IBIMA Publishing
Communications of International Proceedings
https://ibimapublishing.com/p-articles/46ISM/2025/4628525/
Vol. 2025 (29), Article ID 4628525

# Geographic Information System for Monitoring Agricultural and Rural Development: A Human Rights-Based Approach to Post-War Reconstruction in Ukraine*

Shamil IBATULLIN[1], Oksana SAKAL[2], Roman DERKULSKYI[3], Andriy DOROSH[4] and Vitaliy KRUPIN[5]

[1,2,3,4]Land Management Institute, National Academy of Agrarian Sciences of Ukraine, Kyiv, Ukraine
[1,2,5]Institute of Rural and Agricultural Development, Polish Academy of Sciences, Warsaw, Poland

Correspondence should be addressed to: Shamil IBATULLIN, shamilibatullin@gmail.com

* Presented at the 46th IBIMA International Conference, 26-27 November 2025, Ronda, Spain

## Abstract

This paper presents a conceptual framework for developing a geographic information system (GIS) designed to monitor agricultural and rural development in Ukraine with integrated human rights assessment components. The proposed system addresses critical challenges facing Ukraine's rural territories in the context of post-war reconstruction, including food security degradation, land resource management, infrastructure destruction, and protection of vulnerable population groups. The study outlines a comprehensive monitoring framework structured around six indicator blocks: security situation, food security, land resources and land use, agro-food system infrastructure, socio-economic conditions of rural territories, and human rights observance. The system architecture incorporates modular design principles, spatial database technologies, and advanced analytical capabilities to support evidence-based policy development and decision-making at multiple governance levels. Integration of geospatial analysis and socio-economic assessment methods aims to provide a tool for a human rights-based approach implementation into rural development management during Ukraine's post-war reconstruction.

**Keywords:** geographic information system, agricultural development monitoring, human rights-based approach, food security, land relations, rural development, post-war reconstruction, spatial analysis, Ukraine

## Introduction

The ongoing war in Ukraine has severely impacted the country's rural territories, limiting the food production. Beyond economic disruption, the war generates massive and interconnected challenges including mass displacement, infrastructure destruction, demographic crisis, and threats to global food security. Human rights in post-war reconstruction have different dimensions: a safe environment, the right to adequate food, land, and resources necessary for decent living standards. Small farmers are affected the most through land loss, production displacement, and supply chain disruption.

Agricultural land mining and contamination made it unsuitable for cultivation, posing significant life and health threats. Ukraine currently lacks monitoring capabilities for spatial identification of these contaminated lands. Comprehensive demining and reclamation programs are critical both for restoring agricultural production and protecting fundamental

**Cite this Article as:** Shamil IBATULLIN, Oksana SAKAL, Roman DERKULSKYI, Andriy DOROSH and Vitaliy KRUPIN, Vol. 2025 (29) "Geographic Information System for Monitoring Agricultural and Rural Development: A Human Rights-Based Approach to Post-War Reconstruction in Ukraine " Communications of International Proceedings, Vol. 2025 (29), Article ID 4628525, https://doi.org/10.5171/2025.4628525

human rights. Post-war reconstruction must create sustainable rural livelihoods that provide access to healthcare, education, administration and ensures food security through investments in agricultural diversification and strengthening natural and human capital resources.

Recent literature reveals significant applications of geospatial technologies in Ukraine's agricultural and rural development monitoring, particularly in post-war reconstruction contexts. Raihan (2024) provides a systematic review highlighting the increasing importance of GIS and Remote Sensing for evidence-based policy and sustainable practices in low- and middle-income countries. Nazarenko & Martyn (2024) identify key challenges in applying geospatial technologies to Ukraine's reconstruction – data inaccuracy, technological limitations, and skilled professional shortages – while highlighting innovations like GIS for Regional Development and the Digital Restoration Ecosystem for Accountable Management (DREAM).

