EQA - International Journal of Environmental Quality
ISSN 2281-4485 - Vol. 70 (2025): 76 - 86
Journal homepage: https://eqa.unibo.it/

published by

GIS modeling of radioecological criticality in Ukrainian Polissia: a foundation for sustainable regional planning

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Article info
Received 5/5/2025; received in revised form 20/5/2025; accepted 13/6/2025
DOI: 10.6092/issn.2281-4485/21903

Abstract
The Russian military aggression has caused significant losses of Ukraine's agricultural lands, posing threats to food security and sustainable regional development. In this context, Ukrainian Polissia emerges as a potential area to offset these losses. However, radioecological risks stemming from the Chornobyl disaster necessitate a scientifically grounded approach to land use. This article presents a GIS-based methodology for comprehensive radioecological-landscape zoning, utilizing the Radioecological Criticality Index (RECI). The RECI integrates natural factors (soil cover, topography, hydrography), anthropogenic factors (land use), and radioecological factors (^{137}Cs contamination, radiation dose rates). Testing of the methodology near Rozsokhivske village (Zhytomyr Oblast) confirmed its effectiveness in identifying zones of varying criticality levels, which correlate with landscape characteristics. The methodology leverages open geospatial data (Copernicus, SRTM), striking a balance between accuracy and accessibility. Its adaptability enables the application of RECI to assess other types of contamination (chemical, organic) and in other regions, including post-conflict areas, within international programs such as UNEP and IAEA. This development supports sustainable regional planning, aligning with Sustainable Development Goals (SDGs 2, 13, 15) and the EU Soil Strategy 2030. It provides a tool for ecosystem restoration, optimization of agricultural land use, and evaluation of ecosystem services. Limitations include dependence on data quality and the need for periodic coefficient updates. The methodology serves as a versatile foundation for managing degraded territories, ensuring ecological safety and economic stability.

Keywords: *GIS modeling, radioecological criticality, Ukrainian Polissia, sustainable land use, radioactive contamination, food security, land rehabilitation.*

Introduction

The Russian military aggression has not only devastated a portion of Ukraine's agricultural lands but also poses a significant threat to global food security, particularly for countries reliant on Ukraine's agricultural exports, such as grain and oil. The current challenges, driven by the temporary loss of substantial agricultural territories due to military actions, demand urgent solutions to ensure regional food security and the economic stability of the state. Restoring production in alternative regions, such as Polissia, could serve as a critical factor in stabilizing both domestic and global markets. A key context is Ukraine's declared commitment to aligning its policies with the Sustainable Development Goals (SDGs) at both national and regional levels. The ongoing war presents serious obstacles to achieving these goals, particularly SDG 2 (Zero Hunger), SDG 6 (Clean Water and Sanitation), SDG 8 (Decent Work and Economic Growth), SDG 13 (Climate Action), and SDG 15 (Life on Land) (Ali *et al.* 2023; Appiah-Otoo and Chen, 2023). Consequently, revitalizing agriculture based on principles of sustainable land use has emerged as a top priority in national policy. Vast areas of arable land in southern and eastern Ukraine

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DOI: 10.6092/issn.2281-4485/21903

