



UDC: 551.3/796.5

<https://doi.org/10.59849/2409-4838.2025.3.150>

## THE STUDY OF LANDSLIDES IN THE NAKHCHIVAN AUTONOMOUS REPUBLIC BASED ON THE STATISTICAL FREQUENCY RATIO METHOD

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Received: 05.02.2025

Accepted: 25.06.2025

*A methodological approach has been developed for the geospatial analysis of landslide resilience in the Nakhchivan Autonomous Republic using satellite and ground-based data. Within this methodology, the systematic mapping and assessment of various factors determining landslide susceptibility, including slope steepness, slope aspect, elevation zones, river basins, and vegetation index, have been carried out. As a result of the study, it was found that the territory of the autonomous republic falls within the main active landslide zones. The high risk of landslides in these zones poses a potential threat to the region's infrastructure and population. The analysis emphasizes the importance of developing appropriate strategic measures and monitoring systems to reduce the likelihood of landslide occurrences. Thus, the obtained results provide essential information for enhancing safety measures in the Nakhchivan Autonomous Republic.*

**Keywords:** *Satellite images, Landsat 9, ASTER radiometry, statistical frequency ratio, pixel classes*

### INTRODUCTION

Satellite images have been actively used in the study of landslides since the 1990s. Satellite imagery data is used both for the identification and mapping of landslides, as well as for the monitoring and analysis of the dynamics of landslide objects and processes. Recently, landslide monitoring has been conducted in the radio range of satellite imagery, as radar interferometry allows for the detection of the relief structure of the Earth's surface. Currently, satellite images in both visible (optical) and radio ranges are a vital source of data for landslide detection [3, 6, 10-11].

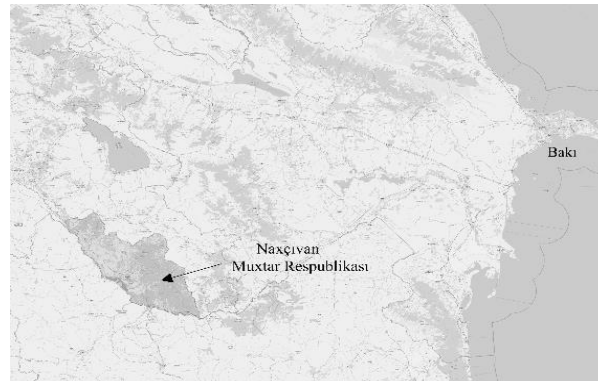
A landslide is a hazardous natural event that occurs when a mass of soil and layered rocks detaches due to erosion and moves down a slope under the influence of gravity [11]. Landslides are among the most dangerous natural disasters worldwide, often resulting in significant economic damage and loss of human lives [3, 6]. In the Nakhchivan Autonomous Republic, especially in the northern mountainous regions, landslides sometimes lead to human casualties and material losses. Geological and geomorphological features, the density of river basins, and anthropogenic factors can all influence the occurrence and activation of landslides. To minimize the damage caused by landslides, studying the factors that drive landslide processes and landslide susceptibility remains a relevant issue [7, 12].

The purpose of the present study is to determine landslide susceptibility in areas of the Nakhchivan Autonomous Republic that are active landslide zones and to develop landslide susceptibility maps for these regions. Experience shows that landslide processes are statistically associated with several factors. As a result, when analyzing landslide susceptibility, statistical approaches are most commonly used. To assess landslide susceptibility and create maps of potential landslide development, we used the Frequency Ratio (FR) method and the Landslide Susceptibility Mapping (LSM) approach [3, 7]. A landslide susceptibility map is the process of determining and classifying the spatial distribution of land units according to their susceptibility to landslides.



## STUDY AREA

The Nakhchivan Autonomous Republic is located in an isolated region in the southwestern part of the country. Two-thirds of its territory consists of mountainous areas with elevations above 1000 meters. The main part of the autonomous republic is made up of the Lesser Caucasus mountain ranges and their mid- and low-altitude branches, stretching toward the Araz River valley (Figure 1).



**Fig. 1.** Nakhchivan Autonomous Republic

The climate of the autonomous republic is predominantly dry and sharply continental. The absolute minimum temperature is  $-31^{\circ}\text{C}$  (Dərvişlər), and the absolute maximum temperature is  $+44^{\circ}\text{C}$  (Culfa). The climate conditions in the mountainous and high mountainous areas (northern part) differ significantly from those in the lowland areas, mainly along the Araz River [7]. This sharp contrast in natural and climatic conditions is also reflected in the vegetation cover. The region exhibits deserts and semi-deserts, steppe vegetation, mountain meadows and steppes, subalpine and alpine meadows, forests (in patches), oases, and small forests along riverbanks [12].

