Impact of military conflicts on landscape transformation (a case study for the Aghdam district of the Republic of Azerbaijan)

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ABSTRACT

Problem statement: The Aghdam district of the Republic of Azerbaijan, under occupation for nearly 30 years, became an area of intensive degradation of both natural and anthropogenic landscapes. The scale of destruction caused by military and technological activities has led to significant ecological, social, and economic losses. The damage to natural and anthropogenic ecosystems is estimated to exceed 200 billion US dollars. More than 50 natural monuments were destroyed, and the infrastructure of 58 rural settlements and one city were devastated. Over 90,000 mines pose a constant threat and hinder the restoration of these areas.

Objective: To conduct a landscape-oriented study aimed at assessing the consequences of military and technological activities, determining structural, genetic, and functional changes in the landscapes of the Aghdam district, and systematizing the transformed landscapes.

Methods: Satellite imagery, field research data, and archival materials were applied during the research procedure. A systematic approach was applied for the analysis, classifying, and assessing the scale of transformation of natural and anthropogenic landscapes.

Results: It was unraveled that the transformation of landscapes resulted from both direct and indirect impacts from military and technological activities. The classification of landscapes in the region revealed 2 main classes, 6 types, and 21 subtypes. The analysis identified a high degree of ecological degradation. Military actions exacerbated the degradation of natural components. Direct impacts included the destruction of forests, pastures, hydrological objects, and infrastructure, while indirect consequences have been experienced in the disturbance of natural balance and the deterioration of soil and water quality. An important aspect of the research is to identify functional changes in landscapes. The worsening environmental situation has led to a reduction in biodiversity, decreased water retention capacity, and an increased risk of soil erosion. In anthropogenic landscapes, there has been a complete loss of economic value in several areas, complicating the restoration process. The implemented classification provides the identification of major landscape groups based on the degree of transformation:

- Landscapes with minimal transformation (10% of the area), where changes are limited to local disturbances.
- Landscapes with moderate transformation (25%), are characterized by changes in vegetation structure and soil cover.
- Landscapes with high degrees of transformation (40%), where significant changes occur in ecosystems due to direct impacts.
- Landscapes with a complete loss of natural functions (25%), including areas that were destroyed by mines, infrastructure, and other military objects.

Conclusion: The research systematized landscape changes and revealed the scale of the consequences of military conflicts. The presented results enable the application of a landscape-oriented approach to monitoring and restoring territories, including the development of reclamation, demining, and ecological function restoration measures. The proposed classification of transformed landscapes can serve as a foundation for future research and the development of sustainable land management strategies.

Keywords: *military-technological impact, landscape, ecosystem, occupation, anthropogenic transformation, belligerative landscape, cultural landscape, pollution, landscape structure.*

Introduction and research status. The recent increase in military conflict hotspots worldwide creates complex and long-term problems for the restoration of natural and anthropogenic ecosystems. Given the relevance of this issue for the future of humanity and the preservation of the natural genetic fund, it is attempted to investigate the landscape-ecological features of the Karabakh region of Azerbaijan, which was under occupation for a long period and subjected to direct military-technological impact, using the ex-

ample of the Aghdam district.

The anthropogenic transformation of natural landscapes is a long and complex process. In the Aghdam district, human economic activity began in ancient times, and as a result of this, the anthropogenic load on landscapes steadily increased. As a result, initially, small anthropo-ecosystems gradually transformed into complex modern landscape complexes with elements of contemporary transformation [13, 19].

The purpose of the research work. The work aims to explore the trends in the development of modern landscapes, particularly anthropogenic landscapes, under the military-technological influence. The military-technological impact is a powerful ecological factor in the transformation of natural ecosystems.

Material and methods. In the course of the research, we applied the following methods: analysis of historical-genetic series, comparative method of natural analogs, and the landscape method based on field data and GIS technologies.

Research area. Aghdam district is an administrative-territorial unit in Azerbaijan, located in the western part of the country. It holds significant importance in the history and culture of the region, as well as strategic value.

