

**ASSESSMENT OF THE ECOLOGICAL SAFETY OF THE UKRAINIAN POLISSYA
REGION BASED ON LANDSCAPE-ECOLOGICAL AND RADIOECOLOGICAL
APPROACHES UNDER MARTIAL LAW**

Vladyslav Parakhnenko^{1✉}, Vitaly Honcharuk², Oleksandr Balabak¹,
Marina Dekarchuk², Serhii Dekarchuk², Petro Borovyk¹, Mykhailo Shemiakin¹

¹ *Uman National University,*

1, Institutska Str., Uman, 20305, Ukraine,

² *Pavlo Tychyna Uman State Pedagogical University,*

2, Sadova Str., Uman, 20300, Ukraine

vladparachnenko@ukr.net

<https://doi.org/10.23939/ep2026.01.050>

Received: 06.11.2025

© Parakhnenko V., Honcharuk V., Balabak O., Dekarchuk M., Dekarchuk S., Borovyk P., Shemiakin M., 2026

Abstract. The article examines the environmental impact of military operations on Ukraine's natural landscapes from the perspective of environmental safety. The aim of the study is to develop an integrated methodological approach to assessing military and environmental risks based on a combination of landscape-ecological, radioecological, and geoecological analysis using geoinformation technologies. During the study, a system for the spatial identification of environmentally hazardous areas was developed, taking into account the degree of landscape structure disturbance, levels of radioecological load, and the intensity of military impact. The results obtained made it possible to establish patterns in the spatial distribution of environmental risks and to identify areas with critical levels of degradation of natural components. A model for the integrated assessment of environmental safety was proposed, which provides for the ranking of territories according to the priority of restoration measures. Novelty lies in the introduction of an interdisciplinary approach to the analysis of military-ecological threats, combining landscape-spatial modeling with radioecological assessment and geoinformation analysis. The practical significance of the results lies in the possibility of their application to improve the environmental monitoring system, plan environmental safety measures, and develop strategies for the environmental rehabilitation of territories affected by military actions.

Keywords: environmental safety, military-ecological risks, landscape-ecological analysis, radioecological assessment, geoinformation technologies, ecosystem restoration.

1. Introduction

During the current armed conflict, Ukraine faces significant risks to environmental safety due to infrastructure destruction, degradation of natural landscapes, and man-made accidents (Anisimov et al., 2024). The large-scale environmental consequences of military operations, in particular the destruction of hydraulic structures on large water bodies, lead to the accumulation of toxic substances in bottom sediments, creating an additional danger to aquatic ecosystems and public health in various regions of Ukraine (Kirvel et al., 2024). Military actions near nuclear facilities pose a particular threat, increasing the risk of radiation accidents and making research in the field of radioecology especially relevant (Makhinko et al., 2025).

Under conditions of military stress on the environment, traditional environmental protection approaches need to be methodologically rethought and integrated. Combining the principles of landscape ecology, which provides analysis of the spatial organization and functioning of ecosystems, with radioecology methods aimed at assessing and predicting radiation contamination, forms the scientific basis for a multifactorial analysis of environmental hazards and increases the validity of management decisions in areas of military impact (Pakholok et al., 2023).

For citation: Parakhnenko, V., Honcharuk, V., Balabak, O., Dekarchuk, M., Dekarchuk, S., Borovyk, P., Shemiakin, M. (2026). Assessment of the ecological safety of the Ukrainian Polissya region based on landscape-ecological and radioecological approaches under martial law. *Journal Environmental Problems*, 11(1), 50–60. <https://doi.org/10.23939/ep2026.01.050>

This approach allows for the simultaneous consideration of spatial-structural, radiation, and anthropogenic factors that determine the vulnerability of ecosystems in areas affected by military operations (Raichuk et al., 2025). Unlike previous studies, which focused primarily on individual environmental aspects, this work is based on the development of the achievements of Ukrainian scientific schools, in particular the Institute for Nuclear Power Plant Safety Problems of the National Academy of Sciences of Ukraine and the Institute of Agroecology and Nature Management of the National Academy of Agrarian Sciences. These institutions have conducted research combining landscape approaches, radioecological analysis, and geoinformation technologies to assess the state of ecosystems. This work builds on this experience, integrating these methods to identify critical hazard zones and develop adaptive environmental protection strategies in areas affected by the war (Romanchuk et al., 2017).

The aim of the study is to scientifically substantiate and develop an integrated methodology for assessing the environmental safety of Ukraine's territories in the context of armed conflict, based on a combination of the principles of landscape ecology and radioecology, with the aim of identifying, spatial differentiation and forecasting of military-ecological risks, as well as identifying priority areas for environmental rehabilitation and adaptive management of natural systems in war-affected areas.

2. Materials and Methods

The study was conducted in the central and northern regions of Ukraine, specifically in the territories of Chernihiv, Kyiv, Kharkiv, and partially Cherkasy regions, which are characterized by high levels of anthropogenic pressure, disturbance of natural landscapes, and increased radioecological risks in conditions of military influence (Starodub et al., 2024).

