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# Morphodynamic processes in the coastal zone of the Caspian Sea (Gobustan, Azerbaijan): distribution and risks of manifestation

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**ABSTRACT**

**Problem statement.** This study aims to analyze hazardous morphogenetic processes associated with the active development of tourism and recreational activities in the southeastern part of the Greater Caucasus. The importance of this problem lies in the fact that the creation of a National Geopark with internationally significant is planned in the territory of Gobustan.

**Purpose -** The study area – Gobustan, as an integral part of the mobile epigeosynclinal orogenetic zone, is characterised by a rather complex geological and geomorphological structure. Located in the southeastern subsidence of the Greater Caucasus, near the Caspian Sea and representing part of the geosynclinal folded area of the same name, it is very promising in terms of tourism and recreation. Due to the significant diversity of the geological formations widespread, the tectonic structure, and the differentiated nature of intense neotectonic movements, the landforms of the territory are characterised by dangerous morphodynamic processes (earthquakes of magnitude 7-8, mud volcano eruptions, landslides, mudflows, ravines, etc.).

**Research method.** Based on our field geological and geomorphological studies, cartographic material, and the use of aerial photographs (ACS) from 1996, 2000-2020 at a scale of 1:60,000, the morphogenetic tension areas of Gobustan have been revealed for the first time. At the same time, the most dangerous processes (landslides, mudflows), as well as the morphometry of the landform (vertical and horizontal dismemberment, steepness and exposure of slopes) were highlighted.

**Research results.** Territories with characteristic geological and geomorphological conditions, where morphogenetic processes differ in the nature of manifestation and degree of tension (weakly, moderately and tense): the area of a slightly tense territory (I b.) is 298.81 hectares (53.4%), the area of medium-stressed territory (II b.) - 217.67 hectares (38.9%), the area of the tense territory (III b.) - 43 hectares (7.7%). As a result of a detailed study of the collected information and data, the study area according to the nature of the surface and elevations, as well as under the condition of morphometric tension and taking into account varying degrees of morphogenetic danger, the territory of Gobustan was zoned according to the distribution of morphogenetic processes and landforms: the middle mountains (with absolute heights up to 1300-1700 m), the lowlands (with absolute heights up to 800-1000 m) and the lowland zone (with absolute heights up to 50-100 m). In these zones, some morphogenetic processes pose a real threat to the development of recreational and tourism activities that are exclusively dependent on the landforms, and the construction of the corresponding infrastructure.

**Conclusion**. The research results will make it possible to use the data obtained to develop a Program for the safe and sustainable functioning and development of the geosystems of Azerbaijan for recreational and tourism development. The relevance of this work also lies in the fact that it is planned to create a National Geopark with internationally significant in the territory of Gobustan.

***Keywords***: *morphometric indicators; morphogenetic processes; morphodynamic tension; danger; natural risk; anthropogenic impact.*

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**Introduction.** Today, the rapidly developing recreation (leisure industry) has become one of the important sectors of the Azerbaijani economy. The main problem of recreational development of the territory of the republic is nature protection, various aspects of which should be taken into account when creating territorial recreational systems. The implementation of recreational activities, especially within specially protected natural areas (national reserves, national protected areas, and national parks), requires scientific justification, taking into account the assessment of the study area for the suitability of various types of tourism and recreation (Zouros, 2008; Yaholnyk, Manyuk, 2017; Brilha, 2018; Shimshek, 2020; Niemets, Kandyba, Kobylin, Kostrikov, Dobrovolskaya, 2021; Briggs, Dowling, Newsome, 2021; Tovisetkul, Lengvttaya, Verathanatchakul, Benjaku, 2021; Lukáč, Štraba, Čerhega, Khouri, 2021; Kuhn, Santos, Jesus, Kolya, Reis, 2022). Such an assessment, in our opinion, includes recreational zoning of the territory, the development of systems of geomorphological, geological, and environmental criteria, the determination of the degree of natural risk, etc. Therefore, unstable and peculiar landforms can become the main threat to tourist and recreational development (Budagov, Alizade, Tarikhazer, 2005).

The study area - Gobustan, as an integral part of the mobile epigeosynclinal orogenetic zone, is characterised by a rather complex geological and geomorphological structure. Located in the southeastern subsidence of the Greater Caucasus, near the Caspian Sea and representing part of the geosynclinal folded area of the same name, it is very promising in terms of tourism and recreation. Due to the significant diversity of the geological formations widespread, the tectonic structure, and the differentiated nature of intense neotectonic movements, the landforms of the territory are characterised by dangerous morphodynamic processes (earthquakes of magnitude 7-8, mud volcano eruptions, landslides, mudflows, ravines, etc.). Therefore, in the process of developing the territory of Gobustan for the development of tourism, the problem of studying, evaluating, and predicting the formation of modern dangerous natural destructive processes is of no minor importance. Geodynamically active, differentiated development of a set of endogenously and exogenously determined processes of land formation invariably changes the morphological (morphometric) type of landform, which is very important to take into account when developing extremely unstable mountain geosystems for recreation. The relevance of this work also lies in the fact that it is planned to create a National Geopark with internationally significant in the territory of Gobustan.

**The purpose of the research** is to analyse dangerous morphogenetic processes in connection with the active development of tourist and recreational activities in Gobustan. Based on the field geological and geomorphological studies, literary and cartographic material, and interpretation of aerospace images (ASI), the study aims to identify areas of morphodynamic intensity of Gobustan, taking into account dangerous morphogenetic processes and lanform morphometry. Ultimately, the research aims to carry out zoning of the territory of Gobustan according to the distribution of morphogenetic processes and landforms (low-lying, low-mountain, and mid-mountain zones). Independently, each zone is characterised by a different level of eco-geomorphological vulnerability, some of which pose a real threat to the development of recreational and tourist activities.

