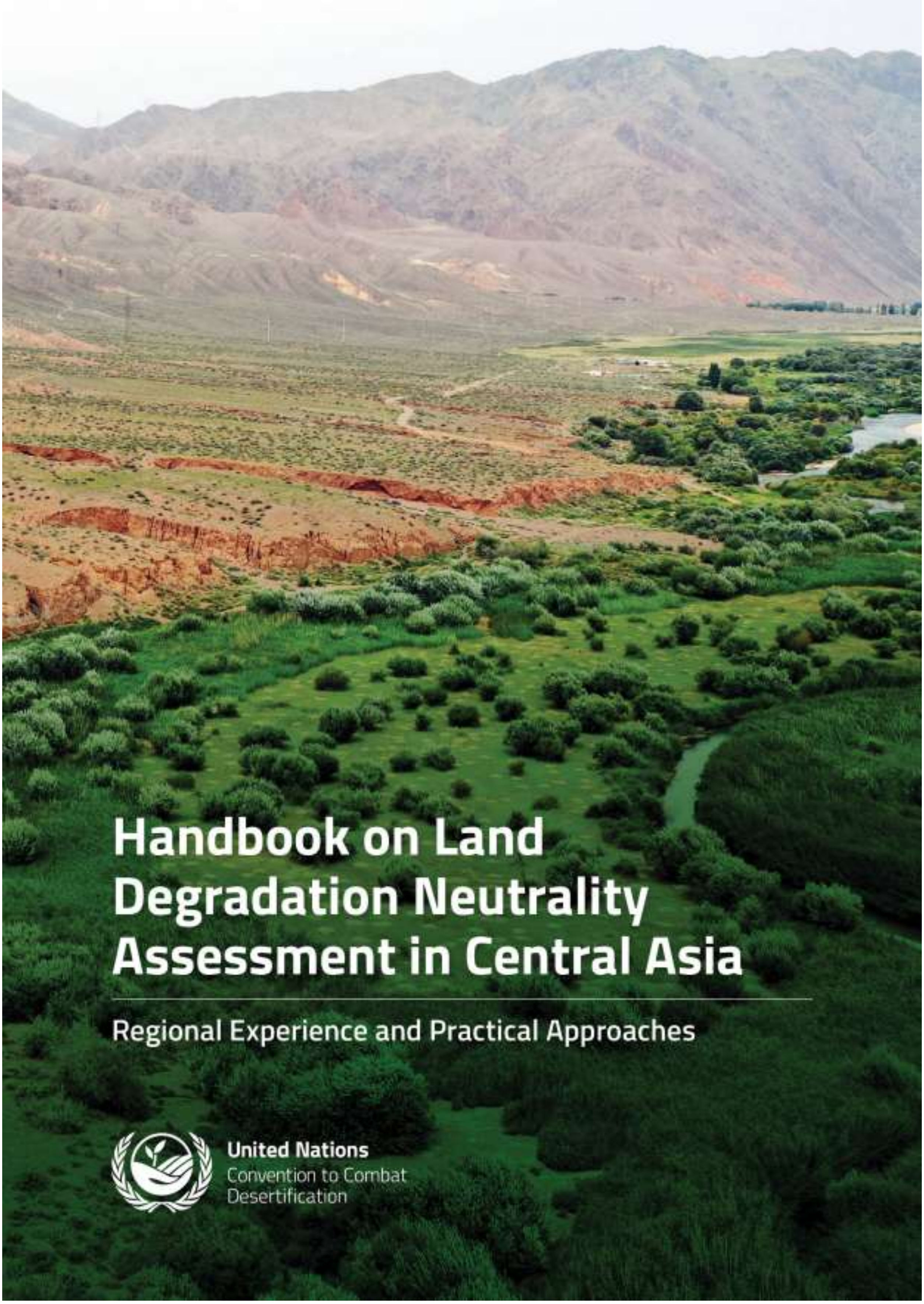

Handbook on Land Degradation Neutrality Assessment in Central Asia

Regional Experience and Practical Approaches

United Nations
Convention to Combat Desertification

HANDBOOK ON LAND DEGRADATION NEUTRALITY ASSESSMENT IN CENTRAL ASIA: REGIONAL EXPERIENCE AND PRACTICAL APPROACHES

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CONTENT

Acronyms

Acronym	Full form
1OAO	One Out, All Out
ADB	Asian Development Bank
ALOS	Advanced Land Observing Satellite
ANN	Artificial Neural Network
AVHRR	Advanced Very High Resolution Radiometer
BAU	Business-as-Usual
CACILM	Central Asian Countries Initiative for Land Management
CA	Central Asia
CA-ANN	Cellular Automata – Artificial Neural Network
CCI-LC	Climate Change Initiative Land Cover
COP	Conference of the Parties
CRIC	Committee for the Review of the Implementation of the Convention
DDI	Desertification Difference Index
DLDD	Desertification, Land Degradation and Drought
EC	Electrical Conductivity
EOSDA	EOS Data Analytics
ESA	European Space Agency
ESA CCI	European Space Agency Climate Change Initiative
EVI	Enhanced Vegetation Index
FAO	Food and Agriculture Organization of the United Nations
FAOSTAT	FAO Corporate Statistical Database
GBRT	Gradient Boosted Regression Trees
GDP	Gross Domestic Product
GEF	Global Environment Facility
GIMMS	Global Inventory Modeling and Mapping Studies
GIPROZem	State Institute for Land Survey Works
GIS	Geographic Information System
GISHAGI	State Institute of Agricultural Aerial Photographic Geodetic Surveys (Kazakhstan)
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GLASS	Global Land Surface Satellite
ICARDA	International Center for Agricultural Research in the Dry Areas
IG RAS	Institute of Geography of the Russian Academy of Sciences
IPCC	Intergovernmental Panel on Climate Change
IRG	Interregional Group
IWRM	Integrated Water Resources Management
KazNIIZhiK	Kazakh Research Institute of Livestock and Fodder Production
KIGAM	Korea Institute of Geoscience and Mineral Resources
KSTU	Kyrgyz State Technical University
LAI	Leaf Area Index

Acronym	Full form
LCCS	Land Cover Classification System
LDN	Land Degradation Neutrality
LDN TSP	Land Degradation Neutrality Target Setting Programme
MLR	Multiple Linear Regression
MODIS	Moderate Resolution Imaging Spectroradiometer
MOLUSCE	Modules for Land Use Change Evaluation
NDSI	Normalised Difference Salinity Index
NDVI	Normalised Difference Vegetation Index
NDWI	Normalised Difference Water Index
ODK	Open Data Kit
PRAGA	Participatory Rangeland and Grassland Assessment
PRAIS	Performance Review and Assessment of Implementation System
QGIS	Quantum GIS
RMSE	Root Mean Square Error
RUB	Russian Rouble
RUSLE	Revised Universal Soil Loss Equation
SAGA GIS	System for Automated Geoscientific Analyses Geographic Information System
SAR	Synthetic Aperture Radar
SAVI	Soil-Adjusted Vegetation Index
SDG	Sustainable Development Goal
SI	Salinity Index
SLM	Sustainable Land Management
SMART	Specific, Measurable, Achievable, Relevant and Time-bound
SRTM	Shuttle Radar Topography Mission
STI	Science, Technology and Innovation
TVI	Transformed Vegetation Index
UAV	Uncrewed Aerial Vehicle
UNCCD	United Nations Convention to Combat Desertification
UNDP	United Nations Development Programme
UNDP/GEF	United Nations Development Programme / Global Environment Facility
USD	United States Dollar
USFS	United States Forest Service
USSR	Union of Soviet Socialist Republics
XGBoost	Extreme Gradient Boosting

Introduction

This Handbook has been prepared in the context of the implementation of activities under the road map of the Interregional Group "Central Asia–Russia" (IRG), established at the initiative of the delegations of the countries of the region in 2019 at the fourteenth session of the Conference of the Parties to the United Nations Convention to Combat Desertification (UNCCD), held in New Delhi, India. The IRG comprises the Republic of Kazakhstan, the Kyrgyz Republic, the Republic of Tajikistan, Turkmenistan, the Republic of Uzbekistan and the Russian Federation — countries linked not only by a shared historical legacy and geographical proximity, but also by comparable challenges in the areas of desertification, land degradation and drought (DLDD), land management and adaptation to climate change.

The document has been prepared in response to a request from the IRG participating countries, formulated during the meeting of the Group's Bureau in May 2024 [103], at which the report of the working group on land degradation neutrality (LDN) was presented.

The document is conceived as a regional reference source and an operational instrument that synthesises the experience available in the region in the assessment, interpretation and practical application of approaches to land degradation neutrality. It neither replaces the methodological approaches set out in the Good Practice Guidance for SDG indicator 15.3.1, nor substitutes the procedures for official national reporting submitted by countries through the PRAIS portal. The additional indicators, regional interpretations and analytical approaches proposed in the Handbook are intended to support the verification of results, the clarification of the drivers of degradation and evidence-informed decision-making at the national, subnational and local levels. Taking into account the scientific and methodological expertise accumulated in the region in the field of land degradation assessment, the Bureau recommended the development of a project proposal for the preparation of a "Handbook on LDN Assessment in Central Asia", adapted to the fullest possible extent to the specific natural, socio-economic and institutional conditions of the countries of Central Asia.

Alignment with the global agenda and the regional request

The preparation of this document is not an isolated initiative; rather, it is consistent with UNCCD efforts to strengthen knowledge exchange, technology transfer, the dissemination of practical instruments and support for innovative approaches to sustainable land management. In this respect, the Handbook is aligned with decision 18/COP.16, "Knowledge sharing, technology transfer and innovation" [68], which emphasises the need to strengthen knowledge-sharing mechanisms and to promote practical solutions for addressing desertification, land degradation and drought, including the achievement of land degradation neutrality (LDN). In that decision, Parties are encouraged to facilitate the dissemination of practical tools and methodological solutions that support sustainable land management and the implementation of national LDN targets.

The present Handbook has been developed as an applied, end-user-oriented instrument designed to support countries in further refining methodological approaches to the assessment, monitoring and achievement of LDN, with due regard to regional specificities. The Handbook does not introduce a new official methodology for reporting on SDG indicator 15.3.1. Instead, it proposes regionally adapted approaches to the interpretation, verification and practical use of LDN assessment results. It proceeds from the premise that global approaches, however universal in design, require careful calibration to the specific circumstances of the arid and semi-arid territories of Central Asia, with their distinctive land-use patterns, irrigated agricultural systems and extensive pastoral livestock production. The operational orientation and accessibility of the document are ensured through a structured presentation of the methodology in the form of step-by-step algorithms, decision-making schemes, matrices for interpreting indicators and checklists for national experts. The Handbook includes standard calculation approaches, examples of adapting global datasets to the national level and recommendations on the minimum set of input data required for a reproducible assessment. This format affords the possibility of using the Handbook as a working instrument for specialists of relevant national institutions, while maintaining coherence with the global methodological frameworks of the Convention.

Methodological basis and consideration of regional experience

In preparing the Handbook, the authors drew upon the fundamental approaches recommended by the UNCCD, thereby ensuring its consistency with global reporting standards and its scientific robustness. The key documents that provided the basis for the study were: *Good Practice Guidance. SDG Indicator 15.3.1. Proportion of land that is degraded over total land area, 2021* [66]; *Addendum to the good practice guidance. SDG indicator 15.3.1 Proportion of land that is degraded over total land area. Version 2.0* [70]; *The Scientific Conceptual Framework for Land Degradation Neutrality (LDN), 2017* [47]; *Land Degradation Neutrality Target Setting – A Technical Guide, 2016* [64]; *Achieving Land Degradation Neutrality at the country level. Building blocks for LDN target setting* [65]; *Trends.Earth. A new tool to assess the health of the land that supports us* [52]. These documents established the methodological framework, while the experience accumulated by the countries of the region provided the substantive basis for contextualising that framework and demonstrating its regional specificity. The present Handbook draws a clear distinction between the official methodological basis for calculating SDG indicator 15.3.1 and the supplementary analytical approaches proposed for the conditions of Central Asia. The official calculation of SDG indicator 15.3.1 is based on three global sub-indicators: trends in land cover, trends in land productivity and trends in soil organic carbon stocks. The supplementary and alternative indicators considered in this document are used to clarify the causes of degradation, verify results, assess risks and support management decisions. Where such indicators are applied to refine land status in the context of official reporting, it is important to ensure a transparent description of the methodology, proper documentation of the approaches used and consistency with national assessment procedures.

Particular value for the present work was derived from the analysis of the results of recent projects and initiatives implemented in Central Asia and adjacent territories. These include:

- The results of initiatives on the setting of voluntary LDN targets (LDN TSP 1.0 and LDN TSP 2.0) in the countries of the region [37–41];
- Projects of the United Nations Development Programme (UNDP), the World Bank, Food and Agriculture Organization (FAO) and other international partners;
- Experience in applying the LDN methodology within projects related to the assessment of pasture degradation, salinisation of irrigated lands and productivity trends in agroecosystems, including materials prepared with the support of government-funded projects in the countries of the region and other development institutions [14, 15, 16, 28–33, etc.];

- National reports submitted by the countries of the region to the UNCCD through the PRAIS portal;
- National and cross-country initiatives, including strategies, programmes and road maps [83, 98, 99, 104–106, 109–111, etc.].

Consideration of the results of these projects has enabled not only a description of the proposed approaches, but also a demonstration of their applicability through real-world examples.

Inclusive development process and authorship

It is important to emphasise that the Handbook was developed in close dialogue with all relevant stakeholders. Throughout the preparation period, interim findings of the study were regularly discussed with national experts and representatives of the IRG participating countries. Key milestones in this process included the presentation of preliminary findings and the collection of expert comments during events held on the margins of the twenty-third session of the Committee for the Review of the Implementation of the Convention (CRIC) of the UNCCD in Panama (December 2025), as well as discussions at meetings of the Bureau of the Interregional Group "Central Asia–Russia", including in-person meetings held in Almaty (October 2025) and Moscow (April 2026).

