Фізична географія та геоморфологія (2025) 48, 1(129), 18-25
https://doi.org/10.17721/phgg.2025.1/129.02

Оригінальні дослідження / Original Research

Research of the differentiation characteristics of seliteb complexes and their impact on the transformation of natural landscapes of the northeastern slope of the Greater Caucasus based on GIS

Rashad Rahib Sadullayev

Baku State University, 33, Akademik Zahid Khalilov St., Baku, AZ1148, Azerbaijan

Abstract

The article investigates the seliteb landscape complexes of the northeastern slope of the Greater Caucasus and their differentiation regularities. The seliteb complexes of the northeastern slope of the Greater Caucasus have formed as a result of long-term natural-historical processes and exhibit a unique development dynamic compared to other regions, which is of significant scientific and practical importance.

Based on the analysis of Landsat 7 satellite images using GIS, it has been determined that the total area of seliteb complexes in the northeastern slope of the Greater Caucasus is 47,229 ha (6.7% of the region). The differentiation characteristics of the seliteb complexes were studied using Geographic Information Systems (GIS) and satellite images, and the research area was divided into five hypsometric levels (up to 500 m; 500–1000 m; 1000–2000 m; 2000–2500 m; 2500–4466 m) using the DEM → Analyst Tools → Raster Reclass → Slice → Natural Breaks algorithm. To determine the density (share) of seliteb complexes within each hypsometric (elevation) zone, the formula $K_{seliteb}=(\Sigma S_c)/(\Sigma H_z)$ was applied.

It has been determined based on GIS that the most densely populated zone in the northeastern slope of the Greater Caucasus is the flat, foothill, and low mountain areas located at an elevation of 28–1000 m. The main network of settling complexes is concentrated in the plain-valley, sloping plain, and foothill zones. In higher hypsometric zones, settlement is mainly seasonal and temporary. Therefore, the anthropogenic transformation of natural landscapes is much lower compared to the plains and foothill zones. As the elevation increases, the number and area of settling complexes decrease, which is accompanied by a weakening of the impact on natural landscapes.

The change characteristics of urban-settling landscapes in the region over the years 1989, 2010, and 2024 were studied based on Landsat remote sensing images.

The differentiation of seliteb complexes within natural landscape types was analyzed using GIS, and a landscape-ecological buffer map was created. The settling landscapes of the northeastern slope of the Greater Caucasus have been sharply transformed and belong to regularly and intensively used complexes. These complexes are classified into three categories based on their transformation characteristics.

Keywords

seliteb complexes, GIS, population settlement, hypsometric zones, landscape transformation

Received: 8 April 2025 / Accepted: 16 May April 2025 / Published online: 30 May 2025

Дослідження характеристик диференціації селітебних комплексів та їх впливу на трансформацію природних ландшафтів північно-східного схилу Великого Кавказу на основі ГІС

Рашад Рахіб Садуллаєв

Бакинський державний університет, вул. Академіка Західа Халілова, 33, Баку, AZ1148, Азербайджан

Анотація

У статті досліджуються селітебні ландшафтні комплекси північного схилу Великого Кавказу та закономірності їх диференціації. Селітебні комплекси північного схилу Великого Кавказу сформувалися в результаті тривалих природно-історичних процесів і демонструють унікальну динаміку розвитку порівняно з іншими регіонами, що має значну наукову та практичну цінність.

На основі аналізу супутникових знімків Landsat 7 за допомогою ГІС було визначено, що загальна площа селітебних комплексів на північному схилі Великого Кавказу становить 47 229 га (6,7% регіону). Характеристики диференціації селітебних комплексів досліджено за допомогою ГІС та супутникових знімків, а досліджувану територію поділено на п'ять гіпсометричних рівнів (до 500 м; 500–1000 м; 1000–2000 м; 2000–2500 м; 2500–4466 м) за допомогою алгоритму DEM → Analyst Tools → Raster Reclass → Slice → Natural Breaks. Для визначення щільності (частки) селітебних комплексів у кожній гіпсометричній зоні застосовано формулу $K_{seliteb}=(\Sigma S_c)/(\Sigma H_z)$.

Встановлено за допомогою ГІС, що найбільш густонаселеною зоною північного схилу Великого Кавказу є рівнинно-передгірна та низькогірна територія на висоті 28–1000 м. Основна мережа селітебних комплексів зосереджена в рівнинно-долинних, схилових та передгірних зонах. У вищих гіпсометричних зонах поселення є переважно сезонними та тимчасовими. Отже, антропогенна трансформація природних ландшафтів значно нижча порівняно з рівнинними та передгірними зонами. З підвищенням висоти кількість і площа селітебних комплексів зменшуються, що супроводжується зниженням впливу на природні ландшафти.

