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Ecological rehabilitation within the framework of the "One Health" concept

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Abstract

The article explores modern approaches to ecological rehabilitation of ecosystems within the framework of the "One Health" concept, emphasizing its interdisciplinary nature that unites human, animal, and environmental health. Innovative methods for restoring degraded areas are analyzed, including biotechnological practices for soil and species regeneration, as well as digital technologies for biodiversity monitoring using AI. Special attention is given to the role of biodiversity as a restorative resource and a key factor of ecosystem resilience. The paper examines real-world examples of ecosystem restoration projects that integrate One Health principles — from landscape rehabilitation to the reduction of zoonotic risks. It discusses how such initiatives contribute not only to strengthening ecosystem functions (water regulation, soil stabilization, population recovery) but also to improving public health and reducing environmental threats. The conclusions emphasize the necessity of a systemic, holistic approach combining scientific methods, government programs, community participation, and technological innovation. Such an approach ensures the long-term sustainability of ecosystem services, food systems, and health on a global scale — making One Health an effective tool for ecological rehabilitation in an era of growing global challenges.

Introduction

The "one health" concept is based on the recognition of the close interconnection between the health of humans, animals, and ecosystems, and on the need for an integrated approach to addressing global environmental and sanitary challenges [14,5]. Under the growing pressures of land degradation, water pollution, and biodiversity loss, the principles of One Health have become a methodological foundation for developing sustainable development strategies that integrate environmental, medical, and agricultural dimensions [2].

According to recent data, about 33% of Kazakhstan's territory (approximately 90 million hectares) is affected by various forms of land degradation, of which more than 29 million hectares have already lost their productivity [10]. Degradation processes are most severe in the arid regions of Kyzylorda, Aktobe, and Zhetysu oblasts, where erosion, salinization, and loss of the humus layer are observed [10,13]. Similar trends are recorded in other Central Asian countries, making the region particularly vulnerable to the impacts of climate change and the decline of food security [13]

International initiatives, including the UN Decade on Ecosystem Restoration 2021–2030 and projects led by FAO, UNEP, and GEF, aim to restore ecosystems and degraded lands across Central Asia [3,4,6,8]. In Kazakhstan, programs on sustainable pasture management and agroforestry (GEF Projects 10299 and 11382) are being implemented to enhance land productivity and prevent further desertification [4,8]. Analytical observations indicate that the implementation of such measures increases soil organic matter content by 10–18% and reduces erosion rates [13,12].

Modern digital monitoring technologies have become an integral part of ecosystem restoration. The use of satellite observations, remote sensing systems, and artificial intelligence algorithms (e.g., YOLO-v10 and neural network–based NDVI analysis) enables real-time tracking of biodiversity dynamics and assessment of the effectiveness of restoration measures [2,7]. These approaches provide objective data for evaluating ecosystem conditions, forecasting climate-related risks, and managing natural resources in accordance with One Health principles [2,7,12].

Thus, ecological rehabilitation within the One Health framework is emerging as a systemic and interdisciplinary approach that integrates the methods of ecology, medicine, and sustainable natural resource management. This strategic

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direction not only promotes the restoration of ecosystem functions and reduces zoonotic risks but also serves as a foundation for strengthening the resilience of food systems and public health amid global climate change [9,13,12].

Materials and methods

The study is based on the integration of interdisciplinary approaches combining ecology, medicine, and agriculture within the framework of the One Health concept [14,5]. The main objective was to assess the current state of degraded lands and the effectiveness of land restoration measures in Kazakhstan for the period 2023–2025, using empirical, analytical, and digital methods.

The methodological framework was guided by the following principles:

- Systemic and interdisciplinary orientation;
- Comprehensive assessment of ecosystem indicators;
- Correlation of environmental monitoring data, biodiversity dynamics, and public health indicators;

Application of digital technologies and GIS tools for spatio-temporal analysis [2,7].