In addition to official meetings, and with the support of the UNCCD secretariat, a series of consultations and in-depth interviews was organised with key experts and representatives of the scientific community, line ministries and specialised agencies from all countries of the Central Asian region. The comments received were systematised and taken into account in the revision of the text, thereby strengthening the substantive completeness of the document and its alignment with the priorities and practical needs of the countries concerned. The author team of the Handbook was established on a broad and representative basis. Experts from all six IRG participating countries contributed to the preparation of the document, including members of the IRG Bureau, national focal points and leading specialists in land resources assessment, remote sensing and sustainable land use. This collaborative modality ensured the integration and synthesis of national experience, thereby enhancing the validity, balance and practical relevance of the proposed methodological solutions. Coordination of the work, as well as scientific and methodological guidance, were provided by the UNCCD secretariat. Project management, including the organisation of the consultation process and scientific editing, was ensured by the Programme Officer for Scientific Affairs of the Science, Technology and Innovation (STI) Unit, under the overall supervision of the Unit Chief. Expert support on specialised thematic areas was provided by an international technical consultant and a dedicated expert group composed of IRG representatives. This cooperation structure ensured the collective character of the development process, the alignment of the Handbook with UNCCD methodological standards and its integration into the global science-policy context on land degradation neutrality.

Objectives and structure of the Handbook

The objective of the present Handbook is to demonstrate how the global methodology for calculating SDG indicator 15.3.1 may be applied and interpreted with due regard to the natural, socio-economic and institutional conditions of the countries of Central Asia. Particular attention is devoted to data verification, the clarification of the drivers of degradation and support for decision-making, while maintaining coherence with the UNCCD methodological framework. To this end, the document includes:

1. An analysis of the results of setting and updating voluntary LDN targets in the countries of Central Asia, together with a synthesis of good practices and lessons learned.
2. The development of core principles for the selection and calculation of alternative and supplementary national indicators.
3. An assessment of the prospects for the practical application of the LDN concept to identify good practices in sustainable land use with a view to advancing land restoration projects.
4. An analysis of approaches to establishing LDN targets at the national, subnational and local levels.
5. A synthesis of recommendations for the further development of the LDN target-setting process (LDN TSP 2.0) in the countries of the region.

The structure of the present Handbook provides a logical progression from the understanding of global principles to their practical application, taking into account regional specificity.

The first part presents the overall scheme for LDN assessment, based on an analysis of the core UNCCD recommendations and the Trends.Earth toolkit. It sets out the fundamental approaches to defining the three principal indicators that constitute the basis for calculating SDG indicator 15.3.1 — land cover change, land productivity and soil organic carbon stocks — as well as the principles for establishing the baseline. This section serves as an introduction to the methodology, enabling specialists who are not familiar with it in detail to obtain a comprehensive understanding of the subject matter.

The second part is devoted to the analysis of knowledge gaps and unresolved methodological issues that arise when global approaches are applied directly in the context of Central Asia. These include, in particular, questions related to adequately reflecting the dynamics of pasture ecosystems, accounting for the salinisation of irrigated soils, selecting representative time periods for defining the baseline under conditions of high interannual climate variability, and addressing problems associated with the historical context of land use.

The third part proposes concrete ways of addressing the issues identified. Each methodological solution is illustrated by examples, or case studies, from the countries of the region. This approach does not merely present a particular method; it also demonstrates its applicability using real data from Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, Uzbekistan and the Russian Federation. In this way, the Handbook is transformed from a simple compendium of recommendations into a scientifically grounded science-policy instrument, drawing on extensive regional experience and designed to support management decision-making.

The concluding part presents a synthesis of global methodological approaches and regional experience, which may serve as a basis for the additional interpretation of LDN assessment results and for supporting decision-making in the context of Central Asia. It also formulates recommendations on areas requiring further development, refinement and testing. In this respect, the concluding part offers a practical road map for subsequent work, including the development of regionally adapted approaches to interpreting LDN assessment results and the introduction of sustainable land management practices in Central Asia.

Development and openness to cooperation

The Handbook presented here is regarded as a document to be improved progressively as the LDN methodology evolves, new scientific evidence becomes available and global datasets and monitoring instruments are updated. Given the dynamic nature of the UNCCD scientific and methodological knowledge base, the provisions of the present Handbook may be refined and supplemented in subsequent editions.

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Updated editions and accompanying materials will be made available through the official resources of the UNCCD and the Interregional Group "Central Asia–Russia". Information on amendments introduced will be reflected in subsequent versions of the document, indicating the date of the update and providing a brief description of the revisions.

This approach is intended to ensure the transparency, reproducibility and continued relevance of the methodological recommendations, as well as to support sustained dialogue with the scientific and expert community of the countries of the region.

Acknowledgements

The author team expresses its sincere appreciation to the representatives of the IRG Bureau, UNCCD national focal points and experts from Kazakhstan, Kyrgyzstan, the Russian Federation, Tajikistan, Turkmenistan and Uzbekistan for the materials provided, constructive discussions and valuable comments. Special thanks are extended to the staff of the UNCCD secretariat and the Global Mechanism for their methodological support and assistance in organising consultations.

In preparing the Handbook, in addition to data available in the public domain, materials from the following projects were used in agreement with the rights holders:

- UNDP-Turkmenistan, 2025. UNDP/GEF project "Conservation and Sustainable Management of Land Resources and High Nature Value Ecosystems in the Aral Sea Basin for Multiple Benefits" (Aral Project);
- UNDP-Uzbekistan, 2025. UNDP/GEF project "Conservation and Sustainable Management of Lakes, Wetlands, and Riparian Corridors as Pillars of a Resilient and Land Degradation Neutral Aral Basin Landscape Supporting Sustainable Livelihoods" (Aral Wetlands);
- IG RAS, 2025. State assignment of the Institute of Geography of the Russian Academy of Sciences "Scientific and Methodological Support for the Implementation of the Land Degradation Neutral Balance Concept for Land Assessment at the Subnational Level";
- Sber, 2025. Sber Bank project "Application of Artificial Intelligence Models for Monitoring and Assessing Soil Degradation and Desertification Processes, including on the Basis of Earth Remote Sensing Data".

We hope that this Handbook will provide a sound basis for the further deepening of scientific and technical cooperation in the region and will contribute to the development and implementation of effective projects to combat land degradation and achieve land degradation neutrality in Central Asia and neighbouring countries.

UNCCD Interregional Working Group "Central Asia–Russia"
Astana – Bishkek – Dushanbe – Ashgabat – Tashkent – Moscow
August 2026

FOREWORD Johns Muleso Kharika

Foreword

Land degradation neutrality provides Parties with a common framework for safeguarding the land resources that underpin food security, livelihoods, ecosystem functions and resilience to drought and climate change. Translating this global ambition into effective action, however, requires more than a uniform set of indicators. It requires sound science, reliable national data and a clear understanding of how land systems function under specific environmental, social and economic conditions.

Central Asia offers a particularly important context for advancing this work. The region's arid and semi-arid ecosystems, high climatic variability, extensive rangelands, irrigated agricultural systems and shared natural resources create both significant challenges and valuable opportunities for the implementation of land degradation neutrality. These conditions underline the importance of complementing globally consistent assessment approaches with robust regional and national research capable of explaining the drivers, trajectories and consequences of land degradation.

The Handbook on Land Degradation Neutrality Assessment in Central Asia: Regional Experience and Practical Approaches makes a timely contribution to this objective. It builds on the scientific conceptual framework for land degradation neutrality and the agreed methodological basis for SDG indicator 15.3.1, while examining how assessment results can be verified, interpreted and applied more effectively in the specific conditions of Central Asia. The Handbook does not seek to replace the established methodology for official reporting. Rather, it demonstrates how regional evidence, national datasets, field observations and supplementary analytical methods can strengthen the accuracy, policy relevance and practical utility of LDN assessments.

A particular strength of the publication lies in its grounding in regional scientific knowledge and practical experience. The cases and methodological approaches presented from Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, Uzbekistan and the Russian Federation illustrate the value of regional research in addressing issues that may not be fully captured by global datasets alone. These include the salinization of irrigated land, changes in the condition and composition of rangeland vegetation, the influence of high interannual climatic variability, historical land-use legacies and the identification of persistent degradation hotspots.

Regional studies of this kind are essential to a strong science–policy interface. They make it possible to move beyond the identification of degraded areas towards a more detailed understanding of why degradation is occurring, how rapidly it is progressing and which responses are most appropriate. By linking remote sensing, field-based evidence, local knowledge, time-series analysis and institutional experience, the Handbook provides a practical basis for more targeted planning, investment and sustainable land management.

The publication also demonstrates the importance of regional cooperation. Land degradation, drought, sand and dust storms, water flows and rangeland systems frequently extend across national boundaries. Shared methodological development, comparable assessments, coordinated capacity-building and the exchange of scientific expertise can therefore generate benefits well beyond individual projects or countries. The UNCCD Interregional Group "Central Asia–Russia" provides an important platform for sustaining this cooperation and for ensuring that regional knowledge contributes to the wider implementation of the Convention.

Developed through a broad, inclusive and participatory process, the Handbook brings together the knowledge and experience of national experts, scientific institutions, government representatives, UNCCD national focal points and regional and international partners. This extensive engagement has strengthened its scientific credibility, regional relevance and practical applicability. Its value will ultimately be determined by its effective use in strengthening national monitoring systems, informing land-use planning, supporting the implementation of voluntary LDN targets and guiding investments in avoiding, reducing and reversing land degradation.

Continued investment in regional research, scientific cooperation and national expertise will remain indispensable for ensuring that globally agreed commitments are translated into effective, locally grounded and lasting action for land and people.

Johns Muleso Kharika

Chief

Science, Technology and Innovation Unit

United Nations Convention to Combat Desertification

Part I. FUNDAMENTAL PRINCIPLES FOR ASSESSING LAND DEGRADATION NEUTRALITY (LDN)

Introduction

This Part sets out the initial methodological basis for the complex yet critically important issue of the quantitative assessment of land degradation. Over the past decade, under the auspices of the UNCCD, the international community has undertaken extensive work to establish a coherent, scientifically robust and practice-oriented system. It is this system that provides the means to translate the concept of Land Degradation Neutrality from the realm of theory into concrete measurement and decision-making.

At the core of this Part lies the analysis and synthesis of several key documents that have shaped the contemporary approach to the assessment of LDN:

1. **The Scientific Conceptual Framework for Land Degradation Neutrality (LDN) [47]** — the foundational scientific basis defining the principles, mechanisms and conceptual apparatus of LDN.
2. **Land Degradation Neutrality Target Setting – A Technical Guide [64]** — a practical guide to initiating the process of setting national LDN targets.
3. **Achieving Land Degradation Neutrality at the country level. Building blocks for LDN target setting [65]** — a document detailing the four principal building blocks of the process: stakeholder engagement, assessment, target-setting and the achievement of LDN.
4. **Good Practice Guidance. SDG Indicator 15.3.1 [66]** — the principal technical document containing detailed instructions for calculating SDG indicator 15.3.1 and its three sub-indicators, including the mathematical framework and data-processing procedures.
5. **Addendum to the good practice guidance. SDG indicator 15.3.1 Proportion of land that is degraded over total land area. Version 2.0 [70].**
6. **Trends.Earth [52]** — a tool developed to operationalize the above-mentioned guidance documents, enabling any country to assess trends in land condition by using global datasets and advanced algorithms.

The purpose of this part is to provide an integrated and structured understanding of precisely how land degradation is measured. It does not merely enumerate the principal indicators; rather, it traces the rationale for their selection, examines the principles for establishing the baseline, considers the response hierarchy ("avoid – reduce – reverse") and, most importantly, presents all of this in the form of a working sequence of stages for the basic methodology derived from UNCCD publications. This constitutes the indispensable foundation for understanding the regional specificity and the challenges that will be examined in detail in Part II of the Handbook.

Figure 1. Conceptual scheme of the LDN response system in the countries of Central Asia

Chapter 1. Conceptual framework: from definition to diagnostics

1.1. What is Land Degradation Neutrality?

Land Degradation Neutrality is defined by the UNCCD as "a state whereby the amount and quality of land resources necessary to support ecosystem functions and services to enhance food security remain stable, or increase, within specified temporal and spatial scales and ecosystems" [62, 63]. Early approaches to the practical implementation of the principle of zero net land degradation are considered in [6].

The LDN concept, adopted by the Parties to the UNCCD, establishes a strategic reference point aimed at conserving and restoring land resources. A central element of this concept is the principle of "neutrality". This does not imply the complete cessation of degradation processes, which is frequently impossible under conditions of economic activity, but rather the attainment of a balanced state. Such a balance implies that any new losses of healthy and ecologically functional land (degradation) are offset by equivalent measures for restoration or improvement (gains), within comparable land types and comparable time frames.

