Aqrar elmlər / Agrarian Sciences

INVESTIGATION OF THE IMPACTS OF THE AZERBAIJAN–ARMENIA WAR AND MILITARY CONFLICT ON THE SOILS OF KARABAKH AND EASTERN ZANGEZUR

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Abstract. This paper examines the current environmental condition of the soils of the Karabakh and Eastern Zangezur regions of Azerbaijan, which remained under the occupation of the Armenian Armed Forces for nearly three decades. The assessment is based on comprehensive analyses of the physical, chemical, and organic properties of soils, together with thematic maps produced from multi-temporal Landsat imagery using ArcGIS software. The soil cover was evaluated through an integrated methodological approach, resulting in the development of an anthropogenic soil degradation map. The map illustrates degradation classes, degradation types, and the spatial distribution of the principal degradation factors. Furthermore, the study evaluates the impacts of military-technogenic soil degradation on soil properties and discusses potential contamination pathways and their environmental implications. Mathematical and statistical analyses were conducted on representative anthropogenically degraded soils, while long-term monitoring data were employed to assess temporal changes in soil characteristics and degradation processes. Incomplete image metadata and inconsistencies in the statistical summaries limit quantitative interpretation.

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1. Introduction

Throughout human history, wars have exerted substantial adverse effects on the natural environment (Gerasimov et al., 2021). In 2023, the Uppsala Conflict Data Program recorded 59 active state-based armed conflicts worldwide (Uppsala University, 2024).

Prolonged military conflicts affect not only the immediate areas where they occur but also the surrounding regions by causing widespread environmental degradation. Numerous studies have demonstrated that long-term warfare disrupts the biological equilibrium of soil ecosystems, accelerates soil erosion, and intensifies land degradation. Following the dissolution of the Soviet Union in the early 1990s, several armed conflicts emerged across different regions, including Georgia, the Russian–Chechen conflict, the Azerbaijan–Armenia conflict, and the Russia–Ukraine war, the latter of which continues to the present day.

Modern warfare has become an increasingly significant driver of environmental degradation, disrupting ecological balance and posing serious threats to human health. The Azerbaijan–Armenia conflict and the active phase of military operations extended over approximately three decades. During this period, the territories of Karabakh and Eastern Zangezur were occupied and subjected to prolonged military activities, resulting in severe ecological damage.

One of the major environmental concerns has been the transboundary pollution of Azerbaijan's ecosystems through rivers originating in Armenia, including the Okhchuchay, Bargushadchay, and Karchevan rivers. These watercourses transport mining and industrial wastes into the Araz River basin, causing substantial contamination of floodplain soils and agricultural ecosystems.

The occupation of most of Eastern Zangezur and Karabakh by the Armenian Armed Forces also forced more than one million internally displaced people to migrate to other regions of Azerbaijan. This large-scale population displacement significantly increased anthropogenic pressure across approximately 45–50% of the country's territory, creating serious environmental and socio-economic challenges.

Over the thirty-year period of occupation and armed conflict, profound ecological changes occurred across the diverse ecosystems of Karabakh and Eastern Zangezur. In particular, approximately 247,352 ha of forest ecosystems containing more than 460 species of trees and shrubs, including about 70 endemic species unique to this region, were exposed to significant ecological threats and biodiversity loss (Akhundov, 2024a, 2024b).

Population displacement from Karabakh and Eastern Zangezur occurred along three principal migration routes. Residents of the Zangilan, Jabrayil, and Fuzuli districts migrated toward the Araz River plain; populations from Lachin and Aghdam moved toward the Aran Karabakh region; while inhabitants of the Kalbajar district relocated toward the Goygol–Samukh–Ganja region. This large-scale migration considerably increased anthropogenic pressure on neighboring districts, contributing to the development of linear desertification zones along major transportation corridors.

Prior to the occupation, the Karabakh and Eastern Zangezur regions played a crucial role in Azerbaijan's agricultural production. However, the fertile foothill and lowland soils—including alluvial-meadow, meadow grey-brown, and mountain grey-brown soils—have undergone various forms of anthropogenic and military-technogenic degradation as a consequence of prolonged military activities, resulting in a substantial decline in soil quality, fertility, and agricultural productivity.