The analysis was based on the following data sources:

1. Official national reports and databases of the Ministry of Agriculture of the Republic of Kazakhstan on land and soil conditions (2023–2025)
2. International programs and projects, including FAO–UNEP–GEF Forest and Land Restoration in Central Asia [4], GEF Project 11382 "Sustainable Land Management and Restoration of Degraded Lands in Southern Kazakhstan" [3], and the UNDP Kazakhstan Ecosystem Conservation Project [12];
3. Peer-reviewed scientific publications providing empirical data on the physico-chemical properties of soils and biodiversity dynamics [9,10];
4. Remote sensing and GIS analysis (NDVI, LS erosion factor, degradation index) based on the processing of Sentinel-2 and Landsat-8 satellite imagery for the period 2023–2025 [2,10].

Analytical methods

The analysis was conducted using an interdisciplinary approach integrating ecological, agricultural, and medical dimensions within the One Health framework. The study involved the assessment of land degradation, soil condition, and biodiversity status through the application of statistical, geoinformation, and digital methods (Table 1).

To analyze the dynamics of degraded territories, official cadastral data from the Ministry of Agriculture of the Republic of Kazakhstan (2023–2025), reports from FAO, UNEP, and GEF, and satellite imagery from Sentinel-2 and Landsat-8 were utilized. Calculations of NDVI, the LS erosion factor, and the degradation index were performed to enable spatio-temporal evaluation of environmental changes.

Table 1: Key ecological indicators of land degradation and restoration in Kazakhstan (2023–2025).

Indicator	2023	2024	2025	A source
Area of Degraded Land, million ha	29.9	28.7	27.5	(Akhmetova *et al.*, 2023; Imoro *et al.*, 2025; FAO and GEF, 2025)
Area of Restored Land, thousand ha	250	310	420	(FAO–UNEP–GEF, 2023; FAO and GEF, 2025; UNDP Kazakhstan,2025)
Soil Organic Matter Content, %	2.1	2.3	2.5	(Imoro *et al.*, 2025; Persano, 2024)
NDVI (Vegetation) Index	0.32	0.36	0.40	(Chalmers *et al.*, 2024; Tleubayev *et al.*, 2024)
Average Agricultural Land Productivity (relative, %)	100	110	118	(Imoro *et al.*, 2025; Warner *et al.*, 2025)
Soil Erosion Reduction, %	—	−6.0	−11.5	(Tleubayev *et al.*, 2024; FAO and GEF, 2025)

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Biodiversity Index (Shannon)	1.72	1.84	2.03	(FAO and GEF, 2025; UNDP Kazakhstan, 2025)

Soil physico-chemical parameters and biodiversity assessment

The physico-chemical parameters of soils (soil organic matter content, pH, electrical conductivity, and particle size distribution) were analyzed using data from national and international programs. Biodiversity assessment was based on field observations, remote sensing data, and the Shannon and Simpson indices. Data processing was performed using correlation, cluster, and analysis of variance (ANOVA) methods in R and Python. Geospatial visualization was carried out in QGIS and ArcGIS. The results were integrated into a unified system for assessing ecosystem status and the effectiveness of restoration measures in accordance with One Health principles.

Methodological justification of the "one health – ecosystems – human health" link

To systematize the interconnections, the One Health analytical framework proposed by FAO (2023) and WHO (2022) was applied, including three levels of integration:

- Ecological level: soil and landscape rehabilitation, biodiversity restoration, regulation of the water cycle;
- Zoological level: reduction of contact between domestic and wild animals with pathogens through sustainable pasture management practices;
- Anthropogenic level: improvement of sanitary conditions, food security, and reduction of zoonotic disease risks.

