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# STUDY OF TIME DYNAMICS OF EROSION PROCESSES IN THE HIGH MOUNTAINS OF GREATER CAUCASUS BY SATELLITE INFORMATION

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**Abstract.** This work is devoted to the results of comparative visual analysis and instrumental processing of space and aerial photographs of the Azerbaijani part of the Greater Caucasus Lateral Range to assess the relief conditions affecting the formation of high mountain landscapes. The development of exogenous processes in the mountain-meadow and subnival-nival belts in this area has a great impact on the transformation of high mountain landscapes, degradation of soil and vegetation. There is a certain territorial and time differentiation in the intensity of these processes.

**Keywords:** landscape, geo dynamic, space, zone, meadows, sub nival and nival, slope.

## Introduction

The area in question is characterized by a bright elevation, the transformation of landscapes under the influence of various natural and anthropogenic factors (Belonovskaja & Korotkov, 2000; Budagov et al., 2009; Garibov, 2013; Garibov et al., 2014; Kuliev, 2010; Mardanov et al., 2006, 2016; Mardanov & Dzharullaev, 2017). However, in contrast to low and medium mountainous areas, degradation, denudation and snow accumulation processes in relatively high mountainous areas characterized by mountain-meadow and subnival-nival landscapes are relatively poorly studied, and studies cover separate fragments of mountain-meadow and subnival-nival belts has done.

In particular, the analysis of the degree of degradation of mountain meadows and areas of the subnival-nival belt as a result of erosion and landslides with the help of remote sensing materials can identify the most dangerous areas in terms of the activity of degradation processes. This, in turn, can help to assess land resources, determine the nature of land protection measures, the direction of reforms in the economic structure. This is currently a priority goal of research using aerospace materials in many regions of the world (Escribano et al., 2017; Poklar, 2020). An effective way to achieve these goals in high mountainous conditions is to use remote sensing materials, including aerial photographs taken at regular intervals. A number of studies conducted in the Azerbaijani part of the Greater Caucasus have been devoted to work in this area. Their visual and instrumental processing greatly simplifies the solution of a number of tasks and is considered very promising both from a scientific and applied point of view.

## 1. Research object and methods

The mountain-meadow and subnival-nival belts of the Greater Caucasus, the Main Caucasus and the Lateral Ranges and their branches are under the influence of various landform-forming processes that form a landscape as in other countries (Barnard et al., 2001; Cruden & Varnes, 1996; D'Amato Avanzi et al., 2004). Visual decoding of black-and-white aerial photographs at a scale of 1:25000, their comparative analysis with the data of field studies on the typical high mountain massifs of the southern and north-eastern slopes of the Greater Caucasus in subsequent years, allowed to identify the most degraded mountain-meadow areas. Compiled soil-erosion maps of individual settlements and the whole area are the basis for comparing them with the data of field and chamber geomorphological, climatic, geobotanical and soil surveys, the development of soil-erosion processes leading to the entry of these massifs into the subnival-nival zone. allowed to determine the factors. It should be noted that research in this area is carried out in other countries (Apollo et al., 2018; Borrelli et al., 2017; Burylo et al. 2011; Geitner et al., 2021; Freppaz et al., 2010; Jiao et al., 2009; Makarov et al., 2003; Stanchi et al., 2012).

Based on the visual decoding of aerial photographs, a map-scheme of the area around the Gizilgaya peak was compiled with the help of deciphering features of

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landscape elements. These symptoms have been identified based on numerous field studies and are quite reliable.

During the research, great attention was paid to the development of optimal ways to solve the problem of efficient use of land. This problem is unique in the context of changes in the economic structure in the complex geodynamic conditions of high mountainous areas (Paunović & Jovanović, 2019; Waligo et al., 2013; Shi et al., 2021).

## 2. Results received

As mentioned above, the mountain-meadow and, in part, the rocky belt mainly cover the watershed zone of the Main Caucasus Range and the Lateral Range and the slopes of the adjacent branches. These belts are characterized by frost erosion and gravity, nival-solifluction processes, landslides and landslides in some places, especially in the upper rocky zone characterized by the presence of small modern glaciers in the Tufan, Bazarduzu and Shahdag peaks. Preservation of traces of ancient glaciation varies due to intensive erosion and deep (up to 1500 m) ravine fragmentation. In the highest parts of the shale strip of the Tufan anticlinorium, Tufan, Bazarduzu, etc. Traces of ancient glaciation are well preserved on the peaks, in areas where there are denudation-resistant marls and sandstones among the shales, as well as in the Shahdag and Gizilgaya massifs, which are composed of hard-to-wash limestones. In severely eroded areas of the highlands, in areas where easily washable Jurassic shales develop, and even at high absolute altitudes (Mount Khinalig, 3718 m), traces of icing are poorly preserved. The relief here can be characterized as glacial erosion.

Due to the lithological features of the Main Caucasus Range, which is composed of layers of shales and sandstones, traces of ancient glaciation are weaker than in the neighboring Shahdag massif. The limestones predominate in this massif, and glacial relief forms are better preserved in these rocks.