The Aghdam district is situated on the Karabakh plain and borders the Khojavend, Tartar, Barda, Aghjabadi, and Fuzuli districts of the country. The area of the district covers approximately 1,150 square kilometers.

Aghdam district became one of the most affected regions as a result of the Armenian-Azerbaijani conflict, particularly during the First Karabakh War (1991–1994). The destruction led to the loss of historical heritage, the district's economic potential, and the forced displacement of more than 140,000 residents.

Since the early 1990s, as a result of the Karabakh conflict, a large part of the Aghdam district was occupied by Armenian forces. The city of Aghdam, the administrative center of the district, was almost destroyed, turning into a "ghost town." Thousands of homes, public buildings, schools, hospitals, and infrastructure facilities were destroyed or rendered unusable. Until 2020, the ruins of Aghdam were primarily used for military positions and the illegal extraction of construction materials.

After the signing of the ceasefire agreement in 2020, the district was returned under Azerbaijan's control, and restoration work has begun.

The destruction of the Aghdam district was a tragedy not only for its residents but also for the entire country. After the conflict ended in 2020, the Aghdam district became one of the symbols of Azerbaijan's recovery. New residential neighborhoods, schools, hospitals, and infrastructure facilities are being built. The restoration of the region is a priority project for the Azerbaijani government, focusing on the return of internally displaced persons to their native lands.

Result and discussion. The settlement of Somutepe, stretches back to the 2nd millennium BC, the burial mound of Sumurlu-tepe from the Bronze Age, the settlements of Goshatepe and Ilanlitepe from the Eneolithic period, and other historical and cultural monuments of the region are indicators that anthropogenic transformations in this area have ancient historical roots. The first anthropogenic transformations began in the forest-steppe landscapes of the low mountains and denudational-accumulative plains. The fact that these landscapes possess the necessary natural resource potential for human life created conditions for the expansion of residential areas and agricultural lands.

Arid forest ecosystems, which were one of the main structural elements of the forest-steppe landscape type, became the most affected by anthropogenic impact over time [4, 8]. Historically, the region was widely covered with arid forest ecosystems consisting of long-legged oak, wild pistachio (*Pistacia mutica*), and other tree and shrub species. Later, with the expansion of anthropogenic impact, these forests were cut down and turned into agricultural and pasture lands. Currently, these forests have survived only in a small area called the Sultanbud forest.

The creation of agro-industrial complexes during the intense development of agriculture has accelerated the anthropogenic impact on natural landscapes. Large areas, particularly within natural complexes of low mountains and partly sloping denudational-accumulative plains, turned into monocultural agroecosystems consisting of vineyards. This, in turn, further enhances the transformation and identification of biodiversity in the natural forest-steppe landscapes, which are characterized by rich landscape-ecological diversity.

During the nearly 30 years of occupation, the landscapes of the Aghdam district underwent a massive military-technological transformation. Virtually all the settlements under occupation, including the city of Aghdam, were completely destroyed and turned into ruinous landscapes. Destroyed roads, irrigation systems, numerous pits dug for military vehicles, military fortifications, trenches, and so on became the key components of belligerent landscapes (Fig. 1) [8, 10, 18].

Dry-steppe, xerophytic-shrubby, and semi-desert landscapes of the low mountain and sloping foothill plains of the region are secondary natural-anthropogenic formations that arose in place of former forests and forest-steppes.

The study of anthropogenic changes and landscape transformation was addressed by F.N. Milkov

[11], J.A.G. Jaeger [9], M.G. Nazarov [12], Niko-laishvili, et al [13], Denysyk, H., Kanskyi, V. et al [3] and others' works, who made valuable scientific and methodological conclusions during their research.

In Azerbaijan, studies have also been conducted on the anthropogenic transformation of modern landscape complexes and their classification. For example, Y.A. Garibov [6] categorized anthropogenic landscapes in Azerbaijan by categories, subcategories, and variants.

M.A. Suleymanov [16], in his research, proposed a classification of anthropogenic landscapes based on natural landscapes, using class, type, subtype, and species as the classification units.

