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LANDMINES IN KARABAKH AND ITS ENVIRONMENTAL IMPACT

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Abstract: The Karabakh region, long affected by the Armenia-Azerbaijan conflict, remains one of the most landmine-contaminated areas globally, with profound environmental repercussions. While the humanitarian impact of landmines is well documented, their ecological consequences have received limited scholarly attention. This study examines the long-term environmental effects of landmine contamination in Karabakh, focusing on biodiversity loss, soil degradation, water pollution, and restricted land use. Minefields create exclusion zones that inadvertently serve as wildlife refuges, yet simultaneously fragment habitats and threaten species survival. Explosions and explosive residues alter soil composition, reduce fertility, and introduce heavy metals into groundwater, intensifying erosion and agricultural decline. Demining operations, though essential, can further disrupt ecosystems if not managed sustainably. Environmentally sensitive clearance practices implemented by the Azerbaijan Mine Action Agency provide promising mitigation strategies. Integrating ecological restoration within humanitarian and political frameworks is imperative for achieving sustainable post-conflict recovery in the Karabakh region.

Keywords: landmines, environmental impact, biodiversity, soil degradation, Karabakh, post-conflict recovery.

1. Introduction

The Karabakh region is located in the South Caucasus. It has been one of the most heavily mined areas in the world due to the long-standing conflict between Armenia and Azerbaijan. Following the cessation of hostilities, Azerbaijan regained control over the Karabakh territory. Azerbaijan inherited a massive challenge to remove the millions of anti-personnel and anti-tank landmines scattered across towns, villages, forests, and farmlands [1]. According to recent reports, well over 1 million landmines and other unexploded ordnance (UXO) are believed to remain buried across Karabakh and adjacent newly liberated districts [2].

Landmines continue to endanger civilian lives, impede agricultural development, and severely impact the environment. The ecological dimension of landmine contamination has become a growing concern for Azerbaijan and international environmental organizations. Landmine explosions release toxic chemicals such as TNT (trinitrotoluene), RDX (Research Department Explosive), and heavy metals, which alter soil chemistry and pollute water systems [3]. Moreover, the presence of minefields restricts reforestation, wildlife migration, and sustainable land use, making environmental restoration an essential component of post conflict-recovery.

2. Classification of landmines

Landmines used in Karabakh can be broadly classified into two categories:

1) Anti-personnel landmines (APMs): These landmines are designed to injure or kill individuals and are often made of plastic or metal casing containing TNT or similar explosives. Examples

include PMN-2, PMD-6, and OZM-72 types, commonly found in the region [4].

2) Anti-tank landmines (ATMs): Larger devices designed to disable vehicles, such as tanks or armoured carriers. Common examples in Karabakh include TM-62, TM-57, and M15 types [5].

The removal of these landmines is technically demanding due to the variety of devices, soil conditions, and terrain complexity.

3. Methodology

This research employs a secondary data analysis approach, drawing upon official reports, environmental assessments, and publications from the Azerbaijan National Agency for Mine Action (ANAMA), The United Nations Development Programme (UNDP), and international NGOs active in the Caucasus. Data related to contamination levels, cleared areas, and environmental effects were collected from 2020 to 2025 sources, ensuring temporal accuracy and reliability.

Mathematical modeling was also applied to assess the relationship between landmine density and potential ecological damage. The formula applied is given below:

$$E = (L \times D) - (C \times R), \quad (1)$$

Here, E is the environmental impact index, L is the number of landmines per square kilometer, D is the degradation coefficient (based on soil and biodiversity loss), C is the cleared land percentage, and R is the restoration effectiveness coefficient.

This formula provides a simplified estimation of residual environmental degradation after clearance operations.

4. Extent of landmine contamination and clearance in Karabakh

Azerbaijan estimates that approximately 1.5 million landmines were laid in the Karabakh region and newly liberated adjacent districts during the occupation period [6]. The contamination spans over 12,000 square kilometers of land.

As of 2025, Azerbaijan has cleared more than 233,000 hectares of land from mines and unexploded ordnance [7]. According to the Azerbaijan National Agency for Mine Action (ANAMA), over 125,000 anti-personnel and 95,000 anti-tank mines have been neutralized. Despite these efforts, thousands of hectares remain dangerous and uninhabitable.