**Materials and methods of research.** The issues of eliminating or minimizing the dangerous consequences of nature management of mountain geosystems in recent decades have been the subject of attention of researchers, as a result of which certain experience has been gained in developing the problem of nature management (Baynes, Lee, Stewart, 2002; Brardinoni, Slaymaker, Hassan, 2003; Chacon, Irigaray, Fernandez et al., 2006; Corominas, van Westen, Frattini et al., 2014; Schlögel, Doubre, Maletl et al., 2015).

Gobustan is characterized by the manifestation of morphogenetic processes, among which the most threatening are seismicity and non-tectonic activity, landslides, and mudflows. Their activation can lead to high risks and dangerous environmental, as well as socio-economic consequences.

The danger posed by morphodynamic processes encourages researchers to look for the most advanced approaches and tools for their prediction. In recent years, probabilistic-statistical methods have been increasingly used for forecasting purposes (Guzzetti, Reichenbach, Cardinali, Galli, Ardizzone, 2005; Lee, Pradhan, 2007; Castellanos Abella, Van Westen, 2008; Oh, Lee, 2011; Cantarino, Carrion, Goerlich, Martinez Ibañez, 2019; Roccati, Paliaga, Luino, Faccini F, Turconi L, 2021).

According to Imrani, Huseynzade, Bilalov (2024) "*Currently, there is no general methodology for recreational and touristic landform analysis. This is explained by the rules that impose numerous types of recreation on geomorphological conditions*". Imrani, Huseynzade, Bilalov (2024) divides the existing methods of recreational and tourist analysis into the following groups: 1. The use of certain morphometric features using GIS, where "*analysis is carried out in advance according to specified standards*"; 2. Field studies, where the analysis of the landform is carried out by description and observation. To assess the structure of hazardous morphogenetic processes, a number of authors (Imrani, Veliyeva, 2021, 2023 and others) used the method of expert statistical estimation of the distribution area (intensity) of the process in the geo-ecological region. This method was used to assess these processes within the allocated zones of the territory of Gobustan for the purpose of tourist and recreational development.

The development of technical means for remote sensing of the Earth from space and obtaining high-resolution aerospace images (ASI) made it possible to improve the efficiency and increase the amount of information in the course of the study in order to study the dangerous morphogenetic processes of Gobustan. The data obtained from deciphering different-scale and different-time ASI data make it possible to quickly compile risk maps that objectively display the quantitative and qualitative characteristics of dangerous morphogenetic processes. The study was carried out in the ArcGIS software package, the use of which create a favourable condition for performing the necessary manipulations with cartographic materials and satellite images and obtain the necessary information about the estimated indicators.

**Factors of development of morphogenetic processes and risks of their formation.** In recent years, the number of morphodynamic processes in the territory of the Gobustan has increased dramatically. If earlier these processes were mainly developed in the upper parts of the middle and high mountains, at the present moment, these processes are actively developing in the low-mountain and foothill zones of the basin. Along with natural factors, technogenic activity has played a significant role in this area (earthworks on slopes in the process of road construction, construction of tourist facilities, etc.). Morphodynamic processes are long-term successive events, starting from their formation and ending with the results. Sometimes there is a need only to prevent their devastating consequences. In many cases, it is impossible to eliminate the root cause of these processes, and then it becomes beneficial to reduce the consequences than to try to eliminate the cause. More often they are formed under the influence of geological-tectonic, topographic, hydrological-climatic and anthropogenic factors. Warnes notes (1981): *"In most cases, many factors operate simultaneously; therefore, trying to find out which of them caused the dangerous process is not only difficult, but also wrong. Often the latter factor acts as a trigger."*

**Research results.** The territory of Gobustan occupies a significant part of the region of the south-eastern periclinal subsidence of the Greater Caucasus. The northern border of the territory runs along the southern slope of the Greater Caucasian Range along the line connecting the villages of Astrakhanovka and Ambizlar, as well as the peaks of the Gady and Kurkachidag Mountains. In the east, Gobustan borders the Absheron Peninsula, and the valley of the Pirsaatchay River serves as the western border of the region.

Gobustan is characterised mainly by direct tectonic lanforms, where ridges with absolute heights up to 800-1100 m correspond to anticlinal folds, while basins and valleys correspond to synclinal folds. In places, elements of the inversion lanforms are traced. Late Pliocene planation surfaces are widely developed in the extreme western part of the region. In the eastern direction, there is an increase in the differentiation of tectonic movements, which are reflected in folding and topography. In this direction, immersion of structures and a decrease in the heights of the lanforms are observed. Mud volcanic activity is intensifying, which forms the main background of the lanforms in some places. In the southeastern part of Gobustan, an inversion lanforms are widely developed due to litho-structural features. Arid-denudation processes and the landforms created by them (badlands, clayey karst, suffosion basins) are widely developed.

In view of the above, the study area has been divided into the following zones according to the nature of the surface, the altitude and the degree of eco-geomorphological vulnerability: highland (with absolute heights up to 1300-1700 m), low mountain range (with absolute heights up to 800-1000 m) and lowland zone (with absolute heights up to 50-100 m). The morphology of the listed lanform steps is closely related to the features of the geological structure and lithology of rocks, the intensity, direction, and degree of differentiation of neotectonic movements. Neotectonic movements in Gobustan were accompanied by transgressions and regressions of the Caspian Sea, which left a series of seashore terraces. The rivers of the region gradually (discontinuously) engrafted and formed terraced valleys, while arid climatic conditions led to the widespread development of a complex of arid-denudation landforms, due to which the study area has a variety of types and originality of landforms (Karimov, Tarikhazer, Karimova, 2023).