Fig. 1. Destroyed village of the Aghdam district

E.K. Alizade, M.J. Ismayilov, and others [1] categorized landscapes that underwent anthropogenic transformation based on changes in natural components. The degree of transformation of modern NTC (natural-territorial complexes) was used for grading: unchanged, slightly changed, moderately changed, strongly changed, and transformed.

In the naming of landscapes, more attention was paid to the main components of the natural complex. All anthropogenic changes are based primarily on the natural foundation of the landscape and can express it in specific ways.

Anthropogenic impacts manifest differently in the transformation of natural complexes. These impacts can be partially grouped as follows: agricultural activity, forestry, industrial-technological, population settlement, tourism and recreation, etc. The influence of this activity on landscape transformation is diverse as well. Despite covering small areas, construction works, and mining, culminate in the fundamental changes in landscapes, with almost all natural components undergoing complete transformation. While other sources of anthropogenic transformation do not directly affect the vertical structure of landscapes, they cover large areas and cause significant changes in the horizontal spatial structure of landscapes.

Analysis of the transformation characteristics of the landscapes in the Aghdam district revealed that there are virtually no landscapes that have not been transformed as a result of strong anthropogenic im-

pact. Other types of transformation are sufficiently represented in the local landscapes.

Considering the uniqueness of the landscape transformation in the Aghdam district, two classes of transformation were identified:

1. Landscapes with military-technological transformation;

2. Purposefully transformed cultural anthropogenic landscapes.

I. Landscapes with Military-Technological Transformation

It should be noted that military actions during the occupation, as a unique type of anthropogenic factor, played a significant role in the degradation of natural-landscape complexes in the Aghdam district and the disruption of the natural-ecological balance.

In the landscape structure of more than half of the district's territory, elements reflecting the nature of military actions can be found. These can briefly be called military-technological or belligerent landscapes. Military-technological landscapes in the region can be divided into two types based on their formation characteristics:

A. Military-technological landscapes formed under the direct influence of military actions; B. Military-technological landscapes transformed under the indirect influence of military actions;

1. Military-technological complexes include all complexes formed as a result of military actions and that underwent military-technological transformati-

ons. These include the following: combat trenches, road-communication complexes, military-technical structures, technological complexes involved in combat operations, defensive fortifications, battlefields, destroyed irrigation systems, destroyed residential complexes, craters formed by explosive ordnance, etc. [2] (Fig. 2).

2. Landscapes transformed under the indirect influence of military actions: These include all complexes within the direct sphere of influence of military-technological complexes and those formed due to the indirect impact of military activities. This type also includes all occupied territories, which have numerous military barracks, secondary fortifications, dirt roads, military objects inside protected areas, etc. [5, 7, 20].

Fig. 2. Trench and defensive wall near the village of Tapgaragoyunlu (Aghdam district)

In the pre-occupation period, large vineyards, fertile grain fields, residential rural and urban landscapes surrounded by orchards, etc., existed in the places of military-technological complexes in the Aghdam district. That is, anthropogenic transformations were aimed at improving human life, and, to some extent, measures were taken to preserve the natural ecological balance. Along with the destruction of settlements, economic objects, and infrastructure during the occupation, military actions led to changes in the relief, destruction of soil and rock properties, deforestation, and the formation of belligerent landscapes such as barricades, trenches, and communication routes. During the occupation of Aghdam, more than 90,000 anti-personnel and anti-tank mines were placed. This is a source of danger to human life.

A completely different trend can be observed in the landscapes along the front line. In the frontline zone, natural landscapes were completely destroyed,

and more complex military complexes were constructed, affecting all ecosystems of the frontline landscapes. Characteristic features of the relief here include fortifications (trenches, ditches, firing points, etc.). On these territories, the upper layer of soil is contaminated with heavy metals and other chemical compounds and loses its fertility, and vegetation degrades. In the upper layer of the landscape in buffer zones, where intensive combat took place, from explosions, spills of petroleum products, etc., a layer was formed that poses a threat to human health and requires more than 10 years for decontamination [8].

During the occupation, in the direct military contact zone on the territory of the Aghdam district, more than 20 large fires were set during the plant vegetation period. As a result, thousands of hectares of land were affected by fires, causing enormous environmental damage. The results of these intentional fires were captured on satellite images [7, 17].