The objects of the study were natural and transformed landscape complexes. Natural landscapes include forest ecosystems, river valleys, and floodplains. Transformed landscapes are represented by urbanized areas with high building density and developed transport infrastructure, as well as industrial zones associated with the operation of industrial enterprises and man-made facilities (Shvydenko et al., 2025).

The methodological basis of the study was an integrated approach combining methods of landscape-ecological analysis, radioecological assessment, and geoecological spatial analysis. To assess the state of ecosystems

and levels of ecological danger, indicators of landscape structure disturbance, military load intensity, and radioecological pollution parameters were used.

The information base for the study was formed from official data from state environmental monitoring, in particular materials from open information resources of the Ministry of Environmental Protection and Natural Resources of Ukraine and the State Agency of Ukraine for the Management of the Exclusion Zone. In addition, international reports and analytical materials in the field of radioecology were used, in particular publications by the International Atomic Energy Agency, the European Commission, and the United Nations Environment Programme.

To analyze the spatial differentiation of environmental changes, remote sensing data was used, including satellite materials from the Sentinel-2 mission obtained through the Copernicus Open Access Hub platform. The information was processed and summarized using statistical analysis, spatial generalization, and interdisciplinary interpretation of the results.

Sampling plan. The selection of territories and soil and water samples was carried out according to the following principles:

The selection of sites was carried out taking into account the intensity of military and anthropogenic impact. The seasonal factor was taken into account: samples were taken in the spring and autumn of 2022–2024 to assess seasonal pollution dynamics.

Soil and surface water samples were collected from areas with varying levels of military and anthropogenic impact. Soil samples were taken from the top layer (0–20 cm) using spot sampling with the formation of composite samples. Water samples were taken from the surface layer of rivers and reservoirs into sterile containers. Sampling was carried out in the spring and autumn of 2022–2024. In total, more than 150 soil and water samples were taken.

Laboratory methods and quality assurance. Measurements of Cs-137 and Sr-90 radionuclide levels in soil and water were performed using NCRPU and IAEA methods.

Standard spectrophotometric and atomic absorption methods were used for heavy metals and chemical contaminants.

Repeat measurements, calibration samples, and laboratory standards were used for quality control.

All samples were labeled and stored in conditions that ensured stability of indicators.

QGIS and ArcGIS were used for spatial analysis and modeling of environmental risks.

The data sources were Sentinel-2 satellite images (Copernicus Open Access Hub), cadastral maps, location of protected areas. A multi-layer cartographic model was created, including: landscape types, levels of radioactive contamination, building density, location of industrial facilities.

The integrated model of anthropogenic load was based on four groups of indicators: structural and spatial, technogenic and chemical, socio-economic, and ecological stability of landscapes (Stakhova et al., 2025).

Data normalization allowed us to classify territories according to three risk levels: low, medium, and high. The model allowed us to identify “hot spots” of increased ecological and radioecological vulnerability.

The data underwent descriptive and correlation analysis, including tests for normality of distribution and

analysis of variance (ANOVA) to compare different types of landscapes. Spatial statistics included the calculation of fragmentation indices, building density, and vector analysis of pollutant distribution.

Ukrainian regulatory and legal acts on environmental safety, radioactive contamination control, and protection of natural areas were studied and analyzed (Radchenko et al., 2022). The following methods were applied: content analysis of legal texts, comparison of legal norms with practical monitoring data and GIS analysis.

This approach allowed us to integrate environmental and legal aspects into a model of territorial environmental safety (Fig.1) (Stakhova et al., 2025).