The main processes are more related to physical wear. These processes determine the nature of erosion processes in the mountain-meadow zone, which is characterized by grasslands. Here, physical and chemical erosion is generally characterized by low intensity. Intensive physical erosion, along with the active disintegration of rocks along the tectonic fault system, creates the conditions for the formation of avalanches and eruptions. Their materials cover the slopes of the Shahdag and Gizilgaya massifs and the ravines that cut them in the form of large fragments of limestone. Large avalanches and eruptions form large piles on the slopes of these massifs, especially on the eastern edge of the Shahnabad depression.

Erosion processes on the north-eastern slope of the Main Caucasus Range and the Lateral Range are developing in different conditions from the southern slope of the Main Caucasus Range. The low slope compared to the southern slope leads to less intensity of crumb transport and more active accumulation of soil-forming derivatives. This leads to the formation of a fairly thick soil profile. Under these conditions, erosion processes occur to a greater extent under the influence of human economic activity.

The side chain can be seen as a clear example of the nature of erosion processes in the data of the decoding of 1: 25000 scale photographs of individual key points taken in 1983.

The plateau-shaped Gizilgaya peak and the surrounding area are represented by wide ridges of rocks, covered with snow. The harsh climatic conditions in this area complicate soil formation processes and lead to the formation of underdeveloped primitive mountain-meadow soils. The accumulation and displacement of sediments leads to the accumulation of moisture in the soil, on the one hand, and the decrease in the penetration of solar radiation to the surface, on the other hand, by increasing the reflection. However, it should be noted that the flat-flattened shape of the peak causes a relatively small intensity of the formation and displacement of ufant-scattering piles compared to steeply sloping peaks.

Another point covers the area around the villages of Khinalig, Galaykhudat and Alik, south of the Gizilgaya peak (Figure 1). Absolute heights range from about 1900–2700 m. This is a zone of subalpine meadows that have been severely affected by anthropogenic impact, and is characterized by severely eroded areas, covered by large photons in aerial photographs and covering large areas. The intensive use of the surrounding landscape for pasture and mountain farming is reflected in the ubiquitous development of cattle trails. These paths are shown in dark lines in aerial photographs.

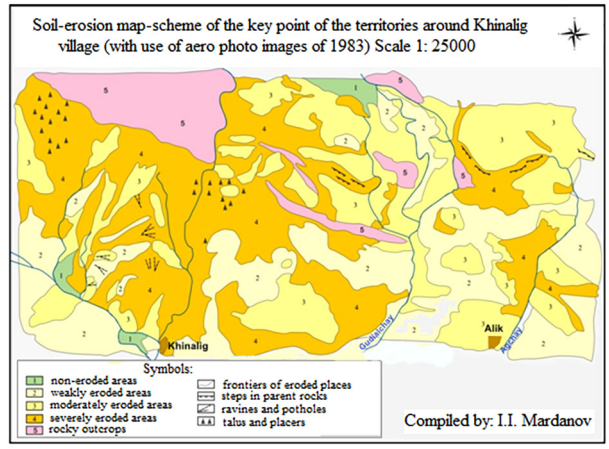


Figure 1. Soil-erosion map-scheme of the key point of the territories around Khinalig village: 1 – non-eroded areas; 2 – weakly eroded areas; 3 – moderately eroded areas; 4 – severely eroded areas; 5 – rock protrusions

The agricultural terraces around the village of Khinalig are almost indistinguishable from the cattle trails in these depictions. Within this area, there is a semi-rigid landslide stream to the east of Galaykhudat village, which is largely covered with meadow vegetation. To the north of Alik village and to the south-east of Jack village, on the right bank of the Agchay River, a tree-like landslide flows from the

south-east to the north-west, corresponding to the heavily eroded area. Its length was 1,750 m, measured on an aerial photograph in 1983, and 2,500 m above the ground. To the north of Galaykhudat and Alik villages, there are long protrusions of parent rocks in the form of steps. These protrusions form a ravine along the Gudyalchay gorge down from the village of Galaykhudat. Slightly eroded soils are found in less inclined areas between Gudyalchay and Agchay, on the left bank of Gudyalchay south of Galaykhudat village and west of Khinalig village.

Around the Gudyalchay field, south and southeast of Galaykhudat, at 1873 m and 1850 m absolute altitudes, there are shrubs with higher humidity and higher air temperatures, which are typical for the lower part of the subalpine zone. It is hoped that the inclusion of this area in the Shahdag National Park and the construction of a highway to the village of Khinalig, instead of the old dirt road depicted in aerial photographs and washed away in sloping areas, could significantly improve the soil and environmental situation around the villages. However, there is a need for constant monitoring of the condition of the asphalt pavement and various engineering measures to protect the road from external influences.

