RATIONAL USE AND PROTECTION OF LAND AS COMPONENTS OF STATE ENVIRONMENTAL POLICY

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Abstract. The article substantiates the theoretical, methodological and institutional foundations for considering rational land use and land protection as interrelated components of state environmental policy. It is argued that the contemporary understanding of land resources should go beyond their productive function and be based on the concepts of natural capital, ecosystem services, soil health, sustainable land management and land degradation neutrality. The current Ukrainian legal and strategic framework is analysed together with the latest European approaches to soil protection, including the EU Soil Strategy for 2030, Regulation (EU) 2024/1991 on nature restoration and Directive (EU) 2025/2360 on soil monitoring and resilience. Special attention is paid to land degradation caused by the war, explosive ordnance contamination, physical and chemical disturbance of soils and the need to combine humanitarian demining with post-clearance environmental assessment. An integrated model of environmental land policy based on the sequence "diagnosis – prevention – regulation – restoration – monitoring – adaptive management" is proposed. Priority areas for Ukraine include establishing a comprehensive soil-health monitoring system, integrating ecosystem services into spatial planning, identifying degraded and environmentally sensitive land, developing result-oriented economic incentives, restoring natural landscape elements and harmonising national soil policy with the EU acquis. It is concluded that rational land use and land protection should be regarded as a unified mechanism for managing land-based natural capital and ensuring environmentally safe, climate-resilient and economically sustainable development.

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INTRODUCTION

Land resources constitute a fundamental component of a country's natural capital, provide the spatial basis for socio-economic development, and simultaneously perform a broad range of ecological functions. The soil cover supports food production, water regulation, carbon sequestration, nutrient cycling, biodiversity maintenance, and landscape resilience to climatic and technogenic pressures. Accordingly, the effectiveness of land policy cannot be assessed solely through productivity or short-term economic returns from land use; it must also be evaluated in terms of its capacity to conserve natural capital and sustain ecosystem services.

The contemporary scientific paradigm reinforces this requirement by defining soil health as the capacity of soil to function as a living ecosystem that sustains plants, animals, and humans and provides a wide range of ecosystem services. Consequently, land-condition assessment should encompass not only agrochemical characteristics but also the physical, biological, hydrological, and functional parameters of soil systems [15; 16].

For Ukraine, this issue is particularly acute because of the long-term intensive agricultural development of its territory, the high share of arable land, erosion, humus losses, disruption of the natural structure of agricultural landscapes, land contamination, and the limited effectiveness of mechanisms for conserving degraded and low-productivity land. The Biodiversity Conservation Strategy of Ukraine until 2035 indicates that even before the onset of the full-scale war, degraded and low-productivity soils covered more than 6.5 million ha, while approximately 10.6 million ha of arable land, or about 32% of the total arable area, was affected by water erosion [9].

The full-scale war has created an additional set of risks, including mine and other explosive contamination, mechanical destruction of soil profiles, crater formation, compaction by heavy machinery, contamination with heavy metals and combustion products, and damage to drainage and irrigation systems, shelterbelts, and natural ecosystems. Research demonstrates that warfare causes interrelated physical, chemical, and biological changes in soils, the effects of which may persist over long periods [19]. According to RDNA5, as of 31 December 2025, recovery needs in Ukraine's agricultural sector exceeded USD 55 billion, while needs related to explosive-hazard management and debris clearance approached USD 28 billion [23].

Under these conditions, rational land use and land protection can no longer be treated as separate domains of land regulation. They should be understood as interdependent components of state environmental policy that jointly support food and environmental security, climate adaptation, territorial resilience, and environmentally sound post-war recovery.

The theoretical foundations of contemporary sustainable land-resource management have developed at the intersection of the concepts of natural capital, ecosystem services, sustainable land use, soil health, and Land Degradation Neutrality. Bünemann et al. argue for moving beyond a narrow understanding of fertility toward a multi-criteria assessment of soil quality that accounts for specific threats, soil functions, and ecosystem services [15]. Lehmann et al. conceptualise soil health as an integrative category linking soil science, agricultural production, climate policy, water management, and societal well-being [16].

Land Degradation Neutrality (LDN) is of particular methodological importance. Cowie et al. define it as a framework for maintaining or increasing land-based natural capital built around the response hierarchy Avoid – Reduce – Reverse: prevent degradation, reduce its impacts, and restore land that has already been degraded [14]. The ecosystem dimension of this logic is developed by Keesstra et al., who demonstrate that nature-based solutions can simultaneously improve soil condition, regulate surface runoff, reduce erosion, and lower drought and flood risks [17].