The **highlands** in the north of Gobustan are limited by a system of mountain ranges, ridges, and individual ridge-shaped uplands of east-west trending. The ridges gradually decrease, branching off and moving away to the southeast. The extreme in the northeast is the Gady-Kurkachidag Ridge, which lies through the peaks of the Gady and Kurkachidag Mountains, and gradually plunges into the upper reaches of the Vegver River valley. The Kemchi-Gabandag Ridge stretches to the south-west of the Gady-Kurkachidag Ridge, almost parallel to it, traced through the peaks of the Kemchi and Gabandagh Mountains. The Aladash-Shakhandagh Ridge stretches to the south-west of the Kemchi-Gabandagh Ridge, uniting the hills of the same name, which are flat, slightly concave oblong-narrow plateaus. Wide plateau-like watersheds, broken by soft ledges into separate isolated plateaus, forming large steps in the rocks of the Upper Cretaceous and Tertiary age, are characterised in the northern and northwestern parts of Gobustan, between the valleys of the Pirsaatchay, Gozluchay, and Chikilchay Rivers. The zone under consideration differs from the previous one not only in the greater smoothness of the forms but also in the roundness of their outlines in the plan. The main orographic elements here are: Duzan, Gyumbidag, Yurtandag, Astrakhan, and other plateaus.

**Low mountains**. The Sundu and Maraza plateaus lie to the south-east of the mid-mountain ridges of Gobustan, and end in the south-east with the remnant massif beneath the town of Gizhaki. The Maraza plateau is separated from the Sundu by a gentle ledge, complicated by a relatively narrow Kalidzhan Ridge, with a maximum height of 1078 m, elongated in a northwestern direction. To the east of the Sundu plateau, the Akhundagh, Shimshabi, Kayblar, and others Ranges stand out. On the watershed of the latter, the Kayblar and Shayblar Peaks stand out, which have steep southern slopes (completely cut by gullies) and gently-sloping northern ones. To the east of the Kayblar Ridge, near the area of Dzhangi, the Buransyz-Dzhulgin Valley begins, adjoining the gorge of the same name and extending in a south-easterly direction to the Gishlag (wintering place) of Buransiz. To the west of the Buransyz-Dzhulgin Valley, the ridges and uplands of At-Yal, Sungurdagh, Baygushgaya, and others, dissected by ravines, stand out. At the foot of the At-Yal Mountain, a deep winding ravine with numerous branches originates, which runs parallel to the left channel of the Jeyrankechmez River. The At-Yal Ridge and a series of plateaus located to the south of it are separated from South Gobustan by the wide

Jeyrankechmez depression (distinguished in the literature as South-East Gobustan). In the west, the Galandartapa, Umbaki, and Zakirtapa Ridges and the Sherbetdagh-Gochigaya-Nardaran monoclinal Range, with a height of about 600-700 m, border the Jeyrankechmez depression. A characteristic feature of the Jeyrankechmez depression is a calmer lanform, in some places complicated by several large and isolated mud volcanoes: Toraghay, Boyuk Kanizadag, Kichik Kanizadag, Aghtepe, Davalidagh, etc. All these large orographic units, against the background of adjacent valleys, are mud volcanoes (Figure 1).