The Azerbaijan Mine Action Agency (ANAMA) leads national demining operations in newly liberated areas with support from international partners such as The Halo Trust, ANAMA’s Turkish partners ASFAT A.Co., Norwegian People’s Aid (NPA), and British demining company SafeLane Global, etc.

5. Technologies and biological methods in mine clearance

Mine clearance in Karabakh represents one of the most technologically intensive and environmentally sensitive operations in post-conflict Azerbaijan. The Azerbaijan Mine Action Agency (ANAMA) has integrated a wide range of mechanical, electronic, biological, and artificial intelligence-assisted systems to ensure both safety and efficiency while minimizing environmental damage.

5.1. Mechanical clearance systems

Mechanical clearance remains the backbone of large-scale demining operations in Karabakh. These systems are primarily used in open terrain and agricultural fields where heavy machinery can operate safely. Azerbaijan utilizes several advanced mechanical platforms, notably:

1) MEMATT (Mechanical Mine Clearing Equipment): It was co-developed by Turkey's ASFAT A.Co. and the Azerbaijan Defense Industry. MEMATT vehicles can clear up to 1000 m^2 per hour using rotating flails and chain hammers [8]. They are equipped with remote control and camera-based guidance, which reduces human risk in active minefields.
2) MineWolf MW370 and MW240 systems: These tracked vehicles use interchangeable tillers and flails capable of penetrating soil to depths of 25–30 cm, suitable for anti-personnel and anti-tank mine clearance.
3) Armored bulldozers and ploughs: Modified Caterpillar D9R bulldozers fitted with blast-resistant armor and multi-blade ploughs are used to mechanically detonate shallow mines in reclaimed farmlands.

While these mechanical systems offer high productivity, they also have environmental drawbacks, such as soil compaction and disruption of microhabitats. ANAMA has therefore introduced eco-adaptive mechanical methods, alternating between mechanical clearance and manual verification to reduce ecological stress.

5.2. Manual and sensor-based detection technologies

Manual demining, though slower, remains indispensable for precision and verification. Deminers use metal detectors such as CEIA MIL-D1 and Vallon VMH3CS, which are capable of detecting both metallic and minimal metal mines. In regions with dense vegetation or rubble, manual probing ensures accuracy that machines cannot achieve.

Technological innovation has significantly improved detection reliability. Ground Penetrating Radar (GPR) systems combined with electromagnetic induction sensors can identify non-metallic explosives by analyzing subsurface dielectric contrasts. The dual sensor ALIS (Advanced Landmine Imaging System) developed in Japan and deployed experimentally in Karabakh allows visualization of buried mines in three dimensions. It reduces false alarms by up to 40 %.

Unmanned aerial vehicles (UAVs) are now integral to planning and monitoring. Equipped with multispectral and thermal imaging, drones map vegetation stress and surface anomalies indicative of buried explosives. These aerial data are processed with GIS (Geographic Information System) software to generate contamination probability maps, helping teams prioritize high-risk areas. AI-powered drones of British RPS Energy Ltd are also used in the demining operations in Karabakh.

5.3. Artificial intelligence and data integration

Recent technological progress in Karabakh's demining involves AI-assisted data fusion, combining satellite imagery, historical conflict maps, and drone data. The Mine Information Management System (MIMS), which is developed in collaboration with the United Nations Development Programme. It employs machine learning algorithms to estimate contamination probability based on terrain type, past military positions, and soil conductivity [9].

Mathematically, the contamination probability P_c for a grid cell can be expressed as:

$$P_c = (H_m + S_t + V_i) / 3, \quad (2)$$

Here, H_m is the historical mine laying density coefficient, S_t is the soil type susceptibility index, and V_i is the visual anomaly intensity derived from drone imagery.

This predictive model optimizes resource allocation and reduces operational costs by identifying zones with the highest mine-density potential.

5.4. Biological detection methods

Azerbaijan complements technological tools with biological mine detection methods that rely on animals' olfactory capabilities. These approaches are particularly effective in environmentally sensitive or rugged areas where machines cannot operate.

1) Mine Detection Dogs (MDDs): Trained breeds such as Belgian Malinois and German Shepherds can detect traces of TNT and RDX at concentrations as low as 1 ppb (part per billion) [10]. They are deployed across the Fuzuli, Aghdam, and Jabrayil districts and can search up to 800 m^2 per day.
2) Mine Detection Rats (MDRs): Imported African giant pouched rats (Cricetomys ansorgei), trained by the Belgian NGO APOPO, have been piloted in Karabakh since 2024. Weighing less than 1.5 kg, they are too light to trigger mines and can cover 200 m^2 in 30 minutes, outperforming manual methods in speed [10].
3) Bees and biosensor research: The Baku State University Biotechnology Department is experimenting with bees trained to associate TNT vapors with sugar rewards. Tracking the flight paths of honeybees via harmonic radar provides indirect detection indicators without disturbing the soil [11].