Ukrainian research increasingly focuses on integrating land protection with spatial planning, land management, and territorial recovery. Bavrovska substantiates the need to mainstream environmental considerations into land policy through land management, remote sensing, and information-analytical systems [20]. Saik et al. combine LDN with land-use planning, the ecosystem approach, and natural-capital conservation, stressing the need to reduce anthropogenic pressure on environmentally vulnerable land [18]. Datsenko et al. emphasise the adaptation of sustainable land-use systems to wartime and post-war recovery conditions and the strengthening of the institutional framework for land policy [21], whereas Bielska et al. examine the relationship between changes in agricultural land use and territorial-planning documents in Poland and Ukraine [22].

Despite these advances, an integrated functional model remains insufficiently developed in which rational land use and land protection are

treated not as parallel regulatory domains but as interdependent elements of a single environmental-governance cycle. This conceptual gap determines the logic of the present study.

The purpose of the study is to provide a theoretical and methodological justification for rational land use and land protection as interrelated components of state environmental policy and to identify priorities for transforming Ukraine's land-resource management system on the basis of the ecosystem approach, the principle of Land Degradation Neutrality, soil-health monitoring, and European environmental-governance standards.

To achieve this purpose, the study synthesises contemporary theoretical approaches to rational land use; analyses Ukraine's regulatory and strategic framework; systematises war-related land risks; characterises current European soil-protection policy directions; develops an integrated model linking land and environmental policy; and proposes a system of policy instruments and performance indicators.

The study draws on Ukrainian legislation and strategic documents, European Union regulatory instruments, materials produced by FAO, UNCCD, the World Bank, and the European Commission, and recent academic publications addressing sustainable land-resource management, land degradation, soil health, ecosystem services, and post-war recovery.

The methodological framework combines: a systems approach to conceptualise land use as part of a socio-ecological system; analysis and synthesis to generalise regulatory and scientific provisions; comparative analysis to contrast Ukrainian and European approaches to soil protection; institutional analysis to identify the functions of legal, economic, spatial, and information mechanisms; and a structural-functional method to develop an integrated model of state environmental policy in the land-resources domain.

1. Rational Land Use within Contemporary Environmental Policy

In contemporary interpretation, land is not merely an object of ownership and economic use but a multifunctional natural asset. Rationality in land use should therefore be assessed by relating economic and social outcomes to changes in the stock of land-based natural capital. Land use cannot be considered rational when short-term productivity gains are accompanied by long-term losses of soil organic matter, increased erosion and compaction,

contamination, biodiversity decline, deterioration of landscape water-regulation functions, or rising future restoration costs.

The Land Code of Ukraine provides the legal basis for this approach by identifying rational land use and land protection among the principles of land legislation [1]. However, the contemporary substance of the concept should extend beyond formal compliance with designated land-use categories. It should include the environmental acceptability of land-use intensity, preservation of soil functions, compatibility with landscape structure, the social interests of communities, and long-term economic efficiency.

Accordingly, rational land use is proposed to be understood as an environmentally, economically, and socially justified land-use regime under which current use does not diminish the land resource's long-term capacity to perform productive, ecological, climate-regulating, and social functions. This definition shifts the emphasis from maximising a single production outcome toward maintaining the multifunctionality of the land system.

In practical terms, this entails five interrelated transitions:

– from maximising productivity to optimising the aggregate provision of ecosystem services;

– from management at the individual-parcel level to landscape and territorial levels;

– from responding to degradation after it occurs to preventing degradation;

– from assessing primarily fertility to comprehensively assessing soil health;

– from reliance on administrative restrictions to an integrated mix of regulatory, economic, information-analytical, and spatial-planning instruments.

Within such a system, land protection ceases to be an external constraint on economic activity and becomes a condition for preserving productive capacity, reducing environmental risk, and maintaining long-term economic returns.

The Law of Ukraine «On Land Protection» defines land protection as a system of legal, organisational, economic, technological, and other measures aimed, inter alia, at rational land use, preventing unjustified conversion of agricultural land, protecting land from harmful anthropogenic impacts, and restoring and improving soil fertility [2]. The Law of Ukraine «On State

Control over Land Use and Protection» directly links state control with the rational use and reproduction of natural resources and environmental protection [3].

Rational land use and land protection are therefore connected through a two-way functional relationship. Land protection establishes environmental limits and conditions for economic activity, whereas rational land use provides the practical means through which those conditions are implemented. The State Environmental Policy Strategy of Ukraine until 2030 reinforces this logic by orienting public policy toward an ecosystem approach, balanced use of natural resources, conservation and restoration of natural ecosystems, and the use of monitoring systems, strategic environmental assessment, environmental impact assessment, and environmental audit [4].

Functionally, environmental policy in the land-resources domain can be structured into three interrelated blocks: preventive measures aimed at avoiding degradation, contamination, and excessive anthropogenic pressure; regulatory measures defining environmentally acceptable land-use regimes; and restorative measures involving reclamation, conservation, renaturalisation, and the recovery of ecosystem functions in degraded areas. This sequence reflects a damage-prevention logic and reduces reliance on costly restoration after degradation has occurred.