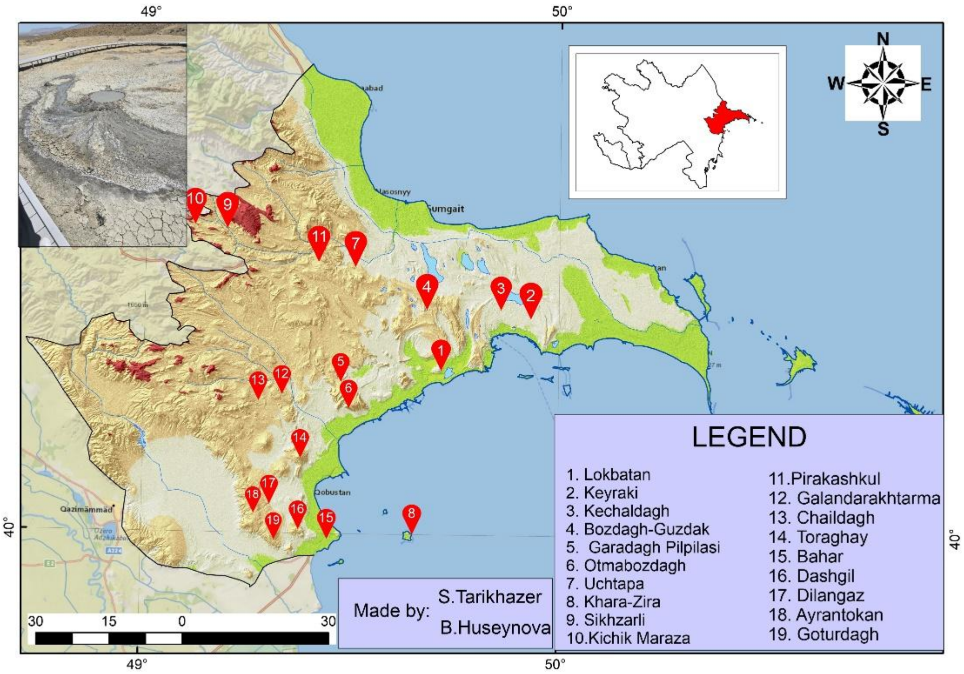


Fig. 1. Mud volcanoes in the Jeyrankechmez depression

The Pritoroghay Valley is distinguished to the west of the Aghtepe and Kanizadag uplands, which is filled with synclinally occurring Absheron deposits. In the northern part of the valley, narrowing, the Davalidagh upland goes around from the west and connects with the valley of a deep ravine, extending in a latitudinal direction and originating far to the northeast, in the area of the Sundi nomad camp. In the northwest, the Pritoroghay Valley is limited by the Galandartapa upland and the northeastern slopes of the At-Yal Ridge. In the central part of this valley, a large mud volcano Toraghay (400 m) rises in the form of a truncated cone. The slopes of this upland are strongly dissected by narrow and deep ravines radially diverging from the centre, forming a badland. Between the ravine, located at the foot of the city of At-Yal, and the valley of the Jeyrankechmez River, a "monumental" remnant rises above the surrounding plain - the Gushgaya Mountain, with a relative height of 50 m. The layers that make up the Gushgaya Mountain are an alternation of dense clays and sands, occurring almost horizontally, since the Gushgaya Mountain is located in the middle part of the Gushgaya syncline, which can be traced in the northwest-southeast direction.

The largest orographic element of South Gobustan is the Alat ridge, which stretches from the northwest to the southeast for a distance of 50 km. The width of this ridge varies between 5-7 km. It begins in the northwest in the area of the Gungormaz Gorge and is the southeastern branch of the Langabiz Ridge. The northeastern slope of the Alat Ridge is gently sloping and dissected by gullies and ravines directed towards the Jeyrankechmaz depression. The southwestern slopes are very steep, precipitous in places, heavily dissected by transverse ravines descending towards the Navagin valley.

The **lowland zone** within Gobustan stretches in a narrow strip along the coast of the Caspian Sea. Its landforms are characterised by high and medium-altitude remnants of marine terraces, giving the territory the character of hilly-wavy, abrasion-accumulative, and slightly dissected plains covered with aeolian deposits in the form of superimposed sand ridges and dunes.

In the course of the study, using the method of expert-statistical assessments of the distribution area (intensity) of morphogenetic processes, a map-scheme distribution of morphogenetic processes and landforms of the territory of Gobustan (Figure 2). Separated zones are individually characterised by varying degrees of ecogeomorphological hazard, and some morphogenetic processes there pose a real threat to tourist and recreational activities. The structure of morphogenetic land-forming processes within the selected zones is given in the form of a diagram (Figure 3).

An analysis of modern dangerous land-forming processes in the study area, the mountain system, which is currently being intensively developed for the development of tourism, etc., makes it possible to conclude that the most dangerous processes in Gobustan are earthquakes, mud volcano eruptions, landslides, mudflows, etc. All these processes form the general morphodynamic tension (Karimov, Tarikhazer, Karimova, 2023).

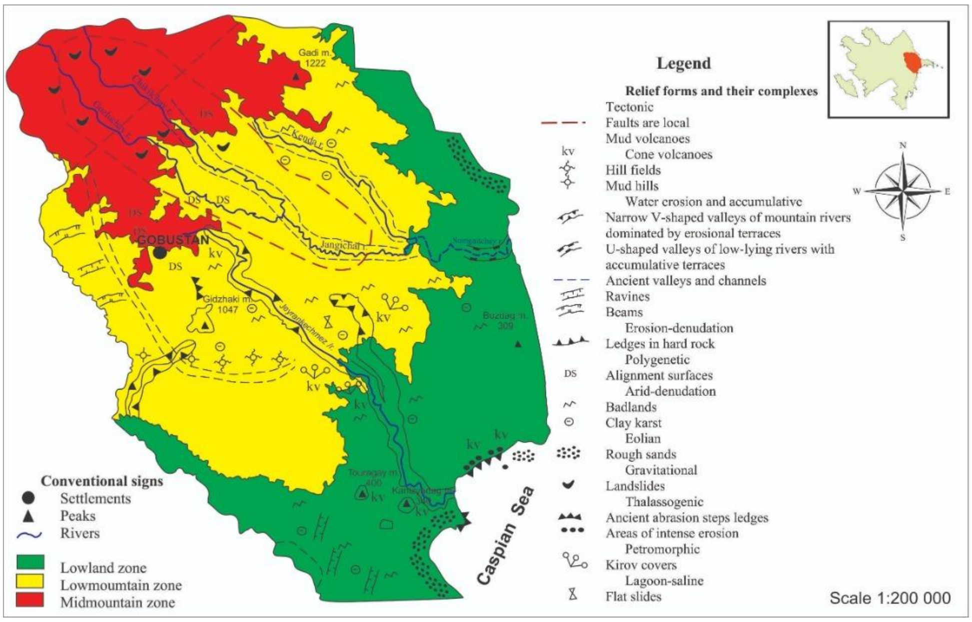


Fig. 2. Map-scheme of the zoning of the territory of Gobustan according to the distribution of morphogenetic processes and landforms (drawn up Tarikhazer, 2023)

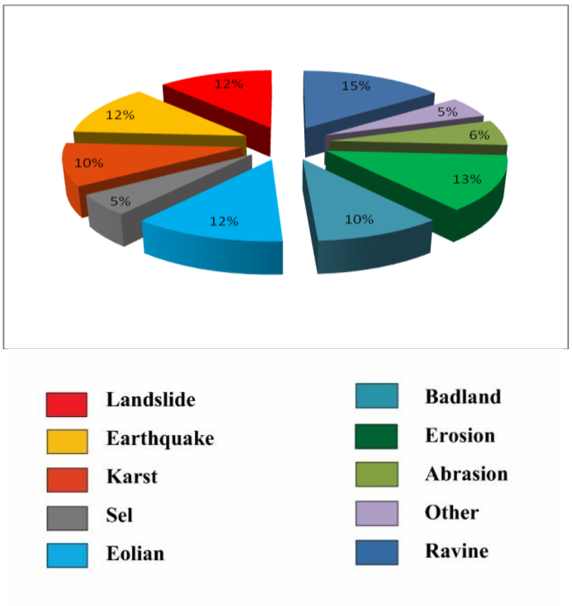


Fig. 3. Structure of morphogenetic processes within Gobustan

One of the most significant risk factors recorded within Gobustan is landslide and mudflow processes. They increase morphodynamic tension, which damages settlements, as well as tourist and recreational infrastructure (Tarikhazer, 2020, 2022$_a$).