Характеристики змін урбанізованих ландшафтів у регіоні за роки 1989, 2010 та 2024 досліджено на основі супутникових знімків Landsat. Диференціація селітебних комплексів у межах природних типів ландшафтів проаналізована за допомогою ГІС, а також створено ландшафтно-екологічну буферну карту. Селітебні ландшафти північного схилу Великого Кавказу зазнали значної трансформації та належать до регулярно та інтенсивно використовуваних комплексів. Ці комплекси класифіковано на три категорії на основі їхніх трансформаційних характеристик.

Ключові слова

селітебні комплекси, ГІС, поселення населення, гіпсометричні зони, трансформація ландшафтів.

Надійшла до редакції: 8 квітня 2025 / Прийнята: 16 травня 2025 / Опублікована онлайн: 30 травня 2025

Corresponding author:
Rashad Rahib Sadullayev, Baku State University, 33, Akademik Zahid Khalilov St., Baku, AZ1148, Azerbaijan
Email: reshad.sdlyv@gmail.com

1. Introduction

The seliteb complexes of the northeastern slope of the Greater Caucasus have formed as a result of long-term natural-historical processes and exhibit a unique development dynamic compared to other regions. The study of the differentiation of these complexes based on GIS, satellite images, and DEM is a significant scientific and practical approach that ensures their more accurate study and conservation.

The area of the northeastern slope of the Greater Caucasus is approximately 7,000 km², with a population of 547,100 people, resulting in a population density of 79 people per km² (8.04% of Azerbaijan's total area and 5.38% of its population). The level of urbanization is relatively low (Amanov, 2022). According to data from early 2024, 33.6% of the population in this region lives in cities, while 66.4% resides in rural areas. The urban population constitutes 3.32% of the country's total urban population, while the rural population makes up 7.83% of the nation's rural population (Demographic Indicators…, 2024; *The statistical compilation*…, n.d.).

The population, settlement patterns, and settlement problems in the northeastern slope of the Greater Caucasus have been studied from various perspectives by researchers such as Mehraliyev E. Q. (1996), Afandiyev V. A. (2002), Amanov R. R. (2022), and others. From a settling-landscape perspective, the region has been analyzed by researchers including Museyibov M. A. (1998, 2013), Garibov Y. A. (2012), Garibov Y. A. et al. (2020), Hasanaliyeva L.H. (2015), Sadullayev R. R. (2020, 2023, 2024a, 2024b) among others.

2. Methodology

According to the analysis of Landsat 7 satellite images based on GIS, it has been determined that the total area of seliteb complexes in the northeastern slope of the Greater Caucasus is 47,229 ha (6.7% of the region) (Sadullayev, 2024, p.56). In order to determine the differentiation patterns of seliteb landscapes, the northeastern slope of the Greater Caucasus has been divided into five hypsometric levels using the GIS application with the DEM → Analyst Tools → Raster Reclass → Slice → Natural Breaks sequence (Fig.1).

In the northeastern slope of the Greater Caucasus, the following formula has been proposed to determine the settlement density (share) of settlement complexes within each hypsometric (elevation) zone (Sadullayev, 2020, p. 151; Sadullayev , 2023, p 7; Sadullayev, 2024, p. 92):

$$(1)\ K_{seliteb}=(\sum S_c)/(\sum H_z)$$

Here : $K_{seliteb}$ - the density of the seliteb landscapes; S_c - area of seliteb complexes; H_z - is the area of the hypsometric zone

This approach allows for a more accurate assessment of the structure and dynamics of seliteb landscapes in the northeastern slope of the Greater Caucasus.

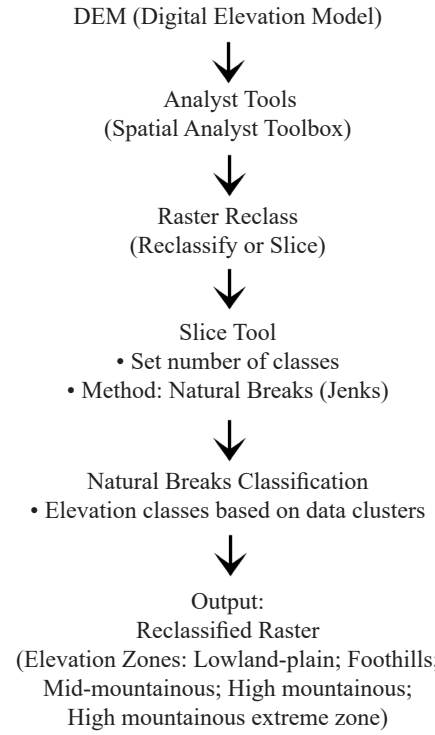

Fig. 1. The scheme of hypsometric zone division using GIS application

3. Results

The application of the proposed formula (1) revealed the following hypsometric differentiation characteristics of the settlement complexes: (Table 1).