A key distinction of the contemporary approach is the transition from controlling isolated negative processes to systematically managing the functional condition of soils. FAO emphasises that soil is effectively non-renewable on a human timescale while simultaneously supporting food production, water regulation, biodiversity, and climate regulation [13]. Land-protection policy should therefore rely on an integrated set of physical, chemical, biological, and functional indicators (Table 1)**.**

In Ukraine, an important step in this direction was the adoption of Cabinet of Ministers Resolution No. 848 of 23 July 2024 approving a new procedure for land and soil monitoring [6]. The transition to a new monitoring model should focus not on the mechanical accumulation of parcel-level information but on developing a spatially coherent data system describing soil condition, dynamics, and functional capacity. Such an information base is essential for linking regulatory decisions to measurable environmental outcomes.

Table 1

Groups of Indicators for Assessing Soil Health and Their key characteristics

Group	Key characteristics
Physical condition	structure, bulk density, water infiltration, erosion, compaction
Chemical condition	organic carbon, pH, nutrients, salinity, contamination
Biological condition	biological activity, soil biodiversity
Functional condition	productivity, water regulation, carbon sequestration, capacity to provide ecosystem services

The land degradation neutrality concept (LDN) provides a methodological bridge between land protection, spatial planning, and restoration. Its core logic is that policy should first prevent new losses of natural capital, then reduce degradation pressures, and only thereafter compensate for residual losses through restoration [14]. The Avoid – Reduce – Reverse hierarchy therefore changes the economic logic of public intervention by shifting priority from financing damage remediation toward investing in degradation prevention.

For Ukraine, implementation of LDN should be directly linked to land management and spatial planning. Territories should be differentiated not only by land category and designated use but also by ecological resilience, degree of degradation, ecosystem-service value, risk of soil-function loss, and environmentally acceptable intensity of economic use. Research supports combining LDN with the ecosystem approach and land-use planning [18], while comparative evidence from Poland and Ukraine demonstrates the importance of aligning agricultural land-use change with territorial-planning documents [22].

In this context, land management should perform not only the function of organising rights and boundaries but also a territorial ecological-design function: identifying zones of restricted use, optimising agricultural-landscape structure, conserving natural and semi-natural elements, developing ecological networks, and spatially targeting restoration measures.

The Concept of the National Target Program for Land Use and Protection, approved in 2022, provides a systemic framework for transforming land policy [5]. Between 2024 and 2026, this framework was strengthened by several interrelated strategic decisions. The Law of

Ukraine «On the Basic Principles of State Climate Policy» formalised the linkage among climate, land, and environmental policy and envisaged, inter alia, nature-based solutions, conservation of degraded land, and incentives for environmentally oriented practices [7]. The strategy for reforming state environmental supervision creates conditions for a transition toward risk-based environmental control [8].

The Biodiversity Conservation Strategy of Ukraine until 2035 translates a number of land-policy objectives into measurable targets. These include increasing natural elements in agricultural landscapes to at least 5% of agricultural land by 2030, creating or restoring at least 15,000 km of shelterbelts and protective strips by 2027, increasing by 20% the share of agricultural land under sustainable land-use systems by 2030, and removing part of degraded, low-productivity, technogenically contaminated arable land and illegally cultivated steep slopes from intensive cultivation [9]. The concept of rational land use is thus progressively shifting from a declarative legal norm toward a framework of measurable environmental outcomes.

The European vector reinforces this transition. The EU Soil Strategy for 2030 recognises healthy soils as a foundation of food security, biodiversity, climate resilience, and societal well-being [10]. Directive (EU) 2025/2360 on soil monitoring and resilience establishes a common framework for monitoring and assessing soil health, managing contaminated sites, preventing degradation, and limiting land take and soil sealing; its long-term objective is to achieve healthy and resilient soils by 2050 [11]. Regulation (EU) 2024/1991 on nature restoration further links land policy with the restoration of agroecosystems, organic soils, biodiversity, and climate policy [12].

For Ukraine, approximation to these approaches requires harmonisation not only of formal legal requirements but also of monitoring methodologies, indicator sets, spatial monitoring units, and decision-making procedures. Policy effectiveness should be judged by verified improvements in land condition rather than merely by the completion of individual measures.

2. War as a Driver of Land and Environmental Policy Transformation

The full-scale war fundamentally changes the meaning of rational land use. A parcel may be legally designated for agriculture yet remain unsafe

because of mine contamination or environmentally unsuitable because of soil-profile destruction, compaction, chemical contamination, or disturbed water regimes. Legal availability therefore does not automatically imply ecological or functional suitability.

War-related impacts require multi-level diagnosis. Earth observation and satellite data can rapidly identify changes in land cover, craters, fires, damage to irrigation and drainage systems, and vegetation disturbance, whereas field and laboratory investigations are required to determine soil physical and chemical properties, contamination levels, and risks associated with future use. The integration of remote and ground-based information should therefore underpin the mapping of dangerous, contaminated, and degraded areas [19].