In many parts of this region, landslides are fixed on mountain slopes and sea terraces. This is evidenced by the badlands and clayey karst developed here. Landslides, in the region activate when atmospheric precipitation exceeds the average annual norms - up to 400 mm (on the territory of Azerbaijan, the minimum average annual precipitation, i.e., less than 150-200 mm, falls on the southeastern part of Gobustan). In our opinion, the climatic conditions of Gobustan practically cannot be the main factor in the manifestation of landslides. Here, the main role is played by geological and geomorphological factors, and in recent years - the activation of the anthropogenic factor. Most landslides are developed in the river basin of Pirsaatchay, in the upper and middle reaches of the tributaries of the Sumgayitchay River (Gozluchay, Chikilchay, and Tudar Rivers). For example, the Sarydash landslide stream is developed in the river basin of Gozluchay, 2-2.5 km long and 1 km wide. Landslide processes were also actively developing on 106-111 km of the Baku-Shamakhi highway (length 122.7 km) (Figure 4; Figure 5). In recent years, due to anthropogenic pressure, landslides have intensified in the settlements of Gobustan (Table 1).

In the course of the study, we carried out a comparative analysis of landslide processes based on B.A.Budagov's research [1973] with the results of our data based on the interpretation of colour ACIs of 1996 and 2000-2020, with a scale of 1:60000 and field studies. It was revealed that over the past 50 years, the area of Gobustan, subject to landslide processes, has increased by 1.5-2 times. For example, it has expanded from 2.5 ha to 4.8 ha in the village of Gurbanchi; and from 4.2 ha to 6.1 ha in the villages of Poladly and Jahirli.

The rivers of the territory of Gobustan, which include Sumgayitchay, Pirsaatchay, and Jeyrankechmez Rivers, are mud-bearing, with possible floods throughout the year, the catchment areas of which are located at a low altitude (up to 2700 m). In connection with the high-altitude position of watersheds, the main role in the formation of river runoff belongs to rains, which make up 50-60%. The snow cover on the watersheds of the rivers is short, and their share in the annual runoff varies within 5-15%. Groundwater feeding on rivers reaches 20%. The sources of mudflow formation on the rivers of Gobustan are confined to the height of 800-1000 m. A characteristic feature of the upper part of the mudflow basins is the presence of predominantly argillaceous shales in the surface layers of old screes. During dry periods, this material occupies large areas within mudflow centres, which becomes wet during heavy rains, turns into mud, and flows down slopes in the form of streams. Mud streams merge and flow into the riverbed (Table 2) (Figure 6).

In the study area, non-structural mudflows are observed, the nature of the formation and passage of which is influenced by the orographic features of the territory (Guliyeva, Tarikhazer, Kuchinskaya, Karimova, 2019). Due to geological, geomorphological, soil and plant factors, as well as the aridity of the climate, there are favourable conditions for the manifestation of mudflow processes (Table 3).

The detailed study of the dynamics of the development of mudflow sources, the features of the accumulation of mudflow materials and their readiness for demolition, the study of the nature of changes in river beds, the state of banks and protective structures (currently one of the main measures is the construction of mudflow protection dams), potential routes of mudflows, and, on this basis, carrying out ecological and geomorphological measures to stabilize the environmental situation are of great importance. Therefore, timely information about the threat of the development of such dangerous morphogenetic processes as landslides and mudflows will significantly reduce the risk and amount of damage from these processes (Tarikhazer, $2020_a$, $2022_b$).

A map of the morphodynamic tension of Gobustan was compiled (Figure 7) as a result of a detailed study of the accumulated information and data extracted in the field and on the basis of decoding the ACI, as well as taking into account mudflow and landslide manifestations and under the condition of morphometric tension.

The area of the weak stress zone (I b.) makes 298.81 ha (53.4%), the area of the medium stress zone (II b.) is 217.67 ha (38.9%), while the area of the stress zone (III b.) equals to 43 ha (7.7%).

The deepening of morphodynamic processes expresses a real impact on the stability of mountain geosystems and exacerbates their anthropogenic impact (Karimov, Tarikhazer, Karimova, 2023).