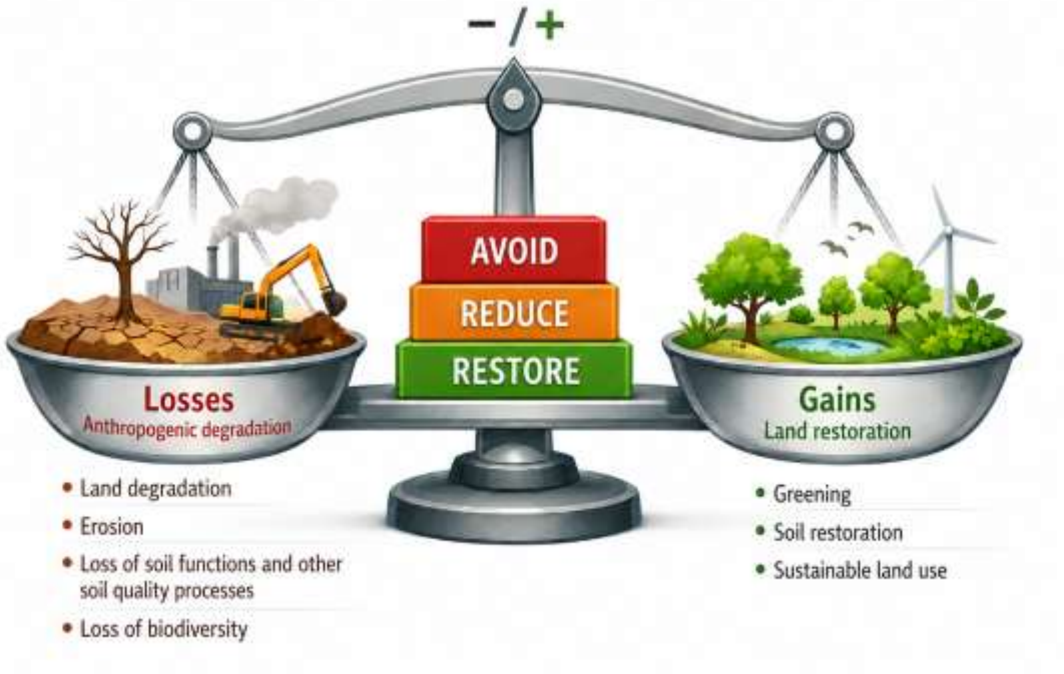


Figure 2. Conceptual scheme of LDN: "Balance of losses and gains"

The Scientific Conceptual Framework for LDN, set out in [7], is based on five modules: Vision, Frame of Reference, Mechanism for Neutrality, Achieving Neutrality and Monitoring. This structure emphasises that LDN is not a one-off assessment, but a cyclical process of planning, action and monitoring.

1.2. Response hierarchy: avoid, reduce, reverse

The basic concept of Land Degradation Neutrality was described in detail in [2]. The key principle embedded in the conceptual framework is the Response Hierarchy. It establishes the priority order for actions when planning interventions:

- **Avoid:** Preventing degradation is the most effective and economically efficient pathway. It entails the protection of healthy and productive land through sustainable management (for example, grazing regulation and protective afforestation).
- **Reduce:** Where degradation is already occurring or is unavoidable, efforts should be made to reduce its rate and extent (for example, by introducing water-saving technologies on irrigated land to prevent salinization).
- **Reverse:** Measures to restore already degraded land. This is the most resource-intensive and long-term pathway and is applied where the avoidance and reduction of degradation are no longer sufficient.

Figure 3. LDN response hierarchy

Chapter 2. Measurement system: SDG indicator 15.3.1 and its components

For monitoring progress towards achieving LDN, the United Nations Statistical Commission approved SDG indicator 15.3.1: **"Proportion of land that is degraded over total land area"** [54]. According to the Good Practice Guidance, this indicator is integrated and is calculated on the basis of three sub-indicators, each of which reflects different aspects of land condition and related ecosystem functions. Additional indicators, including salinity indices, erosion models, agrochemical monitoring data, grazing-pressure indicators and other national datasets, may be used to interpret, verify and refine assessment results. Where such indicators are used to determine or refine the status of a land unit in the context of official reporting, methodological transparency, documentation of the approaches applied and consistency with national assessment procedures should be ensured.

2.1. Three global sub-indicators: methods and metrics

1. Land-cover dynamics

This sub-indicator addresses the question: *"Has the type of land cover changed?"* The assessment is undertaken by comparing two or more maps for different years.

- **Methodology.** For the purposes of the UNCCD global assessment, global classifications (for example, ESA CCI [11]) are aggregated into seven basic classes: tree-covered areas, grasslands, croplands, wetlands, artificial surfaces, bare land and water bodies.
- **Transition matrix.** Not every change in class constitutes degradation. A specific matrix is used for interpretation, in which each possible transition (for example, from "forest" to

"cropland") is assessed as "degradation", "improvement" or "stability". The matrix may be global or nationally adapted, provided that the methodological decisions are documented.

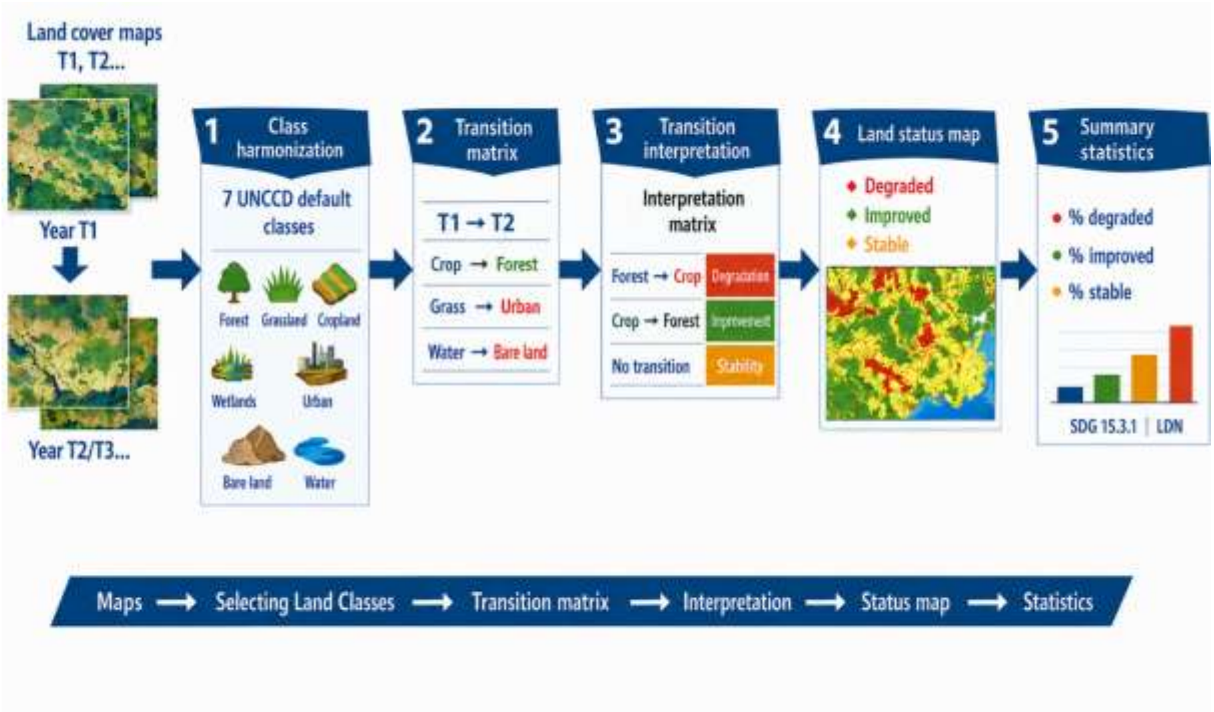


Figure 4. Algorithm for assessing land-cover change

Case 1. Land-cover change dynamics in Kazakhstan from 2001 to 2020 [34].

Context: To assess transitions from one land class to another at the national level, it is necessary to visualise these changes and establish precisely where they occur.

Application of the method: Based on data generated automatically using the Trends.Earth module, cartographic materials are produced that make it possible to compare land-cover conditions in different years.

Result: Cartographic processing provides information on reciprocal changes among land classes, including areas of transition, directions of change, their spatial distribution, as well as potential zones of degradation and improvement.

a) b)

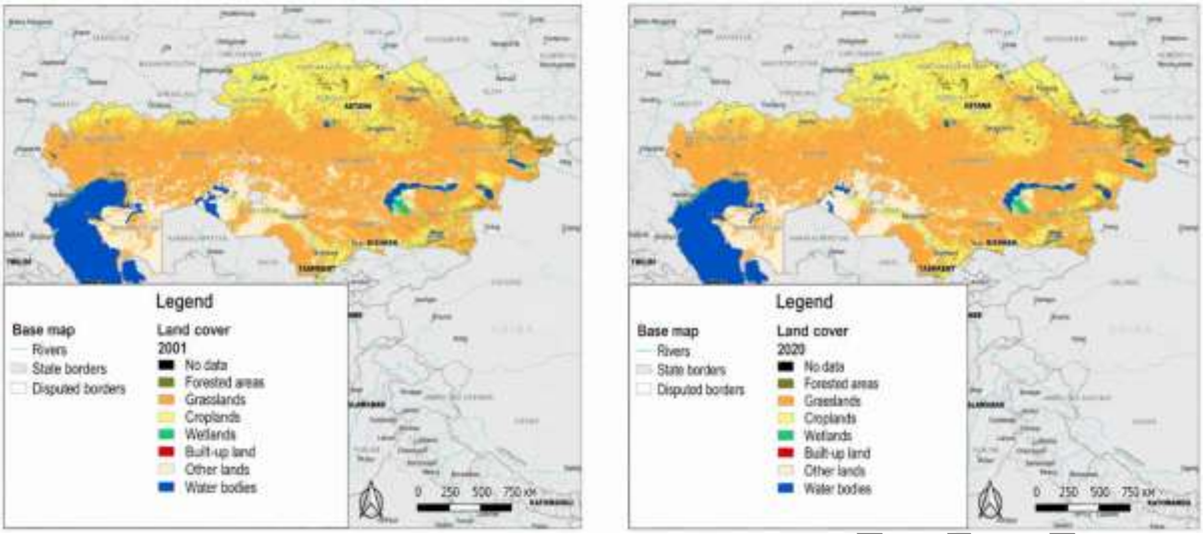


Figure 5. Map schemes of land-cover composition in Kazakhstan in 2001 (a) and 2020 (b)

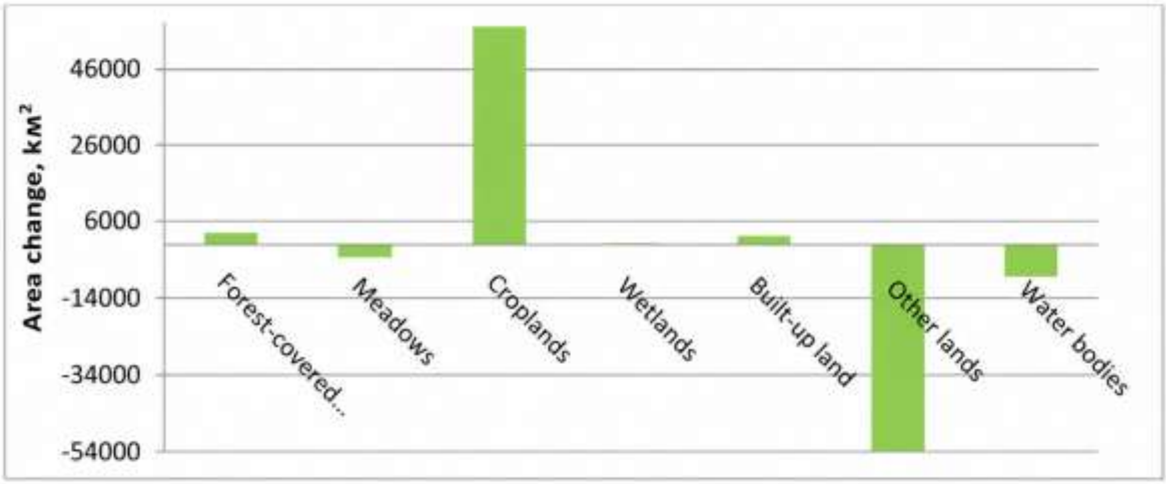


Figure 6. Changes in the areas of land-cover types in Kazakhstan over the period 2001–2020

2. Land productivity dynamics

This sub-indicator is frequently regarded as one of the most sensitive **indicators of land degradation.** It addresses the question: *"Has vegetation productivity on a given land unit improved compared with the previous period?"* The assessment is based on multi-year time series of vegetation indices (NDVI, derived from MODIS/AVHRR satellites) and comprises three mandatory metrics:

- **Trajectory (Trend):** A statistically significant productivity trend over the entire observation period. It is calculated using the non-parametric Mann–Kendall test. A sustained decline in NDVI is interpreted as degradation.
- **State:** A comparison of the average productivity of recent years (usually three years) with the historical average for the baseline period. A significant decline indicates recent degradation.

- **Performance:** A comparison of the productivity of a specific land unit with that of other land units having similar soil-vegetation potential. If the productivity of the land unit is less than 50% of the maximum for that land type, it is considered degraded.

Case 2. Land productivity dynamics in Bukhara Region of Uzbekistan (based on materials from the UNDP-Uzbekistan project, 2025 [121]).

Methodology: Multi-year time series of vegetation indices, primarily NDVI calculated from remote-sensing data, are used to assess land productivity dynamics. The analysis includes the assessment of long-term productivity trends, comparison of the current state with the historical level, and comparison of the productivity of a land unit with areas having similar biophysical potential. This approach enables the identification of zones of sustained decline, stability or improvement in land productivity.

Context: In order to formulate investment tasks for different land types at the sub-national level, it was necessary to determine whether land productivity was increasing or decreasing over the long term, and precisely where.

Application of the method: Based on data generated automatically using the Trends.Earth module, cartographic analysis is carried out and extensive matrix tables are produced for subsequent calculations.

Result: Processing of the primary results may provide, in graphical form, such information as: overall data on productivity status; aggregation of information on improvement, degradation and stable productivity conditions; distribution of the main changes by land category; and overall conclusions.