2. Materials and methods

The study area covers a total of 706,369 ha as a geographically continuous region and, from an administrative perspective, wholly or partially encompasses the districts of Barda, Aghjabadi, Fuzuli, Jabrayil, Zangilan, Gubadli, and Lachin in Azerbaijan. Although these territories have been liberated from occupation, a substantial proportion of the area remains contaminated with landmines, limiting access for comprehensive field investigations.

Geographically, the study area is situated in the southeastern part of the Lesser Caucasus and extends toward the Kura and Araz river basins. While the Aran Karabakh Plain along the Kura River remained outside the occupied territory, the floodplain landscapes of the Araz River were subjected to occupation for nearly three decades. The geographical extent of the study area and the locations of the sampling sites are presented in Figure 1.

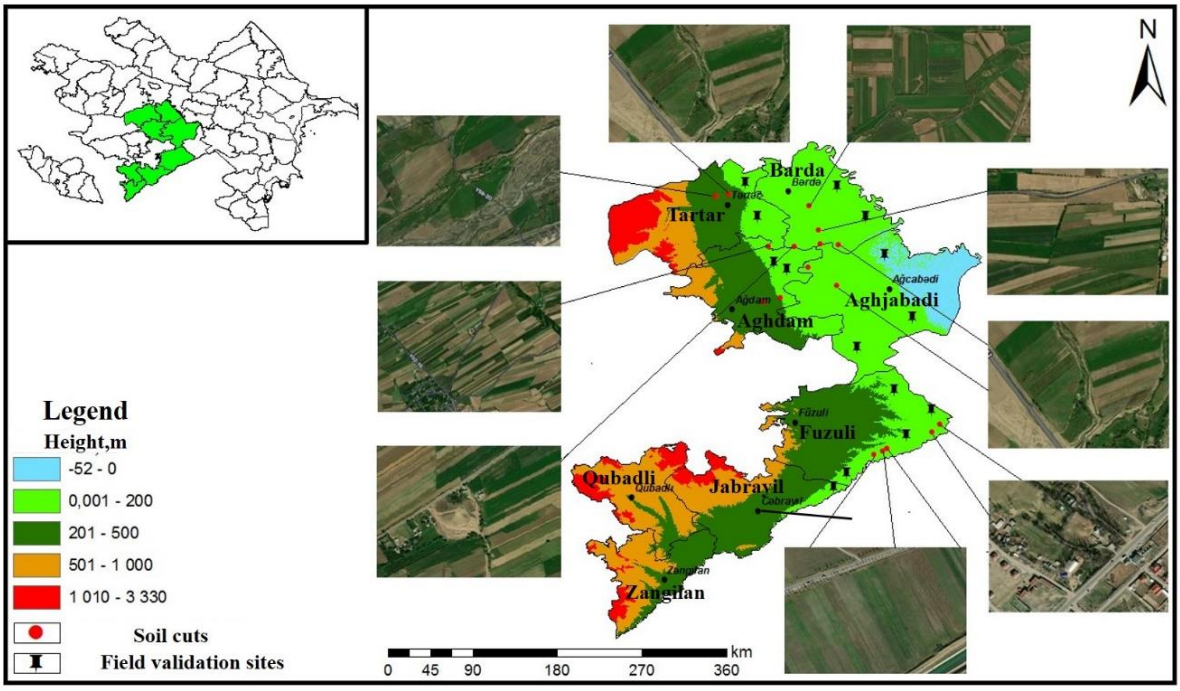


Fig. 1. Location of the study area and soil sampling sites.

The research was conducted through an integrated approach combining desk-based investigations, field surveys, laboratory analyses, remote sensing, Geographic Information Systems (GIS), and statistical data analysis. A geographical research methodology appropriate to the spatial scale of the investigation was adopted.

Soil samples collected during the field survey were subjected to comprehensive laboratory anal-

yses. The measured parameters included hygroscopic and natural soil moisture (gravimetric method), total nitrogen, total organic matter determined according to the I.V. Tyurin method, particle-size distribution using the N.A. Kachinsky method, soil pH measured potentiometrically in a water suspension, exchangeable Ca^{2+} and Mg^{2+} determined by the D.V. Ivanov method, exchangeable Na^{+} determined according to the K.K. Gedroits method, carbonate content measured using a calcimeter, and water-soluble salts determined by the complete water extract method following the D.V. Ivanov procedure.