The return of war-affected land to economic use should follow a sequential pathway: safety assessment – humanitarian demining – post-demining environmental assessment – evaluation of soil condition and functional suitability – selection of a use or restoration scenario - continued monitoring. This sequence distinguishes environmentally oriented recovery from the mere physical return of a parcel to cultivation.

Ukraine's state programme compensating the costs of humanitarian demining of agricultural land illustrates the gradual expansion of areas potentially returned to use. As of July 2026, 16,410 ha of agricultural land had been returned under completed contracts, while operations were ongoing on approximately another 11.7 thousand ha [24]. However, the indicator 'cleared of explosive ordnance' is insufficient for long-term environmental safety; it must be complemented by soil-environmental assessment and determination of an appropriate subsequent land-use scenario.

Post-war land-recovery policy should combine demining, reclamation, remediation of contaminated soils, anti-erosion measures, restoration of vegetation cover and water-regulation functions, and, where appropriate, conservation or renaturalisation. Decisions on whether land should return to intensive agriculture, be used under restrictions, be conserved, or be restored as a natural ecosystem should be based on safety, ecological condition, economic feasibility, and ecosystem-service value.

Based on the analysis, state environmental policy in the land-resources domain should be conceptualised as a closed adaptive cycle (Figure 1).

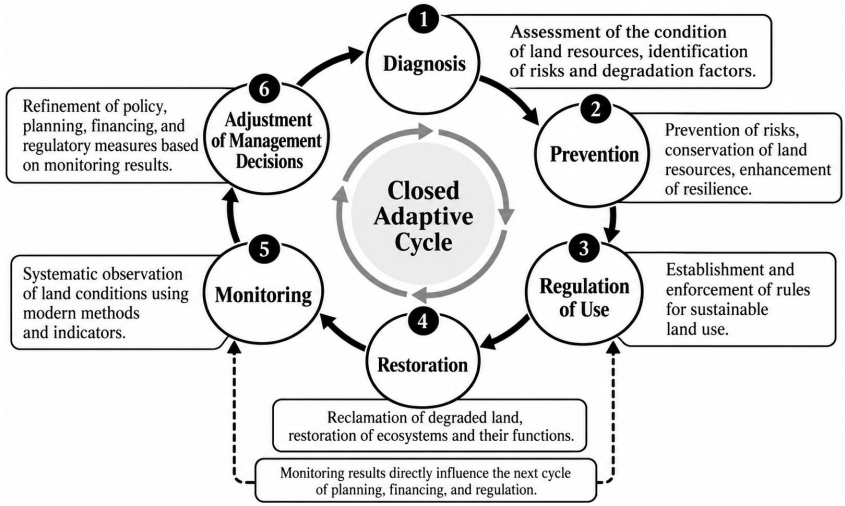


Figure 1. Conceptual Model of the Adaptive Cycle of State

Implementation of the model requires coordinated action across five interrelated governance levels (Table 2).

A defining feature of the proposed model is the shift from controlling how land is used toward managing the outcomes of land use. For example, public support for land users should be linked not only to the implementation of a particular agronomic measure but also to verified trends in soil organic carbon, erosion status, vegetation cover, biodiversity, or other relevant indicators.

Practical implementation requires a combination of four groups of instruments. Regulatory instruments include environmental standards, use regimes for valuable and vulnerable land, restrictions on ploughing slopes, floodplains, and riparian areas, and reclamation and conservation requirements. Economic instruments should create material incentives for preserving natural capital through payments or compensation for ecosystem services, support for conserving degraded land, organic production, agroforestry, soil-conservation farming, and nature-based solutions.

Table 2

Governance Levels of the Integrated Model of Rational Land Use and Land Protection

Level	Core content
Legal and regulatory	environmental standards, restrictions, norms, and liability
Spatial	zoning, land management, agricultural-landscape optimisation, ecological networks
Economic	incentives, compensation, payments for ecosystem services, green finance
Information	land and soil monitoring, Earth observation, GIS, registers of degraded and contaminated land
Ecosystem	restoration of natural functions, nature-based solutions, conservation

Spatial-planning instruments should align economic activity with the ecological carrying capacity of territories through comprehensive spatial development plans, land-management documentation, ecological networks, and regional plans for agricultural-landscape optimisation. The information-analytical component should integrate field surveys, agrochemical assessments, Earth observation, geographic information systems, cadastral data, registers of degraded and contaminated land, and risk-assessment models.