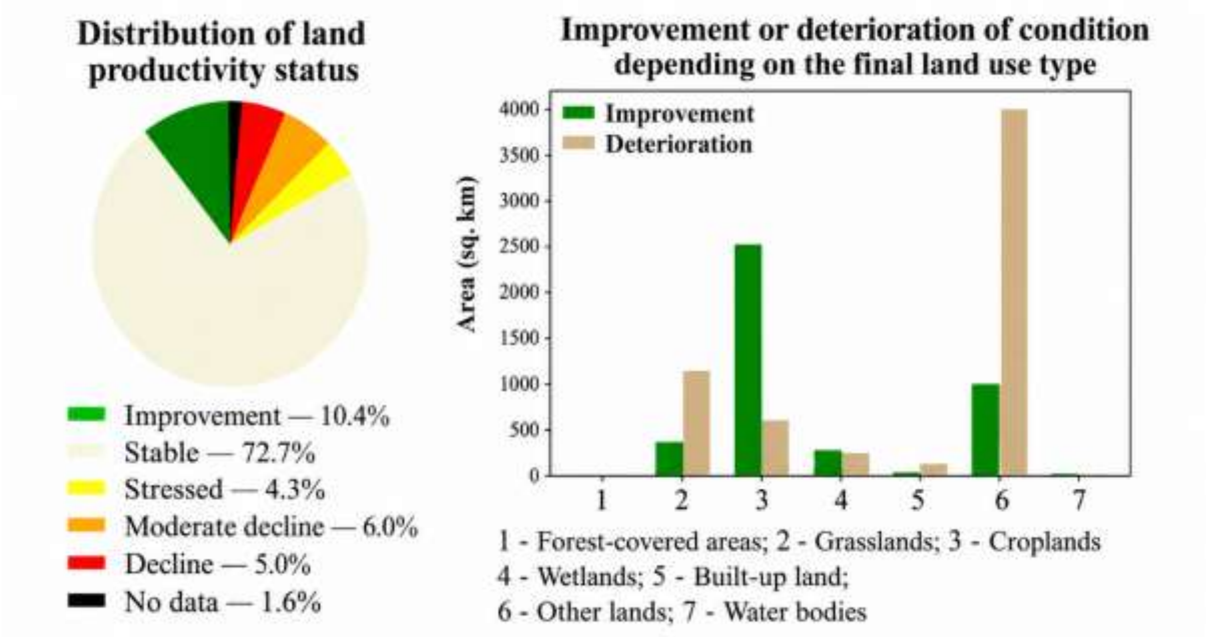


Figure 7. Land productivity dynamics in Bukhara Region over the period 2001–2020

3. Dynamics of soil organic carbon stocks

Soil organic carbon stocks constitute an important integrated indicator of soil condition, health and fertility. Given the complexity of their direct assessment at the global level, the assessment of soil organic carbon-stock dynamics uses data on changes in land use, reference carbon-stock values and carbon stock-change factors aligned with IPCC approaches [22]. This approach makes it possible to assess not direct emissions and removals as such, but changes in soil organic carbon stocks associated with changes in land cover, land use and land management.

Case 3. Dynamics of soil organic carbon stocks in the Aral Sea region (based on materials from the UNDP-Uzbekistan project, 2025 [121]).

Context: The calculation of changes in soil organic carbon stocks is an important component of reporting, integrated into the Trends.Earth analytical system.

Application of the method: Based on data generated automatically by Trends.Earth, a map is prepared and cartographic analysis is carried out.

Result: The data, determined to a considerable extent by the available global information on average soil carbon content in specific ecosystems, are not always corroborated by ground-based measurements.

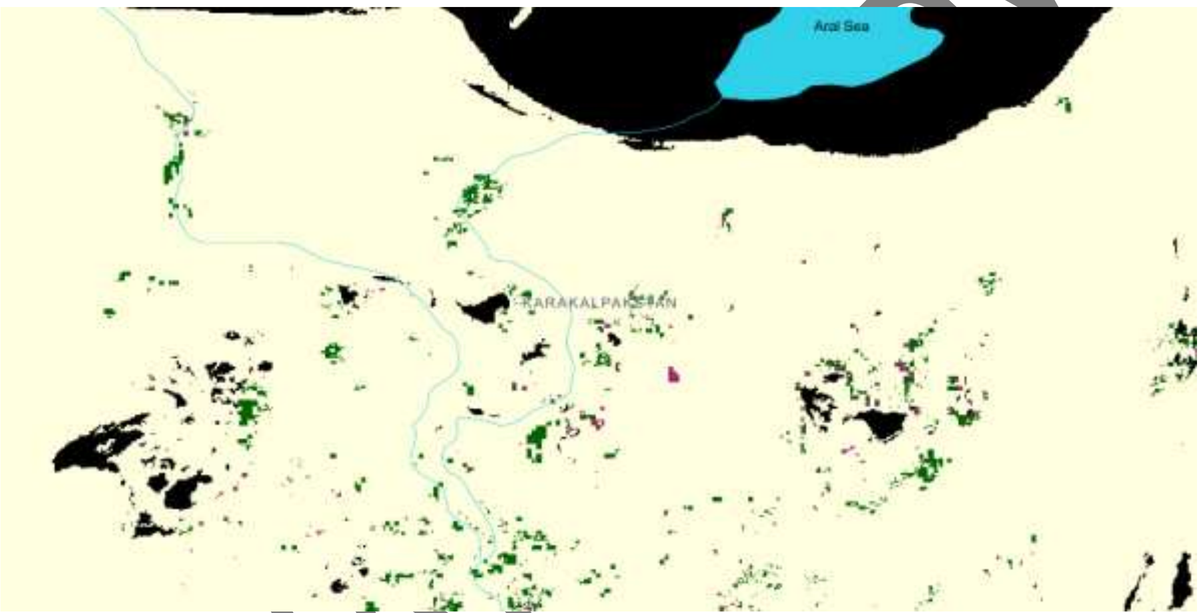


Figure 8. Dynamics of soil organic carbon stocks in selected areas of the Aral Sea region in 2001–2020 (green indicates improvement; red indicates degradation)

Table 1 — Comparative characteristics of SDG indicator 15.3.1 sub-indicators (according to Trends.Earth defaults)

Sub-indicator	**What does it measure?**	**Key metrics**	**Spatial resolution (default)**
Land-cover dynamics	Change in land-cover class	Transition matrix between seven classes	300 m (ESA CCI)
Land productivity dynamics	Change in biological productivity	Trajectory, State, Performance (based on NDVI)	250 m–1 km (MODIS, AVHRR)
Soil organic carbon dynamics	Change in soil carbon stocks (0–30 cm)	Calculation based on IPCC coefficients and land-use data	250 m (global soil maps, depending on the dataset used)

2.2. Integration: the “One Out, All Out” principle

The three sub-indicators are integrated into a single SDG indicator 15.3.1 using the conservative “One Out, All Out” (1OAO) principle (the “one negative result is sufficient” rule, or the full-coverage rule), as detailed in the Good Practice Guidance:

- **Degradation:** A land unit is considered degraded if **at least one** of the three sub-indicators shows a significant negative change (degradation).
- **Improvement:** A land unit is considered improved if **at least one** indicator shows improvement and **none** indicates degradation.
- **Stability:** If none of the indicators shows significant changes.

The 1OAO principle forms the basis of official reporting, while additional indicators may be used by countries to interpret, verify and refine results, provided that the methodology and data sources are described transparently. This approach ensures the high sensitivity of the method, reducing the risk of overlooking a problem even when it manifests itself in only one aspect.

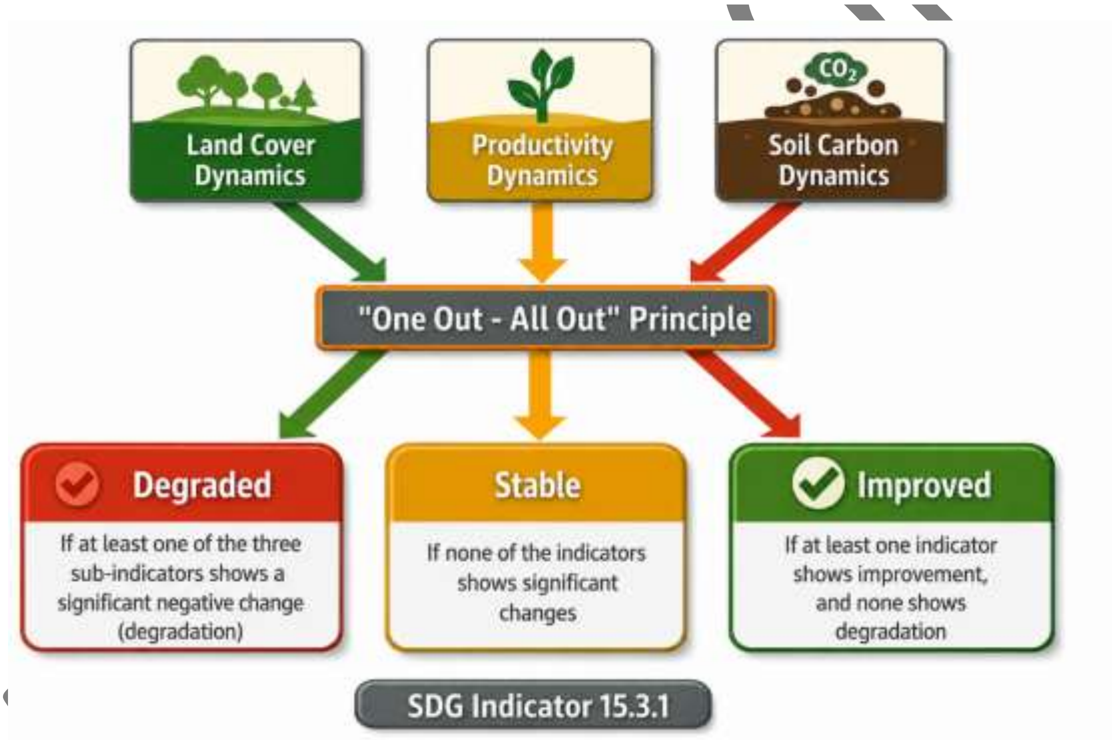


Figure 9. The “One Out, All Out” principle, 1OAO

Chapter 3. The target-setting process: four “building blocks”

The document “Transforming our world: the 2030 Agenda for Sustainable Development” [53] established the global goals that frame the international sustainable development agenda. The incorporation of LDN principles into national plans and instruments may be considered as a process comprising four sequential stages, or “building blocks” [65].

Block 1: Leveraging LDN. This stage initiates the process: the establishment of national coordination mechanisms, the engagement of all stakeholders (inter-institutional coordination), and the review of existing policies and strategies with a view to integrating LDN targets.

Block 2: Assessing LDN. This constitutes the technical core of the process. It includes the establishment of the baseline (see Chapter 4), the calculation of the three subindicators, and the identification of degradation “hotspots” and “bright spots”.

Block 3: Setting LDN targets and associated measures. On the basis of assessment results, specific, measurable, achievable, relevant and time-bound (SMART) targets are formulated. These may be national or subnational and should be accompanied by a package of policy measures and practical actions on the ground.

Block 4: Achieving LDN. This is the stage of implementation, monitoring and adaptive management. It includes the delivery of planned measures, the tracking of progress through repeated assessment cycles, and the adjustment of strategies, where necessary.

Chapter 4. The baseline and implementation tools: the point of reference and the means of measurement

4.1. The baseline: selecting the period for comparison

In order to address neutrality, a point of reference is required. At the global level, the UNCCD has defined indicative time frames for reporting, as set out in the guidance on target setting and reporting [47, 64, 66].

Baseline period: 2000–2015. The baseline is established on the basis of data analysis over the agreed baseline period and reflects the initial condition of land against which subsequent changes associated with degradation, stability or improvement are assessed.

Reporting periods: Subsequent intervals against which the baseline is compared; for example, 2016–2019 (for the 2022 voluntary reporting round) or 2016–2023 (for the 2026 voluntary reporting round).

The PRAIS 4 reporting manual [72] defines the procedure and requirements for the preparation of voluntary national reports. The 15-year baseline period was proposed for global-level assessment on the grounds that, for many dynamic natural processes, it provides the possibility to smooth the influence of short-term climatic fluctuations (droughts or wet years) and to identify persistent anthropogenic trends [47]. Methodological approaches to establishing a baseline for the monitoring of LDN indicators in the Russian Federation are presented in [90].

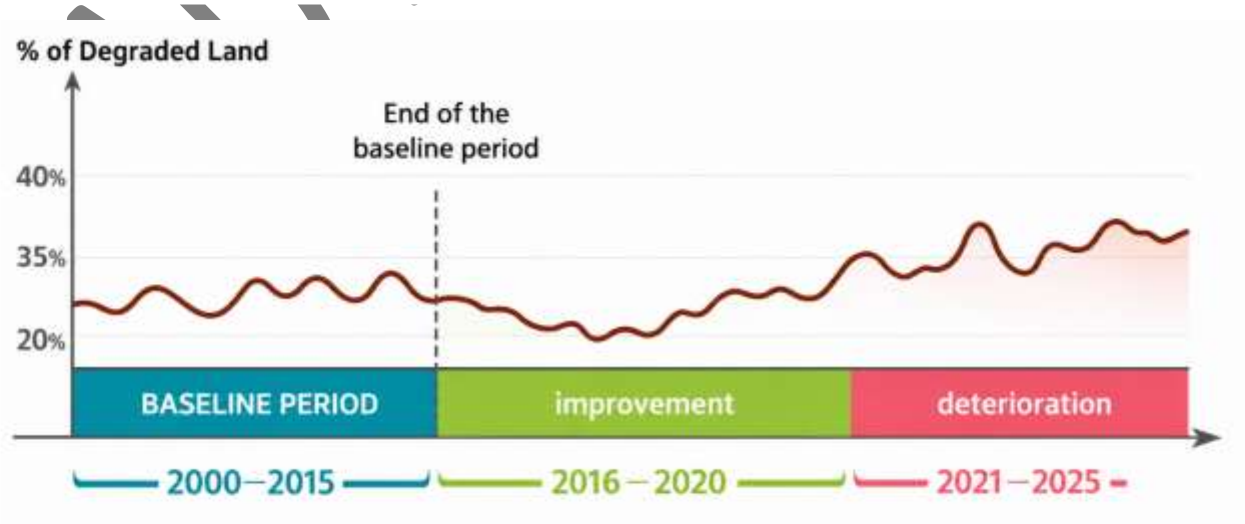


Figure 10. Principle of comparison with the baseline period.