The first hypsometric zone: the area between −28–500 m encompasses the plains and flatland zones. The seliteb landscapes in this hypsometric zone make up 54.5% (25,782 ha) of the region's settlement complexes (Sadullayev, 2020, p. 152). In the plains and flatland areas, seliteb complexes with complex configurations differ from those in other zones both in terms of number and the area they cover (Sadullayev, 2024a, p. 93; Garibov, 2012). In the northeastern slope of the Greater Caucasus, 44.4% of the population is concentrated in the 0–200 m elevation range. This hypsometric zone stands out from others in terms of the number of settlements (155 settlements) and total population (216,504 people) (Amanov, 2022, p. 24). The Samur-Davachi plain and the Qusar sloping plain in this hypsometric zone have been historically settled areas, offering favorable climate-relief conditions for the development of agricultural landscapes and livestock farming (Museyibov, 1998, p. 9; Sadullayev, 2020, p. 152). The Samur-Dəvəçi plain, widely used as winter pastures, along with Khachmaz district, Khudat city, and other settlements, has developed within this zone.

The second hypsometric zone: covering elevations between 500–1000 m, this zone encompasses 36.2% (17,131 ha) of the region's seliteb complexes (Sadullayev, 2023, p. 8; Sadullayev, 2024a, p. 93-94). Within this zone, alongside the mountainous relief, flatland forms (such as the Qusar sloping plain) also occupy significant areas. Due to favorable agro-climatic conditions, important cities such as Quba and Qusar, along with other settlements, are located within this

zone (Museyibov, 1998, p. 9).

The third hypsometric zone: covering the 1000–2000 m interval, it encompasses the submontane areas. This zone accounts for 8.1% (3,809 ha) of the seliteb complexes in the northeastern slope of the Greater Caucasus (Sadullayev, 2024b, p. 56; Sadullayev, 2024b, p. 94; Sadullayev, 2023, p. 9). The natural conditions of this hypsometry are favorable for population settlement and economic activities, providing ample opportunities for agriculture, livestock farming, and the development of resort and recreational centers.

Table 1. Hypsometric differentiation of settlement complexes

S/s	Hypsometry, m	The area of the hypsometric zone, ha	The area of seliteb landscapes, ha	The ratio of seliteb landscapes to the area of the hypsometric zone, %	Share in total seliteb landscape, %
1	Up to 500 m	257 512	25 782	10	54,5
2	500-1000	171 981	17 131	10	36,2
3	1000-2000	131 223	3 809	2,9	8,1
4	2000-2500	84 244	547	0,6	1,2
5	2500-4466	51 650	0	0	0

The fourth hypsometric zone: covering the 2000–2500 m elevation range, is located in the high mountain areas. In this zone, there are 547 ha of sliteb complexes, which account for 0,6% of the hypsometry and 1.2% of the setliteb complexes on the northeastern slope (Sadullayev, 2023, p. 9). The lowest number of settlements in the region (approximately 10 settlements) and the smallest population (3,667 people) are observed above the 2000 m elevation (Amanov, 2022, p. 24). The area is characterized by deep river valleys and slopes exceeding 20°, making the areas above 2000–3000 m elevation less suitable for settlement and habitation. This hypsometric zone primarily consists of summer pastures, forming the base for livestock grazing. Due to the abundant pasture resources, these high-altitude areas are utilized for livestock farming, supporting local agricultural activities and contributing to the region's economic development (Museyibov, 1998, pp. 9-10; Sadullayev, 2020, p. 153).

The fifth hypsometric zone: covering the 2500–4466 m elevation range, encompasses the high mountainous area of the northeastern slope of the Greater Caucasus. Due to the extreme relief and climatic conditions, this zone is not considered suitable for permanent human settlement, and no permanent seliteb complexes exist. It is mainly used for grazing and meadow lands (Sadullayev, 2023, p. 9; Sadullayev, 2024a, p. 95). Additionally, the region provides opportunities for mountaineering and hunting tourism. The high mountain areas, with their natural beauty and challenging conditions, offer unique opportunities for tourists and nature enthusiasts interested in mountaineering and extreme sports, making them attractive destinations (Fig. 2).