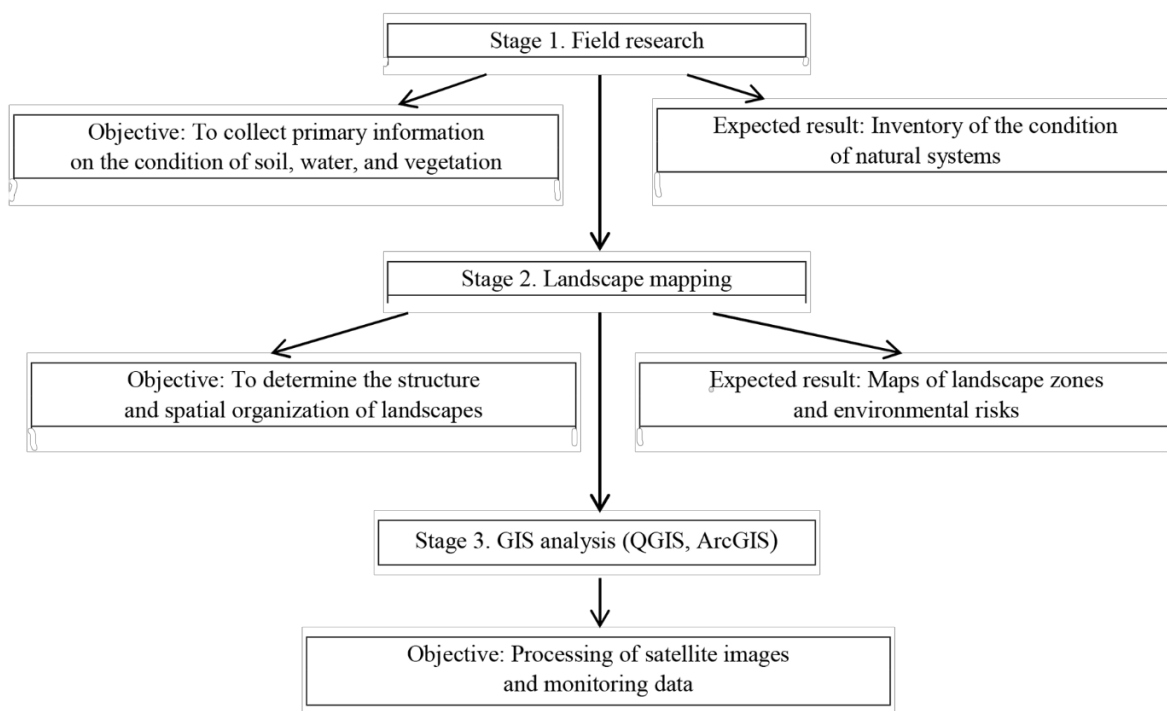


Fig. 1. Block diagram of the stages of landscape and environmental research

The spatial organization of natural and transformed ecosystems of the central and northern regions of Ukraine was studied and their resistance to military and anthropogenic impact was assessed.

A classification of landscapes by type and level of disturbance was carried out, which allowed to identify zones with different levels of ecological tension. Based on the integration of field research data and state monitoring, spatial models of ecological security were formed, which reflect the differentiation of ecological risks and determine territories of increased and critical danger.

The results obtained allow to establish the patterns of the spread of military-ecological threats and to determine priority areas of environmental protection and restoration measures, creating a scientific basis for effective management of ecological security in conditions of military stress.

To summarize the main approaches and stages of assessing the radioecological state of the studied territories, Table 1 is given, which systematizes the applied methods, their purpose and the results of use within the framework of the current study.

The Table 1 shows the main stages of the study, during which radioecological methods were used to assess the scale and dynamics of radiation pollution.

At the first stage, soil and water sampling was carried out to determine the concentrations of key radionuclides, primarily cesium-137 (¹³⁷Cs) and strontium-90 (⁹⁰Sr), which are characterized by a long half-life (~30 years) and the ability to accumulate in ecosystems,

affecting the radiation state of the environment and the functioning of food chains.

The second stage involved laboratory spectrometric analysis to identify radionuclides and determine their quantitative content. The results allowed the construction of radiochemical pollution profiles for different types of landscapes and the following of the vertical and horizontal differentiation of radioactive elements.

Table 1

Radioecological research methods

Method	Purpose of use	Expected result
Soil and water sampling	Analysis of radionuclide concentrations	Data on levels of Cs-137, Sr-90, etc.
Laboratory spectrometric analysis	Detection and quantitative assessment of radionuclides	Chemical profiles of radiation contamination
Modeling the spread of radionuclides	Predicting the migration of pollutants in the environment	Predictive maps of radioecological risk

The result of such modeling is predictive maps of radioecological risk, based on an integrated risk assessment using the methodology of the IAEA (Talerko et al., 2023) and UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation, 2020). This methodology combines quantitative indicators of territory contamination density, radionuclide migration potential, and exposure levels for the environment and population, allowing for a comprehensive assessment of environmental risk for different landscape zones.

Thus, the comprehensive use of field, laboratory, and modeling methods provides a systematic assessment of the current state of radiation contamination and forecasts its consequences. This is particularly relevant for areas of Ukraine affected by the Chernobyl accident and military actions, which may result in the secondary displacement of radionuclides into the environment.

The Table 2 improves the conditions for ensuring environmental safety, which requires not only natural science approaches, but also effective legal and managerial approaches.

Table 2

Legal and administrative methods of ensuring environmental safety

Method	Purpose of use	Expected result
Content analysis of regulatory and legal acts	Identifying gaps in the legal framework	Recommendations for improving legislation based on an analysis of 25 regulatory and legal documents of Ukraine in the field of environmental protection and nature management, including laws, resolutions of the Cabinet of Ministers, and subordinate acts
International comparative law	Assessment of the compliance of Ukrainian legislation with European standards	Integration proposals in the field of environmental safety based on a comparison with 15 key international and European regulatory documents (e.g., EU directives, UN conventions)
Zoning of territories	Identification of areas of high environmental vulnerability	Legal zoning and monitoring system

One of the key tools is content analysis of regulatory and legal acts, which allows identifying gaps and contradictions in the current legislation. To this end, 25 key Ukrainian documents in the field of environmental protection and nature management were analyzed, including laws, resolutions of the Cabinet of Ministers, and subordinate acts. This allows for the formulation of specific recommendations for improving legislation aimed at increasing the effectiveness of regulation in the field of environmental protection.

The application of international comparative law, which ensures the assessment of the compliance of the national legal system with European and global standards, is also important. A comparison was made with 15 key international and European documents (EU directives, UN conventions). This approach contributes to the harmonization of Ukraine's environmental policy with international obligations and creates conditions for integration into the European environmental security system.