Multi-temporal Landsat satellite imagery, together with remotely sensed data, was processed to generate and compare thematic maps representing environmental conditions before and after the occupation. These datasets enabled the assessment of temporal changes in land use, vegetation cover, soil conditions, and land degradation patterns.

To ensure the reliability and statistical validity of the laboratory results, all analyses were performed in four replicates (n = 4). Statistical processing was carried out according to the methodology of Dospekhov (1985), including the calculation of arithmetic means, confidence intervals, standard errors, coefficients of variation, and other descriptive statistical parameters.

During the field investigations, topographic maps at scales of 1:25,000 and 1:100,000 were used for navigation and site selection. The geographical coordinates of all sampling locations were recorded using a Global Positioning System (GPS) receiver.

3. Results and discussion

During the occupation, Azerbaijan's environment and natural resources sustained extensive damage, including the exploitation of mineral resources, destruction of forest ecosystems, soil degradation and pollution of water resources (Akhundov, 2024a, 2024b).

During the 44-day Second Karabakh War, the use of artillery, missiles and other weapons exposed the ecosystems of Karabakh and Eastern Zangezur to additional environmental pressures (Piriyev & Həşimov, 2023). Military operations and the reciprocal use of force affected soils, vegetation, freshwater resources and wildlife, with potential implications for human health.

Because much of the study area remains contaminated with landmines, environmental assessment relied primarily on comparative analyses of multi-temporal satellite imagery. The interpretation of remotely sensed data was performed using established methodologies widely applied in remote sensing and environmental monitoring studies (Jensen, 1996; Mohamed et al., 2015).

Previous pedological investigations conducted by numerous researchers identified 21 major soil taxonomic units within Karabakh and Eastern Zangezur (Gasanov, 1969; Salaev, 1966; Sharifov, 1984). By comparing the results of the present post-occupation soil survey with historical data collected before the occupation, it was possible to evaluate the environmental impacts of prolonged military activities on soil cover and ecosystem integrity.

To assess changes in land surface conditions, maps illustrating soil surface temperatures during the vegetation period for 1992 and 2022 were prepared (Figures 2 and 3).

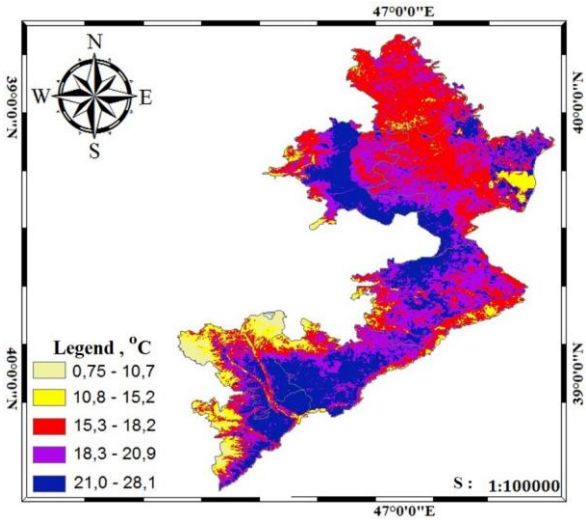


Fig. 2. Land surface temperature during the vegetation period (1992).

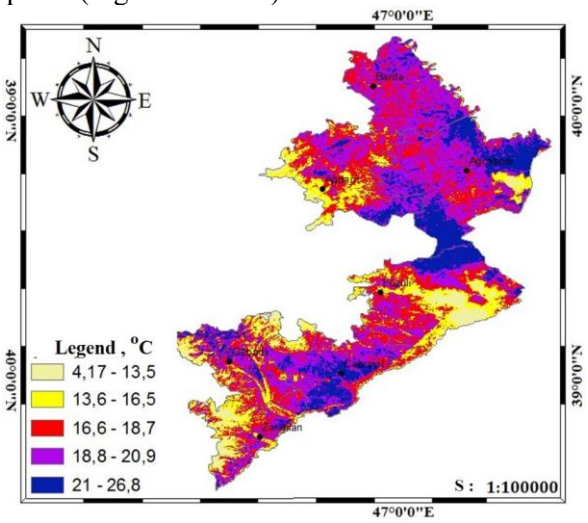


Fig. 3. Land surface temperature during the vegetation period (2022).