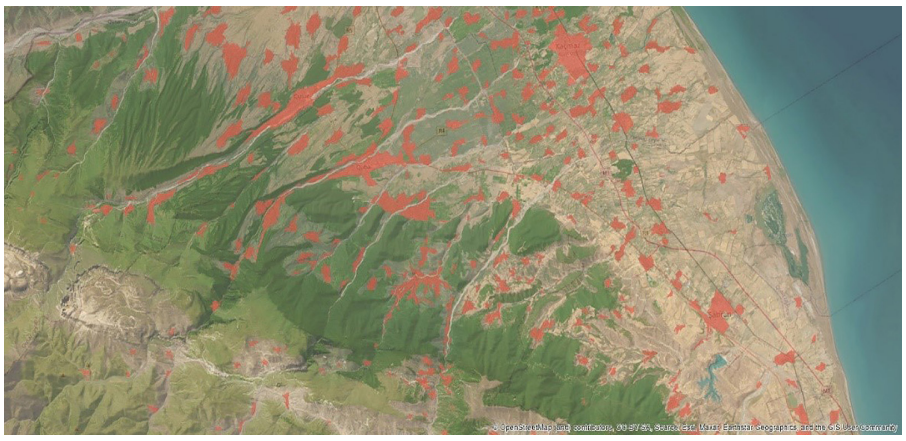

Fig. 2. Differentiation of seliteb complexes according to hypsometric zones

CİS-based analyses indicate that the most densely populated zone on the northeastern slope of the Greater Caucasus is the lowland, foothill, and lower mountain areas, located at elevations between −28 and 1000 meters. Relatively low settlement density is characteristic of the mid-mountainous zones between 1000 and 2000 meters and elevations above 2000 meters (Sadullayev, 2020, p. 154). In higher hypsometric zones, settlement is primarily seasonal and temporary in nature. As a result, the anthropogenic ransformation of natural landscapes is significantly lower compared to the lowland and foothill zones (Museyibov, 1998, p. 9; Sadullayev, 2024a, p. 95). In mountainous areas, seasonal settlements, particularly related to agricultural and livestock activities, are more widespread. Extreme natural conditions and limited anthropogenic influences create better opportunities for the preservation of natural landscapes, with ecosystems experiencing less change and local flora and fauna remaining in their natural state.

On the northeastern slope of the Greater Caucasus, the seliteb complexes are predominantly represented by extensive, dispersed, and networked landscape units. These complexes exhibit various configurations, including chain-like, circular-radial, clumped, and scattered forms, among others.

For comparison, it can be noted that while the share of seliteb complexes in the overall landscape of the Ceyrancol and Gobustan regions is 1.5% (Garibov, 2012, p. 93; Sadullayev, 2020, p. 151), this figure reaches 11.2% (22,810 ha) in the Samur-Dəvəçi lowland (Sadullayev, 2020, p. 151).

The Samur-Davachi lowland is one of the most densely populated areas in the Republic of Azerbaijan. The strategic-geographical location of the lowland, its flat terrain, favorable climate conditions, and fertile soils have contributed to the intensive settlement of the population. As a result of population growth, the establishment of new residential areas, as well as social and economic infrastructures, has accelerated the transformation of natural landscapes. In the Samur-Davachi lowland and the neighboring foothill areas, extensive, both dispersed and circular, seliteb complexes are predominant.

In the lower mountain zone of the northeastern slope of the Greater Caucasus, the number of seliteb landscapes with a chain-like distribution increases. Along the Qudyalçay valley, from Quba to the Kusnet village, as well as along the Qusarchay valley in the direction of Qusar-Zindanmuruğ, a ring of settlements is located. Every year, the density of villages and the population living there increases, resulting in the tightening of the ring of seliteb complexes (Garibov, 2012, pp.93-94; Sadullayev, 2024a, p. 96).

The hydrographic network has a significant impact on the region's population and settlement patterns. A large portion of villages and urban-settlement complexes are primarily concentrated along river valleys and areas relatively close to freshwater sources (Amanov, 2022, p. 10). Infrastructure such as the Samur-Absheron canal, the Chanarch canal, and the Tachtakorpu reservoir play a crucial role in ensuring a stable water supply for both the urban population and agriculture (Ahmadzade & Hashinov, 2016). These water sources are not only essential for improving the living conditions of the population and the efficient use of water resources but also contribute to the sustainable development of the economy, while ensuring the protection of water sources.

As the elevation increases on the northeastern slope of the Greater Caucasus, the number and area of seliteb complexes decrease, which is accompanied by a weakening of the impact on natural landscapes. The main network of seliteb complexes in the region is concentrated in the flat-oval, sloping plains, and foothill zones. GIS analysis has shown that in the flat and plain areas up to 500 m in elevation, the number of seliteb complexes is 257, while in the sloping plains between 500–1000 m, this number drops to 142, and in the 1000–2000 m range, it further decreases to 50. As one moves towards the middle mountain zone, the number of settlements sharply decreases due to the influence of the relief and climatic conditions (Sadullayev, 2020, pp. 153-154; Sadullayev, 2023, p. 9). In areas above 2000 meters, only about 20 settlements have been recorded. In these areas, settlement is historically linked to agriculture, especially livestock farming, and other activities adapted to the challenging mountainous conditions. The settlements in the mountainous regions are typically located in places with limited infrastructure, difficult natural conditions, and fewer people moving to these areas compared to the foothill regions.

There are significant differences in the population size, growth rate, and the proportion of urban population across the administrative districts of the northeastern slope of the Greater Caucasus (Amanov, 2022, p. 10). These factors include the natural-geographical conditions such as elevation, climate, and soil conditions, as well as the settlement areas and their existing social and infrastructural conditions.