A key weakness of the current governance system is the gap between regulatory requirements and actual environmental outcomes. Policy evaluation should therefore be reoriented toward changes in land-based natural capital. A core indicator set may include:

– the share of degraded land in the total territorial area;

– the area of land showing positive, stable, and negative productivity trends;

– soil organic carbon content and trends;

– the area of eroded land and the intensity of erosion processes;

– the area of conserved, reclaimed, and restored land;

– the share of agricultural land under sustainable land-use systems;

– the share of natural and semi-natural elements within agricultural landscapes;

– the area of land contaminated or damaged by hostilities;

– the area cleared of explosive ordnance and environmentally assessed after demining;

– the area in which key ecosystem functions have been restored.

This indicator system enables a transition from counting completed measures to evaluating changes in the quality and functional capacity of land resources. It therefore provides a basis for results-based financing and adaptive management.

The transition from conventional land protection towards adaptive environmental governance requires not only a revision of regulatory principles but also a fundamentally different information architecture. In the conceptual model proposed in this study, land policy is understood as a closed adaptive cycle comprising diagnosis, prevention, regulation of use, restoration, monitoring, and adjustment of management decisions. The effectiveness of this cycle depends on whether reliable information on the actual condition of land and soils can be systematically collected, spatially integrated, interpreted and transformed into management decisions. Digitalisation should therefore be understood not merely as technical modernisation of land administration, but as an institutional mechanism through which environmental objectives can be translated into measurable land-management outcomes.

This issue is particularly important for Ukraine, where land-resource governance must simultaneously address long-term soil degradation, climate-related risks, biodiversity loss, changes in agricultural land use and the unprecedented environmental consequences of the war. The existing system consequently faces a dual transformation: it must move from fragmented inventories and predominantly administrative records towards continuous spatial monitoring of land and soil functions, while progressively aligning national information systems with European approaches to soil health and environmental monitoring.

Directive (EU) 2025/2360 on soil monitoring and resilience provides an important regulatory benchmark. It establishes a common framework for monitoring and assessing soil health, strengthening soil resilience and managing contaminated sites, with the long-term objective of achieving

healthy soils by 2050 [11]. For Ukraine, approximation to this model implies a gradual transition from recording individual violations or land-use characteristics towards evaluating the environmental condition, dynamics and functional capacity of soils.

In a linear model of environmental regulation, information is primarily used to establish compliance with predefined legal requirements. In an adaptive model, by contrast, information becomes an integral component of each management stage. Diagnosis establishes the initial ecological condition; prevention relies on predictive information about degradation risks; regulation differentiates permissible land-use intensity according to environmental capacity; restoration requires evidence for selecting interventions; monitoring evaluates whether the desired environmental result has been achieved; and the resulting evidence becomes the basis for adjusting the next cycle of planning, financing and regulation.

Accordingly, the information component of land policy should perform four interrelated functions: diagnostic, predictive, evaluative and corrective. The diagnostic function identifies the condition and spatial distribution of degradation processes; the predictive function anticipates where environmental deterioration is likely to occur; the evaluative function determines whether programmes and incentives generate measurable improvements; and the corrective function ensures that monitoring results influence subsequent decisions. Such a model is consistent with the Land Degradation Neutrality hierarchy Avoid – Reduce – Reverse, which gives priority to preventing degradation before reducing impacts and restoring already degraded land [14].

This shift also changes the criteria used to assess policy effectiveness. The amount of financing allocated, number of projects implemented or hectares formally covered by a programme should be complemented by outcome indicators reflecting changes in soil health, erosion intensity, vegetation condition, ecosystem connectivity and other functions of land natural capital [25; 26]. Monitoring is therefore not the final stage of the policy cycle but the informational starting point of the next management iteration.

No single data source can adequately characterise the ecological state of land. Soil systems are spatially heterogeneous, dynamically respond

to management and climate, and perform multiple functions that cannot be represented by one indicator. Adaptive governance should therefore integrate field observations, laboratory measurements, Earth Observation data, cadastral and administrative information, spatial planning data, climatic information and predictive models.

Field soil surveys remain indispensable because soil organic carbon, pH, nutrient status, bulk density, contamination and many biological properties require direct measurements or laboratory analyses. Their value increases when sampling programmes are embedded in a geospatial framework and combined with remote sensing and digital soil mapping [26; 28]. Digital soil mapping provides a methodological bridge between point observations and continuous spatial information. SoilGrids 2.0, for example, integrates soil observations and environmental covariates using machine-learning methods and provides global predictions of major soil properties together with spatially explicit uncertainty [28].

For Ukraine, digital transformation should involve not only the creation of new datasets but also harmonisation, georeferencing and quality assessment of existing soil, agrochemical, cadastral and environmental information. Data produced by different institutions are difficult to combine when they use incompatible coordinate systems, sampling schemes, classifications or analytical procedures. The resulting information architecture should therefore be interoperable by design and should distinguish data origin, quality, spatial resolution and methodological limitations.

The proposed multi-source structure is summarised in Table 3, which links legal, environmental, spatial, climatic, war-impact and socio-economic information with specific management applications.