Comparison of Figures 2 and 3 shows differences in the spatial distribution of land surface temperature between 1992 and 2022. These patterns may reflect changes in vegetation cover, land use and irrigation infrastructure, together with differences in weather and image acquisition conditions. The maps alone do not establish a uniform increase in temperature across the study area.

Vegetation loss and damage to irrigation infrastructure can reduce soil moisture, particularly in low-mountain, foothill and lowland landscapes. However, the temperature maps and the land-cover maps presented here do not directly quantify changes in soil moisture.

Long-term military occupation and active combat operations severely disrupted pedogenic processes, accelerated soil contamination, and intensified erosion. Modern weapons not only caused extensive damage to flora and fauna but also produced numerous crater-like landforms that destabilized mountain forest brown, grey-brown, and alluvial-meadow soils, thereby accelerating erosion and reducing soil fertility.

Furthermore, approximately 70–75% of the gently sloping plains and low-mountain landscapes along the Araz River consist of slopes steeper than 7°. Continuous movement of heavy military vehicles across these fragile terrains for nearly three decades substantially disturbed soil structure and promoted the development of both sheet and gully erosion.

Land-use and land-cover (LULC) maps generated from satellite imagery show differences between 2001 and 2020 (Figures 4 and 5). The mapped distributions of cultivated land, vegetation and infrastructure provide a basis for assessing spatial changes during the occupation period.

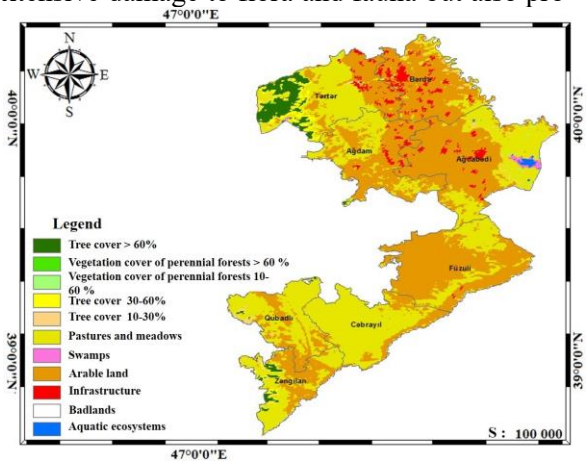


Fig. 4. Land use and land cover in the study area (2001).

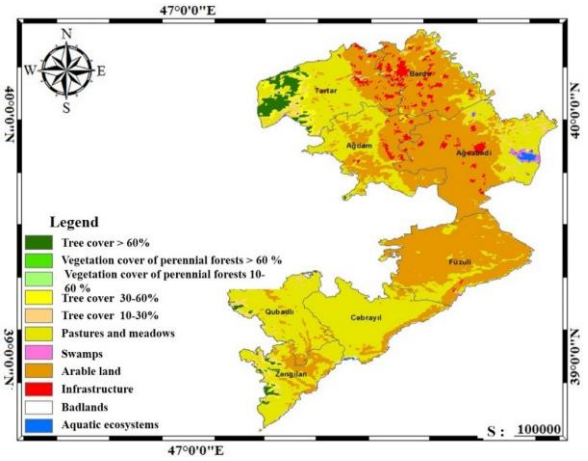


Fig. 5. Land use and land cover in the study area (2020).

Supervised classification of satellite imagery was used to compare land cover in 2001 and 2020. The ratios available for this comparison are presented in Table 1. Because absolute areas and the direction of the reported ratios are not specified, the table cannot independently establish the magnitude or direction of change in each class.

Table 1

Reported land-cover ratios for the 2001–2020 comparison

Land-cover class	**Area ratio**	**Share ratio**
Forests (tree cover >60%)	1.293	1.294
Perennial forest vegetation (cover >60%)	5.499	6
Perennial forest vegetation (cover 10–60%)	2.165	2.5
Forests (tree cover 30–60%)	0.801	0.792
Forests (tree cover 10–30%)	0.438	0.439
Meadows and pastures	0.978	0.978
Wetlands	0.773	0.783
Croplands	1.043	1.043
Infrastructure	0.993	0.992
Bare land	0.039	0.025

Land-cover class	Area ratio	Share ratio
Aquatic ecosystems	0.919	0.912

Note. Only the supplied ratios are shown. Absolute areas and percentage shares were unavailable; the ratio direction was not specified.