In terms of both the number and density of seliteb complexes, the Khachmaz district stands out in particular. This district contains a total of 151 settlements, of which 2 are cities, 12 are towns, and the density of seliteb complexes is 14.3%. In the Qusar district, the number of seliteb complexes is 90 (1 city, 1 town, 88 villages), and their overall distribution is 8.8%. In the Quba district, the number of seliteb complexes is 157 (1 city, 7 towns, 149 villages), and the overall distribution indicator is 5.0%. In the Shabran district (1 city, 68 villages), this indicator is 4.4%. The Siyazan district has the lowest density of seliteb complexes in the region (3.2%) with 1 city, 1 town, and 32 villages (*The statistical compilation*….(n.d.); Sadullayev, 2020, p. 153). (Table 2).

Table 2. Differentiation of seliteb complexes by administrative districts

S/s	Administrative districts	Area of seliteb complexes (km2) (2024)	Proportion in %
1	Qusar	127	8,8
2	Quba	134	5,0
3	Chacmaz	135	14,3
4	Shabran	47	4,4
5	Siyazan	29	3,2
		Total: 472 km2 (47 200 ha)	Average value: 7%

According to L.H. Hasanaliyeva (2015), there are 5 settlements located above 2000 m in this region, while R.R. Amanov's (2022) research suggests there are 10. However, based on the conducted research and the analysis of satellite imagery using GIS technologies, it has been determined that there are exactly 17 settlements located in this elevation range. These settlements account for 3.39% of the region's total settlements, 1.2% of the total seliteb-settlement area, and 0.7% of the population. The settlements located above 2000 m in the northeastern slope of the Greater Caucasus are as follows: Qusar district: Sudur, Quturghan, Arcan, Kenarchay, Yerghi-Kek, and Alich villages. Quba district: Chinaliq, Bostankesh, Qalaychudat, Qriz, Cek, Haput, Adur, Qarchun, Zeyid, Buduq, and Daliqaya villages (Fig. 3).

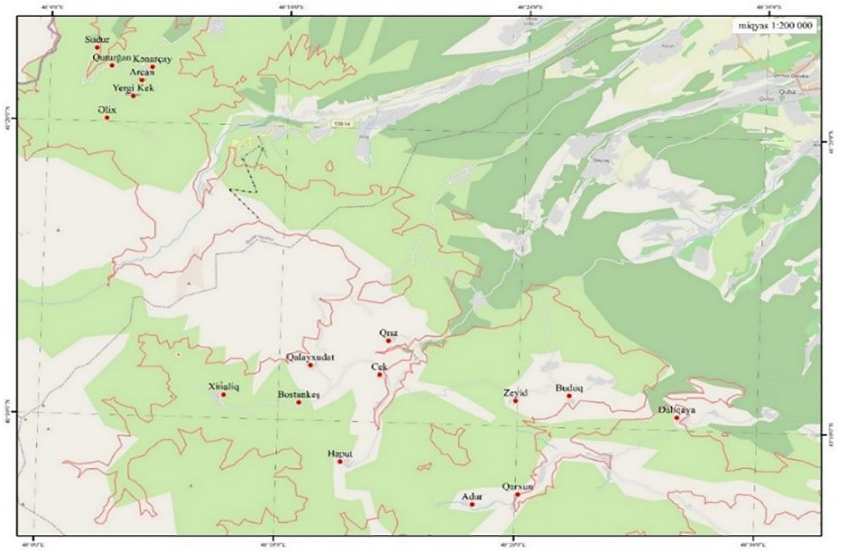

Fig. 3. Village-seliteb complexes located in the hypsometric zone above 2000 m on the northeastern slope of the Greater Caucasus

Based on analyses conducted using Landsat remote sensing images, the changes in the urban-settlement landscapes of the region over the years 1989, 2010, and 2024 were studied. According to the research, the area of urban-settlement zones in the region was 2095 ha in 1989, 4234 ha in 2010, and 4794 ha in 2024. Over the past 35 years, the area of urban-settlement zones on the northeastern slope of the Greater Caucasus has increased 2,3 times, while the population has grown by 0,5 times.

The growth trend of urban-seliteb complexes varied across different cities. For instance, in the city of Quba, this indicator increased 3,1 times (from 315 ha to 980 ha) between 1989 and 2024. In the cities of Khachmaz and Qusar, this expansion was approximately 2 times, while the urban-seliteb landscape area of Siyazan grew by 1,6 times. The growth indicator in the city of Shabran reached the maximum level in the region during the mentioned period, with a 3,7 times increase. (Table 3).