have been rendered unusable due to occupation, landmine contamination (with Ukraine currently being the most heavily mined country in the world), soil and water pollution, and infrastructure destruct-tion, including irrigation systems following the demolition of the Kakhovka Hydroelectric Dam (Tsaryk and Kuzyk, 2022; Tuchkovenko and Stepanenko, 2023). According to estimates from the EcoZagroza platform (Ministry of Environmental Protection and Natural Resources of Ukraine, n.d.), as of April 2025, over 1.18 million m^2 of soils have been damaged, with losses exceeding €486.82 million, and these figures continue to rise. In this context, there is an urgent need to maximize the use of previously underutilized or degraded lands, particularly in Ukrainian Polissia, which could become a key region for offsetting losses in agricultural production. However, this region presents unique ecological and radioecological risks associated with the aftermath of the Chornobyl disaster, climate change (Tarariko *et al.,* 2024), and specific soil cover characteristics. Consequently, integrating these lands into agricultural use requires a scientifically grounded approach and comprehensive surveys of extensive territories. Radioactive contamination in Ukrainian Polissia resulting from the Chornobyl nuclear accident remains a multifaceted issue encompassing environmental, social, and economic dimensions (Prister, 2020; Raichuk *et al.*, 2023, 2024). In the long term following the disaster, particularly given the reduced availability of suitable agricultural lands due to military actions, the importance of returning contaminated lands to productive use has grown (Drebot *et al.*, 2022). The factors influencing the redistribution of radionuclides in landscapes and their relative significance have evolved (Prister, 2020), necessitating modern approaches to assessing radioecological risks. Furthermore, Ukraine's three-level classification system for contaminated zones is misaligned with the current situation and approaches to territorial rehabilitation, leading to inconsistencies in land-use planning. Traditional methods of direct radioecological mapping, which rely on in-situ measurements, are labor-intensive, costly, and limited in spatial coverage (Dubois *et al.*, 2004; Titova, 2002). Integrated Geographic Information System (GIS) methodologies combine remote sensing and spatial analysis for landscape zoning and the assessment of radioactive and other forms of contamination (Dubois *et al.,* 2004; Freitas and dos Santos, 2014). These approaches enable risk forecasting and the development of strategies for multilevel sustainable regional development (Salt and Dunsmore, 2000). Such research is well-documented both in Ukraine and internationally, evolving with scientific innovations and emerging threats. For instance, Lev *et al.* (2023) employed GIS to model ^{137}Cs activity following wildfires in the Chornobyl Exclusion Zone, while Prister *et al.* (2018) developed preventive zoning for radioecological monitoring. Tyshchenko *et al.* (2023) applied GIS to assess the condition of nature reserves and agricultural lands, and Matvieieva *et al.* (2019) and Beresford *et al.* (2002) modeled radionuclide migration in ecosystems. Alipbeki *et al.* (2016) integrated GIS with satellite data to analyze secondary contamination, and Salt and Dunsmore (2000) created a decision-support system for managing radioactively contaminated lands. Grytsyuk *et al.* (2006) demonstrated how multilayer GIS matrices identify radioecologically critical landscapes. These approaches enhance the assessment of population radiation exposure, identification of vulnerable zones, and development of rehabilitation strategies, underscoring the critical role of GIS in comprehensive radioecological risk management. However, in Ukraine's current context, high-quality GIS mapping and modeling of the comprehensive radioecological status of territories face several challenges. These include outdated or low-quality data, data fragmentation, limited accessibility (e.g., local archives, restricted access to survey areas), underestimation of human factors (in terms of radiation dose formation), and intensifying climate change. Additionally, ongoing military actions signifycantly alter territorial conditions and hinder the acquisition of up-to-date data. Therefore, the **objecttive** of this study is to develop an integrated GIS methodology for comprehensive radioecological-landscape zoning and mapping of Ukrainian Polissia, based on the Radioecological Criticality Index (RECI). This index accounts for the primary factors influencing the radioecological criticality of lands. The first phase involves developing the RECI, incorporating natural, anthropogenic, and social factors. The subsequent phase entails practical zoning and GIS mapping to assess risks and plan measures using the most accessible and current data sources. The development of RECI aligns with European approaches to sustainable land use, particularly within the framework of the EU Soil Strategy 2030 (European Commission, 2021), which emphasizes the need for regional models to assess degraded lands. Furthermore, the methodology has the potential to be integrated into international programs, such as UNDP's Recove-

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ry and Peacebuilding, and can be adapted for monitoring in other post-conflict regions with support from UNEP and IAEA.