## MATERIAL AND METHODS

The study of landslide processes utilizes satellite and sub-satellite (subspace) complex data, as described below. Complex satellite and sub-satellite data are currently used for environmental monitoring research. Satellite and sub-satellite data complement each other [8]. Such data allow for the reliable and rapid detection of landslide locations and provide detailed insights into their characteristics [2, 5].

The satellite materials for landslide detection consist of data obtained from multispectral and radar studies. The initial satellite multispectral data are raw, unprocessed data. Processed digital satellite images are used to address thematic issues such as remote sensing of landslide locations. Multispectral images obtained from the Landsat 9 satellite were used to assess the normalized NDVI (Normalized Difference Vegetation Index). The accuracy of these images has been enhanced by utilizing panchromatic channel images. The calculation of NDVI from Landsat 9 images is based on the comparison of radiation absorption by plants in channel 5 and radiation reflection in channel 4 [4]. To obtain satellite data on the structure of the relief, radar imagery distributed in GeoTIFF format in the WGS84 coordinate system from NASA's Terra satellite's ASTER radiometer was used [9, 10].

The statistical frequency ratio method is a simple and useful model for assessing landslide susceptibility. This approach is based on observed relationships between the factors associated with landslide distribution. In the study area, this method allows for determining the connection between the locations where landslides occur and the factors that cause them. According to the frequency ratio method, each causative factor is divided into several classes. Based on satellite images, landslide susceptibility is calculated using the following formula [3, 6]:



$$FR_i = \frac{S_i/P_i}{S/P}, \quad (10)$$

Here,  $FR_i$  – frequency ratios;

$S_i$  –  $i$  the number of landslide points (pixels) in class;

$P_i$  –  $i$  the number of points (pixels) in class;

$S = \sum S_i$  – the total number of landslide points (pixels) on the map of the study area;

$P = \sum P_i$  – the total number of points (pixels) on the map of the study area.

The landslide susceptibility index is calculated using equation (10) by summing the frequency ratio values of the classes of each factor:

$$LSI = \sum_1^n FR_i, \quad (11)$$

Here,  $LSI$  – landslide susceptibility index.

## RESULTS AND DISCUSSION

The main objective of the frequency ratio methodology is to create a landslide susceptibility map. The mapping of slope process manifestations can be accomplished by interpreting multispectral images obtained through both field studies and remote sensing. In the territory of the Nakhchivan Autonomous Republic, it seems appropriate to use the following geospatial data to draw an electronic digital landslide map:

- Slope steepness,
- Slope aspect,
- Elevation zones,
- River basins,
- Vegetation index.

The results of landslide formation using the frequency ratio method are presented in map form in Figure 2 and summarized in the table below. The types of landslides depicted in Figure 2 were identified through years of field research. The mapping of slope steepness, slope aspect, elevation zones, and river basin factors was conducted using the global digital elevation model (GDEM) from the Terra satellite's ASTER radiometer (with spatial resolution capable of 1 arc second, approximately 30 meters horizontally) [1]. The mapping of the normalized vegetation index was based on Landsat 9 satellite data.

In Figure 2, the cartographic data is divided into five classes: Class 1 - very low, Class 2 - low, Class 3 - moderate, Class 4 - high, Class 5 - very high risk indicators. Class 4.5 corresponds to the active zone depicted in the first image of Figure 2. As practical results indicate, when the FR value exceeds 1.0, there is a stronger correlation between landslide frequency and landslide susceptibility factors. Conversely, when the FR value is less than 1.0, it suggests a weaker relationship between landslide frequency and the landslide factors [6, 9].

As shown in the cartographic data in Figure 2, the territory of the Nakhchivan Autonomous Republic is located in a potential zone for landslide development, except for a very narrow flat foothill zone extending from east to west (shown as Class 1 in the table). The mountainous and foothill areas, which constitute the main part of the republic, are subject to high landslide processes. Remote sensing methods provide reliable and timely information about the distribution of local landslides in these areas.