Table 3. Growth trend of urban-settlement landscapes (1989-2024)

Cities	1989 Population (thousand people)	urban seliteb area (ha)	2010 Population (thousand people)	urban seliteb area (ha)	2024 Population (thousand people)	urban seliteb area (ha)
Chacmaz	41.8	758	63,0	1290	69,5	1384
Quba	26.6	315	38,1	824	39,6	980
Qusar	15.7	448	18,6	850	23,8	895
Siyazan	19.4	298	24,9	445	26,7	476
Shabran	18.4	276	22,6	825	24,6	1012
By region	121.9	2095	167,2	4234	184,2	4794

For the first time, the urban-seliteb landscapes on the northeastern slope of the Greater Caucasus were analyzed using GIS technology, and a 1000-meter landscape-ecological buffer zone was created using the Toolbox → Analysis Tools → Buffer sequence (Fig. 4). The width of this buffer zone primarily varies based on natural landscape conditions and the intensity of anthropogenic pressures (İbrahimov & Sadullayev, 2023).

According to the calculations, the area covered by the 1000-meter buffer zone of the seliteb complexes is 325,388 ha, which constitutes 46.5% of the region's area and is 6.7 times larger than the existing seliteb-settlement area. Additionally, the area covered by the 500-meter buffer zone is 191,661 ha, which is 4 times larger than the existing seliteb-settlement area and covers 27.5% of the region.

The differentiation of seliteb complexes within the natural landscape types of the study area was analyzed based on GIS, and the following results were obtained: In the plain-semi-desert landscapes, the share of settlement complexes is 3.5%. In the low mountain arid and semiarid landscapes, it is 1%; in the medium and low mountain landscapes, it is 9%; in the arid mountain-forest landscape, it is 5.2%; in the mountain-forest landscape, it is 3.8%; and in the high mountain landscapes, it is 0% (Sadullayev, 2024a, p. 97) (Table 4).

The setliteb landscapes on the northeastern slope of the Greater Caucasus are considered to be highly transformed, regularly, and intensively utilized complexes (Garibov et al., 2020, pp. 77-79). These complexes have been classified into 3 main categories and 8 different groups based on their transformation characteristics and mapped using Geographic Information Systems (GIS). The classification reflects the various landscape-ecological and settlement features of the area. Each category identifies a landscape type that has been subject to specific transformation processes and is further divided into appropriate groups (Fig. 5).

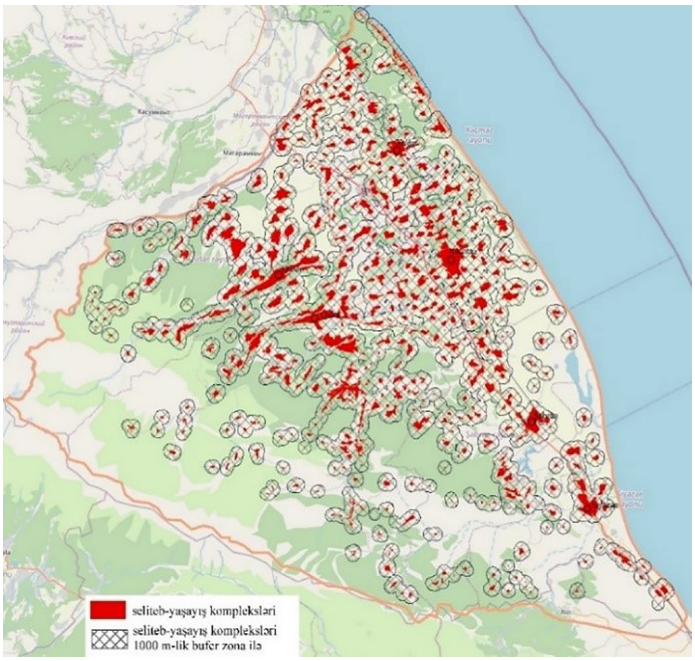

Fig. 4. Landscape-ecological buffer zones (1000 meters) of seliteb-complexes

Table 4. Differentiation of settlement complexes within natural landscape types

S/s	Landscape types	Area of the landscape type (km2)	Area of the seliteb complexes (km2)	% ratio to the landscape type
1	High mountain landscapes	352	0	0
2	Mountain-grassland landscape	1372	18	1,3
3	Mountain-forest landscape	620	23.4	3,8
4	Arid mountain-forest landscape	646	33.8	5,2
5	Medium and low mountain landscapes	526	47.8	9
6	Low mountain arid and semi-arid landscapes	3592	347	1