Materials and Methods

Development of the Radioecological Criticality Index (RECI)

To facilitate the prioritization of remediation efforts in radioactively contaminated regions and to support land-use planning and agricultural safety measures through adaptive land management, a comprehensive Radioecological Criticality Index (RECI) was developed for the Polissia region of Ukraine. This study draws on data from open sources and the findings of prior radioecological research in Ukrainian Polissia, including mathematical modeling of radionuclide migration in agro-landscapes (Atlas. Ukraine. Radioactive contamination, n.d.; Avila *et al*., 2013; Cherniavskyi *et al*., 2023; Chobotko and Raichuk, 2018; Chobotko *et al*., 2019a, 2020; Hromyk *et al*., 2020; Ivanov and Khomutinin, 2015; Krasnov *et al*., 2007; Kyrylchuk and Palamarchuk, 2022; Linkov and Schell, 1999; Linkov *et al*., 2006; Prister, 2020; Raichuk *et al*., 2019; Romantschuk *et al*., 2021). The components (indicators) of RECI were determined based on the most significant factors influencing the radioecological criticality of a territory and the accessibility of these data to a broad audience. Each indicator was assigned a corresponding coefficient with a specific gradation (Raichuk *et al*., 2025), reflecting both the variability of terrestrial conditions and the capabilities of the selected data source – such as GIS portals, national maps, or regulatory standards (Table 1). The coefficients for the RECI were developed with consideration of the specific patterns of radionuclide migration and accumulation in the landscapes of Ukrainian Polissia. For hydrographic conditions (H_c), a gradation of coefficients was established, ranging from 1.3 for areas within 500 m of water bodies to 0.7 for territories beyond 1000 m. This reflects the decreasing risk of secondary contamination with increasing distance from water bodies, based on data concerning ^{137}Cs migration in river floodplains (Par-yeniuk *et al*., 2020; Pazinych and Filipovych, 2014). The coefficients for terrain morphology T_m and runoff accumulation R_i were derived from empirical data linking slope steepness to ^{137}Cs redistribution (Shevchenko and Akinfiev, 2020; Shevchenko and Bublias, 2013) and field observations of radionuclide wash-off following heavy rainfall (Pazinych and Filipovych, 2014). The soil cover coefficients S_c for Polissia's soil types were calculated by averaging data from available studies (Hromyk, 2012; Konoplev *et al*., 2020; Labunska *et al*., 2021; Musych *et al*., 2019; Pri-ster, 2008; Procházka *et al*., 2022;). These calculations included transfer factor (TF) estimates for agricultural crops based on direct measurements (Raichuk, 2012), long-term monitoring data, and modeling of radio-nuclide migration in the soil-to-plant system (Chobotko *et al*., 2020). Land cover (L_c) was classified accor-ding to its capacity to accumulate radionuclides. The highest coefficients (1.6–2.0) were assigned to forest areas due to their high ability to retain and deposit radioactive substances (Krasnov *et al*., 2007, IAEA , 2000; Chobotko *et al*., 2020; Linkov and Schell, 1999; Chobotko and Raichuk, 2018). Arable lands were assigned coefficients of 1.0–1.6, reflecting their lower retention capa-

Table 1. *Data sources for GIS mapping and modeling of RECI*

Layer name, designation	Data source
Hydrographic conditions (H_c)	OpenStreetMap (n.d.)
Terrain morphology (T_m)	SRTM (Shuttle Radar Topography Mission) (NASA, n.d.)
Runoff accumulation intensity (R_i)	SRTM (Shuttle Radar Topography Mission) (NASA, n.d.)
Dominant soil cover (S_c)	Публічна кадастрова карта України (State Service of Ukraine for Geodesy, Cartography and Cadastre, n.d.)
Land cover (L_c)	The Copernicus Global Land Service – CGLS (VITO, 2015) or ESA WorldCover (Zanaga et al., 2022)
Landscape/ecosystem contamination level (considering exploitation level) (C_l)	Public cadastral map of Ukraine / local data (State Service of Ukraine for Geodesy, Cartography and Cadastre, n.d.)
^{137}Cs contamination of the territory (T_c)	National Atlas of Ukraine (IG NASU et al., n.d.)
Population radiation dose (D_l)	General dosimetric certification in Ukrainian Settlements / own research (Likhtarov et al., 2013)