The map of the morphodynamic intensity of Go-

Fig. 4, 5. Landslide phenomenon at 106 km of the Baku-Gobustan-Shamakhi road (photo November 12, 2015, Tarikhazer)

*Table 1*

Dates of manifestation of the most dangerous landslide processes in Gobustan for 2001-2021

| № | Date of landslide manifestation | Landslide parameters | Consequences of the landslide |
|---|---|---|---|
| *1* | *2* | *3* | *4* |
| 1. | April 2001 | Length 100-110 m, width 20-15 m | The landslide occurred in the village of Tekla Mirzababaly at an altitude of 800-1000 m and slides into the valley of the Khalkhalchay River |
| 2. | April-May 2003 | Length 800 m, width 200-220 m | A landslide is developed in the northern part of the village of Jeirli. Locally, 3 landslides appeared |
| 3. | October 2003 | Length 600, width 320 m | Landslides appeared in the central and western parts of the village of Jeirli. Numerous landslide cracks are developed |
| 4. | April 2004 | Length 400-1000 m, width 800 m | The landslide is developed at an altitude of 880-1050 m in the central part of the village of Gurbanchi |
| 5. | April 2006 | Length 300-320 m, width 40-70 m | Intensification of a landslide at an altitude of 950-1000 m in the village of Chalov |
| 6. | October 2006 | Length 600 m, width 320 m | Intensification of a landslide in the northern part of the village of Jeirli at an altitude of 920-1000 m |
| 7. | October 2008 | Length 380 m, width 90-1000 m | Intensification of a landslide in the western part of the village of Chalov |
| 8. | April 6, 2012 | Length 150-180 m, width 30 m | In the village of Gobustan, ancient rock paintings and pre-historic caves of the Gobustan State Reserve were under threat |
| 9. | Nov. 12, 2015 | Cracks with a width of 2-5 cm, a length of 1.5-2 m were formed on the asphalt pavement | Part of the Baku-Gobustan-Shamakhi roadway collapsed at 106 km. Asphalt Road sagged in several places. Deformation occurred on the supporting wall |
| 10. | June 3, 2016 | Length 60 m, width 30-35 m | At 106-107 km of the Gobustan-Shamakhi highway, numerous cracks appeared. Traffic was blocked. Traffic was blocked |
| 11. | Oct. 19, 2016 | Length 100 m, width 60 m | Cracks appeared in 3 residential buildings of Gobustan settlement |
| 12. | Nov. 14, 2016 | Length 110-115 m | Communication with 4 settlements of Gobustan district is blocked |
| 13. | Dec. 19, 2016 | Cracks with a width of 2-3 cm, a length of 1-1,5 m were formed on the asphalt pavement | Baku-Gobustan-Shamakhi highway traffic blocked for 109-110 km |
| 14. | Feb. 17, 2017 | Length 40-45 m | Activating a landslide. The Gobustan-Shamakhi Road sank to a depth of 40-50 cm for 105 km |
| 15. | July 21, 2017 | Cracks with a width of 3-4 cm, a length of 0,5-1 m were formed on the asphalt pavement | A landslide intensified at 106-107 km of the Baku-Gobustan-Shamakhi highway. Asphalt sagged in two places |
| 16. | Aug. 28, 2017 | Cracks with a width of 5-6 cm, a length of 1-1.5 m were formed on the asphalt pavement | A landslide intensified at 106-107 km of the Baku-Gobustan-Shamakhi highway. |
| 17. | Sept. 12, 2017 | Length cracks with a width of 2-3 cm, a length of 1 m were formed on the asphalt pavement | A landslide intensified at 106-107 km on the Baku-Gobustan-Shamakhi highway. Traffic blocked |
| 18. | Oct. 19, 2017 | Cracks appeared on the asphalt pavement with a length of 2-3 m, a depth of 10-20 cm, in some places up to 30 cm | The asphalt of the Baku-Gobustan-Shamakhi Road has sagged in some places. Traffic bloked |
| 19. | 24 April 2018 | There were numerous cracks 1-2 cm wide of the roadway | Landslide-subsidence phenomena are developed on the Baku-Gobustan-Shamakha highway. Road signs installed along the road overturned for 107-109 km. |
| 20. | Feb. 5, 2019 | There were numerous cracks 1-3 cm wide of the roadway | On the 111-115 km of the Baku-Gobustan-Shamakhi highway, subsidence and landslide processes are observed in several places |
| 21. | June 24, 2020 | Numerous cracks are wide 5-7 cm | In the village of Poladly, a six-meter recently repaired rural road was damaged |
| 22. | March 31, 2021 | Length 80-90 m, width 50 m | In the village of Jairli, small cracks formed on the walls of more than 40 houses. As a result of the landslide, two residential buildings were in disrepair |

*Source:* Compiled by Tarikhazer (2023)

*Table 2*

Mudflow-bearing River basins of Gobustan

| River | Total area of the river Pool ($km^2$) | Basin area (before exit to the take-out cone) ($km^2$) | Total formation of debris foci ($km^2$) | Area of formation of mudflow foci before reaching the take-out cone (%) |
|---|---|---|---|---|
| *1* | *2* | *3* | *4* | *5* |
| Sumgaitchay | 1750 | 1500 | 260 | 17.3 |
| Pirsaatchay | 2280 | 995 | 193 | 19.4 |
| Jeyrankechmez | 896 | 412 | 245 | 59.5 |

Fig. 6. Debris, formed as a result of a mudflow that occurred on the Sumgayitchay river, May 21, 2010 (Photo was taken by Tarikhazer)

bustan will allow revealing the modern commitment to the flow of specific processes, predicting, and weighing the threat coming from dangerous morphodynamic processes, which with each new case take on all the impressive relevance and tension in the study area.

**Scientific novelty and practical significance**. For the first time, a tourist and recreational analysis of the landforms of Gobustan were carried out, which makes it possible to identify favourable and unfavourable zones for the construction of the necessary infrastructure and the development of certain types of tourism. In the zones (in Figure 6, these are weak (I b.) and medium stressed (II b.) territories), which have favourable geological and geomorphological conditions, it is possible to create cycling, horseback, camel, pedestrian modes of transport. The presence of the Gobustan Reserve here fits perfectly into the concept of ecotourism development in Azerbaijan, which is given great attention at the state level. With minimal financial costs and with minimal intrusion into nature, several areas of ecotourism can be developed at once - scientific, adventure, historical. In a zone characterized by unfavourable (tense territory - III b.) geological and geomorphological conditions, it is possible to contemplate unusual mud volcanic landscapes from above. To do this, it is enough to organize points for paragliding, gliders and gyroplanes, balloon flights and helicopters.