Starting from the war in 2020, when the territory was fully returned under Azerbaijan's control, the situation has begun to change. Enormous work is being done to clear the buffer zone, dismantle enemy fortifications, and so on. As a result, the territories that had been occupied for 30 years are now returning to economic circulation.

In the satellite images of the Aghdam district (2020–2023), which relate to the period of occupation (Fig. 3), horrifying images of military-technological transformation are clearly visible. Two-thirds of the district was occupied. On this territory, as a result of direct military vehicle influence, the relief of natural and cultural landscapes was altered, the soil-vegetative cover degraded, and natural-territorial complexes (NTC) were transformed into belligerative landscapes [7, 14].

Based on the results of field studies (2022-2023) and the interpretation of high-resolution satellite images, a large-scale (1:100,000) digital map titled "Anthropogenic Transformation of Landscapes in the Aghdam District" (Fig. 4) was developed. Based on the analysis of the map, 2 classes and 21 types of landscapes were identified, which sharply differ from each other in terms of their types and structure of transformation.
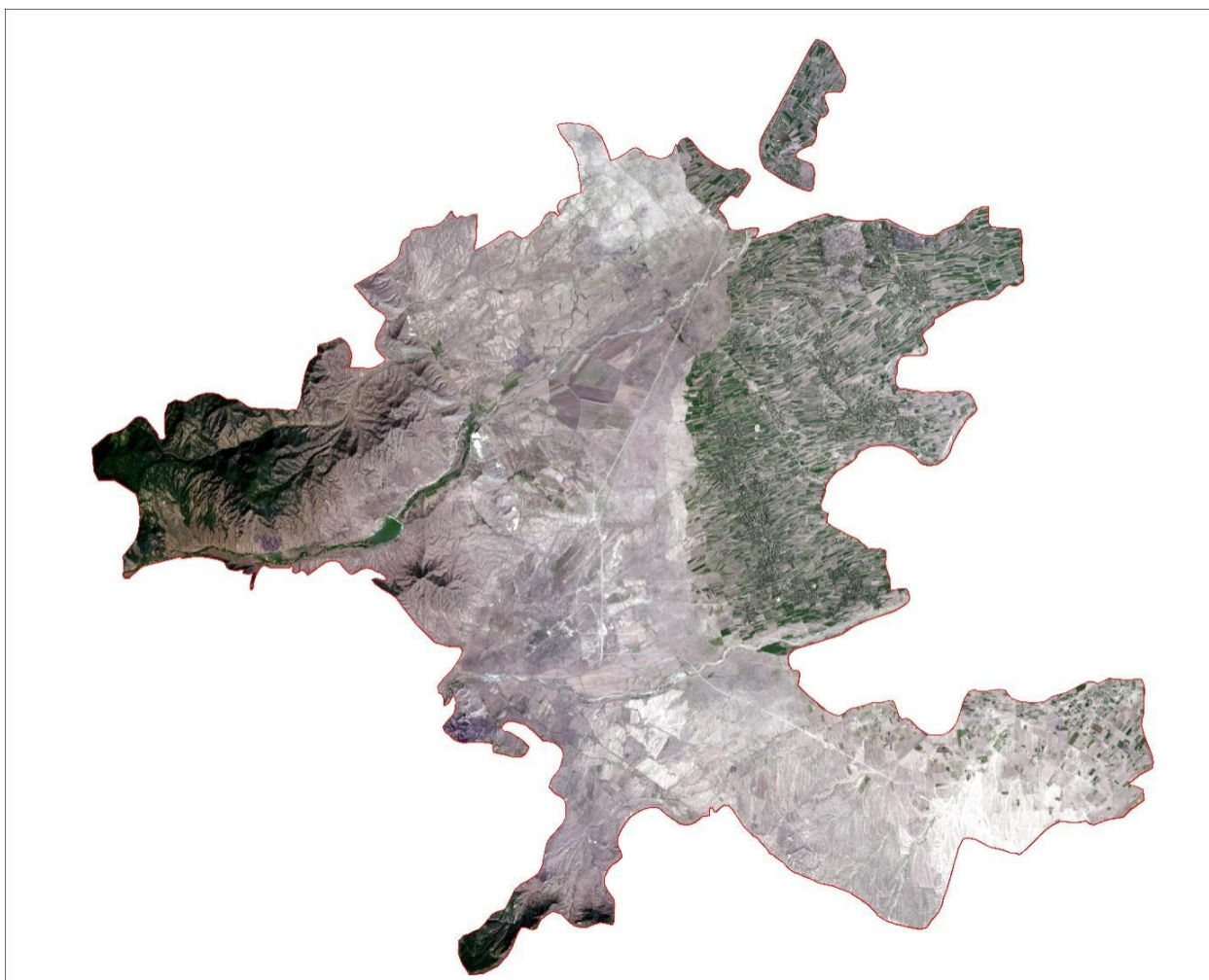