Dorosh et al. (2024) emphasize the critical need for continuous land resource monitoring through GIS and remote sensing following 2022 hostilities. Notably, Kussul et al. (2024, 2025) present methodologies for automated detection of war-damaged fields using satellite data and machine learning, and an innovative geospatial framework analysing over 10,000 rural settlements using OpenStreetMap and humanitarian datasets to quantify infrastructure accessibility. Strategies for integrating human rights into land management and rural policy are explored in recent damage and needs assessments led by international organizations (World Bank, 2024). Earlier work by Borodina et al. (2010) established foundations for integrated modelling approaches combining food security analysis with sustainable rural development.

Recent advances in geographic information technologies offer new opportunities for monitoring complex rural development indicators. This paper presents a conceptual framework for a GIS designed to ensure comprehensive monitoring of agricultural and rural development while accounting for human rights considerations.

## Theoretical and Methodological Framework

### *Conceptual Foundations*

The proposed integrated platform for systematic data collection, processing, analysis, and its spatial visualization incorporates economic, ecological, and legal dimensions for multidimensional rural transformations assessment.

Human rights constitute a central analytical dimension, encompassing the food security (according to FAO standard), a safe environment, secure land ownership, and participation in decision-making on natural resource use. Land relations encompass socio-economic and legal relations regarding land ownership, use, and disposal.

### *Methodological Principles*

The methodological design integrates geospatial analysis, socio-economic assessment, and human rights monitoring approaches, guided by four core principles:

**Systematicity** considers agricultural and rural development as a complex economic, social, ecological, and legal system. Indicators are structured, but flexible as system dynamics evolve.

**Spatial differentiation** accounts for legal and spatial variations in socio-economic development and natural-climatic conditions. Spatial analysis aggregates indicators by regions, districts, territorial communities, and settlements, with geocoded data classification and zoning ensuring spatial visualization.

**Multidisciplinarity** integrates economics, geography, ecology, law, and sociology to enable comprehensive assessment and analysis of interdependencies among different dimensions.

**Human rights-based approach** ensures vulnerable population protection and equitable resource distribution remain central to analytical outputs and policy recommendations.

### *System Architecture*

The system has five primary modules: (1) **data collection and primary processing module** acquires data from diverse sources (open APIs, state registries, satellite imagery, surveys) and performs validation, normalization, classification, processing, and geocoding; (2) **spatial database module** (PostgreSQL/PostGIS) provides storage and management for spatial and attribute data; (3) **analytical module** for spatial analysis, statistical methods, and machine learning to identify patterns, trends, and anomalies in agricultural and rural development; (4) **visualization and user interface module** presents results through interactive maps, graphs, and tables using open solutions (Metabase, Kibana); (5) **decision support module** for risk assessment, scenario modeling, and sensitivity analysis. The system implements data warehouse principles for centralized data management optimized for analytical processing.

## Comprehensive Monitoring Indicator Framework

The system groups indicators into six blocks covering key dimensions of agricultural and rural development. Table 1 presents the comprehensive framework with key indicator categories for each monitoring dimension.

**Table 1. Six-Block Monitoring Indicator Framework**

| Block | Indicator Categories | Key Metrics |
|---|---|---|
| **Security Situation** | Territory security status | Occupation duration, distance to combat lines, classification (occupied/deoccupied/frontline/safe), combat encounter dates |
| | Mine danger | Mined agricultural land area, mining density, demined territory per period, accident frequency |
| | Military action intensity | Shelling frequency, infrastructure damage, threat levels, safe field access periods |
| **Food Security** | Food availability | Production volumes, food reserves, import/export volumes, crop losses |
| | Food accessibility | Price indices, food expense share in budgets, humanitarian aid distribution, assistance program coverage |
| | Food utilization | Child malnutrition rates, dietary calories, nutrition balance, food insecurity prevalence |
| | Provision stability | Seasonal price fluctuations, supply chain resilience, reserve adequacy |
| **Land Resources and Land Use** | Land use structure | Agricultural land area, crop structure, uncultivated arable land |
| | Land resource quality | Humus content, eroded areas, acidity levels, contamination (heavy metals, chemicals) |
| | Land relations | Ownership structure, registered plots, farm sizes, land prices and dynamics, transaction volumes |
| | Fair access to land | Small farm representation, conflict frequency, transaction transparency |
| **Agri-Food System Infrastructure** | Production infrastructure | Machinery provision, grain storage capacity, processing enterprises, irrigation functionality |
| | Transport accessibility | Road density and condition, market/administrative center access, railway accessibility, logistics costs |
| | Digital infrastructure | Internet coverage, access to electronic services |
| | Energy infrastructure | Electricity reliability, renewable energy utilization, energy |