The third component is zoning of territories, which involves the identification of areas of increased environmental vulnerability and the establishment of a special legal regime for their use. This allows for the creation of a system of targeted environmental monitoring and natural resource management that takes into account real environmental risks. Together, these methods form a comprehensive basis for improving environmental safety, combining legal, managerial, and integration mechanisms into a single sustainable development strategy.

3. Results and Discussion

Based on the analysis of regulatory and legal acts, mapping results, radioecological studies, and basic geocological data, it was established that the level of radioecological risk is directly related to the type of landscape, the nature of military impact, and the existence of legal restrictions on the use of the territory. The highest concentrations of radionuclides (Cs-137, Sr-90) were found in agricultural areas and in regions of the forest-steppe zone that were destroyed as a result of hostilities, where there is no adequate monitoring and control of the state of the environment (Varzhel et al., 2022). Thus, refined categories were used: geographical zone (forest-steppe) and type of land use (agricultural land), which makes the conclusion logically consistent.

In particular, nature conservation areas and protected zones showed relatively lower levels of radioecological contamination, which indicates the effectiveness of existing protection and access restriction mechanisms. In contrast, buffer and suburban areas that

have been actively affected by human activity and military operations have recorded elevated levels of radionuclides, due to heavy traffic, destruction of infrastructure, and the lack of a clear control system.

A legal analysis has shown that there is no integrated system of radioecological monitoring at the national level, and the existing provisions are fragmentary and do not provide adequate control (Yatsik et al., 2018; Zamula et al., 2023). This creates conditions for the accumulation of radioactive contamination in soil and water, even in regions with high environmental protection status.

Research was conducted in 2023–2025 in the Polissya and forest-steppe geographical zones, which made it possible to assess the current state of radioecological safety. However, in order to identify long-term trends, it is necessary to systematically combine GIS analysis, laboratory control, and legal regulation in order to form a unified risk management strategy (Parakhnenko & Honcharuk, 2025).

The Table 3 reflects the results of our own research conducted in 2023–2025 and demonstrates the application of basic landscape and ecological methods. The number of studies for each year was determined based on the actual surveys, landscape mapping, field observations, and GIS analysis that were carried out within the planned experimental routes and projects.

Landscape mapping and GIS analysis were carried out sequentially, with a gradual increase in the volume of work, reflecting the development of the research base and the integration of digital technologies into spatial analysis. Field studies were carried out in parallel to verify and refine the digital modeling data.

Table 3

Landscape and ecological research methods

Method	2023	2024	2025
Landscape mapping	12	15	18
GIS analysis	20	24	30
Field research	10	12	4

Thus, the Table 3 provides substantiated information about the scope and nature of the research performed, demonstrating the actual dynamics of the application of methods without conclusions about “growing interest in the topic”.

The Table 4 presents the results of own field studies of invasive plant species conducted at control sites in the Forest Steppe and Polissia during 2023–2025. The number of species was determined by actual observations, including monitoring of adults and seedlings of foreign plants. Previously, most of the results of such studies were not discussed, and specific species remained undetermined, so it was relevant to clarify the species composition. In the Forest Steppe, an increase in the number of invasive species was registered from 25 in 2023 to 35 in 2025; among them, *Amaranthus retroflexus* (late sedge), *Solidago canadensis* (Canadian goldenrod) and *Robinia pseudoacacia* (common robinia) dominated. In Polissia, the number of invasive species increased from 15 to 28, with the most common being *Heracleum sosnowskii* (Sosnowski’s borscht), *Impatiens parviflora* (small-flowered slum) and *Ailanthus altissima* (alaitus).

Table 4

Dynamics of invasive species in forest-steppe and Polissya zones (2023–2025)

Zone	2023	2024	2025
Forest-steppe	25	30	35
Polissya	15	20	28

The obtained data make it possible to establish species of invasive plants in different landscape zones, trace the dynamics of their number and determine the priority directions of control and environmental protection measures, which contributes to the preservation of ecological balance and stability of natural systems.

The Table 5 shows the actual results of measurements of the active concentration of Cs-137 and Sr-90 radionuclides in soil during 2023–2025. The unit of measurement is becquerels per kilogram (Bq/kg).

Table 5

Active concentration of radionuclides in soil (Bq/kg, 2023–2025)

Radionuclide	2023	2024	2025
Cs-137	120	135	150
Sr-90	80	95	110

The active concentration of Cs-137 increased from 120 Bq/kg in 2023 to 150 Bq/kg in 2025.

The active concentration of Sr-90 increased from 80 Bq/kg in 2023 to 110 Bq/kg in 2025.

The purpose of the table is to provide factual data on changes in the level of radioactive contamination of soils during the study period. The Table 6 shows the level of radioecological risk depending on the type of territory. In protected areas, this indicator is relatively low, but still tends to increase: from 20 in 2023 to 25 in 2025. This indicates the effectiveness of the existing protection system, although even in such conditions, the impact of military factors and climate change leads to a gradual increase in danger. Significantly higher indicators are recorded in agricultural landscapes: the risk level has increased from 60 in 2023 to 85 in 2025. This is explained by both the active use of soils and weak control over their radioecological condition.