Fig. 3. Satellite Image of Anthropogenically Transformed Landscapes of the Aghdam District (2020)

In the class of military-transformed landscapes, 14 types of landscapes were distinguished according to the intensity of military-technical activities. Among them, the largest areas —7.7% and 7.5% of the total area are occupied by strongly disturbed and transformed military-technical forest-steppe landscapes and fundamentally altered and disturbed belligerent landscapes (table).

II. Deliberately transformed cultural anthropogenic landscapes.

The second class of transformed landscapes encompasses modern cultural landscapes that have been deliberately altered in non-occupied areas. Within this class, 7 types of landscapes were distinguished (table). Of these, the largest area (8.5%) is occupied by urban and residential landscapes. The larger area of urban and residential landscapes in territories not subjected to occupation is related to the settlement of refugees from the occupied territories of the Karabakh region. According to the latest statistical data [15], the rural population density here is more than 300 people per km². This process increases the demographic load on modern landscapes.

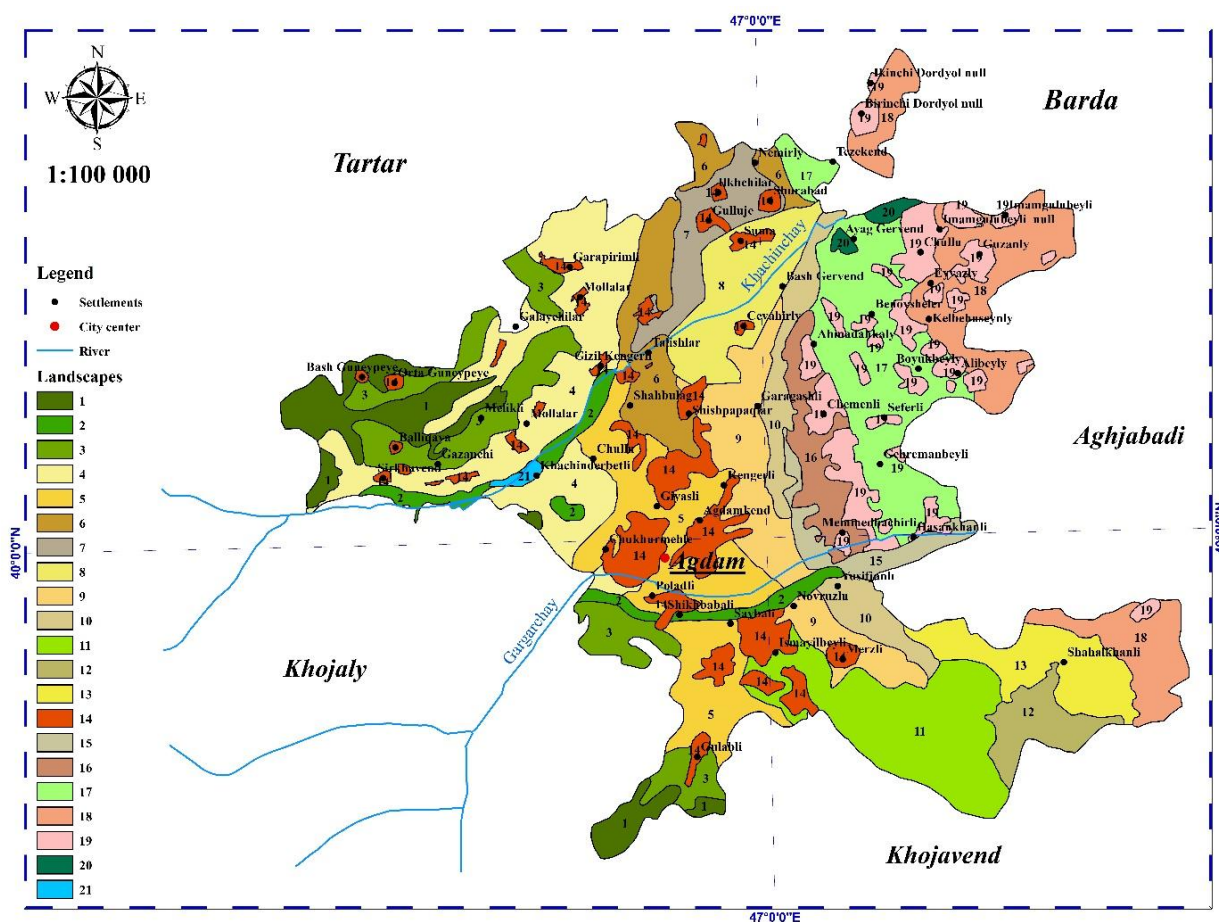In addition to this, the lower reaches of the Tartar