The land-cover maps provide spatial evidence relevant to the assessment of land degradation. A quantitative estimate of agricultural or forest losses requires the absolute area of each class, a clearly defined comparison ratio and an assessment of classification accuracy.

In addition to physical degradation, the soils of Karabakh and Eastern Zangezur were contaminated with heavy metals, including Pb, Zn, Cu, Mo, Co, and other potentially toxic elements during both the occupation period and the active military phase. Moreover, extensive and uncontrolled exploitation of mineral deposits resulted in widespread contamination of surrounding landscapes, adversely affecting soil quality, vegetation cover, and ecosystem functioning.

The most fertile soils of Karabakh and Eastern Zangezur are the alluvial-meadow soils, which have developed on the floodplains of the Araz and Kura rivers and on the young terraces of their tributaries. The tributaries of the Kura and Araz rivers, including the Tartar, Hakari, Khachin, Bargushad, Gargar, and Okhchuchay rivers, transport weathered materials from the Karabakh Mountain Range, the Karabakh Volcanic Plateau, and adjacent mountainous regions, forming extensive alluvial deposits. During nearly three decades of occupation, these river valleys were subjected to the greatest military-technogenic impacts. Prior to the occupation, approximately 85–90% of the local population was concentrated within these valleys, where intensive agricultural activities had created highly productive cultivated landscapes on alluvial-meadow soils. During the occupation, perennial plantations, particularly orchards and mulberry plantations used for sericulture, were almost completely destroyed, while the soils underwent severe physical and chemical degradation.

Considering the morphological and physicochemical variability of the alluvial-meadow soils in the foothill zones and Araz lowlands, the available laboratory data were summarized statistically (Table 2). The reported surface-horizon humus content was 2.84 ± 0.96%, while total nitrogen was 0.20 ± 0.04%. Historical investigations reported humus contents of 3.36–3.79% and total nitrogen contents of 0.16–0.23% (Gasanov, 1969). The humus values suggest a decline, whereas the present nitrogen value falls within the historical range. The uncertainty terms require verification before formal significance testing.

Among the exchangeable base cations, Ca^{2+} reached 23.86 ± 5.68 cmol(+)/kg within the accumulative horizon and gradually decreased with soil depth. Exchangeable Mg^{2+} averaged 5.86 ± 2.26 cmol(+)/kg and was higher in the deepest horizon. In contrast, exchangeable Na^{+} exhibited its highest concentration in the upper horizon and was lower in the underlying horizons. Compared with pre-occupation data, sodium concentrations increased considerably, indicating progressive soil degradation. Likewise, the accumulation of $CaCO_3$ increased substantially during the past three decades. The particle-size analysis further demonstrates that these soils possess a heavy-textured composition, with the physical clay fraction (<0.01 mm) dominating the soil matrix. The clay fraction (<0.001 mm) averaged 31.4 ± 7.08% in the surface horizon and gradually decreased with increasing depth.

The environmental degradation of the alluvial-meadow soils in Karabakh and Eastern Zangezur predates the most recent military conflict in certain river basins, particularly those of the Bargushad and Okhchuchay rivers. Owing to their transboundary nature, these rivers have long been affected by mining and metallurgical waste originating upstream within Armenia. Consequently, soils within these catchments have experienced elevated contamination by potentially toxic heavy metals, including Cu, Mo, Pb, and Zn.

The integration of multiple methodological approaches with extensive field observations and analytical datasets enabled the preparation of a comprehensive anthropogenic soil degradation map for the study area. The classification methodology adopted in this study follows approaches proposed by previous researchers (Allan, 1980; Babaev & Garivani, 1997; Bananova, 1993; Kharin & Kalenov, 1978; Zonn & Oglovskii, 1984).

The results indicate that 23.9% of the study area is affected by slight anthropogenic degradation, 50.9% by moderate degradation, 16.3% by severe degradation, and 7.8% by very severe degradation, with approximately 1.1% assigned to the reference class (Figure 6). The principal degradation types identified include vegetation degradation, secondary salinization, soil erosion, mining-induced pollution, and military-technogenic degradation.