| Block | Indicator Categories | Key Metrics |
|---|---|---|
| | | production efficiency |
| **Socio-Economic Conditions** | Demographics | Rural population, age structure, migration balance, population density |
| | Employment and income | Agro-industrial employment, salaries, poverty rates, income diversification |
| | Human capital | Education levels, professional training access, worker qualifications, gender equality |
| | Social infrastructure | Medical/educational accessibility, cultural/sports facilities |
| | Community resilience | Public organization participation, cooperation readiness, crisis adaptive capacity |
| **Human Rights and Social Justice** | Right to land | Land rights security, illegal alienation cases, access to justice |
| | Right to adequate food | Hunger prevalence, water access, food assistance for vulnerable groups, violation complaints |
| | Participation in decision-making | Council representation (gender/age), consultation frequency, information access, complaint effectiveness |
| | Protection of vulnerable groups | Women farmers' equality, children's rights, displaced persons' protection, disability accessibility |
| | Labor rights | Legislation compliance, workplace safety, fair wages |

Source: Authors' research results.

All indicators require geocoding with presentation capabilities at multiple spatial levels (local to national), supporting aggregation and disaggregation for different territorial units.

## Technological Implementation Approach

Server-side components include PostgreSQL/PostGIS spatial database to store and manage spatial and attribute data, Java/Spring-based server software implements business logic and APIs, and GeoServer for publishing spatial data and services. Client-side components: HTML5, CSS3, and JavaScript-based web interfaces integrating OpenLayers or Leaflet for map functionality and D3.js/Chart.js for data visualization, supplemented by mobile applications for field data collection. Analytical tools: QGIS and Python libraries including GeoPandas and Shapely for spatial analysis, with NumPy, pandas, and scikit-learn supporting statistical analysis and machine learning capabilities. Integration components provide APIs for connecting with other information systems for data exchange.

Monitoring comprehensiveness requires integration of diverse sources: official statistics, earth remote sensing data, state registries, and supplementary sources like sociological surveys, human rights reports, public environmental monitoring. Data integration requires developing methods for geocoding unstructured data, validating multi-source information, coordinating data with different spatial-temporal resolutions, and assessing dataset uncertainty and reliability. Analytical methodologies encompass spatial analysis, temporal analysis, machine learning, and visual analysis through cartographic visualization and interactive dashboards.

The home page serves as the central hub, providing quick access to main functions representing the six monitoring directions, with each containing visual elements and key statistics. The thematic maps interface divides into a side control panel and main map area. The control panel enables selection of thematic layers, detail levels, analysis periods, and filtering options with intuitive legends. The main map area utilizes Leaflet JS library with OpenStreetMap base layers, thematic overlays, navigation tools, and information panels. Figure 1 demonstrates the system's thematic mapping capabilities for visualizing security situation indicators.

The analytical dashboards support comprehensive data analysis through configurable filters, KPI cards with trend indicators, and interactive visualizations. Scenario modelling capabilities enable visualization of development trajectories and policy intervention impacts.

The database browser provides structured access to all indicators with search, filtering, and download capabilities. Export functionality supports multiple formats. API documentation enables programmatic access through REST endpoints.