Fig. 4. Anthropogenic landscape transformation map of the Aghdam district.

Legend

I. Landscapes subjected to military-technical transformation:

1. Oak-hornbeam forests of the foothills, subjected to relatively weak transformation.
2. Weakly transformed shrub-grassland river valley landscapes.
3. Moderately transformed arid woodland and shrubland landscapes of the foothills.
4. Secondary dry steppe complexes of the foothills and intermountain depressions, heavily transformed due to fires and military equipment.
5. Strongly military-technically transformed xerophytic-shrubby steppes on the site of former vineyards on degraded gray-brown soils.
6. Strongly military-technically transformed xerophytic-shrubby steppe complexes of denudational-accumulative foothill plains.
7. Intensively transformed dry steppes of denudational-accumulative plains with fragments of military-technical changes.
8. Moderately transformed dry steppes of alluvial-accumulative plains on gray-brown soils with disrupted agroecosystems.
9. Radically transformed dry steppes on accumulative-denudational hill-belligerative badlands.
10. Strongly disturbed military-technical dry steppe complexes and radically transformed belligerative landscapes.
11. Forest-steppe complexes of accumulative-denudational plains, whose surface is heavily disturbed and transformed due to military-technical impacts and fires.
12. Badland belligerative landscapes of accumulative plains under the military-technical influence and fire impact.
13. Heavily disturbed and transformed dry steppe landscapes of moderately dissected plains due to fires and military-technical impacts.
14. Urban and rural landscapes, were deliberately destroyed during the occupation.

II. Deliberately transformed cultural landscapes:

15. Moderately transformed pasture-mowing complexes on gray-brown soils of slightly sloped, hilly-rolling accumulative plains.
16. Semi-deserts, intensively transformed into plantation-garden complexes of accumulative plains on light gray-brown soils.
17. Intensively transformed agro-irrigation landscapes of accumulative plains.
18. Semi-deserts, consisting of strongly transformed cultural agro-irrigation complexes.
19. Settled rural and urban landscapes, consisting mostly of one- or two-story houses with gardens and crops.
20. Moderately transformed oak-pistachio arid forests on riverine hilly plains.
21. Reservoirs.