The spatial analysis clearly demonstrates that soil erosion, military-technogenic contamination,

and secondary salinization constitute the dominant degradation processes within the study area.

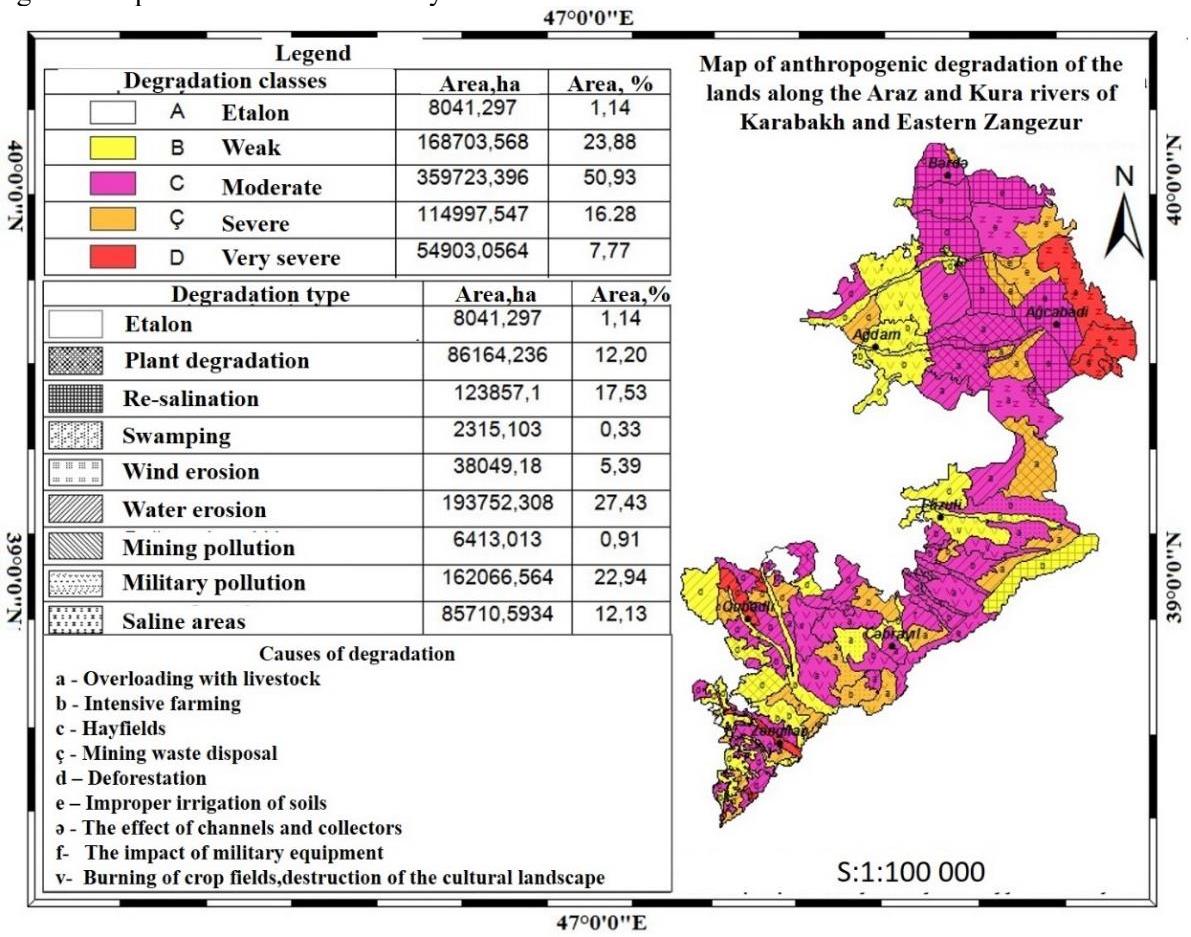


Fig. 6. Anthropogenic soil degradation in the Araz and Kura river basins of Karabakh and Eastern Zangezur.