For the purposes of official reporting, the 2000–2015 baseline period retains its role as the initial point of reference. At the same time, in the conditions of Central Asia, where interannual climatic variability is high, the analysis of longer time series may serve as an additional diagnostic tool. Such analysis does not replace the fixed baseline; rather, it supports the interpretation of deviations from it, helps to distinguish persistent degradation trends from temporary climatic fluctuations, and provides a basis for clarifying the drivers of the observed changes.

4.2. Implementation tool: Trends.Earth

In order to enable each country to undertake such an assessment independently, a dedicated tool—Trends.Earth—was developed. It is a free, open-source plugin for the QGIS geographic information system, developed by Conservation International with support from the GEF, widely used in country support processes and compatible with UNCCD approaches.

Trends.Earth automates the calculation of all three subindicators, their integration under the 1OAO rule, and the generation of final maps and statistical tables. Its principal advantages are as follows:

- **Accessibility:** it does not require costly software.
- **Data integration:** it includes built-in global datasets (MODIS, ESA CCI and SoilGrids), which provide the possibility to conduct assessments on a consistent data basis even where national monitoring systems are absent — "using the built-in default datasets".
- **Reproducibility and transparency:** the algorithms are open, ensuring comparability of results across countries.
- **Flexibility:** countries may upload their own, more precise national data for the purposes of verification or substitution of global datasets.

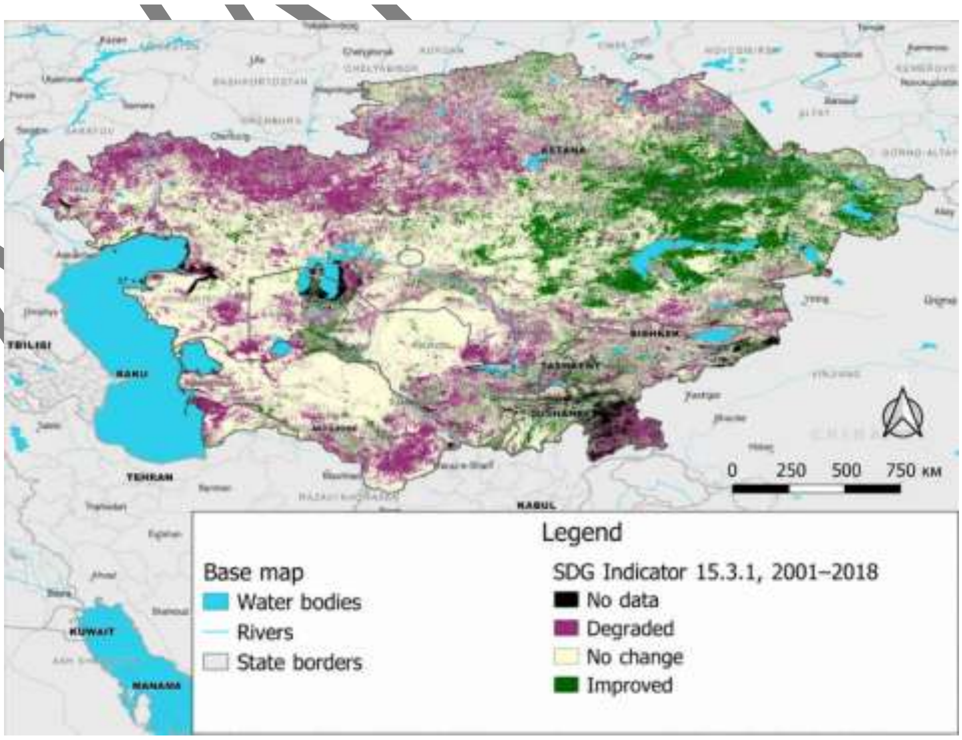


Figure 11. Example of a cartographic representation of SDG indicator 15.3.1 calculations for the Central Asian countries using Trends.Earth [34].

Chapter 5. Working scheme of the LDN assessment methodology: synthesis of the guidance documents

On the basis of the foregoing, the complete LDN assessment methodology may be presented as a multi-stage algorithm that integrates the provisions of all key UNCCD documents.

Figure 12. General scheme of the LDN assessment methodology

Conclusion to Part I

Thus, a coherent system for global land monitoring has been presented. Its foundation is the scientific conceptual basis—the LDN concept proposed by the UNCCD (LDN Scientific Conceptual Framework) [47]. Its framework is the four-building-block process, comprising engagement, assessment, target setting and action. Its precise measurement instrument consists of the three sub indicators integrated under the One Out, All Out rule, accompanied by detailed calculation guidance (Good Practice Guidance). Finally, its operational tool, accessible to every specialist, is the Trends.Earth module.

However, as demonstrated by the practice of implementing this methodology in the countries of Central Asia, global approaches require substantial regional adaptation in the interpretation of results. High interannual climatic variability, the specific nature of irrigated agriculture in the arid zone, the historical "background" of the Soviet period in the character and structure of land use, and the challenge of selecting a representative baseline period all give rise to distinctive methodological challenges that the global model does not always adequately capture. These challenges—or, as the authors refer to them, methodological knowledge gaps—and the ways in which they may be addressed on the basis of accumulated regional experience are examined in Part II of this Handbook.

PART II. ADAPTING THE GLOBAL LDN METHODOLOGY TO THE CONDITIONS OF CENTRAL ASIA: KEY CHALLENGES AND UNCERTAINTIES

Introduction

As demonstrated in the previous part, the development and implementation of the LDN concept has become an important milestone in international efforts to combat desertification. The global methodology proposed by the UNCCD provides a unified approach to assessing land condition on the basis of SDG indicator 15.3.1 [61]. However, any universal model, however robust, encounters challenges when applied in regions with pronounced specificities. Central Asia constitutes precisely such a case.

The direct application of global algorithms without adaptation to Central Asian conditions may lead to a number of systemic inconsistencies and interpretative ambiguities. The region's natural and climatic characteristics—deep-rooted aridity and increasing aridization, high continentality of climate and substantial interannual variability—are combined with a specific historical context of land use and current institutional features of land-resource governance. Taken together, these factors influence the validity of the interpretation of results obtained from global datasets and standard processing algorithms developed on the basis of averaged global parameters.

The purpose of this part of the Handbook is to provide a systematic analysis of the key methodological uncertainties and limitations that arise when the global LDN methodology is applied in Central Asia. It first considers the specificity of the region as an integrated macro-region, since due consideration of natural, socio-economic and institutional factors is a prerequisite for a robust assessment. The subsequent chapters then examine, in sequence, the problematic aspects of the methodology—from the interpretation of land cover dynamics to the selection of a representative baseline—while formulating practical recommendations for their adaptation on the basis of regional scientific and applied experience.

Chapter 6. Central Asia as an integrated macro-region: geographical specificity and socio-economic profile

Before discussing methodological adaptation, it is necessary to address the question of what makes Central Asia a distinctive object for the application of the LDN concept. The answer lies in the complex interaction of natural, socio-economic and historical factors that shape a particular "landscape" of land-use structures and degradation processes.

6.1. Expanding geographical boundaries: a region without artificial divides

When considering Central Asia in the context of sustainable development and land degradation processes, it is appropriate to take into account not only administrative boundaries but also the ecological connectedness of the territory. Within official UNCCD reporting, analysis is undertaken at the national level—within the boundaries of Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan. At the same time, for a sound diagnosis of regional drivers of land degradation and the assessment of transboundary impacts, a broader physical-geographical context should be considered. Issues related to monitoring land degradation and analysing its drivers in the context of achieving SDG 15.3 in the countries of Central Asia are addressed in [23].

Ecosystem processes—including the formation of river runoff, the migration of dust and salt aerosols, the dynamics of pasture ecosystems and climatic gradients—develop irrespective of State borders. In particular, the Amu Darya and Syr Darya basins encompass not only the territories of the five Central Asian countries, but also adjacent areas of Afghanistan and Iran. The mountain systems of the Tien Shan and Pamir, the arid plains of Kazakhstan, Uzbekistan and Turkmenistan, and transboundary water-land complexes together constitute an interconnected natural system. Taking this ecological connectedness into account is essential for analysing causal mechanisms of land degradation, while maintaining the national level of assessment and official reporting on the LDN indicator.

It is precisely such an expanded, ecosystem-based approach that provides the possibility to consider land degradation processes not as a collection of isolated national problems, but as an interconnected regional system of land-use change. In this context, land degradation in Central Asia has a pronounced transboundary dimension and requires harmonised and comparable approaches to its assessment. This includes, inter alia, the harmonisation of zonal threshold values for productivity indicators, the use of compatible metadata and land cover classifications, the development of agreed transition matrices for land cover classes, and the comparability of baselines and data sources. Such coordination of methodological parameters enhances the comparability of LDN assessment results and supports a more comprehensive understanding of regional processes.

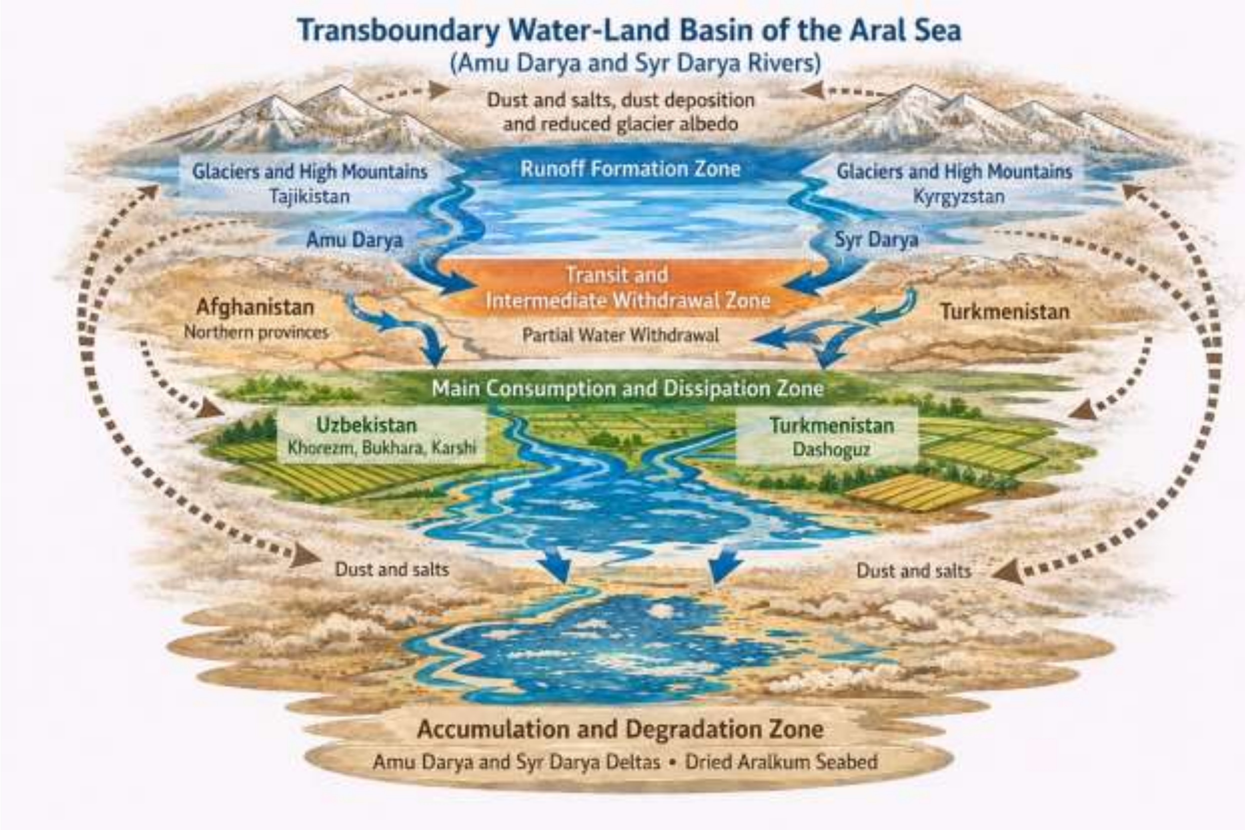


Figure 13. Schematic representation of the transboundary water-land basin of the Aral Sea

6.2. Natural and climatic specificity: the fragility of arid ecosystems

The natural systems of Central Asia are characterised by a high degree of inherent vulnerability, determined by their geographical location. Situated in the heart of Eurasia and separated by high mountain ranges from the air masses of the Atlantic and Pacific Oceans, the territory is subject to a severe continental and arid climate. The direct consequence of this enclosure is an acute moisture deficit, which determines the region's overall specificity.

Annual precipitation decreases progressively towards southern latitudes: while the northern steppes of Kazakhstan receive approximately 300–400 mm, this figure falls below 100 mm in the Kyzylkum and Karakum deserts. Yet the decisive factor is not precipitation in absolute terms, but its ratio to evaporation. Under Central Asian conditions, potential evaporation is so high that it far exceeds precipitation. As a result, soil moisture becomes the "hidden resource" on which both natural ecosystems and agricultural crops depend.

The situation is further complicated by long-term climate-change trends. Since the 1960s, meteorologists have recorded a sustained increase in average temperature. This phenomenon, referred to as aridization, places additional pressure on already depleted water reserves [69]. However, the difficulties of land use in the region are not determined by natural factors alone. In recent years, it has become increasingly evident that the region faces a crisis generated by the simultaneous interaction of human and natural drivers, where shortcomings in land and water management—inefficient irrigation schemes, excessive livestock grazing and the neglect of crop rotation—are no less significant than global climate change [50].