Table 6

Level of radioecological risk

Type of territory	2023	2024	2025
Reserves	20	22	25
Agricultural	60	70	85

The Table 7 illustrates the results of GIS analysis of environmental safety. The number of so-called “hot spots” has almost doubled – from 8 in 2023 to 15 in 2025. This confirms that local pockets of environmental danger are spreading, covering new territories. Spatial mapping makes it possible to identify such areas and plan measures to neutralize them.

Table 7

GIS analysis of environmental safety

Indicator	2023	2024	2025
Hot spots	8	11	15

The Table 8 reflects the results of the legal analysis. The category of “clear regulation” is gradually growing (from 3 in 2023 to 5 in 2025), which indicates certain positive changes in the improvement of legislation.

Table 8

Legal analysis

Category	2023	2024	2025
Precise adjustment	3	4	5
Fragmentary	7	6	6

At the same time, the number of cases of “fragmented regulation” remains relatively high: although it has decreased from 7 in 2023 to 6 in 2025, this is not enough to form a comprehensive legal system in the field of environmental safety.

The Table 9 reflects the actual participation of club members in conferences and the number of scientific publications during 2023–2025.

The number of presentations at conferences increased from 5 in 2023 to 9 in 2025.

The number of publications increased from 2 in 2023 to 5 in 2025.

Table 9
Participation of students from the Chernobyl Bells club in scientific events (2023–2025)

Category	2023	2024	2025
Conferences	5	7	9
Publications	2	3	5

The purpose of the Table 10 is to provide factual data on student activity in scientific work, without making any value judgments about the reasons for this growth.

The Integral Index of Environmental Safety (IIES) is a quantitative assessment of the environmental sustainability and vulnerability of a given territory. It is determined based on the analysis of several components, including: technogenic and chemical indicators (concentration of pollutants in soil and water), structural and spatial indicators (building density, fragmentation of natural areas), socio-economic factors (traffic intensity, level of urbanization), and environmental sustainability (proportion of natural ecosystems, presence of protected areas). The index is calculated on a scale from 0 to 1, where 0 corresponds to the best state of environmental safety and 1 to the highest level of environmental vulnerability. The index value is calculated based on the normalized values of each indicator.

Table 10
Integral index of environmental safety

Region	2023	2024	2025
Polissya	0.65	0.68	0.72
Forest-steppe	0.55	0.6	0.65

According to the table, the integral environmental safety index shows an upward trend in both

regions studied-Polissya and Lisostep-indicating an improvement in the environmental situation in these territories during the period from 2023 to 2025.

In Polissya, the index rises from 0.65 in 2023 to 0.72 in 2025, indicating relatively stable environmental development, which is likely the result of effective environmental protection measures and the preservation of natural ecosystems. This indicates a decrease in anthropogenic impact on the territory and stability of environmental conditions.

At the same time, in the Forest-Steppe, the index also increases from 0.55 in 2023 to 0.65 in 2025, but this indicator remains lower than in Polissya. This can be explained by a higher level of anthropogenic pressure, which is due to more intensive economic activity in the region, in particular agriculture and industrialization. The higher index level in the Forest-Steppe indicates a higher vulnerability of this territory to environmental threats, which requires additional efforts to improve the environmental situation.

Thus, the results of this Table 10 allow us to assess the current state of environmental safety in the Polissya and Forest-Steppe regions, as well as help to identify priorities for future environmental protection measures in these regions.

The Fig. 2 shows the change in the number of invasive species in two natural zones of Ukraine. The forest-steppe region has recorded a steady increase in the number of invasive species – from 25 in 2023 to 35 in 2025. This trend is associated with intensive economic activity, urbanization and a high level of anthropogenic transformation of landscapes, which creates favorable conditions for the spread of alien species.

In the Polissia zone, the dynamics are more pronounced: the number of invasive species increased from 15 in 2023 to 20 in 2024 and to 28 in 2025. The accelerated spread of introduced species in the region may be linked to land-use changes, growing traffic flows, as well as the effects of military actions that break natural barriers to flora and fauna migration.

Among the most common and ecologically dangerous invasive species recorded within the studied areas, *Solidago canadensis* (Canadian goldenrod), *Heracleum sosnowskii* (Sosnowski's borscht), *Robinia pseudoacacia* (common robinia), *Ailanthus altissima* (highest ailant), *Impatiens parviflora* (small-flowered slum) and *Amaranthus retroflexus* (late sedge) stand out, which are characterized by high competitiveness and the ability to displace aboriginal species.