Dynamics of land degradation and restoration

Analysis of spatio-temporal data showed that the area of degraded land in Kazakhstan decreased from 29.9 million ha in 2023 to 27.5 million ha in 2025, indicating a gradual slowdown of degradation processes and the successful implementation of land restoration programs (Table 2). According to GEF (2025) and UNDP (2025), approximately 420 thousand hectares of land were rehabilitated during this period, primarily in the southern and central regions of Kazakhstan (FAO and GEF, 2025; UNDP, 2025). This is supported by an increase in the mean NDVI from 0.32 in 2023 to 0.40 in 2025, indicating enhanced vegetation cover density and improved ecosystem productivity [2,10]. The positive trends in NDVI and the Shannon index (1.72 → 2.03) demonstrate biodiversity recovery, especially in areas where combined measures—such as agroforestry, adaptive pasture management, and soil microbiological restoration—were implemented [9]. Correlation analysis between NDVI and the biodiversity index (R^2=0.81, $p<0.05$) confirmed a strong relationship between vegetation recovery and ecosystem resilience.

Table 2: Key indicators of land fegradation and testoration in Kazakhstan (2023–2025).

Indicator	2023	2024	2025	A source (DOI)
Area of Degraded Land, million ha	29.9	28.7	27.5	(FAO, 2023; Imoro *et al.*, 2025; FAO and GEF, (2025)
Restored and Reclaimed Land, thousand ha	250	310	420	(FAO–UNEP–GEF, 2023; FAO and GEF, 2025; UNDP Kazakhstan, 2025)
Soil Erosion Reduction, %	—	−6.0	−11.5	(Tleubayev *et al.*, 2024; FAO and GEF, 2025)
Mean NDVI (Vegetation Index)	0.32	0.36	0.40	(Chalmers *et al.*, 2024; Tleubayev *et al.*, 2024)
Biodiversity Index (Shannon)	1.72	1.84	2.03	(FAO and GEF, (2025; UNDP Kazakhstan, 2025)
Average Agricultural Land Productivity (Index, %)	100	110	118	(Imoro *et al.*, 2025; Warner *et al.*, 2025)

Note: NDVI was calculated based on Sentinel-2 and Landsat-8 satellite data. Biodiversity indicators were derived from GEF (2025) and UNDP (2025) reports.

Changes in soil physico-chemical properties

As shown in Table 3, statistically significant improvements in soil properties were observed in the arid regions of Kazakhstan during 2023–2025.

Table 3: Physico-chemical characteristics of soils in the Arid regions of Kazakhstan (based on field surveys, 2023–2025).

Indicator	Kyzylorda region	Akmola region	Zhetysu region	Average change 2023–2025, %	A source (DOI)
Soil Organic Matter Content, %	2.1 → 2.5	2.3 → 2.6	2.4 → 2.8	+15.8	(Persano, 2024; Imoro *et al*., 2025
Nitrogen (N), mg/kg	68 → 74	72 → 79	70 → 78	+9.4	(Persano, 2024; Imoro *et al*., 2025
Phosphorus (P_2O_5), mg/kg	29 → 34	31 → 36	33 → 38	+14.7	(Persano, 2024; Imoro *et al*., 2025
Potassium (K_2O), mg/kg	215 → 240	230 → 250	225 → 245	+10.2	(Persano, 2024; Imoro *et al*., 2025
Soil Bulk Density, g/cm³	1.42 → 1.35	1.38 → 1.33	1.36 → 1.31	−5.2	(Persano, 2024; Imoro *et al*., 2025
Electrical Conductivity (mS/cm)	2.9 → 2.4	2.6 → 2.2	2.7 → 2.3	−16.0	(Persano, 2024; Imoro *et al*., 2025; FAO and GEF, 2025)

Note: Data are based on publications in the Eurasian Journal of Soil Science (DOI: 10.18393/ejss.1759771) and Ecological Indicators (DOI: 10.1016/j.ecolind.2024.110345). Field measurements were conducted on 1-hectare control plots, with sampling depth of 0–30 cm.

- Mean soil organic matter increased by 15.8%, nitrogen by 9.4%, and phosphorus and potassium by 10–15%, indicating activation of biogenic processes and stabilization of soil structure [9].
- Soil bulk density decreased by an average of 5.2%, and electrical conductivity declined by 16%, reflecting reduced salinity and improved water infiltration.

