 5.).

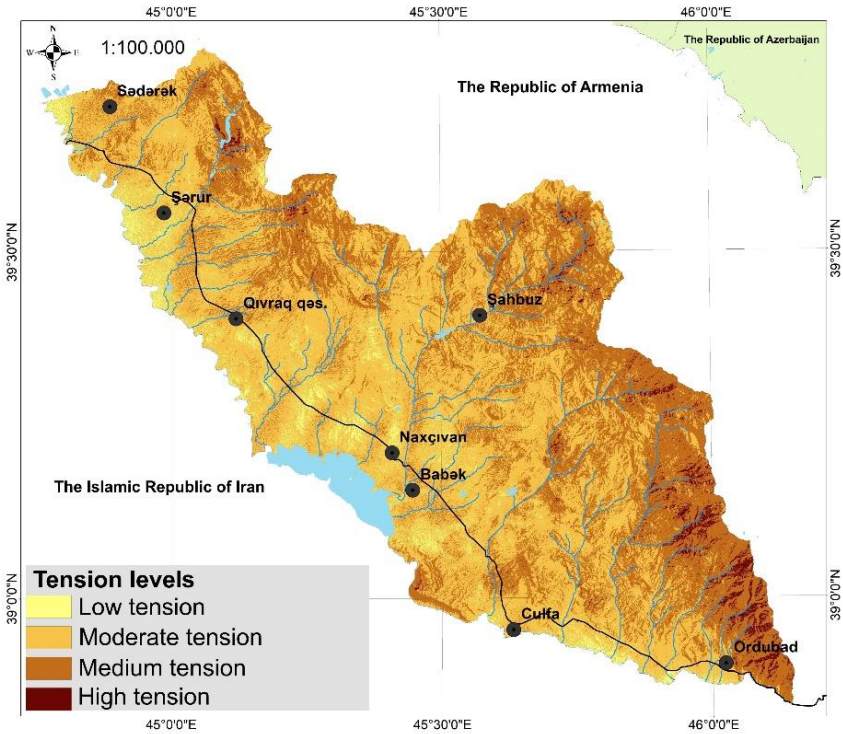


Figure 5. Ecogeomorphological Stress Levels of the Nakhchivan Autonomous Republic

On the map, low values of morphometric indicators are shown with light tones representing areas of low stress, while high values are depicted with dark tones indicating areas of high stress. The statistical calculations performed have been summarized in table form (table 3.).

Table 3.

Distribution of Ecogeomorphological Stress Levels by Area and Percentage Ratio

	Stress Levels	Area	
		km ²	%
1	Low Stress	291,3	5,3
2	Moderate Stress	3143,4	57,1
3	Medium Stress	1949,7	35,4
4	High Stress	118,6	2,2
Total area		5503	100

The results of the study are of significant importance for identifying ways to enhance resilience against natural disasters and ensure safety in the territory of the Autonomous Republic, while also providing a solid theoretical foundation for future scientific research.

CONCLUSIONS

1. The complexity of the geological-geomorphological structure, the presence of numerous active tectonic faults, steep slope gradients, horizontal and vertical dissection, and anthropogenic factors have led to the widespread occurrence of exodynamic processes in the territory of the Nakhchivan Autonomous Republic.

2. The geographical distribution of landslides in the Nakhchivan Autonomous Republic, their morphogenetic types, main driving forces, and the moisture conditions of landslide-prone slopes have been thoroughly analyzed. The zone of the most intense landslide activity includes the upper basin of the Nakhchivanchay River, the Batabat massif, the Bichenek forest, the middle course of the Kukuchay River, and the settlements of Kechili and Zirnel. Both glacial and delapsive types of landslides are widespread in these areas. Overall, landslides composed of dry and moderately moist

material are predominant, while extremely moist landslide types are the least represented.

3. For the first time, a landslide inventory map and a landslide susceptibility map have been developed for the Nakhchivan Autonomous Republic. In the inventory map, landslides are categorized into three main classes (active, moderate, and weak) based on their activity and influencing natural factors. In the susceptibility map, the territory is divided into five classes (very high, high, moderate, low, and very low susceptibility). Analyses show that areas with very high and high susceptibility are concentrated in the Nakhchivanchay valley and its tributaries, especially the Kukuchay basin, as well as the middle courses of the Akhurachay, Alinjachay, and Gilanchay rivers, extending to the high mountainous regions up to the watershed of the Daralayaz and Zangezur ranges. Here, high-energy relief with deep dissection, 8-9 magnitude seismic activity, longitudinal and transverse tectonic faults, poorly developed vegetation cover, and heavy convective precipitation (especially storm-type rainfall) create favorable conditions for landslide development.