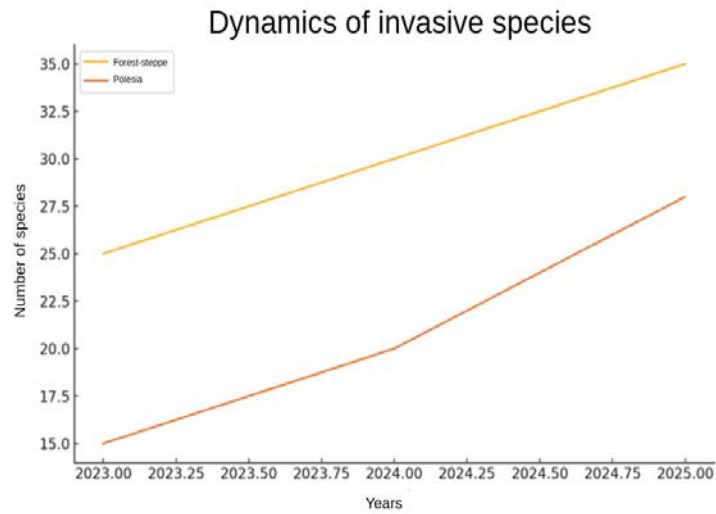


Fig. 02. Dynamics of the spread of invasive species in forest-steppe and Polissya zones (2023–2025)

The comparative analysis presented in Fig. 1 shows that although the forest-steppe zone is consistently characterized by a higher level of invasiveness, the growth rate of the number of invasive species is more dynamic in Polissya.

This indicates the increased vulnerability of the landscapes of Polissya and justifies the need to strengthen monitoring, improve regulatory and legal

regulation and implement comprehensive environmental strategies for curbing biological invasions.

The Fig. 3 shows the dynamics of concentrations of radionuclides Cs-137 and Sr-90 in 2023–2025 at the studied sites. Both radionuclides show a clear trend of gradual growth, indicating an increase in radioecological risks in the medium term.

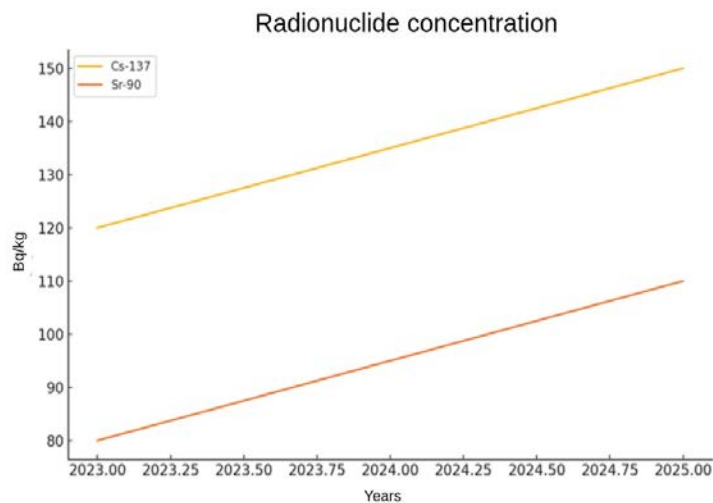


Fig. 3. Level of Cs-137 and Sr-90 concentration in soil by year

The concentration of Cs-137 remains higher than that of Sr-90 throughout the study period. It was 120 Bq/kg in 2023, rose to 135 Bq/kg in 2024, and reached 150 Bq/kg in 2025. This trend indicates the cumulative nature of cesium in soils and biosphere, which is dangerous due to its long-term preservation in food chains.

In the case of Sr-90, there is also a positive trend, from 80 Bq/kg in 2023 to 95 Bq/kg in 2024 and 110 Bq/kg in 2025. Although its concentration is lower than that of Cs-137, Sr-90 is particularly dangerous due to its ability to replace calcium in the bone tissue of living organisms, posing a high risk to public health in contaminated areas.

In general, the Fig. 4 shows a steady increase in radioactive contamination over three years, which can be caused both by military actions (destruction of industrial facilities, forest fires, ammunition explosions), and by the lack of systematic monitoring and

legal regulation in the field of environmental safety. If this trend continues, critical pollution levels could be exceeded in the coming years, requiring the introduction of stricter control and rehabilitation mechanisms.

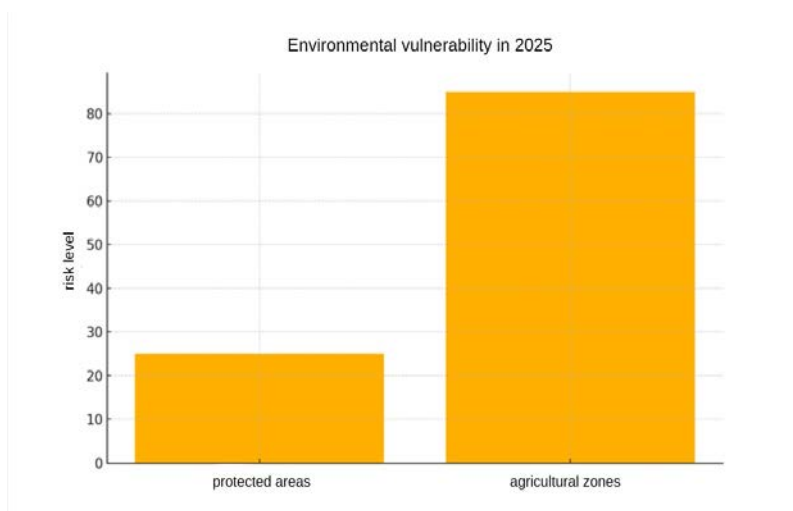


Fig. 4. Comparison of the ecological vulnerability of different landscapes

Ecological vulnerability in this study was defined as an integrated indicator reflecting the cumulative impact of anthropogenic and natural factors on the state of the ecosystem. This concept describes the ability of a territory to function sustainably under external influences, both anthropogenic and natural, and is important for determining its ecological safety.