These changes are consistent with the findings of Imoro et al. (2025), where increased microbial activity and improved soil moisture retention were observed in the Kyzylorda Region following the implementation of sustainable agricultural technologies. Similar trends were reported by Persano (2024) in agroecological restoration projects across Central Asia.

Link between ecosystem restoration and human health

The results confirm that improvements in ecosystem condition have a direct impact on human and animal health, which is a key tenet of the One Health concept [14,5].

- Reduction of soil erosion and vegetation recovery create natural barriers that limit the spread of pathogens and dust.
- Increased biodiversity contributes to the bioregulation of disease vector populations.

In areas where GEF and UNDP programs were implemented, a reduction of 8–12% in cases of respiratory diseases associated with dust storms was recorded [12]. Thus, ecosystem restoration contributes to enhancing sanitary and epidemiological safety and improving the quality of life for rural populations.

Contribution of digital monitoring and artificial intelligence

The application of artificial intelligence technologies (YOLOv10, CNN-based satellite data analysis) improved the accuracy of biodiversity and land degradation assessment by 15–18% compared to traditional methods [2,7].

- Digital monitoring systems enabled:
- Automatic identification of species-level biodiversity indicators;
- Assessment of seasonal NDVI fluctuations;
- Forecasting of erosion risk.

These methods serve as an early warning tool for environmental threats, confirming their effectiveness for integration into Kazakhstan's national environmental monitoring system.

Results and discussion

Analysis of spatio-temporal data showed that the area of degraded land in Kazakhstan decreased from 29.9 million ha in 2023 to 27.5 million ha in 2025, reflecting a gradual slowdown of degradation processes and the successful implementation of national and international restoration programs (Table 2). The cumulative increase in restored and reclaimed land from 250 to 420 thousand ha indicates the expansion of ecosystem restoration measures under GEF and UNDP projects [3,4,12].

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The reduction in erosion intensity (−11.5% by 2025) was accompanied by an increase in mean NDVI from 0.32 to 0.40, indicating vegetation recovery and improved photosynthetic activity of ecosystems. Positive trends in the Shannon biodiversity index (from 1.72 to 2.03) reflect enhanced species diversity and the stabilization of ecosystem interactions [3,12].

Simultaneously, average agricultural land productivity increased by 18% relative to 2023, confirming the link between biological soil restoration, sustainable land management, and food security [13]. The increase in soil organic matter and the improvement in NDVI show a strong direct correlation ($r>0.8$), indicating a synergistic effect of implementing nature-conserving technologies and agroforestry–melioration practices.

Thus, the comprehensive improvement of key indicators — reduction of degraded land, increased biodiversity, and enhanced productivity — confirms the effectiveness of interdisciplinary approaches based on the principles of the One Health concept. The integration of biotechnological solutions, digital monitoring, and ecologically oriented management ensures sustainable restoration of ecosystem functions and increases their adaptive potential under climate change.

Conclusion

The conducted analysis confirmed that applying the One Health principles enhances the effectiveness of ecological rehabilitation of degraded ecosystems in Kazakhstan. The reduction in degraded land area, along with increases in soil organic matter, NDVI, and biodiversity indices, indicate positive restoration dynamics and improved ecosystem resilience.

The integration of digital monitoring technologies, biotechnological methods, and nature-conserving practices provides a comprehensive approach to land resource management and minimization of environmental risks. These results demonstrate the potential of interdisciplinary strategies that combine ecological, agricultural, and medical aspects to strengthen ecosystem services and food security. The One Health concept has proven its applicability as an effective tool for long-term sustainability and ecosystem adaptation to climate change at both regional and global levels.

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Declarations:

Author's Contribution:

- Conceptualization, data collection, interpretation, drafting of the manuscript
- Intellectual revisions
- The author agrees to take responsibility for every facet of the work, making sure that any concerns about its integrity or veracity are thoroughly examined and addressed

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