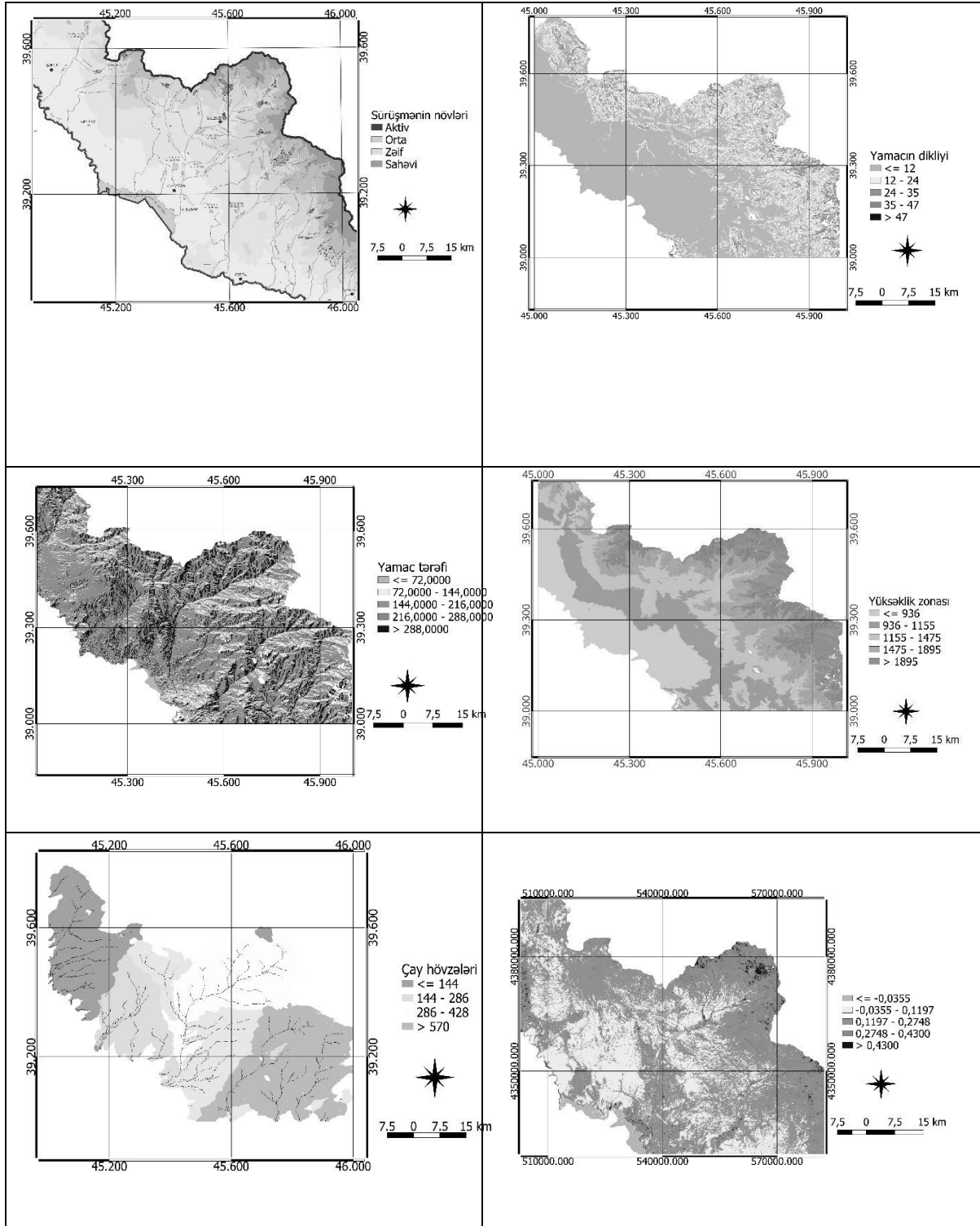


Fig. 2. Results of mapping the factors contributing to landslide formation

Table

Results of calculations using the frequency ratio method for factors contributing to landslide formation

Slope steepness, angle in degrees.					
Pixel classes	$P_i$	$S_i$	$\sum P_i$	$\sum S_i$	$FR_i$
<= 12	376000	4615	722300	12782	0.6936
12-24	180000	3640			1.1427
24-35	86000	2829			1.8589
35-47	59000	1048			1.0038
>=47	21300	650			1.7245
Slope aspects, angle in degrees (from north direction)					
Pixel classes	$P_i$	$S_i$	$\sum P_i$	$\sum S_i$	$FR_i$
<= 72	4900	1760	33664	13067	0.9254
72-144	5040	3622			1.8514
144-216	9360	3749			1.0319
216-288	12240	2874			0.6049
>=288	2124	1062			1.2881
Elevation zones, (m)					
Pixel classes	$P_i$	$S_i$	$\sum P_i$	$\sum S_i$	$FR_i$
<= 935	105000	4708	292710	17118	0.7667
936-1155	79310	4128			0.8900
1155-1475	49500	3453			1.1928
1475-1895	35000	2819			1.3772
>=1895	23900	2010			1.438
River basins, ( $km^2$ )					
Pixel classes	$P_i$	$S_i$	$\sum P_i$	$\sum S_i$	$FR_i$
<= 144	43200	3100	142600	14111	0.7252
144-286	28400	2642			0.9401
286-428	42600	4755			1.1280
>=570	28400	3614			1.2860
Vegetation index (NDVI)					
Pixel classes	$P_i$	$S_i$	$\sum P_i$	$\sum S_i$	$FR_i$
<=-0,355	5000	450	267500	73328	0.3283
-0,355-0,1197	85000	30901			1.3262
0,1197-0,2748	142500	29115			0.7453
0,2748-0,4300	22000	11962			1.9835
>=0,4300	13000	900			0.2526