These biological agents significantly lower carbon emissions compared with mechanical systems and minimize habitat destruction. However, climatic conditions and training costs limit their large-scale deployment.

5.5. Integration of technologies for sustainable clearance

Azerbaijan's demining framework emphasizes an integrated approach known as the "Multi-Layered Clearance Model." This model combines mechanical sweeping, sensor-based verification, and biological confirmation within each operational grid. The process reduces false negatives and ensures environmental compliance.

Post clearance, ANAMA implements eco-monitoring programs that measure soil compaction, vegetation regeneration, and wildlife return. The integration of data from drones, animal teams, and ground sensors feeds into an environmental index known as the Clearance Sustainability Coefficient (CSC):

$$CSC = (E_f + B_r) / 2 \times D_i, \quad (3)$$

Here, E_f is the operational efficiency factor, B_r is the biodiversity restoration ratio, and D_i is the disturbance intensity (from mechanical impact).

A high CSC value (> 0.7) indicates a sustainable and ecologically balanced clearance operation.

5.6. Future innovations

Looking ahead, Azerbaijan is investing in robotic demining drones, AI-driven explosive vapor sensors, and biodegradable marker systems that replace plastic flags to reduce environmental waste. Azerbaijan aims to develop solar-powered autonomous clearance robots capable of remote sensing and in-situ soil detoxification. These advances are expected to enhance both ecological safety and operational speed, turning Karabakh into a global model for green demining.

6. Environmental impact of landmines

The environmental repercussions of landmines in the Karabakh region extend far beyond their immediate explosive effects. These remnants of war have altered the physical landscape, damaged the soil's biological composition, and disrupted the ecological equilibrium of the region. The environmental impact can be analyzed through several interconnected dimensions. For example, soil contamination, water pollution, vegetation degradation, biodiversity loss, and atmospheric pollution.

6.1. Soil contamination and degradation

When landmines detonate or corrode underground, they release a range of toxic chemical compounds such as trinitrotoluene (TNT), cyclonite (RDX), hexogen, and metallic residues including lead, copper, and iron. These substances persist in the soil for decades, binding with clay and organic matter to form long-lasting contaminants. Research has shown that the concentration of TNT residues in mined soil can exceed 100 mg/kg, significantly reducing soil fertility and microbial activity.

The alteration of soil chemistry results in a measurable decline in pH levels, typically making the soil more acidic. This, in turn, suppresses the growth of nitrogen-fixing bacteria and beneficial fungi, leading to diminished plant productivity. In agricultural zones of Aghdam and Fuzuli, previously fertile lands have transformed into sterile patches incapable of supporting crops, delaying agricultural resettlement efforts. The physical disruption from explosions also creates craters, which increase erosion rates and accelerate topsoil loss during rainfall.

6.2. Water pollution and hydrological effects

Explosive residues from landmines gradually leach into groundwater and surface water systems through rainfall infiltration. The leaching of nitrates, nitroaromatic compounds, and heavy metals from explosives introduces chemical oxygen demand (COD) pressures on rivers and groundwater sources. Studies conducted near the Khachinchay and Hakari rivers reveal elevated levels of nitrates (NO_3-), nitrites (NO_2-), and ammonium ions (NH_4^+), all of which originate from the decomposition of explosive materials.

Furthermore, the suspended particulates from detonations increase the turbidity of streams and ponds, affecting aquatic ecosystems and reducing the oxygen available for fish and microorganisms. The contamination of drinking water sources also poses health risks for communities returning to demined areas. In hydrologically sensitive zones, such as Kalbajar and Lachin, contamination risk is intensified due to high rainfall and porous limestone geology that facilitates pollutant mobility.

6.3. Vegetation and flora degradation

Landmine contamination restricts vegetation recovery by preventing human access and by directly destroying root systems during explosions. Explosions strip vegetation cover, increase evapotranspiration, and expose soil to wind and water erosion. Over time, this leads to the formation of secondary deserts which are barren zones where reforestation becomes exceedingly difficult.