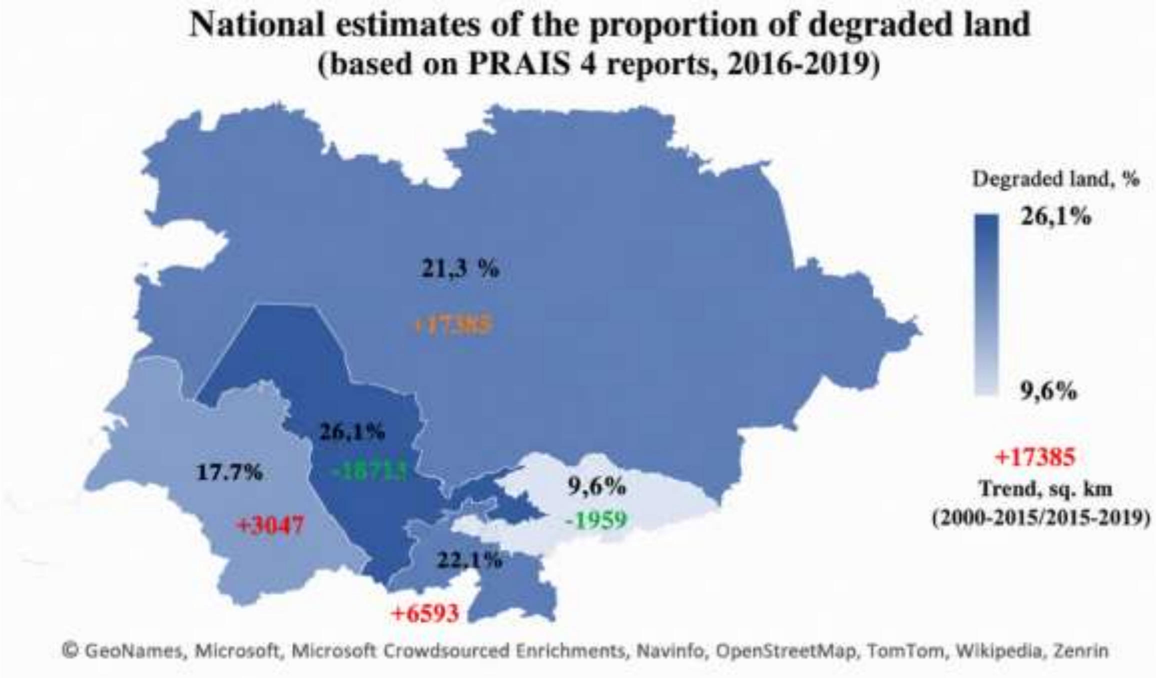


Figure 14. Proportion of degraded land in the Central Asian countries according to PRAIS 4 national reports [55–59].

6.3. Socio-economic features

The socio-economic landscape of the region is as specific as its natural environment and is linked to the condition of land resources through both direct and feedback relationships.

Demographic pressure. The socio-economic development of the region is closely intertwined with its natural conditions, and this relationship with land condition is reciprocal. As of 2024, the population of the five republics had exceeded 80 million people. This represents a major human resource and a powerful driver of future growth. Yet, in a context of depletion of natural assets, the same situation generates serious social risks. The absence of opportunities for self-realisation among younger generations in the agricultural sector creates a strong migratory outflow: land degradation entails declining incomes and a lack of prospects, pushing people first towards major cities and subsequently abroad. In areas of ecological crisis, such as the Aral Sea region, this process has already been described as “social desertification”.

The cost of land degradation. The problem of identifying land degradation “hotspots”, as well as the costs and benefits of restoring degraded land in Central Asia, is considered in [45, 46]. For millions of households, agriculture remains the principal source of income and the basis of livelihoods. However, according to estimates by experts of the Economics of Land Degradation Initiative [10], the damage caused by soil deterioration in Central Asia amounts to USD 5.85–6 billion annually. This substantial figure is composed of lost crop yields, declining returns from pastures and the forced reassessment of land-use practices.

Table 2. Key socio-economic indicators of the Central Asian countries (indicative data for 2024–2025, compiled by the authors on the basis of World Bank and ADB estimates and data from national statistical committees)

Indicator	Kazakhstan	Kyrgyzstan	Tajikistan	Turkmenistan	Uzbekistan
Population, million people	~20.0	~7.0	~10.5	~6.5	~36.0
Share of rural population, %	~42	~63	~73	~48	~50
Share of agriculture in GDP, %	~4–5	~10–12	~20–22	~10–12	~25–27

Chapter 7. Specificity of the Central Asian region as an object for applying the LDN methodology

Taking into account the specificity of Central Asia, as considered in Chapter 6, is a prerequisite for the sound calibration of LDN tools, the interpretation of results and the development of realistic strategies for achieving neutrality. Ignoring these features in the direct application of global methodologies inevitably gives rise to uncertainties, which are analysed in detail below. This chapter systematically describes the key characteristics of the region that are directly relevant to land degradation assessment. For each characteristic, its relevance to the LDN methodology is indicated.

7.1. Natural and climatic features: the “norm” of aridity versus global templates

7.1.1. Aridity as the defining characteristic

The principal feature of the region is its aridity. A large part of the territory (the Kyzylkum and Karakum deserts, the Ustyurt Plateau and the steppe zones of Kazakhstan) is characterised by low and highly unstable moisture availability. The moisture coefficient (the ratio of precipitation to potential evaporation) is below 0.33 across much of the region, corresponding to the category of arid and semi-arid lands.

Relevance for LDN: Low productivity of green biomass in deserts is not a sign of degradation, but an ecological norm. Global algorithms oriented towards vegetation indices in temperate zones often interpret this “norm” as a state of stress or an early stage of degradation. This necessitates the careful calibration of NDVI thresholds and other vegetation indices for different natural zones.

Methodological implication: When establishing the baseline and interpreting the “land productivity” sub indicator, zonal reference values should be used. What constitutes “degradation” in a semi-desert (for instance, a 20% reduction in productivity) may correspond to “stability” in a desert, where natural productivity fluctuations may reach 50% or more.

Figure 15. Climate of Central Asia (data from the open-source Köppen climate explorer (https://koppen.earth/).

Table 3. Average productivity parameters of natural zones in Central Asia (compiled by the authors on the basis of typical NDVI ranges published in scientific literature on arid regions of Eurasia; data source: MODIS MOD13 (2000–2020) (https://modis.gsfc.nasa.gov))

No.	Natural zone	Principal countries/areas	Mean annual NDVI	NDVI at peak vegetation	Productivity class	Vegetation characteristics
1	Sandy deserts (Karakum, Kyzylkum)	Turkmenistan, Uzbekistan, Kazakhstan	0.05–0.12	0.10–0.18	Very low	Sparse shrubs, ephemerals
2	Stony and clay deserts	Kazakhstan, Uzbekistan	0.07–0.15	0.12–0.22	Very low	Wormwood, saltworts
3	Semi-deserts	Kazakhstan, Uzbekistan	0.12–0.22	0.20–0.32	Low	Wormwood–grass communities

4	Dry steppes	Northern Kazakhstan	0.22–0.35	0.35–0.50	Medium	Fescue, feather grass
5	Typical steppes	Northern Kazakhstan	0.30–0.45	0.45–0.60	Medium–high	Grass steppes
6	Forest-steppe	Northern Kazakhstan	0.40–0.55	0.55–0.70	High	Birch groves, meadows
7	Tugai forests in river floodplains	Amu Darya, Syr Darya	0.35–0.60	0.55–0.75	High	Poplar (turanga), willow, reed, Russian olive, tamarisk
8	Irrigated land (agricultural landscapes)	Fergana Valley, southern Kazakhstan	0.45–0.65	0.65–0.85	Very high	Cotton, wheat, rice
9	Foothills (meadow-steppe)	Tien Shan, Pamir-Alay	0.35–0.50	0.50–0.70	High	Grass–forb meadows
10	Mountain coniferous forests	Tien Shan, Altai	0.45–0.65	0.60–0.80	Very high	Spruce, fir, juniper, archa
11	Subalpine meadows	High mountains	0.40–0.60	0.60–0.80	Very high	Alpine grasses
12	Alpine barrens and tundra	>3,500 m	0.15–0.30	0.25–0.45	Low–medium	Short growing season

7.1.2. High interannual and intra-seasonal climatic variability

Precipitation and, consequently, the dynamics of pasture productivity may fluctuate several-fold from year to year. In the interpretation of satellite data, a dry year may be mistakenly classified as degradation, while a wet year may be interpreted as recovery, even where no persistent trend exists. The difference between wet and very dry years may amount to a twofold increase or decrease in NDVI. These natural climatic fluctuations may “mask” weak signals of pasture degradation or recovery.

Relevance for LDN: Conventional analysis comparing land condition across two periods (for example, the “baseline” period of 2001–2015 and the comparison period of 2016–2020) does not provide sufficient capacity to separate long-term, persistent degradation processes from temporary fluctuations caused by climatic anomalies (droughts) or episodic anthropogenic impacts.

Methodological implication: For arid regions, the use of methods that smooth climatic noise is essential. Only in this way is it possible to distinguish long-term anthropogenic degradation from natural climatic fluctuations.

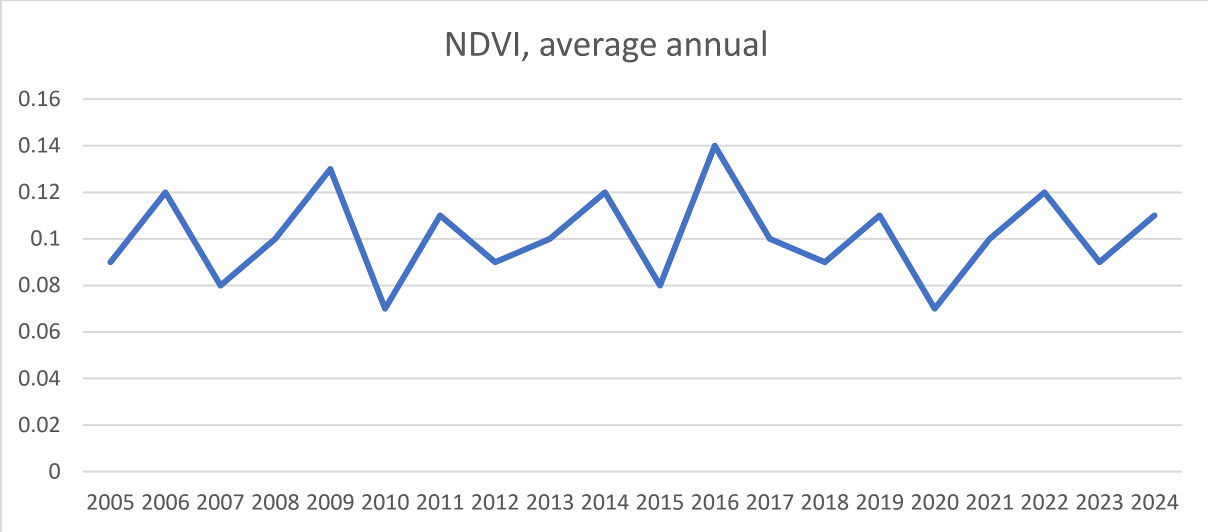


Figure 16. Interannual variability of NDVI for desert pastures in Lebap, Turkmenistan (2005–2024) (based on materials of the UNDP-Turkmenistan project [120])

7.1.3. Glaciers as a strategic reserve and an indicator of climate change

The glaciers of the Pamir and Tien Shan are the region's "water towers". Their melting directly affects water availability and, consequently, the condition of irrigated lands downstream.

Relevance for LDN: Land degradation in downstream areas (changes in runoff regime, salinisation and declining land productivity) may be a direct consequence of changes in the hydrological regime caused by glacier melt in upstream areas. This is an example of a transboundary impact that global LDN indicators, which consider each pixel in isolation, do not capture.

Methodological implication: LDN assessment at the national level should be complemented by analysis of glacier and water-resource conditions. In this regard, regional cooperation should be further developed in order to account for transboundary effects.

7.2. Dominant land-use types and their vulnerability to degradation processes

Three key land-use types may be identified in the region, each characterised by specific mechanisms and manifestations of degradation that are not always fully reflected by standard global indicators.

7.2.1. Irrigated agriculture: the paradox of "green" degradation

Irrigated agriculture is the foundation of the region's food security, while at the same time constituting a major locus of land degradation. The key degradation process in this case is secondary salinisation, associated with the rise of mineralised groundwater [25].

Specificity: Satellite-based land productivity indices may, for a considerable period of time, fail to accurately reflect declining yields on slightly and moderately saline soils, particularly where increased fertiliser doses are applied. In satellite data, a field may continue to display signs of high vegetation activity (remaining "green"), while salts accumulate in the soil, leading to the gradual degradation of its properties. Particularly illustrative examples are found in fields with high cotton biomass (NDVI may reach 0.5–0.6), but with a salt crust forming on the soil surface by the end of the growing season. This phenomenon may be termed "green degradation".

Relevance for LDN: Global indicators (NDVI and land class) may provide a false-positive signal of stability or even improvement on saline soils.

Methodological implication: Specialised soil salinity indicators (spectral indices and field measurements of electrical conductivity) should be introduced in addition to the three core indicators. The assessment should be multi-layered, involving the overlay of salinity maps with productivity maps.

7.2.2. Pastoral livestock systems: quantitative and qualitative degradation

Pastures occupy up to 70–80% of the region's territory. Degradation in these systems is expressed not only as a decline in productivity (decreasing NDVI), but also as changes in the species composition of the sward.

Specificity: Valuable forage grasses (fescue and wheatgrass) are displaced by unpalatable or low-productivity species (with wormwood and ephemerals becoming dominant, and subsequently poisonous plants). The global NDVI records "greening" without distinguishing its quality. A pasture may appear "green" (high NDVI) but be "dead" for livestock production (low forage value).

Duality of processes: The LDN concept is directed towards addressing pasture overuse. However, in Central Asia, the abandonment of remote pastures is also an acute issue. Lands that have ceased to be used may be interpreted by the global productivity algorithm as "improved" (owing to increased biomass), while the economic value of such pastures remains low for the various reasons described below.

Methodological implication: Remote sensing methods should be combined with ground verification, including assessment of species composition, the proportion of grasses and legumes, projective cover, the share of palatable species, the presence of watering points, stages of pasture digression, and infrastructure (watering points, roads and livestock shelters). Data from local communities and pasture committees play a key role. The legal basis for the activities of pasture committees was provided by legislative acts such as the Law of the Kyrgyz Republic "On Pastures" [81].