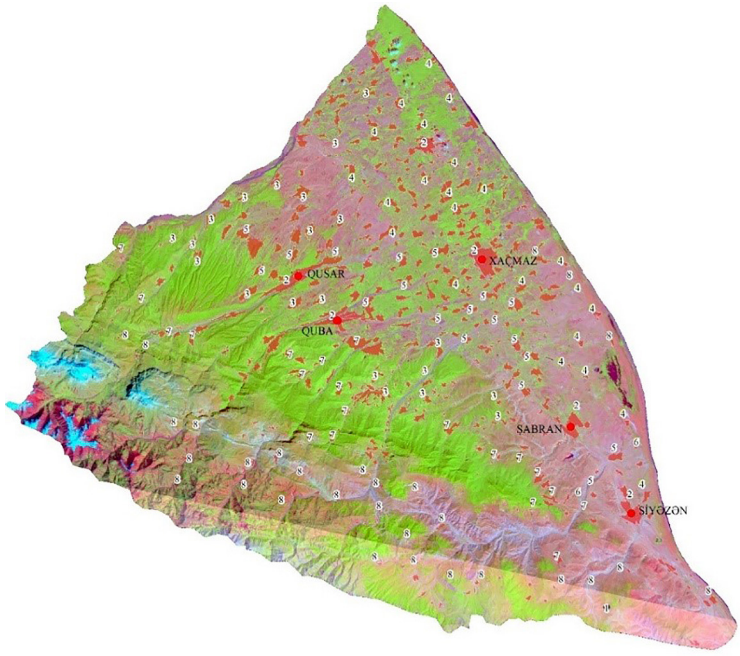

Fig. 4. Map of the distribution of seliteb complexes on the northeastern slope of the Greater Caucasus based on transformation characteristics

Map legend:

Severely transformed, regularly and ıntensively used seliteb complexes:

A. *S*ettlement complexes of various sizes and forms located i*n the semi-desert, dry steppe, intrazonal, and arid sparse forest-shrub landscapes of plains: 1. Low-slope plains: Seliteb complexes that form in a scattered pattern on gently sloping plains. These areas are characterized by poorly developed orchards or green spaces and densely populated settlement complexes.*

B. *Seliteb complexes located in intermountain depressions and high-sloped plains within steppe, forest-steppe, forest-intrazonal, post-forest steppe, and shrubland landscapes: 2. Highly urbanized, artificially covered seliteb complexes: These are large-scale urban settlement complexes located in flattened terrain, with significantly altered hydrogeological and geochemical processes. They feature a high level of urbanization and are surrounded by artificial cover. 3. Selitebs along river valleys and large river terraces: These complexes are scattered and form linear or chain-like patterns, surrounded by orchards or green spaces, located along river valleys and wide river terraces. 4. Selitebs along major roads, railways, and ırrigation systems: These complexes are linear or chain-shaped, extending along broad highways, railway lines, and irrigation systems, surrounded by orchards or green spaces. 5. Selitebs in large river valleys and terraces: These are seliteb complexes located in expansive river valleys and terraces, surrounded by extensive green spaces.*

C. *Seliteb complexes of various sizes and forms located in low and middle mountain areas, river valleys, and intermountain depressions within forest, forest-meadow, forest-shrub, arid sparse forest, subalpine, and alpine meadow landscapes: 6. Selitebs along river valleys, smooth plateaus, and terraced slopes: These complexes are arranged in a chain-like or scattered pattern and are surrounded by orchards or green spaces. 7. Selitebs in intermountain depressions and terraced slopes: These complexes are scattered and surrounded by orchards or green spaces, located in intermountain depressions and terraced slopes. 8.Selitebs in ıntermountain depressions, river valleys, and terraced mountain slopes: These complexes consist of residential houses located close together, with limited orchard or green space, situated in intermountain depressions, river valleys, and terraced mountain slopes.*

Through the application of GIS (Geographic Information Systems) technologies and multi-year analysis of Landsat satellite images, it has been determined that between 1989 and 2024, there has been approximately a 50% increase in the area of settlement-landscapes on the northeastern slope of the Greater Caucasus. This dynamic is closely related to the ongoing socio-economic development in the region, the growth of rural and urban populations, the expansion of infrastructure, and the scaling-up of settlements. In particular, in recent years, there has been an increase in new buildings and agricultural land in rural-settlement areas, accelerating the anthropogenic transformation of natural landscapes. These changes have intensified against the backdrop of population migration toward mountainous areas and the expansion of tourism activities.

Based on the obtained results, it is predicted that this trend will continue in the coming years, with a high probability of further expansion of settlement complexes in terms of area. This, in turn, may have environmental impacts, leading to changes in land cover, an increase in erosion risks, and disruption of landscape balance. Therefore, continuous monitoring and management of these processes are crucial for the sustainable development of the region.

7. Conclusion

The GIS analysis conducted using Landsat 7 satellite images shows that the total area of settlement complexes on the northeastern slope of the Greater Caucasus is 47,229 ha, accounting for 6.7% of the region's total area.

The study area was divided into hypsometric zones using the DEM → Analyst Tools → Raster Reclass → Slice → Natural Breaks algorithm, and the density (share) of settlement complexes within each hypsometric zone was determined using the formula (1) , resulting in the following distribution: 54.5%, 36.2%, 8.1%, 1.2%, and 0%.

Based on calculations by administrative divisions, the differentiation of settlement complexes varies as follows: 14.3% in Khachmaz district, 8.8% in Qusar district, 5.0% in Quba district, 4.4% in Shabran district, and 3.2% in Siyazan district.