The data obtained can serve as an information base for future scientific research on patterns of development of destructive morphogenetic processes in the mountainous geosystems of the Greater Caucasus and in the countries of the Alpine-Himalayan belt, for the rational use of the territory, solving ecogeomorphological problems and ensuring the safety of living and life in populated areas, preventing the risk of manifestation of dangerous processes in the further development of the mountainous areas for the purposes of recreational and tourist development. Anthropogenic factors in the transformation of the nature of the coastal zones of the Caspian Sea cause the activation or emergence of dangerous morphogenetic processes that increase as the anthropogenic load on geosystems increases. The study of anthropogenically caused dangerous morphogenetic processes to establish their qualitative and quantitative characteristics is necessary to predict the likely consequences of human use of natural resources and develop principles for optimising their use. The compiled map-scheme of the morphogenetic processes and landforms zoning of Gobustan and the map of the morphodynamic tension allow assessing the real threat from dangerous morphogenetic processes, the consideration of which will allow carrying out preventive measures during tourist and recreational development.

**Conclusion.** The results of studying the morpho-dynamic processes of the Gobustan for the purposes of tourism and recreation analysis can be used

*Table 3*

Dates of passage of the most dangerous mudflows on the rivers of Gobustan for 1960-2020

| № | Name of the river | Date of the mudslide | Causes of mudflow | Aftermath of mudslide |
|---|---|---|---|---|
| *1* | *2* | *3* | *4* | *5* |
| 1. | Pirsaatchay | 21.04.1960 | Rains | Flooded land plots of the city of Shamakhi |
| 2. | Sumgaitchay | 20.08.1962 | Heavy rains | Flooded land plots and gardens in the lower part of the village of Gochalar |
| 3. | Sumgaitchay | 06.07.1963 | Rains | Significant areas of land between the city of Sumgayit and the village of Pirbeyli were flooded |
| 4. | Sumgaitchay | 23.04.1966 | Rains | Significant areas of land between the city of Sumgayit and the village of Pirbeyli were flooded |
| 5. | Sumgaitchay | 27.04.1967 | Rains | Land plots flooded in the lower part of the village of Cosalar |
| 6. | Pirsaatchay | 06.06.1968 | Long term rains | The land areas of the city of Shamakhi and the village of Gubaly were flooded. Bridge across Baku-Shamakhi Road destroyed |
| 7. | Sumgaitchay | 07.06.1968 | Rains | Sown areas and gardens are flooded. Pirbeili and Hilmilli |
| 8. | Jeyrankechmez | 06.06.1972 | Rains | Flooded land areas near Sangachal station |
| 9. | Pirsaatchay | 14.06.1975 | Rains | Small areas of the city of Shamakhi flooded |
| 10. | Sumgaitchay | 21.05.2010 | Long term rains | Flooded household plots of Hillmilli village (*Fig. 5.)* |
| 11. | Pirsaatchay | 17.05.2017 | Rains | In the village of Poladly, mudflow waters filled the basements of private residential buildings, more than 200 heads of poultry died |
| 12. | Jeyrankechmez | 02.06.2017 | Heavy rains | A 76-km section of the Baku-Shamakhi Road was damaged. Mudflow disabled the bridge on this section of the road. As a result, a traffic jam of more than 500 cars formed on the road. A VAZ-2106 car was carried away by a mudflow. Cars stuck in the silt and water were recovered by rescuers. Heavy equipment was brought to the scene, the channel of the Jeyrankechmyaz River was cleared of silt, the flow of mudflows in a different direction was ensured. |
| 13. | Jeyrankechmez | 14.04.2019 | Rains | Mudflows also destroyed an alternative road leading to the village of Tesi. |
| 14. | Pirsaatchay | 12.07.2010 | Heavy rains | The mudflow in the village of Poladly caused serious damage to the villagers. More than 20 private houses were flooded, rural roads were destroyed, streets were covered with a thick layer of silt. The mudslide destroyed a small bridge over the Pirsaatchay River, damaged a large bridge, washing away one of the supports. As a result of the disaster, gas pipeline, electricity and communication lines failed, poles and trees were felled. |
| 15. | Jeyrankechmez | 15.07.2020 | Long term rains | Mudflow flooded houses and land plots in the village of Yekakhan, internal roads fell into disrepair, the movement of cars is difficult |
| 16. | Pirsaatchay | 12.07.2020 | Heavy rains | Serious damage was caused to the residents of the village of Poladly. More than 20 private houses were flooded, rural roads were destroyed, streets were covered with a thick layer of silt. The mudslide destroyed a small bridge over the Pirsaatchay River, damaged a large bridge, washing away one of the supports. As a result of the disaster, gas pipeline, electricity and communication lines failed, poles and trees were felled. In the village of Ekyakhana, a mudflow flooded houses and land plots, internal roads became unusable, the movement of cars is difficult |

*Source:* Compiled by Tarikhazer (2023)