The analytical values in Table 2 show variation in the physicochemical properties of alluvial-meadow soils among genetic horizons. The comparison with historical descriptions suggests lower humus content and changes in sodium and carbonate accumulation. However, several reported means, intervals and dispersion statistics are internally inconsistent. Consequently, these data should be interpreted descriptively until the original measurements and statistical calculations can be verified.

Table 2

Reported descriptive statistics for alluvial-meadow soil properties in Karabakh

Soil property	Horizon	n	Max.	Min.	Reported interval	Mean	SE	SD	CV, %
Physical clay <0.01 mm, %	A_{11}	4	68.72	43.20	55.96±12.76	55.96	9.025	18.5	33.05
	A_{111}	4	69.76	41.44	55.6±14.16	55.6	10.29	20.58	37.01
	B_1	4	65.92	38.64	52.28±13.64	52.28	10.03	20.06	38.37
	B_2	4	67.52	21.84	44.68±22.84	44.68	17.99	35.99	68.84
	C	4	58.56	51.28	54.92±3.64	54.92	7.26	14.52	26.44
Clay fraction <0.001 mm, %	A_{11}	4	38.48	24.32	31.4±7.08	31.4	6.1	12.19	38.82
	A_{111}	4	34.64	20.88	27.76±6.88	27.76	4.9	9.81	35.34
	B_1	4	34.16	20.00	27.08±7.08	27.08	5.26	10.52	38.85
	B_2	4	34.16	13.63	23.89±10.27	23.89	9.39	18.77	78.57
	C	4	33.76	25.12	29.44±4.32	29.44	3.45	6.91	23.47
Humus, %	A_{11}	4	3.79	1.88	2.84±0.96	2.84	0.86	1.71	60.2
	A_{111}	4	3.29	1.28	2.29±1.01	2.29	0.81	1.62	70.74
	B_1	4	2.23	1.20	1.72±0.52	1.72	0.44	0.87	50.58
	B_2	4	1.22	0.58	0.9±0.32	0.9	0.44	0.88	97.7

Soil property	Horizon	n	Max.	Min.	Reported interval	Mean	SE	SD	CV, %
	C	4	1.36	0.31	0.84±0.53	0.84	0.41	0.82	97.6
Total nitrogen, %	A_{11}	4	0.23	0.16	0.20±0.04	0.20	0.025	0.05	25
	A_{111}	4	0.21	0.08	0.15±0.06	0.15	0.049	0.097	64.7
	B_1	4	0.19	0.07	0.13±0.06	0.13	0.048	0.096	73.85
	B_2	4	0.15	0.05	0.10±0.05	0.10	0.04	0.08	80
Ca^{2+}, cmol(+)/kg	A_{11}	4	29.53	18.18	23.86±5.68	23.86	4.33	8.65	36.25
	A_{111}	4	28.52	18.18	23.35±5.17	23.35	3.98	7.95	38.3
	B_1	4	24.41	16.66	20.54±3.88	20.54	2.81	5.62	27.4
	B_2	4	22.09	14.14	18.12±3.98	18.12	3.03	6.07	33.5
	C	4	19.17	11.11	15.14±4.03	15.14	2.88	5.75	38
Mg^{2+}, cmol(+)/kg	A_{11}	4	8.12	3.60	5.86±2.26	5.86	1.62	3.23	55
	A_{111}	4	8.08	2.92	5.5±2.58	5.5	1.95	3.89	71
	B_1	4	9.02	4.51	6.77±2.26	6.77	2.01	4.02	59
	B_2	4	9.02	2.09	5.56±3.47	5.56	2.77	5.54	99.6
	C	4	11.61	5.86	8.74±2.88	8.74	2.80	5.59	64
Na^{+}, cmol(+)/kg	A_{11}	4	8.25	1.10	4.68±3.58	4.68	2.25	4.49	95
	A_{111}	4	2.47	0.90	1.69±0.79	1.69	0.68	1.36	80.5
	B_1	4	3.60	0.70	2.2±1.35	2.2	0.94	1.88	85
	B_2	4	3.00	0.70	1.85±1.15	1.85	0.75	1.5	81
	C	4	3.39	0.50	1.95±1.45	1.95	0.82	1.64	84.1
CO_2, %	A_{11}	4	7.88	0.71	4.30±3.59	4.30	1.89	3.77	87
	A_{111}	4	8.20	0.60	4.40±3.8	4.40	2.06	4.12	93.6
	B_1	4	5.89	0.76	3.33±2.57	3.33	1.57	3.15	94.6
	B_2	4	17.38	4.77	11.08±6.31	11.08	5.25	10.5	89
	C	4	22.46	4.86	13.66±8.8	13.66	6.7	13.4	98
$CaCO_3$, %	A_{11}	4	17.93	1.60	9.77±8.17	9.77	4.55	9.1	93
	A_{111}	4	18.64	1.36	10±8.64	10	4.56	9.12	91.2
	B_1	4	22.20	6.69	14.45±7.76	14.45	5.66	11.31	78.3
	B_2	4	39.50	10.84	25.17±14.33	24.17	11.9	23.8	94.56
	C	4	51.05	11.04	31.05±20.01	31.05	15.1	30.2	97