## CONCLUSION

The issue of landslide processes is particularly relevant for the Nakhchivan Autonomous Republic. Based on the potential for the development of landslide processes, zoning of the autonomous republic's territory, assessment of landslide hazard, and operational warning based on satellite data are urgent matters. In this regard, the current study investigates the distribution and classification of



local landslide areas in the Nakhchivan Autonomous Republic, the mapping of landslide factors, and landslide susceptibility using satellite and ground-based complex data.

In the study area, cartographic data are divided into five classes based on the degree of landslide potential: very low, low, moderate, high, and very high. The high mountainous, mountainous, and foothill areas, which constitute the main part of the republic's territory, fall into active landslide zones.

The results of the conducted research are crucial for assessing landslide hazards and determining landslide risks in the studied area. The findings can be utilized to evaluate landslide potential in various regions of the Nakhchivan Autonomous Republic.

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## NAXÇIVAN MUXTAR RESPUBLİKASI ƏRAZISİNDƏ SÜRÜŞMƏLƏRİN STATİSTİK TEZLİK NİSBƏTİ METODU ƏSASINDA TƏDQIQI

Q.H. Qurbanov

Peyk və yerüstü məlumatlardan istifadə edərək Naxçıvan Muxtar Respublikasında sürüşməyə davamlılığın geoməkan analizi üçün metodoloji yanaşma hazırlanmışdır. Bu metodologiya çərçivəsində, sürüşməyə həssaslığı müəyyən edən müxtəlif amillərin, o cümlədən səth yamacının dikliyi, yamacın baxarlığı, yüksəkliklər zonası, çay hövzələri və bitki örtüyünün indeksi,



sistemli şəkildə xəritələşdirilməsi və qiymətləndirilməsi həyata keçirilmişdir. Tədqiqat nəticəsində, muxtar respublikanın ərazisinin əsas aktiv sürüşmə zonalarına daxil olduğu məlum olmuşdur. Bu zonalarda sürüşmə riskinin yüksək olması, regionda infrastruktur və əhali üçün potensial təhlükə yaradır. Analiz, sürüşmə hadisələrinin baş vermə ehtimalını azaltmaq üçün müvafiq strateji tədbirlərin və monitoring sistemlərinin inkişaf etdirilməsinin vacibliyini vurğulayır. Beləliklə, əldə edilən nəticələr Naxçıvan Muxtar Respublikasında təhlükəsizlik tədbirlərinin artırılması üçün zəruri məlumatlar təqdim edir.

**Açar sözlər.** *Peyk şəkilləri, landsat 9, ASTER radiometri, statistik tezlik nisbəti, piksel sinifləri.*

## ИЗУЧЕНИЕ ОПОЛЗНЕЙ В НАХЧИВАНСКОЙ АВТОНОМНОЙ РЕСПУБЛИКЕ НА ОСНОВЕ МЕТОДА СТАТИСТИЧЕСКОГО ОТНОШЕНИЯ ЧАСТОТНОСТИ

Г.Х. Гурбанов

Разработан методический подход для геопространственного анализа устойчивости к оползням в Нахчыванской Автономной Республике с использованием спутниковых и наземных данных. В рамках этой методологии проведено систематическое картографирование и оценка различных факторов, определяющих склонность к оползням, включая крутизну склонов, экспозицию склонов, зоны высот, речные бассейны и индекс растительности. В результате исследования было установлено, что территория автономной республики входит в основные зоны активных оползней. Высокий риск оползней в этих зонах представляет собой потенциальную угрозу инфраструктуре и населению региона. Анализ подчеркивает важность разработки соответствующих стратегических мер и систем мониторинга для снижения вероятности возникновения оползней. Таким образом, полученные результаты предоставляют важную информацию для улучшения мер безопасности в Нахчыванской Автономной Республике.

**Ключевые слова:** *спутниковые изображения, Landsat 9, радиометрия ASTER, статистическое частотное соотношение, классы пикселей.*