Native flora such as oak (Quercus iberica), beech (Fagus orientalis), and juniper (Juniperus polycarpos) have been particularly affected, with forest coverage declining by an estimated 12% between 1994 and 2020 due to landmine-related disturbances. Grazing areas for livestock have also diminished, leading to a reduction in rural livelihoods. The absence of grazing, however, has led to the paradoxical creation of "no-human biodiversity refuges," where wild plants regenerate in abandoned minefields. These areas remain ecologically unstable and dangerous for both humans and wildlife.

6.4. Biodiversity loss and faunal impacts

The fragmentation of habitats due to minefields restricts the migration routes of many animal species. Large mammals such as Caucasian leopards (Panthera pardus tulliana), brown bears (Ursus arctos), and red deer (Cervus elaphus) have experienced a decline in population due to habitat isolation and explosions. Birds and small mammals, drawn to unexploded ordnance as nesting or sheltering sites, often trigger accidental detonations. It further disrupts the local ecosystems.

Additionally, demining operations themselves involve mechanical flails and detonations. It can cause temporary disturbances in ecosystems if not managed carefully. However, the Azerbaijan Mine Action Agency (ANAMA) has begun employing eco-sensitive clearance methods, including low-impact mechanical tools, controlled detonations, and post-clearance reforestation programs, to minimize these negative effects.

6.5. Atmospheric pollution and air quality

The detonation of landmines releases gases such as carbon monoxide (CO), nitrogen oxides (NOx), and ammonia (NH_3) into the atmosphere. While individually small, the cumulative impact of thousands of explosions contributes to localized air quality degradation. During extensive clearance campaigns, the combustion of explosive residues can generate dioxins and volatile organic compounds (VOCs), both of which are harmful to human respiratory health.

Mine explosions also produce particulate matter ($PM_{2.5}$ and PM_{10}) that can travel long distances under windy conditions, particularly in open valleys like Jabrayil. This reinforces the need for environmentally adaptive clearance technologies and bioremediation strategies post demining.

6.6. Long-term ecological recovery and remediation

Sustainable recovery of Karabakh's ecosystem requires an integrated approach combining demining, soil bioremediation, and ecological restoration. Post-clearance rehabilitation projects now include phytoremediation (using plants to absorb contaminants) and mycoremediation (using fungi to break down TNT and RDX residues). Such biological methods have shown promising results. It reduces TNT concentration in soils by over 60% within 18 months in pilot studies conducted by ANAMA in 2024.

Mathematically, the recovery rate (R_e) of the ecosystem can be modeled as:

$$R_e = (A_c \times B_r) / (T_s \times P_c), \quad (4)$$

Here, A_c is the area cleared (in km^2), B_r is the biodiversity restoration coefficient ($0 < Br \leq 1$), T_s is the soil toxicity index, and P_c is the pollution concentration factor.

This model helps estimate the potential pace of ecological regeneration in relation to demining progress and soil restoration efficiency.

7. Economic cost analysis

The cost of installing a landmine ranges between $3 and $75 per device, depending on its type. However, removing a single mine costs between $300 and $1,000. It makes demining over 100 times more expensive than installation.

According to the Azerbaijani government, the total cost of clearing Karabakh's landmines is projected to exceed $10 billion USD. This economic burden limits the pace of reconstruction and agricultural revival in liberated districts.

8. Pakneftegaz's proposal for demining operations

Pakneftegaz, a Pakistan-based company, proposes to assist in Karabakh's demining projects by providing skilled manpower and technical expertise. Their involvement would accelerate safe mine clearance, minimize environmental damage, support knowledge transfer to local teams, and help rehabilitate cleared land for agriculture or infrastructure, while strengthening Pakistan–Azerbaijan cooperation.

9. Types of landmines removed

The mines identified and cleared in Karabakh include:

1) Anti-personnel mines: PMN-2, PMD-6, OZM-72, etc.
2) Anti-tank mines: TM-57, TM-62, M15, etc.
3) Improvised explosive devices (IEDs): locally manufactured explosives buried in civilian zones

These devices were found across formerly occupied districts such as Aghdam, Fuzuli, Jabrayil, Kalbajar, and Lachin.