DOI: 10.6092/issn.2281-4485/21903

city due to reduced biomass and other factors (IAEA, 2003; Vynohradska, 2014; Chobotko *et al*., 2020; Gyriy *et al*., 1999). Vegetation cover distribution data were obtained from Copernicus satellite imagery (VITO, 2015) and validated at control sites. The surface types considered included shrubs, grassy vegetation (meadows), agricultural lands, built-up areas (urban territories), bare soil/sparse vegetation, water bodies, wetlands, dense coniferous forest (crown cover >70%), dense broadleaf forest (crown cover >70%), coniferous forest, sparse forest (crown cover 15–70%), broadleaf forest, sparse forest (crown cover 15–70%), and mixed forest (Raichuk *et al*., 2025). The landscape contamination level (C_l) was calculated as a function of ^{137}Cs contamination (T_c) and land cover type (L_c), adjusted by an exploitation index (EI), ranging from 0.1 for protected areas to 0.9 for intensively used agricultural lands. This approach accounts for the influence of anthropogenic factors on radionuclide redistribution. The current ^{137}Cs contamination level (T_c) was determined using available cartographic data, applying the law of radioactive decay to account for the time elapsed since the Chornobyl accident, without additional field surveys. Initial contamination data were sourced from the Atlas of Radioactive Contamination of Ukraine (Atlas Ukraine, n.d.). The radiation dose load coefficient D_l was developed by integrating data from national dosime-tric certification (Likhtarov *et al*., 2013), proprietary dosimetric studies, and mathematical modeling (Chobotko *et al.,* 2019b; Cherniavskyi *et al*., 2023; Raichuk *et al*., 2019). Historical and current zoning regulations, including the repealed fourth zone of radioactive contamination, were considered to create a unified assessment scale. Empirical data on actual population dose loads in various contamination zones were used for coefficient calibration, ensuring alignment between calculated RECI values and radioactive contamination zone classifications. The baseline value of 1.0 corresponds to a dose level of <0.1 mSv/year. The D_l coefficient integrates not only natural and environmental factors but also socio-economic aspects into a single indicator, applicable to both historically contaminated zones and areas with contemporary radiation risks.

GIS modeling and mapping of radioecological criticality of the territory

The GIS modeling methodology is based on the integration of accessible open geospatial, cartographic, and numerical data with validated radioecological models, enabling a comprehensive assessment without the need for extensive field surveys. To create a multilayered map, the QGIS platform was utilized, employing standard spatial analysis tools tailored to the specific characteristics of Ukrainian Polissia. The methodology combines a categorical approach for discrete variables (e.g., soil type, land cover) with continuous spatial data (e.g., contamination levels, topography). Each layer was processed using the most suitable method. For categorical data (soil cover, land-use type), vector layers from public sources were used and classified according to pre-established coefficients. This approach facilitated the delineation of distinct zones with varying levels of radioecological sensitivity without requiring interpolation. Continuous data ^{137}Cs contamination, radiation dose load) were represented as raster layers derived from existing sources (Atlas of Radioactive Contamination, dosimetric certification data). As these data already contain spatially distributed values, additional interpolation was not applied. Instead, values were reclassified according to the RECI scale using QGIS raster calculator tools. Particular attention was given to ensuring consistency in the spatial resolution of all layers, with all data standardized to a uniform grid. To minimize errors in areas with abrupt parameter changes (e.g., at the boundaries between forests and agricultural lands), smoothing techniques were applied, taking into account landscape characteristics. Data sources were selected based on their accessibility, reliability, and spatial resolution (Table 1). The SRTM digital elevation model (30 m resolution) enabled the calculation of runoff and slope erosion parameters using QGIS's built-in tools (Raster Terrain Analysis). Land cover data were obtained from ESA WorldCover satellite products (10 m resolution), ensuring up-to-date information on current land use. For the ^{137}Cs contamination layer, an adapted radionuclide decay model was applied, accounting for the time elapsed since the Chornobyl accident. Radiation dose load data were sourced from national dosimetric certification of settlements, proprietary field studies, and modeling results. The radioecological-landscape mapping method, including the determination of radiological criticality levels, was tested in the area near Rozsokhivske village, Korosten District, Zhytomyr Oblast (zone II of radioactive contamination), at coordinates 51°07'15.2"N 29°00'49.6"E. Validation of the results was performed by comparing them with existing radioecological maps of specific regions (Prister *et al*, 2013, 2015, 2018; Lev *et al*, 2016, 2018) and point measurements available in the scientific literature. The model's error does not exceed 25% for most parameters, which is an acceptable level