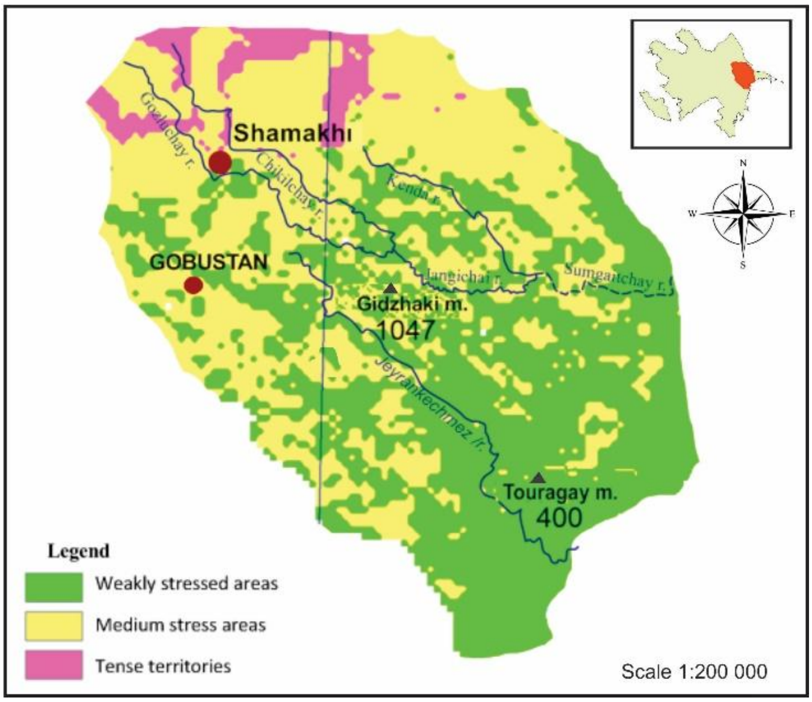


Fig. 7. Map of morphodynamic intensity of Gobustan (drawn up by Tarikhazer, 2023)

in the future to research and formulate more detailed investment projects for developing tourism in the territory of the Gobustan National Geopark.

In addition, the results of fieldwork confirmed the results obtained using GIS technologies. It should be noted that:

— In the development of existing methods for assessing the development of dangerous morphogenetic processes, the use of expert statistical estimates of the area of distribution (intensity) of the process in the geoecological region is justified. The given method and interpretation of multi-scale and multitemporal ACI can significantly increase the reliability of the assessment and prediction of dangerous morphogenetic processes, confirmed by practical results.

— Anthropogenic factors in the transformation of the nature of the mountainous geosystems of the Greater Caucasus serve as an additional and sometimes the main reason for the activation or occurrence of certain processes of land formation. As the anthropogenic load increases on unstable mountain geocomplexes, the morphodynamic stresses caused by this load increase. Therefore, it is considered necessary to expand research further to identify the nature of the impact of the anthropogenic factor on land-forming processes to establish not only their qualitative but also their quantitative characteristics, without which it is impossible to predict the likely consequences of human use of natural resources and develop principles for optimizing their use for purposes of tourism and recreational development.

— To reduce the danger to human life, tourist sites, etc., it is necessary to carry out a preliminary large-scale expert analysis of the eco-geomorphological situation within the selected zones before planning the creation of a National Geopark with internationally significance in the territory of Gobustan.

The reliability of the results of the study and the zoning of the territory of the Gobustan according to the distribution of morphogenetic processes and landforms is confirmed by the current practice: functioning objects (Gobustan State Historical and Art Reserve - Museum of Petroglyphs) within the study area is located in zones with favorable geological and geomorphological conditions. Nevertheless, we believe that the lanforms of a larger area of the study area can be classified as “best” for organized recreation.

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## Морфодинамічні процеси в прибережній зоні Каспійського моря (Гобустан, Азербайджан): поширення та ризики прояву

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Метою даного дослідження є аналіз небезпечних морфогенетичних процесів з урахуванням активного розвитку туристично-рекреаційної діяльності в південно-східній частині Великого Кавказу. Важливість цієї проблеми полягає в тому, що на території Гобустану планується створення Національного геопарку міжнародного значення. На основі власних польових геолого-геоморфологічних досліджень, фондового і картографічного матеріалу, а також з використанням аерокосмічних знімків (АКЗ) 1996, 2000-2020 рр. в масштабі 1: 60 000 вперше виявлені території морфогенетичної напруженості Гобустану. час. При цьому виділено найбільш небезпечні процеси (зсуви, селеві потоки), а також морфометрію рельєфу (вертикальну та горизонтальну розчленованість, крутизна та оголення схилів). Території з характерними геолого-геоморфологічними умовами, де морфогенетичні процеси відрізняються за характером прояву та ступенем напруженості (слабо, помірно та напружено): площа слабонапруженої території (I б.) становить 298,81 га (53,4%), площа середньонапруженої території (II б.) - 217,67 га (38,9%), площа напруженої території (III б.) - 43 га (7,7%). В результаті детального вивчення зібраної інформації та даних, район дослідження за характером поверхні і висот, а також за умовою морфометричної напруженості та з урахуванням різного ступеня морфогенетичної небезпеки територія Гобустану За розподілом морфогенетичних процесів і форм рельєфу районували: середньогір'я (з абсолютними висотами до 1300-1700 м), низовини (з абсолютними висотами до 800-1000 м) і низовинний пояс (з абсолютними висотами до 50-100 м). У цих зонах деякі морфогенетичні процеси становлять реальну загрозу для розгортання рекреаційно-туристичних заходів, виключно залежних від рельєфу, та зведення відповідної інфраструктури.

Результати досліджень дозволять використовувати отримані дані для розробки Програми безпечного та сталого функціонування та освоєння з метою рекреаційно-туристичного розвитку геосистем Азербайджану.

***Ключові слова**: морфометричні показники; морфогенетичні процеси; морфодинамічна напруга; небезпека; природний ризик; антропогенний вплив.*

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