As shown in Table 3, such integration allows land to be analysed simultaneously as a legal object, productive resource, component of natural capital and spatially embedded ecosystem. A productive agricultural field may also be highly erosion-prone, ecologically fragmented or strategically important for food security; adaptive governance must therefore balance these dimensions rather than maximise a single indicator.

Table 3

Proposed information architecture for adaptive land-resource governance

Information layer	Principal data	Main analytical function	Management application
Land administration	Parcels, rights, restrictions, designated use	Identification of management units and legal regimes	Regulation, control, responsibility
Soil condition	SOC, pH, nutrients, density, erosion, salinity, contamination, biological indicators	Assessment of soil health and degradation	Conservation, restoration, sustainable-use requirements
Earth Observation	Vegetation, land cover, bare soil, moisture, land-use change, surface disturbance	Continuous observation and anomaly detection	Early warning and targeting of field surveys
Landscape/ ecosystem data	Wetlands, forests, shelterbelts, water bodies, protected areas, connectivity	Assessment of ecosystem functions and landscape resilience	Spatial planning, agro-landscape optimisation
Climate/ hazard data	Precipitation, temperature, drought, flood and fire risks	Assessment of pressures and future risks	Adaptation and preventive regulation
War-impact data	Explosive contamination, craters, disturbed soils, damaged systems, hotspots	Safety and ecological risk assessment	Demining priorities, post-clearance assessment, restoration
Socio-economic data	Production, land value, employment, infrastructure, accessibility	Assessment of socio-economic consequences	Prioritisation of investments and incentives
Policy-performance data	Interventions, expenditures, environmental outcomes	Assessment of policy effectiveness	Adaptive adjustment of financing and regulation

3. Soil-health Monitoring as the Core of Environmental Performance Assessment

A major limitation of traditional land monitoring is its concentration on land-use categories, quantitative accounting and visible degradation processes. The concept of soil health broadens this framework by focusing

on the capacity of soils to function as living systems and provide multiple ecosystem services [16]. A scientifically robust monitoring system should combine physical, chemical and biological groups of indicators rather than rely exclusively on agrochemical fertility parameters [25; 26].

Physical indicators may include bulk density, aggregate stability, infiltration, erosion and compaction; chemical indicators include soil organic carbon, pH, nutrients, salinity and contamination; biological indicators reflect soil biota and biological activity. Soil organic carbon is particularly important because it is linked to fertility, structure, water retention, biological activity and climate regulation [16]. Nevertheless, the policy meaning of any single value depends on soil type, climate, land use and management history.

The transition to soil-health monitoring therefore requires reference conditions, thresholds and trajectories. Indicators become operationally useful only when values can be interpreted relative to acceptable ranges or desired trends. The European Environment Agency has proposed common indicators and risk-based thresholds for soil organic carbon, nutrients, acidification, pollution, biodiversity, erosion, compaction and sealing [25]. This approach is directly relevant to Ukraine's European integration and to the design of a nationally harmonised soil-health monitoring framework.

Field monitoring alone cannot provide the temporal frequency and spatial coverage required for adaptive management at national, regional and community levels. Earth Observation allows repeated analysis of land-cover change, vegetation condition, soil exposure, crop dynamics, moisture patterns, fire effects, flooding and other environmental processes [27]. Its principal value lies not in replacing field investigations but in identifying spatial patterns, detecting change and prioritising targeted inspection and sampling.

The Copernicus Land Monitoring Service provides harmonised information on land cover and land-use change, ground motion, vegetation state, water-cycle variables and other land-surface characteristics [27]. For Ukraine, systematic use of these products can support methodological compatibility with EU monitoring. Time-series analysis is particularly important because trajectories reveal persistent changes that may be invisible in static maps, including loss of shelterbelts, expansion of bare-soil periods, wetland degradation or declining vegetation productivity.

Hyperspectral data and UAV imagery can add higher thematic or spatial detail. Hyperspectral sensors may support estimation of selected soil and crop characteristics but require robust calibration and careful processing because of their high dimensionality [32]. UAVs can document erosion features, local restoration sites, drainage systems, damaged soil surfaces and shelterbelts at very high resolution. Their use should, however, follow common requirements for georeferencing, metadata and quality control.

GIS provides the analytical environment in which these datasets can be integrated. Degradation processes do not follow cadastral boundaries: erosion follows topography and land cover, flooding follows hydrological systems, and ecological connectivity is a landscape-scale property. Therefore, adaptive policy should operate through a multi-scale hierarchy that links cadastral parcels and agricultural fields with landscapes, river basins, communities, regions and the national territory.

Because public institutions cannot conduct equally intensive field monitoring everywhere, observation systems should be risk-based. For agricultural land, relevant variables may include slope, soil erodibility, tillage intensity, duration of bare-soil exposure, drought frequency, irrigation conditions, salinity, organic-carbon decline and proximity to vulnerable water bodies. For war-affected territories, explosive hazards, mechanical disturbance and possible chemical contamination must also be considered [19].