DOI: 10.6092/issn.2281-4485/21903

. for strategic planning. To reduce uncertainty in critical zones, the model can be further refined through additional localized measurements.

Results and Discussion

The most significant factors influencing the radioecological criticality of territories, the risk of elevated radiation exposure to the population, and subsequent land management strategies are natural factors (soil and vegetation cover, topography), the level of radionuclide contamination, and the specifics of land use (land-use category, exploitation intensity, cultivation practices, and crop types) (Prister, 2020). Terrain morphology substantially affects the distribution and accumulation of radionuclides: flat areas promote the accumulation of radioactive particles, while steep slopes facilitate their wash-off and transport (Paryeniuk *et al.*, 2020; Pazinych and Filipovych, 2014; Shevchenko and Akinfiev, 2020; Shevchenko and Bublias, 2013 The intensity of surface runoff determines the rate of radionuclide movement, which is particularly relevant during heavy rainfall that triggers erosional processes. Soil cover is a critical determinant of radioecological criticality, as it governs radionuclide migration in soil and the soil-plant system. For instance, the sod-podzolic soils of Polissia, characterrized by low organic matter content and high acidity, enhance the uptake of radionuclides into plant products, thereby increasing the radiation dose load on the population (Hromyk, 2012; Hromyk *et al.*, 2020). Ecosystem type also significantly influences radionuclide dynamics. Forest ecosystems retain radioactive substances longer than open areas due to litter, fungi, lichens, and high biomass (Krasnov *et al.*, 2007). The type of agricultural crop cultivated further impacts radionuclide migration: root crops (e.g., potatoes) acelerate radionuclide movement within the soil profile, whereas cereals minimize this process (Iakymenko *et al.* 2013; Rozputnyi *et al.*, 2016; Tkachuk and Kovalov, 2018). Finally, the level of radioactive contamination is the most decisive factor. The radiation dose load on the population was included as a component of RECI, as the internal radiation dose serves as an integrative indicator of radioecological criticality that incorporates socio-economic factors (Chobotko *et al.*, 2018, 2019b). These data account not only for physicochemical factors but also indirectly reflect regional socio-economic characteristics, such as dietary habits, education levels, and population welfare (Chobotko *et al.*, 2019b). A comprehensive analysis of these factors enables accurate assessment of radioecological risks and the development of effective strategies for su-stainable regional management. Consequently, the fol-lowing categories of factors (indicators) were selected for the comprehensive assessment of radioecological criticality and the formulation of RECI:

- natural factors: hydrographic conditions, terrain morphology, runoff accumulation intensity, soil cover type;
- land use: land cover, level of anthropogenic impact on the landscape;
- radioecological data: ^{137}Cs contamination density, population radiation dose load.

The comprehensive Radioecological Criticality Index (RECI) is calculated using the following formula:

$$RECI = H_c \times T_m \times R_i \times S_c \times L_c \times C_l \times T_c \times D_l \times L_d, \qquad [1]$$

where H_c = hydrographic conditions coefficient (distance from a water body); T_m = terrain morphology coefficient (slope steepness); R_i = runoff accumulation intensity coefficient; S_c – predominant soil cover coefficient; T_c = territorial contamination coefficient (^{137}Cs); L_c = land cover coefficient; C_l = landscape contamination level coefficient; D_l = population dose load; L_d = dose load level coefficient.