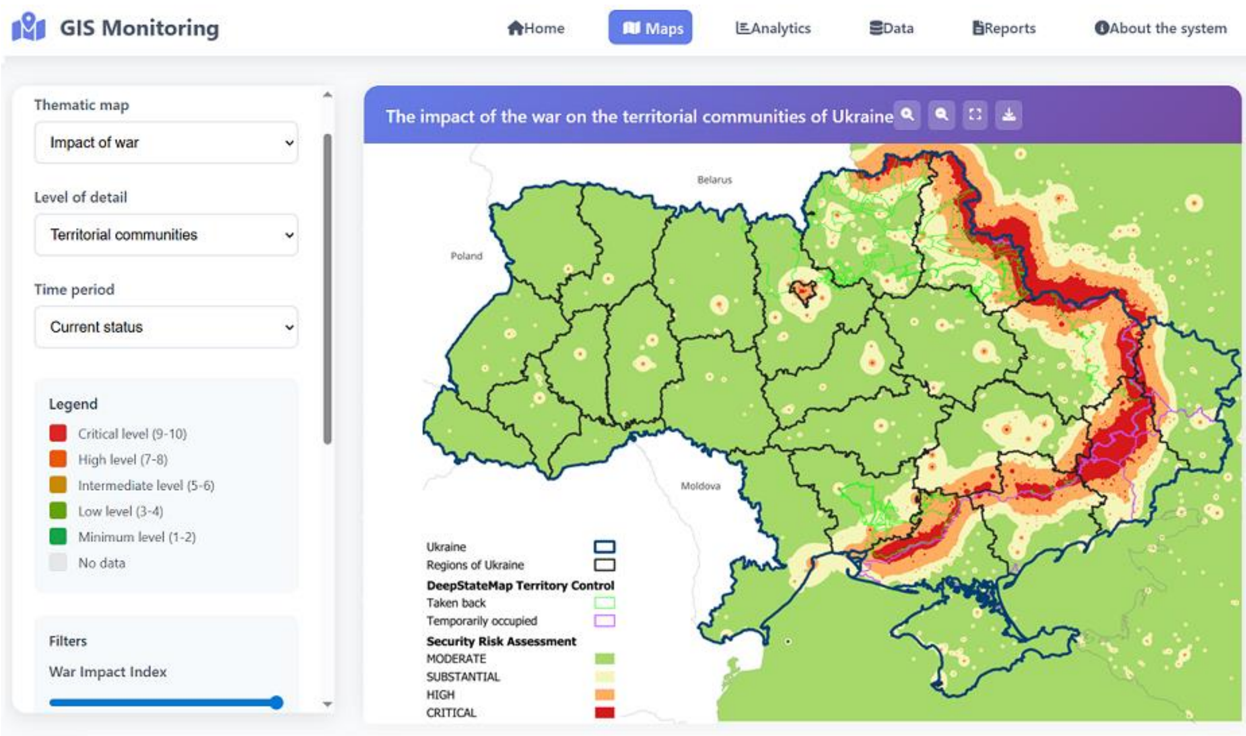


**Fig. 1. Prototype design of the "GIS monitoring" cartographic display page. Source: authors' own GIS monitoring system.**

## Applications for Human Rights Monitoring and Policy Support

The GIS enables comprehensive food security monitoring at multiple spatial levels. At the national level, the system examines production-consumption balances, import dependence, strategic reserves, and food price accessibility across social groups. Regional analysis identifies disparities in food security, problematic regions regarding access, nutritional patterns and health impacts, and self-sufficiency potential. Local monitoring maps territorial zones with food security challenges.

Land ownership and land use structure analysis examines land distribution, identifies concentration processes, assesses land market transparency, and evaluates gender dimensions in resource access. Efficiency and sustainability assessment evaluates productivity across user categories, examines land use system impacts on soil, water, and biodiversity, identifies degraded lands and reclamation efforts, analyses climate change adaptation.