The definition of ecological vulnerability in this context takes into account the following factors. Level of radioactive contamination – concentrations of radionuclides, in particular Cs-137 and Sr-90 in soil and water, which affect the health of the ecosystem. High levels of these elements indicate serious environmental risks.

Degree of anthropogenic pressure – this factor is assessed based on the intensity of agricultural use of the territory, movement of machinery, construction, and other human activities that alter natural landscapes.

The state of environmental protection measures – the presence of protected areas, the degree of their protection, and access restriction regimes. This factor is important because protected areas ensure a high level of ecosystem stability.

The ecosystem's potential for self-recovery is determined by the ability of flora and fauna to restore balance after disturbances, the level of biodiversity, and the ecosystem's resistance to change.

Method for determining ecological vulnerability. Field surveys and data collection on the condition of soil, water, and vegetation were conducted for each control site. Radionuclide concentrations were measured in Bq/kg. The level of anthropogenic impact was assessed on a scale of 1 to 10 (where 1 is minimal impact and 10 is maximum impact).

Aggregated data for each site were calculated using an integrated ecological vulnerability index. This index was calculated as the sum of the normalized indicators for each factor, taking into account their weight, which made it possible to obtain a single quantitative assessment of the vulnerability of the territory.

Results of environmental vulnerability assessment. Protected areas had a relatively low vulnerability level of 25 conventional units. This indicates the effectiveness of environmental protection measures and restrictions on anthropogenic impact in such areas, which allows maintaining ecological balance.

Agricultural areas showed a high level of vulnerability, with an index of 85 conventional units. This vulnerability is associated with intensive land use, significant infrastructure damage, and high levels of radionuclide accumulation due to agriculture.

The Fig. 5 shows a gradual increase in student activity in the scientific field during 2023–2025. The dynamics can be traced by two key indicators: participation in conferences and the number of publications.

Thus, in 2023, the number of student presentations at conferences was only 5, but in 2024 this figure rose to 7, and in 2025 – to 9. This indicates an increase in the level of academic mobility and integration of

young researchers into the scientific community, which is in line with current trends in the development of educational and research practices (Yermolaeva et al., 2022; Khilko, 2021).

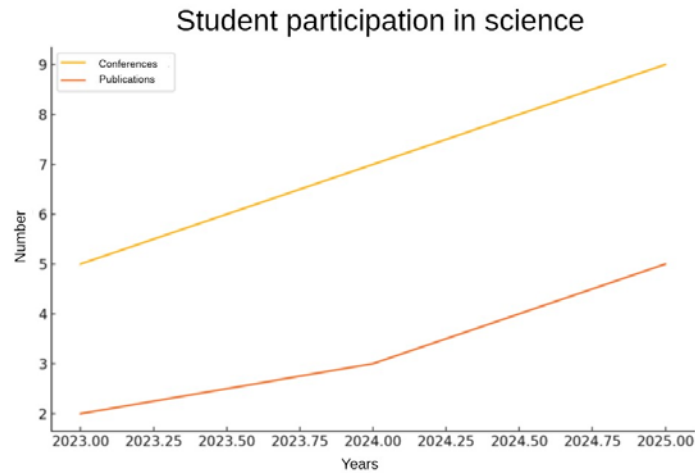


Fig. 5. Student participation in conferences and publications (2023–2025)

Even more telling is the trend in scientific publications. In 2023, students published only two papers, but in 2024 this figure rose to three, and in 2025 to five. The increase in the number of publications indicates the gradual development of students' academic writing skills, mastery of publication ethics standards, and more active participation in international scientific platforms (Radchenko, 2022; Solokha et al., 2024).

Overall, the graph shows a positive trend in the development of student science: participation in scientific events is increasing, the range of publications is expanding, and a new generation of young researchers is emerging, ready to participate in addressing environmental and social challenges (Stakhova et al., 2025; Parakhnenko & Honcharuk, 2025).

4. Conclusions

The conducted research made it possible to assess the state of ecological safety of the landscapes of the Forest Steppe and Polissia in the conditions of the war period based on field and analytical data obtained during 2023–2025. Although the three-year observation period does not allow the formulation of final long-term forecasts, it is sufficient to identify key local and regional trends emerging under the influence of military and anthropogenic loads.

One of the most clear-cut results is the steady increase in the number of invasive species in the landscapes studied. The forest-steppe is characterized by

a constantly high level of invasiveness, while Polissia recorded an acceleration of this process. Such dynamics suggest a weakening of natural barriers, a disruption of ecosystem balance and an increasing threat to local biodiversity. If left uncontrolled, these processes can lead to long-term degradation of natural complexes.

Radioecological studies have shown the presence of local zones of increased soil and water pollution, which form additional ecological pressure on ecosystems. Although the levels recorded are not of a continuous nature, their combination with disturbed and intensively used areas reinforces the overall vulnerability of landscapes and requires constant control.

The assessment of integrated environmental vulnerability revealed significant differences between land use types. Protected areas remain the most sustainable, while agricultural landscapes show high levels of vulnerability due to intensive use, destruction of infrastructure and accumulation of negative impacts. This means that it is the agro-landscapes that should become a priority target for remedial and protective measures.