Each parameter is assigned coefficients based on a classification system (Raichuk *et al.*, 2025). The gradation of values reflects the nonlinear influence of factors on radioecological processes, grounded in empirical data and literature assessments tailored to the conditions of Polissia. To determine the level of radioecological criticality, Equation [1] was implemented in the QGIS Raster Calculator dialog, using layers generated in previous steps as components of the equation. The resulting map was reclassified by assigning radioecological criticality levels to corresponding RECI values, according to the gradation scale outlined in Table 2. The proposed RECI index provides a comprehensive assessment of the radioecological criticality of Ukrainian Polissia territories (Figure 1) by integrating

Table 2. *Radioecological criticality levels of the territory*

RECI Value	Level of radioecological criticality
>185,0	extremely critical
148,1 – 185,0	highly critical
111,1 – 148,0	critical
74,1 – 111,0	moderately critical
37,1 – 74,0	slightly critical
<37,0	not critical

DOI: 10.6092/issn.2281-4485/21903

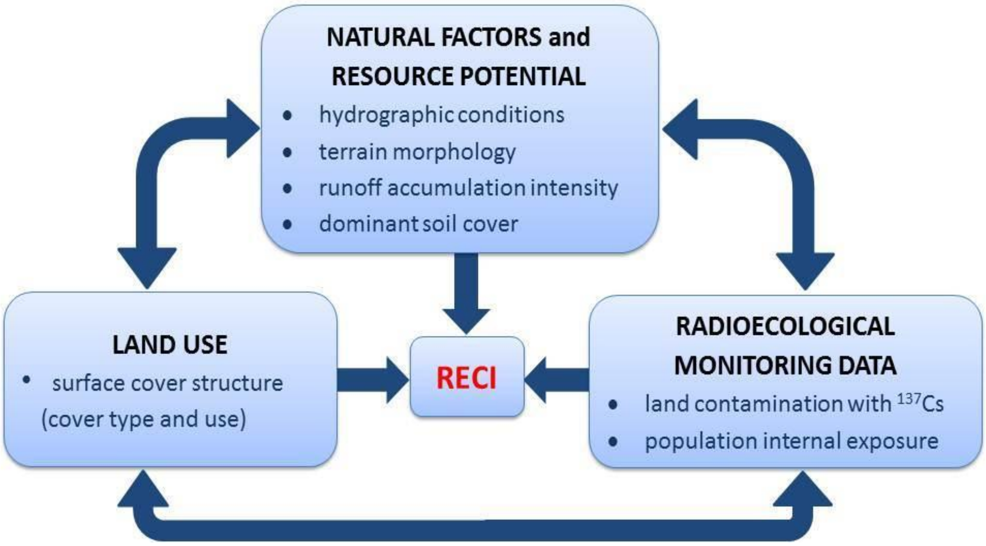

Figure 1
Structure of the Integrated Radioecological-Landscape Map for Ukrainian Polissya. The triangular layout depicts the interplay of three core components converging to form the Radioecological Criticality Index (RECI). Arrows illustrate bidirectional interactions among components and their contribution to the integrated index, supporting GIS-based risk assessment.

three key aspects: natural conditions, anthropogenic impacts, and population radiation dose load. Unlike traditional methods that often overlook landscape-specific factors, this approach accounts for the relationship between soil types (notably the high radionuclide transfer to crops in sod-podzolic soils) and the radiation exposure of local populations. The methodological advantage of RECI lies in its effective integration of open global data (Copernicus, SRTM) with local research findings, achieving sufficient accuracy with minimal resource expenditure (Lev *et al.*, 2018).