Main structural elements of anthropogenic transformation of landscapes in the Aghdam district

#	Landscape Type	Area (km²/%)	Transformation Features	Degree of Transformation
1	Oak-hornbeam forests	59 (5.1%)	Ammunition depots, barracks	Relatively weakly transformed
2	Shrub-grassland	28 (2.4%)	Barracks, militarized roads, communication lines	Weakly transformed
3	Forest and shrubland	79 (6.9%)	Military vehicle shelters, barracks	Moderately transformed
4	Dry steppes	19 (1.7%)	Impact of military equipment	Strongly transformed
5	Xerophytic-shrubby steppes	94 (8.2%)	Impact of military equipment	Strongly transformed
6	Xerophytic-shrubby steppes	54 (4.7%)	Impact of military equipment	Strongly transformed
7	Dry steppes	36 (3.1%)	Military bunkers, trenches for personnel, and military equipment	Strongly transformed
8	Dry steppes	55 (4.8%)	Agroecosystems (for military grain and vegetable crops)	Moderately transformed
9	Dry steppes	74 (6.4%)	Land destroyed by fires, military equipment, etc.	Radically transformed
10	Dry steppes	44 (3.8%)	Antitank ditches, trenches, etc.	Strongly disturbed and transformed
11	Forest-steppe landscapes	88 (7.7%)	Fires and military-technical actions	Strongly disturbed and transformed
12	Belligerent landscapes	86 (7.5%)	Fires and military-technical actions	Radically transformed
13	Dry steppes	48 (4.2%)	Fires and military-technical actions	Strongly disturbed and transformed
14	Urban and residential landscapes	27 (2.8%)	Destroyed houses, roads, administrative buildings, etc.	Radically transformed
15	Pasture-mowing complexes	26 (2.3%)	Irrigated feed crop plantations, etc.	Moderately transformed
16	Semi-desert landscapes	37 (3.2%)	Irrigated fields, orchards, etc.	Intensively transformed
17	Agro-irrigated landscapes	78 (6.8%)	Intensively irrigated fields	Intensively transformed
18	Agro-irrigated landscapes and semi-deserts	7 (0.6%)	Intensively irrigated crops, orchards, etc.	Strongly transformed
19	Settled rural and urban landscapes	98 (8.5%)	One- or two-story houses, cultivated suburban plots	Radically transformed
20	Arid forests	104 (9%)	Logging, tree damage, grazing, etc.	Moderately transformed
21	Reservoirs	4 (0.3%)	Water catchment	Radically transformed

and Khachinchay Rivers flowing through the district were dried up during the occupation, which gave rise to the water scarcity for irrigation in the Karabakh plain. (Fig. 5).

This situation negatively affects the development of agriculture in the area. As a result, the local population has increased the consumption of groundwater. Excessive use of groundwater has lowered the groundwater level, which, in turn, has transformed the surrounding landscapes into a more desertified state.

An analysis of the degree of anthropogenic transformation of the spatial structure of landscapes indicates that 34% of landscapes are subject to strong anthropogenic transformation, 25.5% to radical transformation, 23% to moderate transformation, 10% to intensive transformation, and 7.5% to weak transformation (Fig. 6).

– In the weakly transformed landscapes, even if degradation of certain components (such as flora and fauna) is observed under anthropogenic influence, their restoration is possible.

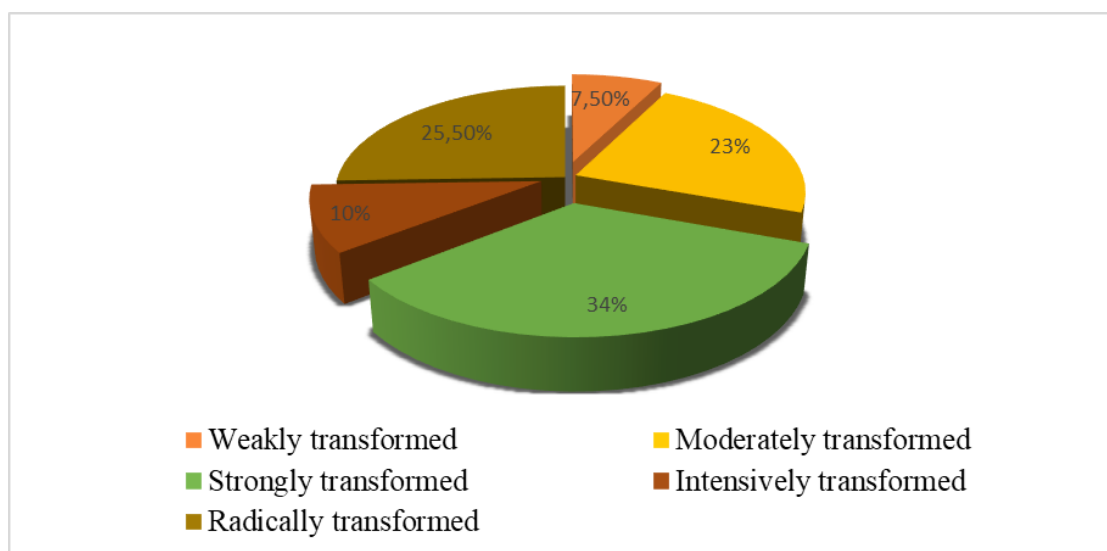Fig. 5. The dried-up riverbed of the Tartar River