A generalised land-risk index may be expressed as $R_i = f(H_i, E_i, V_i, C_i)$, where H_i denotes hazard intensity, E_i exposure, V_i ecological vulnerability and C_i potential consequences for spatial unit i. The index is not intended to replace specialised sectoral methods; rather, it supports allocation of monitoring resources. High-risk areas require more frequent remote analysis, field inspection and sampling, whereas lower-risk territories may be monitored through baseline observation and change-triggered verification.

Predictive models are particularly valuable in erosion management. Research demonstrates that land-use and climate change can substantially alter soil erosion risk over time [30]. Consequently, modelling can identify areas where current land use may become environmentally unsustainable before severe degradation is visible. Machine-learning methods such as Random Forest and Support Vector Machines further expand possibilities

for classification and prediction, but their performance depends on training data, parameterisation and the specific analytical task [31].

Uncertainty must therefore be an explicit component of environmental governance. SoilGrids 2.0 demonstrates good practice by providing both predicted soil properties and spatially explicit uncertainty [28]. Public decision-support systems should distinguish measured conditions, modelled conditions and areas of insufficient information. Where uncertainty is high and management consequences are substantial, additional field evidence should be collected before restrictive or costly decisions are taken.

War-affected land requires an extended monitoring framework because a single parcel may simultaneously be exposed to explosive hazards, physical soil disturbance, contamination, infrastructure damage and disruption of ecosystem functions [19]. Consequently, the return of land to productive use should follow the sequence: hazard assessment – humanitarian demining – post-clearance environmental assessment – evaluation of soil condition and functional suitability – selection of a land-use or restoration scenario – subsequent monitoring.

Digital technologies can support each stage. Satellite and UAV data, together with official mine-action information and historical evidence of military activity, can assist in spatial prioritisation. Remote sensing cannot certify that an area is free of explosive hazards, but it can reveal craters, disturbed surfaces, infrastructure damage and persistent vegetation anomalies that indicate where detailed surveys are most urgently required.

After clearance, environmental assessment should determine whether physical safety is accompanied by ecological suitability. Research on Ukraine confirms that armed conflict may cause simultaneous physical, chemical and biological changes in soils [19]. A released parcel may therefore still require conservation, remediation, restoration or conversion to a different use. Digital systems should explicitly distinguish safety status, environmental status and functional-use status rather than treating them as equivalent.

A spatial decision-support system for war-affected land should integrate mine-action data, soil contamination, physical disturbance, pre-war land characteristics, agricultural value, ecosystem importance, infrastructure accessibility and socio-economic factors. The scale of national recovery needs documented by RDNA5 makes transparent prioritisation indispensable

[23]. Multi-criteria decision analysis can support this task by combining safety, ecological, agricultural and socio-economic criteria while making weights and assumptions explicit.

Restoration programmes are frequently evaluated through output indicators: hectares treated, trees planted, kilometres of shelterbelts established, funds spent or number of interventions completed. These indicators demonstrate implementation effort but do not necessarily show environmental effectiveness. Adaptive governance requires outcome indicators such as reduced erosion, increased vegetation persistence, improved infiltration, higher soil organic carbon, restored connectivity, reduced contamination or increased biological activity [25; 26].

Remote sensing can provide cost-effective long-term monitoring of vegetation recovery and land-cover stability, while field sampling is required to verify changes in soil properties [26; 27]. Public support can therefore be progressively linked not only to the implementation of measures but also to verified environmental results, provided that baselines and safeguards account for climatic variability and other factors beyond the land user's control.

This outcome-oriented logic is central to the proposed adaptive cycle: interventions are followed by monitoring; monitoring generates evidence; and evidence modifies the subsequent design of regulation, financing and restoration measures.

European integration requires compatibility not only of legislation but also of monitoring concepts, data models and assessment methods. Directive (EU) 2025/2360 provides a reference framework for soil-health monitoring and contaminated-site management [11]. Interoperability must therefore be developed at semantic, methodological, spatial, institutional, technological and policy levels. Common definitions, sampling procedures, coordinate systems, metadata standards and responsibilities for data validation are as important as technical database connections.

Copernicus products can support this process by providing common Earth Observation datasets, but national field observations and locally calibrated models remain indispensable [27]. The optimal architecture is a nested system in which European and global products provide harmonised reference information, national monitoring provides systematic country-wide coverage, regional and community systems provide higher-resolution

planning information, and site-specific surveys support individual restoration or regulatory decisions.

Data governance is equally important. Numerous institutions generate land and soil information, including cadastral authorities, environmental and agricultural bodies, regional administrations, territorial communities, research institutions, laboratories and mine-action operators. A national architecture should follow the principle collect once – use many times, while assigning each dataset clear metadata, quality status, responsible institution and access conditions. Open-data principles can strengthen research and accountability, although sensitive information concerning explosive hazards or critical infrastructure may require differentiated access.