The developed coefficient system not only clas-sifies territories by risk level but also serves as a foundation for identifying priority zones for rehabilitation measures or restrictions on economic activities (Cho-botko *et al.*, 2022). This is particularly crucial for re-gions with complex radioecological histories. The prac-tical application of the RECI methodology through GIS mapping demonstrates its effectiveness, as illu-strated by the case study near Rozsokhivske village (Figure 2), where zones of varying radioecological criticality are clearly delineated. The integration of key data layers re-

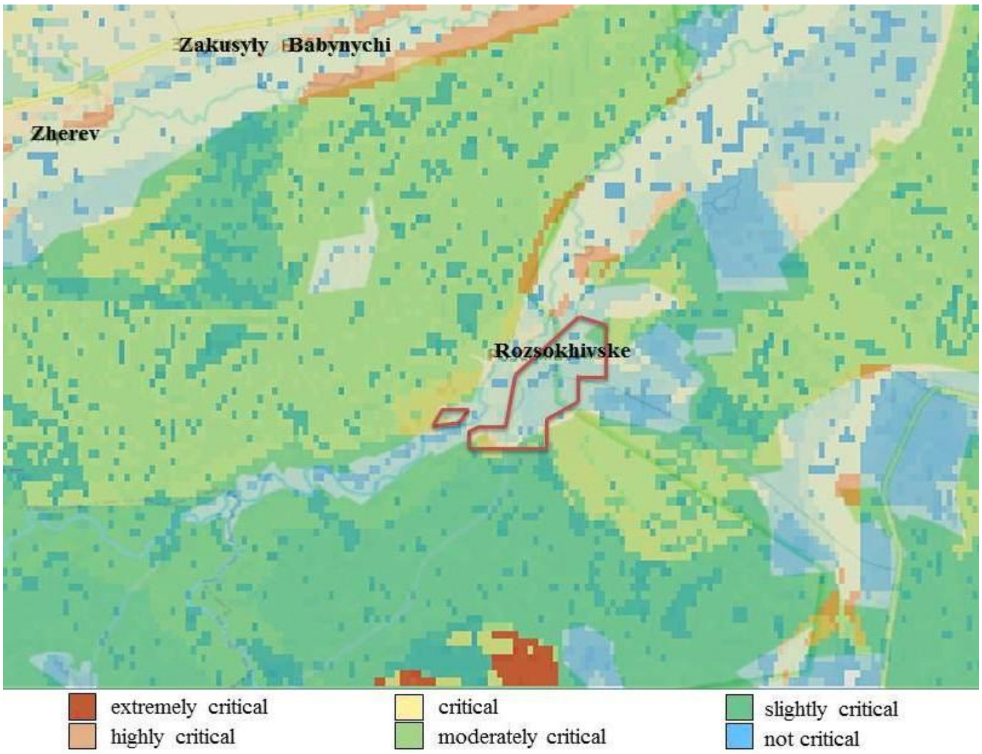

Figure 2
Map of radioecological Criticality Levels near Rozsokhivske village, Zhytomyr Oblast, Ukraine

DOI: 10.6092/issn.2281-4485/21903

vealed spatial patterns that traditional assessment methods often overlook (Davydchuk *et al.*, 1999). The study area near Rozsokhivske village is representative of Ukrainian Polissia in terms of soil cover, hydrography, and radioactive contamination levels. It encompasses all major soil types of the region: sod-podzolic (dominant), meadow (in river floodplains), and meadow-marsh (in topographic depressions), providing a comprehensive representation of the radioecological processes typical of Polissia. The area falls within the second zone of radioactive contamination (zone of guaranteed voluntary resettlement), corresponding to a moderate risk level, making it suitable for assessing radioecological criticality in the context of the long-term post-Chornobyl period. The presence of a river (Uzh River) and slopes of varying steepness allows for the analysis of water runoff's impact on radionuclide redistribution, including the accumulation of ^{137}Cs in floodplain areas due to periodic flooding, the wash-off of radioactive particles from slopes during heavy rainfall, and differences in radionuclide accumulation between well-drained (slopes) and waterlogged (lowlands) areas. Thus, the selected area serves as a micro-model of Polissia's radioecological conditions, enabling the extrapolation of results to other similar regions. The combination of factors – typical soil cover, water runoff, topographic differentiation, and a contamination level suitable for legal rehabilitation and use – makes this area an ideal testing ground for the RECI methodology. This is further supported by the fact that the distribution of radioecological criticality on the map (Figure 2) closely correlates with soil type (highest RECI values in meadow-marsh lands), proximity to the river (increased criticality in floodplains), and slope steepness (lower concentrations in erosion-prone areas). The resulting map reveals significant variability in radioecological criticality even within a small area, underscoring the need for a differentiated management approach. Specifically, the following zones were identified:

- highly critical (RECI 148.1–185.0) and critical (RECI 111.1–148.0) areas in waterlogged lowlands and some forested regions;
- moderately critical (RECI 74.1–111.0) and slightly critical (RECI 37.1–74.0) zones on slopes with sod-podzolic soils;
- relatively safe (RECI <37) areas on elevated terrain and arable lands.

The primary limitations of the methodology are the quality and timeliness of input data. However, the proposed approach strikes a robust balance between accuracy and resource efficiency. The use of open geospatial data combined with validated mathematical models yields representative results sufficient for informed management decisions. The developed methodology provides a scientific foundation for planning rehabilitation measures, optimizing agricultural land use, and evaluating ecosystem services in post-crisis conditions. Future improvements include regular updates to input data, increased granularity for specific settlements, and adaptation of the methodology to other types of anthropogenic impacts. The results confirm that radioecological-landscape zoning can serve as an effective tool for the sustainable recovery of Polissia, balancing ecological safety with economic viability. The proposed methodology is adaptable to other regions with radioactive or other forms of contamination, contributing to sustainable territorial management.

Conclusions

The proposed GIS methodology for comprehensive radioecological-landscape zoning of Ukrainian Polissia, based on the Radioecological Criticality Index (RECI), provides an effective tool for risk assessment and sustainable land-use planning in regions with radioactive contamination. By integrating natural factors (soil cover, topography, hydrography), anthropogenic factors (land use, exploitation intensity), and radioecological factors ^{137}Cs contamination, population radiation dose load) into the RECI, the methodology enables precise identification of critical zones and prioritization of rehabilitation measures. Testing near Rozsokhivske village (Zhytomyr Oblast) confirmed its ability to detect spatial variability in risks, which correlates with landscape characteristics, providing a scientific basis for differentiated territorial management. The methodology holds significant potential for adaptation to other regions and types of contamination, such as chemical (heavy metals, pesticides) or organic (petroleum products), through modification of RECI indicators and coefficients. The use of open geospatial data (Copernicus, SRTM) and versatile GIS tools ensures its flexibility for application in post-conflict or degraded regions worldwide, particularly within international programs (UNEP, IAEA, UNDP's Recovery and Peacebuilding). This contributes to addressing global challenges related to ecosystem contamination and supports alignment with Sustainable Development Goals (SDGs), notably SDG 2 (Zero Hunger), SDG 13 (Climate Action), and SDG 15 (Life on Land). For sustainable regional planning, the methodology offers a

DOI: 10.6092/issn.2281-4485/21903

scientifically grounded approach to restoring agricultural lands, balancing ecological safety with economic feasibility. It aligns with the principles of the EU Soil Strategy 2030, emphasizing regional models for assessing degraded lands, and facilitates the integration of ecosystem services into decision-making processes. Limitations include the quality and timeliness of input data and the need for periodic coefficient recalibration to account for dynamic changes (e.g., climate, land use). Future development of the methodology involves refining it for local conditions, expanding its application to other types of anthropogenic impacts, and integrating it into monitoring systems to support sustainable regional recovery.

Limitations. The assignment of weighting coefficients in the RECI approach is based on expert judgment, which may introduce subjectivity due to the lack of standardized criteria. The accuracy of the RECI index also depends on the quality of input data (e.g., resolution of SRTM data) and regional climate dynamics, such as wildfires or heavy rainfall. To improve reliability over time, periodic updates to the coefficients – such as every five years – are recommended, especially in response to land use changes.

Conflict of interests. The authors declare no conflict of interest.

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