Fig. 6. The degree of anthropogenic transformation of the spatial structure of landscapes

- In landscapes subject to moderate transformation, soil cover disturbances caused by military-technical impacts have already been observed.
- In strongly transformed landscapes, along with changes in relief, alterations in the flow of surface waters also occur.
- In landscapes subject to intensive transformation, their main components are continuously affected by military-technical and human activities.
- Landscapes subject to radical transformation include destroyed settlements and urban complexes, fortified defense structures, and so on.

Conclusions. For the first time, based on satellite images and field research, the transformed natural-anthropogenic landscapes in the studied area, which changed as a result of military-technical activities, were categorized into 2 classes, 6 types, and 21 species according to their structural-genetic and functional characteristics.

Using the selected criteria, landscapes subject to military-technical transformation were mapped according to their degree of transformation: weakly, moderately, strongly, intensively, and radically. The analysis of the digital map revealed that 34% of the natural landscapes in the studied area are subject to strong military-technical transformation, 25.5% to radical transformation, 23% to moderate transformation, 10% to intensive transformation, and 7.5% to weak transformation.

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Вплив військових конфліктів на трансформацію ландшафту (на прикладі Агдамского району Азербайджанської Республіки)

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У статті досліджується вплив наслідків бойових дій на ландшафтну структуру та екологічний стан Агдамського району Азербайджану. Його територія перебувала під окупацією близько 30 років, вона зазнала значних руйнувань, що призвело до екологічних, соціальних та економічних втрат. Протягом 30 років Агдамський район був буферною зоною між конфліктуючими сторонами. Оскільки в орографічному плані більша частина його території являє собою рівнину з незначними перепадами висот, під час бойових операцій обидві сторони активно

використовували міни - як протипіхотні, так і протитанкові - для оборони стратегічних позицій, захисту тилу, зміцнення ліній фронту. За попередніми оцінками, збиток природним і антропогенним екосистемам перевищив 200 мільярдів доларів. В Агдамському районі повністю знищено понад 50 пам'яток природи, а також інфраструктуру 58 сільських населених пунктів і однієї міської території. Крім того, понад 90 000 наземних мін становлять постійну загрозу для місцевого населення, перешкоджаючи зусиллям з відновлення. В статті проведено дослідження впливу військово-технічної діяльності на трансформацію ландшафту в Агдамському регіоні, визначено основні структурно-генетичні та функціональні зміни, систематизовано трансформовані ландшафти. У дослідженні використовувався аналіз супутникових знімків, польові дослідження та архівні дані. Застосовано системний підхід до вивчення структурно-генетичних та функціональних змін природних і антропогенних ландшафтів. Встановлено, що трансформація ландшафту відбулася як внаслідок прямого, так і опосередкованого впливу військово-технічної діяльності. Природно-антропогенні ландшафти області класифіковано на два класи, шість типів і 21 підтип. В ході дослідження виявлено високий ступінь деградації навколишнього середовища, що призводить до значних змін у структурі, функціях і стані екосистем. Проведені дослідження дають оцінку наслідків військово-технічних впливів на ландшафти регіону. Результати можуть стати основою для подальших досліджень з моніторингу та оцінки екологічних змін, викликаних військовими конфліктами, а також для розробки підходів до відновлення території.