The final stage of digital transformation is the development of Spatial Decision Support Systems (SDSS) that connect information with management alternatives. A database answers what information is available; a monitoring system shows how conditions are changing; an SDSS additionally asks what should be done, where, in what sequence and under which constraints. Its role is not to replace administrative judgement but to structure evidence and compare scenarios.

A land-resource SDSS should contain five interrelated modules: diagnosis; risk and forecasting; scenario analysis; spatial prioritisation; and monitoring with feedback.

The digital transformation of land-resource governance in Ukraine can be organised through five overlapping stages. Stage 1 is data inventory and harmonisation: existing soil, cadastral, environmental, agricultural, Earth Observation and war-impact datasets should be inventoried, georeferenced and assessed for quality, duplication and gaps. Common metadata and interoperability standards should be established.

Stage 2 is development of a national baseline of land and soil condition by combining existing field data, targeted new sampling, remote sensing and digital soil mapping. The baseline should distinguish measured from modelled information and explicitly represent uncertainty [28]. Stage 3 is risk-based spatial monitoring, in which permanent observation networks are complemented by targeted sampling in hotspots identified through remote sensing and predictive modelling.

Stage 4 is integration with spatial planning, economic instruments and restoration. Monitoring results must become administratively relevant:

soil-health and land-condition indicators should inform plans, conservation programmes, environmental restrictions, incentives and post-war recovery. Stage 5 is adaptive evaluation and policy correction, under which observed outcomes are compared with baselines and targets and policy instruments are revised where expected improvements do not occur.

The proposed framework has several policy implications. Modernisation of land monitoring should be treated as part of environmental policy rather than a narrowly technical task. Integration is more important than the simple accumulation of data, and soil-health indicators should progressively complement conventional land accounting. Earth Observation should become a permanent tool for early warning, change detection and targeting of field monitoring [25; 27]. Predictive analytics should be accompanied by transparent methods, validation and explicit uncertainty [28; 31].

Post-war recovery additionally requires the integration of safety and environmental information: humanitarian demining is necessary but not sufficient for sustainable return to production, and post-clearance ecological assessment should become part of the recovery pathway [19; 23]. European integration provides an opportunity to establish compatible monitoring standards from the outset, using Directive (EU) 2025/2360 as an important reference point [11].

The broader international context reinforces this need. The 2026 edition of FAO's Status of the World's Soil Resources concludes that, despite significant progress in knowledge and available management solutions, sustainable soil management is not yet being adopted at the scale and pace required globally [33]. The challenge is therefore not only to generate scientific knowledge but to create institutions capable of converting knowledge into routine, spatially targeted and adaptive management.

For Ukraine, the strategic objective should be the formation of a national adaptive land-information and decision-support system in which monitoring results directly influence spatial planning, economic incentives, regulatory measures and restoration programmes. Such a system would support a transition from reactive control of individual land-use violations towards proactive management of land natural capital, thereby strengthening ecological security, climate resilience, agricultural sustainability and the long-term effectiveness of post-war recovery.

CONCLUSIONS

Rational land use and land protection constitute a single functional subsystem of state environmental policy. The distinction between them is primarily instrumental: rational land use defines an environmentally acceptable model of economic behaviour, whereas land protection provides the legal, organisational, economic, technological, and information conditions required to maintain and restore land-based natural capital.

A contemporary understanding of rational land use should be based not only on economic efficiency and the preservation of fertility but also on maintaining the multifunctionality of soils and land ecosystems. Performance assessment should therefore include indicators of soil health, soil organic carbon, erosion resistance, biodiversity, water-regulation functions, and other ecosystem services.

Legislative and strategic changes adopted in 2024–2026 indicate Ukraine's gradual transition toward an integrated ecosystem-based model of land policy. Further development of this model requires closing the gap between strategic objectives, information provision, and practical economic implementation mechanisms. Measurable changes in land condition, rather than mere procedural compliance, should become the principal criterion of policy effectiveness.

European integration provides an additional regulatory and methodological reference point. Alignment with European approaches will require harmonisation of indicators, data-collection and processing methods, spatial monitoring units, procedures for assessing contaminated sites, and decision-making mechanisms.

For war-affected land, physical clearance of explosive ordnance must not be equated with complete recovery. Returning land to economic use should include post-demining environmental assessment, determination of functional suitability, and selection of an environmentally and economically justified subsequent land-use scenario.

A strategic direction for public policy should therefore be the establishment of an adaptive land-resource management system based on the sequence «prevent - reduce - restore - monitor – adjust». Such a model reconciles economic productivity with the conservation of natural capital and creates institutional prerequisites for Ukraine's environmentally safe, climate-resilient, and competitive development.

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