Figure 17. Experience of Kyrgyzstan: pasture committees use mobile applications to collect data on species composition [49].

7.2.3. Rainfed agriculture and fallow land

Rainfed agriculture is widespread in foothill zones, where productivity is determined to a considerable extent by interannual precipitation variability. These territories are characterised by an elevated risk of water erosion on slopes and wind erosion on adjacent plains. Arable lands withdrawn from agricultural production (fallow lands) often demonstrate increasing NDVI values as a result of the natural recovery of herbaceous and shrub vegetation.

Relevance for LDN: An interpretative conflict arises. From the standpoint of the global productivity algorithm, this represents "improvement" (increased productivity). From the standpoint of agricultural production and food security, it represents the loss of arable land. In land accounting systems, such areas may be classified as "unused" or "fallow", which generally does not entail special management or support measures. At the same time, from an ecological perspective, they constitute areas with potential for natural recovery and may be considered as objects for targeted sustainable land management and rehabilitation measures.

Methodological implication: It is necessary to distinguish between ecological recovery processes and the return of land to productive use. To enhance the accuracy of LDN assessment, it is recommended that land cadastre data and the history of land use be taken into account.

7.2.4. Forests and shelterbelts

The region is characterised by low forest cover; nevertheless, forests (including saxaul stands and tugai forests) perform essential environmental protection functions. At present, field-protective shelterbelts established during the Soviet period are in decline.

Relevance for LDN: Degradation of shelterbelts is not always captured by global indicators (the land class may remain unchanged, or shelterbelts may not be identified as a separate class, and productivity may be low from the outset). However, their loss leads to increased wind erosion on agricultural land, which is regarded as land degradation.

Methodological implication: Linear features (shelterbelts) and their condition should be accounted for, which requires high-resolution data and ground surveys.

7.3. Transboundary nature of the problems

Atmospheric and water-borne mass transfers do not recognise borders. Dust and salt storms originating from the dried bed of the Aral Sea (the Aralkum) affect land and glaciers across vast areas, from the Caucasus to Siberia. Water resources formed in the glaciers of Tajikistan and Kyrgyzstan determine the productivity of irrigated areas in Uzbekistan, Turkmenistan and Kazakhstan.

Relevance for LDN: In a number of cases, land degradation processes may be driven by factors originating beyond the borders of individual States. For example, declining pasture productivity may be associated with the transport of dust aerosols from neighbouring territories within a single natural basin. This underscores the transboundary character of certain degradation processes and the need to coordinate efforts for their monitoring and prevention. In this context, achieving LDN requires harmonised approaches to assessment, comparable monitoring methodologies and the development of mechanisms for regional cooperation within the UNCCD framework, while maintaining the national level of official reporting.

Methodological implication: The establishment of regional mechanisms for monitoring and data exchange, as well as platforms for knowledge exchange (for example, initiatives of the "Digital Earth Central Asia" type), may substantially improve the comparability of information and the quality of results interpretation. Such tools support a more accurate assessment of the contribution of national efforts to the broader regional context of land degradation and restoration processes.

7.4. Socio-economic and historical context

7.4.1. Legacy of the Soviet period

The current condition of land in the Central Asian countries has been shaped to a significant extent by historical models of economic development, including the expansion of monocultural production, large-scale programmes for the development of new lands, and the establishment of major irrigation systems. In a number of cases, these approaches were accompanied by insufficient consideration of landscape conditions and established traditional practices of sustainable land use, which had long-term implications for ecosystems and water resources [79, 80, 82, 84–88].

Relevance for LDN: Some degradation processes currently observed (including secondary salinisation and various forms of soil erosion) are cumulative in nature and have developed as a result of long-term human pressure. These processes reflect the historically established condition of land resources, which is not always fully captured when analysing changes within the standard 15-year baseline period used in the global methodology. In some cases, an area may remain in a persistently degraded condition while short-term indicator dynamics are classified as stable.

Methodological implication: The setting of LDN targets should take into account both the prevention of new degradation and the restoration of previously degraded land, which requires the analysis of historical data and extended retrospective monitoring.

7.4.2. Institutional discontinuity of the 1990s and land reform

The transformation of agrarian structures, including the transition from collective forms of farming to various models of land ownership and land use, as well as the introduction of lease mechanisms with differing contract durations, created new institutional conditions for land-resource governance. In some cases, the short-term nature of leases may reduce land users' incentives to make long-term investments in maintaining and restoring soil fertility.

Relevance for LDN: The nature of land use and institutional conditions directly influence degradation trends. LDN assessment based solely on biophysical parameters may not reflect the socio-economic drivers that determine the resilience or vulnerability of land systems.

Methodological implication: In analysing LDN results, it is important to take into account the institutional context, since negative degradation trends may correlate with the characteristics of prevailing land-use models.

7.4.3. Demographic factor and "social desertification"

Central Asia is a region with a rapidly growing and young population, which creates substantial pressure on land resources. As demonstrated in the UNCCD study (2023) [67], the relationship between land degradation and migration (internal and external) is not direct but complex and mediated; nevertheless, degradation acts as a very strong indirect trigger. It is not the sole or principal cause of out-migration—unemployment, low incomes and the absence of prospects in rural areas play a key role. Yet it is land degradation, exacerbated by climate change, that undermines the basis of traditional livelihoods, reduces the productivity of pastures and arable land, intensifies water scarcity and thereby initiates “social desertification”: young people leave degrading rural areas, leading to a sustained decline in population and labour force, the deterioration of infrastructure and a further weakening of communities’ capacity to withstand ecological and economic crises.

Relevance for LDN: Land degradation is not only an ecological process, but also a powerful socio-economic one. LDN assessment may serve as a tool for identifying risk zones where environmental stress leads to population outflow. Conversely, land abandonment (as a consequence of migration) may generate false signals of “improvement” owing to the encroachment of ruderal vegetation and/or the formation of low-productivity fallows.

Methodological implication: It is recommended that LDN assessment be complemented by analysis of demographic data (population density and migration flows on the basis of national and international statistical data) in order to provide a deeper understanding of the causes and consequences of degradation.

7.5. Diversity of natural and socio-economic conditions as a challenge for establishing a single baseline

Experience in adapting the LDN methodology at the national level in countries with extensive and naturally diverse territories (see, for example, [31]) demonstrates that applying a single baseline and unified indicator thresholds without prior natural and ecological zoning may reduce the accuracy of results interpretation. Under conditions of considerable intra-country differentiation, zonal characteristics should be taken into account when determining assessment thresholds and parameters.

The contrast of natural zones characteristic of the Central Asian countries—from desert and semi-desert territories to mountain ecosystems and irrigated agricultural landscapes—also necessitates a differentiated approach to the establishment of baselines and the interpretation of LDN indicators. Approaches to assessing land degradation dynamics in Central Asia using a landscape approach are analysed in [9].

Problem: The same type of land cover transition (for example, “irrigated land to shrubland”) may, in one region (for example, in an area with inadequate drainage), constitute a sign of degradation (waterlogging or salinisation), while in another (in foothill areas) it may indicate the restoration of natural vegetation on low-productivity lands.

Relevance for LDN: Central Asia is characterised by high natural and ecological heterogeneity, which requires zonal features to be taken into account when applying the LDN methodology. As emphasised in the Good Practice Guidance for SDG 15.3.1 [66] and the Addendum to the good practice guidance [70], the interpretation of indicators should consider national and subnational contexts. Under these conditions, the application of uniform NDVI thresholds and universal assessment criteria without prior zoning may reduce diagnostic accuracy. It is therefore advisable to use differentiated zonal parameters and adapted baselines while maintaining methodological consistency with global standards.

Methodological implication: Natural-ecological and functional zoning of the territory, taking into account landscape conditions and land-use types, should be considered as one of the priority areas of work. Such an approach provides the possibility to enhance the accuracy of LDN indicator interpretation and to ensure their adaptation to the national context.

For the zones identified, it is recommended to:

✓ Define normative productivity parameters (including baseline NDVI values).

✓ Develop adapted land cover transition matrices.

✓ Establish regional threshold values for determining degradation.

✓ Take into account additional nationally relevant indicators (for example, salinity indicators for irrigated areas or species-composition characteristics for pasture ecosystems).

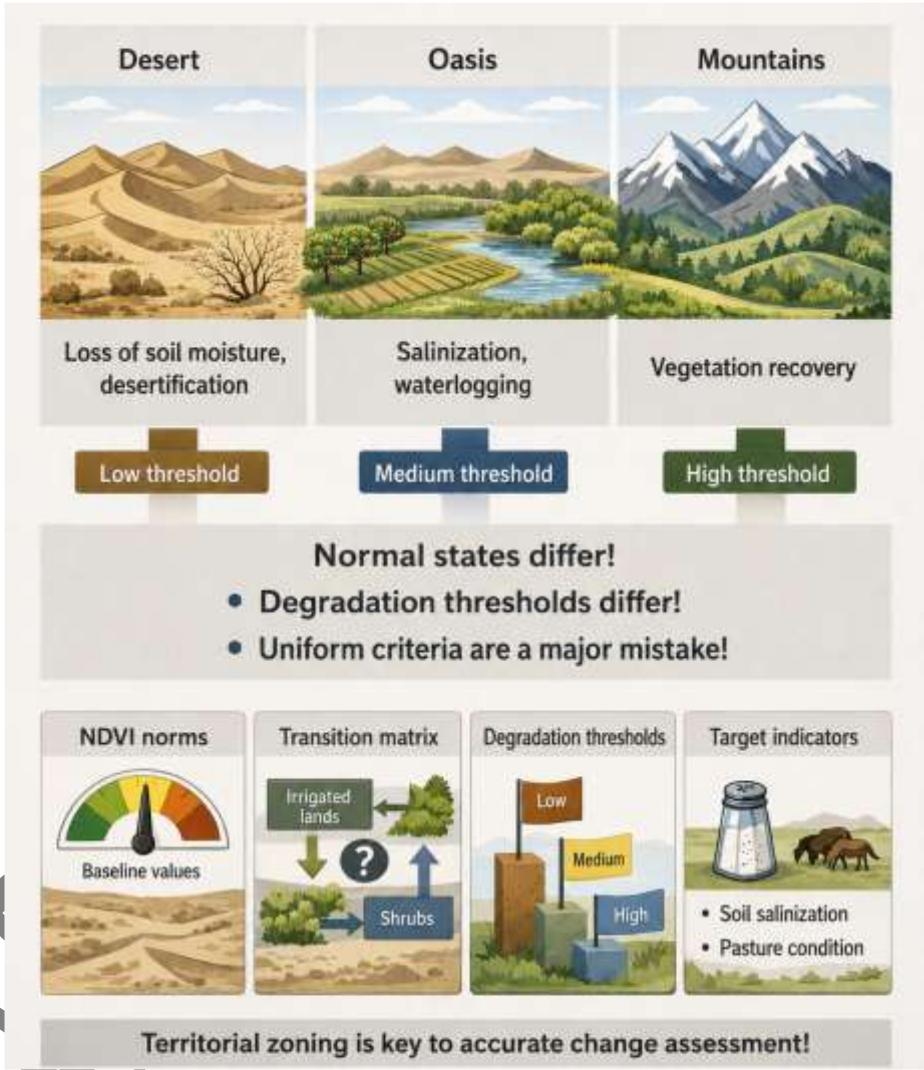


Figure 18. Importance of territorial zoning for establishing relevant LDN indicators and transition matrices

7.6. The need to take account of the "genetic memory" of soils

Studies [31, 89] have demonstrated that many contemporary degradation processes are predetermined by the history of soil formation, including Holocene cycles of wetting and drying, salinisation and desalinisation. Soils possess a form of "genetic memory": areas in which salts accumulated in the past remain, even today, particularly vulnerable to secondary salinisation.

Relevance for LDN: This phenomenon means that, even where an apparent improvement is observed (for example, following soil leaching measures), the risk of a rapid return of salinisation remains high because natural factors have not been fully accounted for. In addition, there are long-term natural trends, such as continuing climate aridisation, that may constrain the durability of achieved results. Global projections of naturally driven soil salinisation under climate change are presented in [19]. Under such conditions, management measures can mitigate adverse impacts and enhance the adaptive capacity of land-use systems; however, their effects should be assessed with due regard to existing natural constraints.

Methodological implication: When formulating LDN targets, it is important to consider the natural constraints of territories and long-term climatic tendencies. Restoration potential should be assessed with reference to the persistent characteristics of soil-landscape systems and their adaptive capacities. In some cases, the appropriate benchmark is not a return to a nominally original condition, but the achievement of a sustainable level of productivity and ecosystem functions commensurate with contemporary natural conditions. This approach is consistent with the LDN principle, which presupposes maintaining or improving the overall balance of land resources while preventing further losses.

7.7. Institutional specificities of monitoring

Monitoring of land condition in the region is undertaken by various specialised agencies, whose coordination with regard to LDN target setting and monitoring may be limited.

Relevance for LDN: The implementation of the LDN concept may be viewed as an opportunity to strengthen inter-agency coordination and harmonise systems for data collection and processing. At the initial stage, however, this process may entail organisational and methodological difficulties related to the alignment of approaches, the allocation of responsibilities and the integration of heterogeneous information systems.

Methodological implication: National plans for achieving LDN should be developed in parallel with the improvement of monitoring systems, the development of integrated GIS platforms and the strengthening of the human-resource capacity of specialised agencies. Satellite-based monitoring data on desertification in Central Asia derived from long-term data series are presented in [17]. A comparable approach using remote-sensing data is applied in [18].

7.8. Summary: Central Asia as a testing ground for adapting the LDN methodology

In summary, Central Asia constitutes a unique, complex and multi-component natural and social system, combining arid climatic conditions, a diversity of land-use forms and specific institutional characteristics. These features provide favourable conditions for testing and adapting the global LDN concept to the circumstances of dryland regions and transitioning economies. The identified specificities do not impede application of the LDN methodology; however, they require its deliberate adaptation, including the calibration of assessment parameters, consideration of zonal differences and refinement of indicator interpretation within the regional context. The key methodological implications of the regional specificity are as follows:

1. The need for zoning and zonal reference values.
2. Priority should be given to trend analysis rather than point-in-time comparisons.
3. The mandatory use of additional, nationally relevant indicators of land condition, including salinisation, pasture species composition and the condition of shelterbelts.