Visual processing of space images with a resolution of 10 meters taken from the European Union's Sentinel satellite in 2017 demonstrates a slightly different soil-ecological conditions in this area (Figure 2). These figures clearly show an increase in non-eroded areas near the villages of Khinalig, Jack and Galaykhudat due to significantly weaker and moderately eroded areas. One reason for this situation is the economic crisis in agriculture, as in other areas in the 1990s. Another reason may be the success of conservation measures. Visually, it can be seen that the heavily eroded areas within the area, from Khinalig village to the north, to the Gizilgaya massif, have been significantly reduced, mainly to the category of moderately eroded areas. At the same time, it should be noted that the moderately eroded areas around the village of Alik still form large areas. The results of the calculation of areas with varying degrees of erosion using ArcGIS 10.2.1 show that moderately eroded areas within the allotted area have a higher proportion than other areas of the Greater Caucasus Highlands according to the 2017 descriptions (Table 1). It can be assumed that if conservation measures do not become more active in the coming years, it is likely that in the short term they will move to the category of severely eroded areas, the area of which is approximately equal to the area that has not been eroded.

## 3. Final

Field surveys conducted in this area in 2008 show that in the areas near the village of Khinalig, including the former agricultural terraces, the soil cover of mountain meadows is well covered with grass. This allowed them to be characterized as neither eroded nor weakly eroded. Moderately and severely eroded areas are located in the Roser River valley, northwest of the village. These areas are actively used as rural pastures. However, visual observations made it possible to identify protrusions of parent rocks, mainly limestone, around the village. At the same time, it should be noted that these areas are not hotbeds of erosion against the background of well-developed soil and vegetation. However, the situation may change in the coming years due to increased grazing. As a result, non-eroded

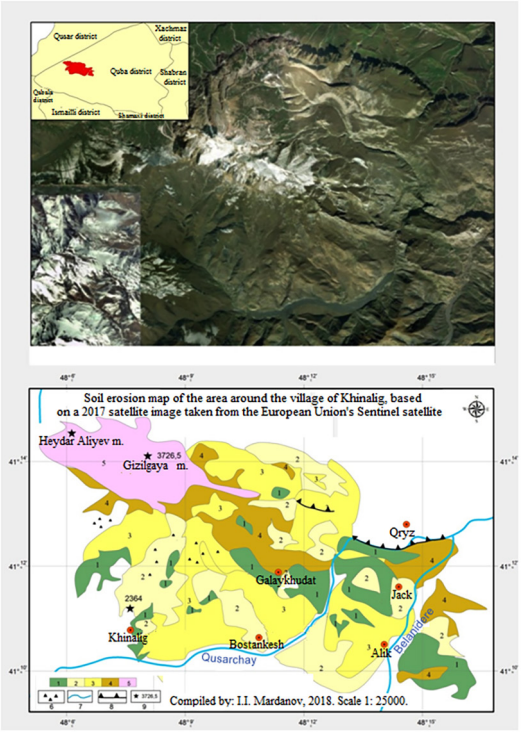


Figure 2. Soil erosion map of the area around the village of Khinalig, based on a 2017 satellite image taken from the European Union's Sentinel satellite. Symbols: 1 – non-eroded areas; 2 – weakly eroded areas; 3 – moderately eroded areas; 4 – severely eroded areas; 5 – protrusions of rocks; 6 – talus and placers; 7 – rivers; 8 – steps in parent rocks; 9 – height indicators. Scale 1: 25000

Table 1. Area indicators for the degree of erosion of the high mountain massifs of the Greater Caucasus

| Massifs | Area, km$^2$ | Area, ha |
|---|---|---|
| Khanyaylag | 1. 3.17<br>2. 4.9<br>3. 1.98<br>4. 2.36 | 317<br>490<br>198<br>236 |
| Shahdag | 1. 51.95<br>2. 50.56<br>3. 30.21<br>4. 6.59<br>5. 17.56 | 5195<br>5056<br>3021<br>659<br>1756 |
| Khinalig | 1. 22.68<br>2. 34.41<br>3. 51.32<br>4. 22.94<br>5. 19.85 | 2268<br>3441<br>5132<br>2294<br>1985 |

areas can become weakly eroded areas in a short period of time. This once again shows the impossibility of the simultaneous existence of the reserve regime and pasture management, and makes it important to implement comprehensive measures to change the structure of the economy, to address the social problems of the region due to its new status.

## Conclusions

The high-mountain territories of the Greater Caucasus within Azerbaijan are very dynamic in terms of the development of exogenous relief-forming processes that leave a big imprint on the economic structure of the region and, in general, on the life of the local population. These processes in turn lead to the formation of a large landscape diversity in the area. For this reason, there is a need for effective monitoring of the exodynamic situation, including with the help of aerospace sounding tools. Such work will allow minimizing the consequences of harmful natural phenomena, identifying the most favorable sites for the construction of economic facilities and correctly planning a system of environmental protection measures. I would like to note that the experience gained in this case can be applied in other high-mountainous territories, and in particular, in the highlands of the Azerbaijani part of the Lesser Caucasus.

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