The monitoring system provides critical support for evidence-based policymaking, as it identifies priority problems and intervention territories, assesses territorial development potential, enables scenario modelling and impact assessment on food security, land relations, and human rights, and ensures stakeholder coordination. Impact assessment capabilities enable preliminary evaluation of planned policies on different population groups' rights and evaluation of cumulative impacts across interventions.

## Conclusion

The proposed GIS concept for agricultural and rural development monitoring with integrated human rights assessment represents an innovative approach to rural territory development management that synthesizes advantages of modern geographic information technologies with sustainable development principles and human rights-based approaches. Key system advantages include monitoring comprehensiveness through integration of economic, social, ecological, and legal dimensions, spatial differentiation enabling consideration of territorial characteristics and development of spatially adapted policies, human rights orientation promoting vulnerable population protection and equitable benefit distribution, participatory design ensuring stakeholder involvement in monitoring and decision-making processes.

Implementation of this system would contribute to improving agricultural and rural development management efficiency, ensuring food security, promoting sustainable land resource use, and protecting rural population rights as essential components of national sustainable development. However, successful implementation requires further research in developing detailed methodological approaches for indicator assessment, algorithms for multi-source data integration, methods for visualizing and analysing spatial-temporal data, and mechanisms for integrating monitoring results into decision-making processes at various governance levels.

## Acknowledgement

This research has been conducted within the project "Substantiation and measures for implementation of a human rights-based integrated approach to rural development, food security and land policy in post-war rebuilding of Ukraine" (acronym “rUAr: Rebuild Rural Ukraine”) financed under the "Long-term program of support of the Ukrainian research teams at the Polish Academy of Sciences carried out in collaboration with the U.S. National Academy of Sciences with the financial support of external partners". Outcomes of the research project reflect only the opinions of the authors and the Polish Academy of Sciences, the U.S. National Academy of Sciences and other partners supporting the program are not responsible for any use of the information contained therein.

## References

- Borodina, O. et al. (2010). Integrated modeling approach to the analysis of food security and sustainable rural developments: Ukrainian case study. IIASA Interim Report, IR-10-017. URL: http://pure.iiasa.ac.at/9465.
- Dorosh, Y., Dorosh, A., Derkulskiy, R. & Bratinova M. (2024). Application of GIS in land management on the example of Ukraine. *Acta Scientiarum Polonorum Administratio Locorum, 23(1), 31-41.* https://doi.org/10.31648/aspal.9140.
- Kussul, N. et al. (2025). Assessment of war-induced agricultural land use changes in Ukraine using machine learning applied to Sentinel satellite data. *International Journal of Applied Earth Observation and Geoinformation*, 140, 104551. https://doi.org/10.1016/j.jag.2025.104551.
- Kussul, N., Svirsh, V. & Potuzhnyi, B. (2024). Integrated Geospatial Analysis for Rural Development Metrics. *International Conference on Computational Linguistics and Intelligent Systems*. In *COLINS,* (1), 141-160. https://doi.org/10.31110/colins/2024-1/011.
- Nazarenko, V. & Martyn A. (2024). Geospatial technologies in post-war reconstruction: challenges and innovations in Ukraine. *Land management, cadastre and land monitoring*, 3. https://doi.org/10.31548/zemleustriy2024.03.07.
- Raihan, A. (2024). A Systematic Review of Geographic Information Systems (GIS) in Agriculture for Evidence-Based Decision Making and Sustainability. *Global Sustainability Research*, *3*(1), 1-24. https://doi.org/10.56556/gssr.v3i1.636.
- World Bank, Government of Ukraine, European Union, and United Nations (2024). The Third Ukraine Rapid Damage and Needs Assessment (RDNA3): February 2022 - December 2023. Washington, D.C.: World Bank Group. 191 p. URL: http://documents.worldbank.org/curated/en/099021324115085807.