10. Conclusion

The Karabakh region is heavily contaminated with landmines. It creates both a serious humanitarian crisis and long-term environmental problems. Azerbaijan has launched comprehensive demining operations, utilizing advanced technologies, trained animals, and partnerships with international organizations to tackle this issue. These efforts are gradually helping the region recover ecologically and economically. However, sustainable management of demining activities, combined with environmental restoration and continued international cooperation, is essential to make Karabakh safe and fertile again. Initiatives like the proposal from Pakneftegaz highlight a new era of cross-border collaboration in environmentally sensitive post-conflict reconstruction.

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МИНЫ В КАРАБАХЕ И ИХ ЭКОЛОГИЧЕСКИЕ ПОСЛЕДСТВИЯ

Камран Хан

Резюме: Регион Карабаха, длительное время подвергавшийся последствиям армяно-азербайджанского конфликта, остаётся одним из наиболее заражённых минными полями районов мира, оказывая значительное воздействие на окружающую среду. В то время как гуманитарные последствия мин хорошо изучены, их экологические эффекты остаются недостаточно исследованными. Настоящее исследование посвящено долгосрочному экологическому воздействию минного загрязнения в Карабахе с акцентом на потерю биоразнообразия, деградацию почв, загрязнение водных ресурсов и ограничение использования земель. Минные поля формируют зоны исключения, которые, с одной стороны, непреднамеренно служат убежищами для дикой природы, а с другой — фрагментируют экосистемы и угрожают выживанию видов. Взрывы и остатки взрывчатых веществ изменяют химический состав почв, снижают их плодородие и способствуют проникновению тяжёлых металлов в грунтовые воды, что усиливает эрозию и приводит к сокращению продуктивности сельского хозяйства. Операции по разминированию, хотя и необходимы, могут дополнительно нарушать экосистемы при отсутствии устойчивого управления. Экологически ориентированные методы разминирования, реализуемые Азербайджанским агентством по борьбе с минами, демонстрируют перспективные стратегии смягчения негативных последствий. Интеграция мероприятий по восстановлению экологии в гуманитарные и политические программы является ключевым условием устойчивого постконфликтного восстановления Карабаха.

Ключевые слова: мины, экологическое воздействие, биоразнообразие, деградация почв, Карабах, постконфликтное восстановление.

QARABAĞDA MİNALAR VƏ ONUN ƏTRAF MÜHİTƏ TƏSİRLƏRİ

Kamran Xan

Xülasə: Ermənistan-Azərbaycan münaqişəsi nəticəsində uzun müddət təsirlənmiş Qarabağ bölgəsi dünyada ən çox mina ilə çirklənmiş ərazilərdən biridir və bu, ətraf mühitə ciddi təsirlər göstərir. Minaların humanitar təsirləri yaxşı sənədləşdirilsə də, onların ekoloji nəticələrinə elmi baxımdan hələ kifayət qədər diqqət yetirilməyib. Bu araşdırma Qarabağda mina çirklənməsinin uzunmüddətli ətraf mühit təsirlərini öyrənir, xüsusilə bioloji müxtəlifliyin azalması, torpağın deqradasiyası, suyun çirklənməsi və torpaq istifadəsinin məhdudlaşması kimi aspektlərə diqqət yetirir. Mina sahələri, bir tərəfdən vəhşi təbiət üçün sığınacaq rolunu oynayan ərazilər yaratsa da, eyni zamanda yaşayış sahələrini parçalayır və növlərin sağ qalmasına təhlükə yaradır. Partlayışlar və partlayıcı qalıqlar torpağın tərkibini dəyişdirir, məhsuldarlığını azaldır və yeraltı suya ağır metallar daxil edərək eroziyanı və kənd təsərrüfatının azalmasını gücləndirir. Mina təmizləmə əməliyyatları vacib olsa da, davamlı və ekoloji yanaşma tətbiq olunmadıqda, ekosistemlərə əlavə ziyan vura bilər. Azərbaycan Minatəmizləmə Agentliyi tərəfindən həyata keçirilən ətraf mühitə həssas təmizləmə təcrübələri ekoloji riskləri azaltmaq üçün ümidverici yanaşmalar təqdim edir. Qarabağda davamlı post-münaqişə bərpasına nail olmaq üçün ekoloji bərpa tədbirlərinin humanitar və siyasi çərçivələrlə inteqrasiyası zəruridir.

Açar sözlər: minalar, ətraf mühit təsiri, bioloji müxtəliflik, torpağın deqradasiyası, Qarabağ, post-münaqişə bərpası.