4. For the first time, a landslide potential map of the Nakhchivan Autonomous Republic was created using ArcGIS software. Based on the results obtained, areas with a slope gradient of $45,5^\circ$ or higher are considered potential zones for landslide occurrence.

5. For the first time, using both traditional and modern cartographic methods, a map showing areas widely affected by landslides and rockfalls has been prepared for the territory of the Nakhchivan Autonomous Republic. According to statistical calculations, the total area of these sources is 689.8 km². The analysis of research data shows that potential landslide zones extend both from north to south and from southeast to northwest. The first direction aligns with river valleys, while the second follows a tectonic fault line along the lower part of the middle mountain zone.

6. Based on the complex analysis of morphometric indicators, an ecogeomorphological stress map has been developed. According to the degree of ecogeomorphological stress, the map distinguishes

four zones: low stress (291.3 km²; 5.3%), moderate stress (3143.4 km²; 57.1%), medium stress (1949.7 km²; 35.4%), and high stress (118.6 km²; 2.2%). Moderately stressed areas dominate the studied territory. Even a visual (non-measured) analysis of the map indicates that ecogeomorphological stress increases from the Araz River toward the Zangezur Range. This is explained by the increase in the values of the morphometric indicators that generate such stress.

7. The analysis of geological-geomorphological, particularly morphometric, characteristics of the area shows that phytomelioration measures would be highly effective in the Nakhchivan Autonomous Republic. This is due to the fact that the region is largely lacking in forest resources. Phytomelioration is cost-effective and provides a foundation for afforestation in the autonomous republic. However, it must be carried out considering the local climate, soil, terrain conditions, and the nature of exodynamic processes, with careful selection of plant species.

8. In recent years, the active inclusion of mountainous regions in tourism-related economic activities has increased the anthropogenic load on natural landscapes and accelerated their intensive exploitation. This, in turn, has led to a number of undesirable changes and an increase in the magnitude and recurrence of natural hazards. Slope cutting and construction work must be conducted in parallel with relief conservation measures. Otherwise, exodynamic processes may accelerate, and the operational life of engineering structures may decrease. Forest belts should be established on both sides of roads for slope stabilization and noise reduction.

SUGGESTIONS

1. In areas identified on the map as having high landslide risk, detailed monitoring systems should be established, and ongoing changes and potential hazards in the area must be continuously observed.

2. Considering the widespread occurrence of rockfalls in the region, protective measures should be implemented on slopes with a

high probability of rockfall occurrence.

3. Due to the construction activities carried out by the population in debris flow transit and accumulation zones without proper planning or consideration, continuous public awareness campaigns must be conducted regarding the scale of potential emergencies. A warning system should be established, and regular disaster preparedness and mitigation measures must be implemented.

4. Exodynamic processes, in one form or another, are observed throughout the entire territory of the Nakhchivan Autonomous Republic. With the help of modern equipment and technologies, an inventory of these processes (based on their activity, spatial coverage, and level of hazard) should be conducted, and a corresponding action plan must be developed.

5. In organizing agricultural activities, strict adherence to agrotechnical standards is necessary. Grazing and plowing practices must comply with established norms, and slopes should be plowed along the contour lines. Protective forest belts should be established between plowed areas. China's experience in this field can serve as a model. Additionally, the implementation of drip irrigation systems and rotational cropping and grazing systems is recommended.

6. The practices of developed countries with climatic, soil, and topographic conditions similar to those of the Nakhchivan Autonomous Republic should be adapted and applied in accordance with local conditions.

7. Cliffs should be leveled and backfilled with soil, and vegetation consisting of perennial grasses and shrubs should be planted.

8. Retaining walls should be constructed on cut slopes along roadsides, and roadside protective forest belts should be established along these walls.

9. Monitoring should be conducted along major highway and railway lines; the areas must be thoroughly cleared, and proactive measures should be taken against potential exodynamic processes.

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