Note. n = number of samples; SE = standard error; SD = standard deviation; CV = coefficient of variation. Values and reported intervals are retained from the analytical dataset; their confidence level is unspecified. Some intervals, means and dispersion statistics are internally inconsistent and require verification against the original measurements.

4. Conclusions

This study identifies substantial environmental pressures on the soils of Karabakh and Eastern Zangezur associated with prolonged occupation and military activities. Forest disturbance, changes in land use, erosion and potential contamination form an interconnected set of degradation processes. Field observations, thematic mapping and the available laboratory analyses provide a basis for characterizing their spatial distribution, although incomplete remote-sensing metadata and inconsistencies in the reported statistical summaries limit quantitative attribution.

The degradation map classifies 23.9% of the study area as slightly degraded, 50.9% as moderately degraded, 16.3% as severely degraded and 7.8% as very severely degraded; approximately 1.1% belongs to the reference class. The principal mapped degradation types include water erosion (27.43%), military-technogenic degradation (22.94%), secondary salinization (17.53%) and vegetation degradation (12.20%). Integrated ecological restoration, sustainable land management and long-term soil monitoring are needed to support recovery of the affected territories.

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AZƏRBAYCAN–ERMƏNİSTAN MÜHARİBƏSİNİN VƏ HƏRBİ MÜNAQİŞƏNİN QARABAĞ VƏ ŞƏRQİ ZƏNGƏZUR TORPAQLARINA TƏSİRİNİN TƏDQİQİ

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Xülasə. Məqalədə təxminən otuz il işğal altında qalmış Qarabağ və Şərqi Zəngəzur ərazilərinin torpaqlarının ekoloji vəziyyəti araşdırılır. Tədqiqat torpaqların fiziki və kimyəvi xassələrinin, üzvi maddə tərkibinin təhlilinə, çöl müşahidələrinə və Landsat peyk təsvirləri əsasında ArcGIS mühitində hazırlanmış tematik xəritələrə əsaslanır. İnteqral yanaşma əsasında antropogen torpaq deqradasiyasının dərəcələri, növləri və əsas amillərinin ərazi üzrə yayılması qiymətləndirilir. Allüvial-çəmən torpaqlarının laboratoriya göstəriciləri ümumiləşdirilir, hərbi-texnogen təsirlərin torpaq örtüyünə mümkün nəticələri təhlil olunur. Xəritələşdirmənin nəticələrinə görə ərazinin 23,9%-i zəif, 50,9%-i orta, 16,3%-i güclü və 7,8%-i çox güclü deqradasiyaya məruz qalmış, təxminən 1,1%-i etalon sinfə aid edilmişdir. Əsas proseslər su eroziyası, hərbi-texnogen deqradasiya, təkrar şoranlaşma və bitki örtüyünün deqradasiyasıdır. İlkin statistik məlumatlardakı uyğunsuzluqlar və peyk təsvirlərinin natamam metaverilənləri kəmiyyət nəticələrinin şərhini məhdudlaşdırır. Torpaqların bərpası üçün kompleks ekoloji tədbirlərin, davamlı torpaq idarəçiliyinin və uzunmüddətli monitorinqin zəruriliyi əsaslandırılır.

Açar sözlər: *hərbi-texnogen deqradasiya, antropogen deqradasiya, ətraf mühit, ağır metallar, şoranlaşma, torpaq eroziyası, biomüxtəliflik, çirklənmə, allüvial-çəmən torpaqları*

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