The main conclusion of the work is that the landscapes of the Forest Steppe and Polissia retain the potential for survival and restoration, but this potential is not realized automatically. Recovery is only possible if there is targeted intervention, which should combine systemic environmental monitoring, early detection of invasive species, localisation of areas of increased radioecological risk and spatially sound planning of conservation measures.

The obtained results clearly show that in the conditions of war, environmental security moves from the category of secondary problems to the sphere of critical factors of national stability. The proposed integrated approach can serve as a basis for practical solutions aimed not only at recording environmental losses, but also at forming an effective strategy for the restoration and preservation of natural landscapes in the post-war period.

References

- Anisimov, V. M. (2024). Problem aspects of ensuring environmentally safe nature use during the post-war reconstruction period of Ukraine. *Research Retrieval and Academic Letters*, 5. Retrieved from <https://ojs.publisher.agency/index.php/RRAL/article/view/3203>
- Kirvel, I., Martyniuk, V., Kovalchuk, I., Andronache, I., Korbutiak, V., & Zubkovych, I. (2024). A Cartographic Landscape Analysis of the Geo-Ecological Condition of the Natural Reserve Object—Lake Doshne (Volyn Polissya, Ukraine). *Limnological Review*, 24(3), 385–405. <https://doi.org/10.3390/limnolrev24030023>
- Makhinko, R. G., & Dunaievska, O. F. (2025). Radionuclide contamination of rivers in Zhytomyr Polissia: Analysis of bioaccumulation in hydr obionts. *Balanced Nature Management*, 2, 94–101. <https://doi.org/10.33730/2310-4678.2.2025.337153>
- Pakholok, Y. (2023). Environmental rehabilitation of radioactively contaminated territories as a component of environmental safety. *Scientific Bulletin of Uzhhorod National University. Series: Law*, 77, 9–12. <https://doi.org/10.24144/2307-3322.2023.77.2.1>
- Parakhnenko, V. G., & Honcharuk, V. V. (2025). Methodology and organization of environmental research in the system of landscape ecology and radioecological monitoring of territories contaminated with radionuclides. *Journal Environmental Problems*, 10(2), 119–126. <https://doi.org/10.23939/ep2025.02.119>
- Raichuk, L., Kuchma, T., Shvydenko, I., Chobotko, H., & McDonald, I. (2025). GIS modeling of radioecological criticality in Ukrainian Polissia: a foundation for sustainable regional planning. *EQA – International Journal of Environmental Quality*, 70, 76–86. <https://doi.org/10.6092/issn.2281-4485/21903>
- Romanchuk, L. D., Fedonuk, T. P., & Khant, G. O. (2017). Radiomonitoring of plant products and soils of Polissia during the long-term period after the disaster at the Chernobyl Nuclear Power Plant. *Regulatory Mechanisms in Biosystems*, 8(3), 444–454. <https://doi.org/10.15421/021769>
- Starodub, Y., Mykhalichko, B., Lavrenyuk, H., Kozionova, O., Polcik, H., & Kuplovskyi, B. (2024). Environmental geoinformation monitoring system for civil and fire safety services of Ukraine. *Visnyk of Taras Shevchenko National University of Kyiv. Geology*, 2(105), 104–110. <https://doi.org/10.17721/1728-2713.105.14>
- Shvydenko, I. (2025). Radioecological and landscape complex zoning of Ukrainian Polissia as the basis for the post-war revival of the region. *Bulletin of Agricultural Science*, 103(11), 71–80. <https://doi.org/10.31073/agrovisnyk202511-07>
- Stakhova, I., Kazmirchuk, N., Oliinyk, N., & Baiurko, N. (2025). Ways to restore Ukraine’s environment in the post-war period. *Environment. Technology. Resources, Proceedings of the International Scientific and Practical Conference, 1*, 515–521. <https://doi.org/10.17770/etr2025vol1.8679>
- Talerko, M. M., Lev, T. D., Prister, B. S., & Voitsekhovych, O. V. (2023). Radioecological zoning as a methodological basis for interaction between forecasting systems and monitoring networks. *Nuclear Power and the Environment*, 3(28), 59–74. <https://doi.org/10.31717/2311-8253.23.3.7>
- Varzhel, O. V., & Ishchenko, V. A. (2022). Assessment of the impact of sanitary-hygienic and radiation indicators on the environmental safety of Rivne region. *Visnyk of Vinnytsia Polytechnic Institute*, 164, 38–44. <https://doi.org/10.31649/1997-9266-2022-164-5-38-44>
- Yatsik, A., Gopchak, I., & Basiuk, T. (2018). Assessment of anthropogenic impact on land within the small river basins of Western Polissya in Ukraine. *Land Reclamation and Water Management*, 108(2), 66–71. <https://doi.org/10.31073/mivg20180108-131>
- Zamula, I., & Shavurska, O. (2023). Strategic directions for restoration of environmental security of the Polissia region in the post-war period. *Journal of Innovations and Sustainability*, 7(1), 02. <https://doi.org/10.51599/is.2023.07.01.02>