The analysis of satellite images and GIS technologies has revealed that there are 17 rural-settlement complexes located above 2000 m in altitude. This accounts for 3.39% of the total settlements in the region, 1.2% of the settlement areas, and 0.7% of the total population.

Research conducted from 1989 to 2024 indicates that the area of urban-settlement landscapes on the northeastern slope of the Greater Caucasus has increased 2.3 times. This increase is attributed to population migration, urbanization processes, and economic development.

The differentiation of settlement complexes within natural landscape types has been analyzed using GIS. The share of settlement complexes in low mountain arid and semiarid landscapes is 1%, in plain-semi-desert landscapes 3.5%, in mountain-forest landscapes 3.8%, in arid mountain-forest landscapes 5.2%, in medium and low mountain landscapes 9%, while in high mountain landscapes it is 0%.

For the first time, the application of GIS technology and the Toolbox → Analysis Tools → Buffer sequence was used to define a 1000-meter landscape-ecological buffer zone. This buffer zone is 6.7 times larger than the current urban-settlement area and covers 46.5% of the region.

The settlement landscapes on the northeastern slope of the Greater Caucasus, which have been severely transformed and regularly and intensively used, have been classified into 3 categories and 8 groups based on their transformation characteristics and mapped using GIS technology.

From 1989 to 2024, the area of settlement landscapes in the northeastern slope of the Greater Caucasus has increased by approximately 50%. This growth is related to population increases, the expansion of settlements, and anthropogenic impacts. The further expansion of these areas is expected in the future, which may affect the natural landscapes.

ORCID iD

Rashad Rahib Sadullayev https://orcid.org/0000-0003-3480-4974

References

Afendiyev, V. A. (2002). *Urbanization and Urban Settlements of Azerbaijan (Monograph)*. Baku: Baku University Press.

Ahmadzade, E. C. & Hashinov, A. C. (2016). *Encyclopedia of Melioration and Water Management*. Baku.

Amanov, R. R. (2022). *The Study of Population Settlement in the Quba-Khachmaz Economic Region in the GIS Environment:* PhD Thesis Abstract in Geography. Baku.

Demographic Indicators of Azerbaijan (2024). Baku: DSK. https://stat.gov.az/menu/6/statistical_yearbooks/source/demoqraphy_2024.zip

Garibov, Y. E. (2012). *Optimization of Natural Landscapes of the Republic of Azerbaijan.* Baku: AzTU Press.

Garibov, Y. E., Haciyeva, A. Z., & Sadullayev, R. R. (2020). *The Study of Anthropogenic Transformation of the Natural Landscapes of the Greater Caucasus using GIS Technology: Monograph.* Baku: Müəllim.

Hasanaliyeva, L. H. (2015). *The Impact of Population Settlement on the Landscape Transformation in the Northeast Slope of the Greater Caucasus*: PhD Thesis Abstract in Geography. Baku.

İbrahimov, T. O. & Sadullayev, R. R. (2023). Crucial Problems of the Organization of Biosphere Reserves in Azerbaijan. *Journal of Geology, Geography, and Geoecology, 31*(4), 628–634. https://doi.org/10.15421/112258

Mehraliyev, E. Q. (1996). The Impact of Natural Conditions on Population Settlement. *Constructive Geography of the Republic of Azerbaijan*, 206–218. Baku: Elm.

Museyibov, M. A. (1998). *Physical Geography of Azerbaijan.* Baku: Maarif.

Museyibov, M. A. (2013). *Landscapes of the Republic of Azerbaijan / Textbook.* Baku: Elm ve Texsil.

Sadullayev, R. R. (2020). Application of Geographic Information Systems (GIS) and Remote Sensing in the Study of the Differentiation Characteristics of Settlements (In the Example of the Northeast Slope of the Greater Caucasus). *Materials of the 2nd International Conference on Science and Technology* (151-154).

Sadullayev, R. R. (2023). Study of the Characteristics of Differentiation of Anthropogenic Landscape Complexes Based on Remote Sensing Data and Geographic Information Systems (GIS) (In the Example of the Northeast Slope of the Greater Caucasus). *Chemistry and Biology: Scientific Journal, 1*(3(105)), 5-11.

Sadullayev, R. R. (2024b). Differentiation Characteristics of the Modern Anthropogenic Landscapes of the Northeast Slope of the Greater Caucasus. *Physical Geography and Geomorphology, 47*(1), 53–57. https://doi.org/10.17721/phgg.2024.1-2.06

Sadullayev, R. R. (2024a). *Differentiation Characteristics of the Settlements in the Northeast Slope of the Greater Caucasus.* Baku: Collection of Scientific Articles Dedicated to the Victory Day, 4, 91–99.

The statistical compilation "Demographic Indicators of Azerbaijan" has been published (n.d.). The State Statistical Committee of the Republic of Azerbaijan. https://www.stat.gov.az/news/index.php?lang=az&id=5979