4. The critical importance of ground verification and the participation of local communities.

5. The need to take account of historical context and transboundary effects.

6. The need for institutional reform and inter-agency coordination.

These conclusions provide the basis for the detailed analysis of uncertainties that follows. Only after the regional specificity has been recognised and duly taken into account is it possible to proceed to the development of realistic and effective strategies for achieving LDN.

Chapter 8. Analysis of methodological knowledge gaps and uncertainties in the application of LDN in Central Asia

This chapter sequentially examines the key methodological issues that may arise when global approaches are applied without due regard to the regional specificity of Central Asia. Drawing on experience in applying the LDN concept in southern Russia, Kazakhstan and other Central Asian countries, a number of systemic problems have been identified. These are not incidental, but rather characteristic of this macro-region. They relate not only to natural and climatic specificity, but also to institutional structures, terminological inconsistencies, the historical legacy of land use and objective limitations in the application of global datasets at the regional level.

8.1. The problem of interpreting land cover dynamics

The global subindicator on land cover dynamics is based on the comparison of areas of land-use classes or land cover states at two points in time. As a rule, the comparison is made between the baseline and reporting periods (depending on the tool used), applying a standard transition matrix. Identified changes are classified as improvement, stability or degradation. This algorithm is implemented, inter alia, in tools that operationalise the LDN methodology, such as Trends.Earth. Kyrgyzstan's approaches to adapting the LDN methodology with reference to the national land classification are considered in [5].

Uncertainty 1: Mismatch between global classifications and regional realities. Standard global land cover classifications (for example, ESA CCI, recommended by the UNCCD) have been developed for averaged global conditions. In Central Asia, they often do not always provide a robust basis for interpreting actual changes. For instance, the transition from the class "forest" to the class "grassland" is interpreted by the global matrix as negative, that is, as degradation (deforestation). In an arid-zone context, however, where "forests" often refer to sparse saxaul stands, the situation is more complex. Saxaul woodlands are unique desert ecosystems that may naturally become more open during drought and subsequently recover. Their decline followed by the colonisation of a site by ephemerals (annual grasses) is not always an irreversible degradation process; it may represent a phase of natural cyclical dynamics. The global matrix of land-class transitions does not capture this cyclicity.

Uncertainty 2: Failure to account for the quality and functionality of transitions within a single class. An even more subtle problem concerns changes that occur within the same land class under the global classification. For example, the "grasslands" class may include both highly productive forb-grass communities and low-productivity wormwood wastelands. A transition from the former to the latter constitutes serious degradation, as it reduces forage capacity, yet the global indicator may fail to record the change because the land class ("grasslands") formally remains the same. The same applies to cropland: a transition from "productive irrigated land" to “salinised irrigated land” represents a disaster for a farmer, while remote-sensing data may continue for some time to register the area as “cropland” (the class does not change) until salinisation results in complete loss of vegetation cover and the territory is reclassified as bare soil or degraded land. The example in Table 4 demonstrates how the same pair of transitions (from class A to class B) may be interpreted differently depending on context and regional characteristics. These and similar examples may be used to supplement or refine the standard global transition matrix at the regional level.

Table 4. Example of differences between global and regional interpretations of land cover transition matrices for Central Asia

Transition type (from - to)	Interpretation in the global matrix	Interpretation in the Central Asian regional context	Criteria and conditions for refined interpretation
Saxaul woodland (forest) > ephemeral desert (herbaceous)	Negative (loss of forest = degradation)	Uncertain / requires verification	1. If caused by cutting and overgrazing -> negative. 2. If the result of drought within a natural cycle -> neutral (temporary fluctuation).
Irrigated cropland > fallow land with a crusted surface	Neutral / positive (growth of vegetation on fallow land)	Negative (degradation)	Withdrawal of highly productive land from use owing to irreversible secondary salinisation. Requires substantial investment for restoration to use.
Pasture (forb-grass) > pasture (wormwood-ephemeral)	Neutral (the “grasslands” class remains unchanged)	Negative (degradation)	Change in species composition while projected cover is maintained. Decline in forage value and formation of a “green desert”.
Virgin desert/steppe > rainfed cropland	Positive (land brought into agricultural use)	Uncertain / high-risk	Extremely high risk of wind erosion and soil loss in dry years. May lead to irreversible deflation.

Uncertainty 3: Insufficient consideration of natural and accumulated potential. This problem consists in the fact that existing approaches to LDN assessment often do not take into account the initial (natural) or transformed natural potential of a territory. The absence of a differentiated approach to land-use models based on assessment of natural potential makes it impossible to conduct an adequate LDN assessment or to select land-use practices that are genuinely effective under specific conditions. This is associated with the following issues:

1. **Levelling of differences:** identical sets of practices are applied to land with both high and low natural potential, although the requirements differ substantially.

2. **Incorrect assessment of required effort:** where natural potential is high, degradation risks are low and active intervention may not be required. Where potential is low (degraded land), expanded compensatory measures are needed. Without taking this factor into account, it is impossible to establish an appropriate LDN baseline or to assess whether balance (neutrality) is being achieved or whether resource depletion is occurring.

3. **Conceptual substitution:** without taking account of potential and land-use model [76], individual practices may be incorrectly interpreted as contributing to LDN targets despite their limited or context-dependent effectiveness.

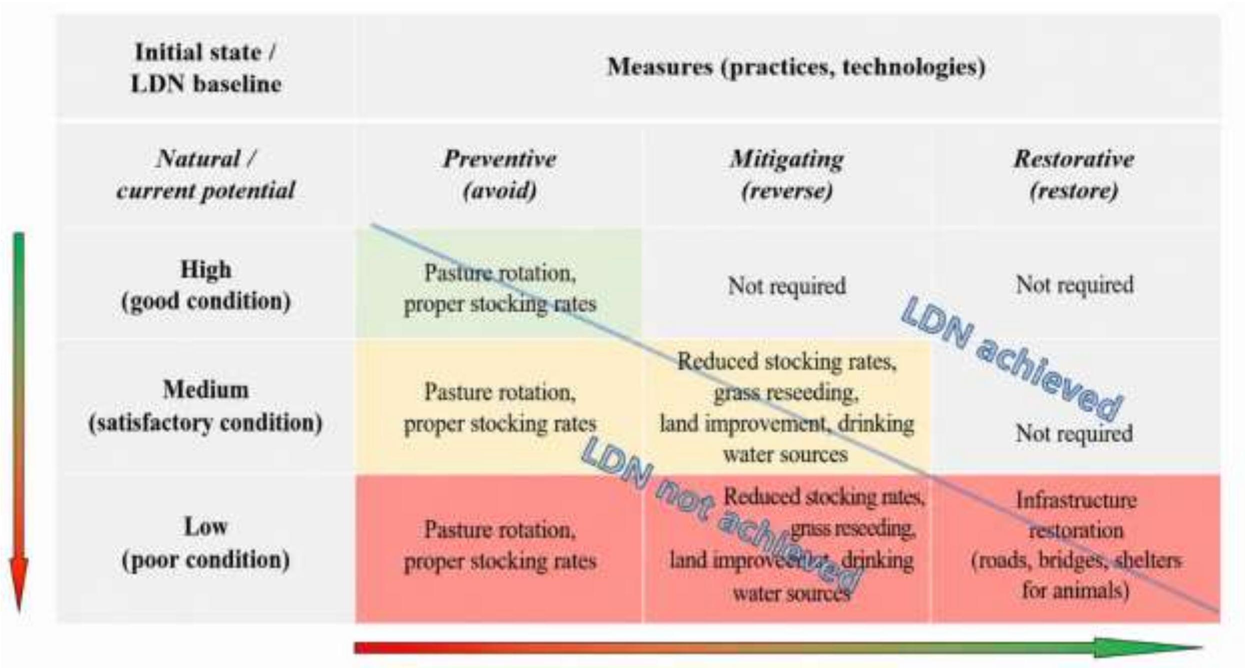


Figure 19. Schematic representation of achieving LDN (using the example of a sustainable land management (SLM) model for pastoral livestock production), depending on the initial condition (baseline) and the hierarchy of compensatory measures. Arrows indicate the direction of change in degradation risk: green - low risk; red - high risk [4].

Ways forward: For countries of the region, it appears advisable to consider the development and application of calibrated transition matrices adapted to local conditions and national targets. Implementing such an approach requires interdisciplinary collaboration among specialists in land use, remote sensing, soil science, agronomy and the management of pasture and forest resources.

8.2. The problem of accounting for salinisation

Secondary salinisation is, without exaggeration, among the key factors of irrigated-land degradation in Central Asia. It is the principal degradation process affecting densely populated oases; paradoxically, however, it is not always fully captured by the standard set of global LDN indicators, creating a risk that its systemic impact will be underestimated.

Uncertainty 1: Absence of a direct indicator in the core set. Salinisation is a gradual process and is inconspicuous in its early stages. At initial and intermediate stages, it may not directly affect the land cover class: the plot continues to be classified as cropland and crops may retain visible signs of vegetation. It also correlates weakly with organic carbon stocks, particularly in mineral horizons. Its effect on productivity, as captured by NDVI, is delayed. By the time the vegetation index begins to decline steadily, the soil may already have been lost for agricultural use, and salt crusts on the surface may begin to "bloom" with white crystals. Thus, remote-sensing methods may primarily detect the late stages of the process, reducing the scope for timely preventive action. Moreover, recent studies, including those undertaken under regional CACILM programme projects [13], demonstrate that traditional land-assessment methods often miss this factor, making the integration of specialised spectral salinity indices a necessary complement to standard NDVI analysis. In some cases, degradation processes in the soil profile may reach a critical stage, substantially constraining or effectively eliminating the agronomic potential of the soil, while above-ground vegetation continues to demonstrate satisfactory vegetation indicators. Such situations are described as the phenomenon of "green degradation", whereby the preservation or even temporary increase of NDVI values masks profound deterioration of soil properties.

Uncertainty 2: The problem of accumulated risks. Specialised studies have convincingly demonstrated that many contemporary land degradation processes are predetermined by the history of soil formation and may be described as the "genetic memory" of soils. For Central Asia, where many soils developed on ancient marine deposits and the alluvial plains of the Aral Sea region and the Hungry Steppe, and were previously subject to repeated cycles of salinisation and desalinisation, this factor is critically important. This means that, even where the ameliorative condition appears to improve (for example, following costly soil leaching measures), the risk of a rapid return of salinisation remains very high owing to the presence of "dormant" salt reserves in underlying horizons and the high predisposition of soil structure to the development of these adverse processes [94, 95].

Box. Practical example: "Why soil leaching does not always help"

In the 1960s–1980s, large-scale leaching works were carried out in the Golodnaya Steppe, an area located along the border between Uzbekistan and Kazakhstan, with the aim of bringing saline lands into cotton-based crop rotation. In many areas, leaching, combined with the construction of a collector-drainage network, made it possible to obtain good yields. However, in other areas where drainage was insufficiently deep and the subsoil horizons contained substantial salt reserves, the effect proved to be short-lived. Within only a few years after intensive leaching had ceased, salts once again rose to the surface through capillary movement, returning the soil to its original condition — and, in some cases, to an even more degraded state.

Ways forward: To increase the sensitivity of LDN assessment to secondary salinisation processes, it is advisable to consider the development and application of specialised national salinisation indicators. Such indicators should be used not as a substitute for, but as a complement to, the three global subindicators, for the verification and refinement of hotspots. A promising direction is the use of spectral salinity indices (for example, the SI - Salinity Index) based on high-spatial-resolution remote-sensing data, including Sentinel-2, which makes it possible to identify sites with varying degrees of salinisation according to characteristic spectral properties of the surface. Maps of the spatial distribution of such indices should be compared with assessments of productivity dynamics and land cover dynamics for integrated interpretation. Ground measurements of soil electrical conductivity using field conductivity meters may be used to calibrate and validate satellite-derived indices. The accumulated experience of Uzbekistan and Kazakhstan in applying GIS technologies to soil salinity mapping could be synthesised and proposed as a basis for regional exchange of practices and methodological approaches.

8.3. The problem of reflecting the dynamics of pasture ecosystems

Pastures are among the most complex objects for remote monitoring within the LDN concept. Their condition is determined not only by the quantity of phytomass, but also - critically - by its quality and species composition.

Uncertainty 1: The "green desert" phenomenon. As noted above, high NDVI values on pastures may be generated by unpalatable or poisonous plants, while valuable forage grasses disappear. In such cases, satellite data indicate "stability" or "improvement", whereas in reality the pastures lose their forage value and undergo qualitative degradation. Studies in Kyrgyzstan and Kazakhstan confirm these discrepancies between satellite indicators and the actual condition of pastures.

Uncertainty 2: Overgrazing vs. undergrazing - an interpretative "trap". In the countries of Central Asia, alongside increased pressure on village-adjacent pastures, the opposite tendency is also observed: a decline in the intensity of use of remote pasturelands, particularly in mountain and desert areas. Changes in the organisational models of transhumant livestock production have led to reduced regular use of certain seasonal pastures.

When grazing pressure decreases, vegetation cover in such areas may recover, but its structure often shifts towards dominance by low-value or ruderal species. This may be accompanied by the accumulation of dry biomass, increased fire risk and simplification of the plant-community structure, with implications for biodiversity and the economic value of rangelands.

Where NDVI values increase, such areas may be interpreted by the global algorithm as demonstrating "improvement". However, without taking account of species composition, pasture suitability and infrastructure provision, including the availability of watering points, access routes and seasonal camps, such an interpretation may be incomplete. The economic accessibility and functional suitability of these pastures are also constrained by remoteness and the condition of infrastructure; these factors should be considered when assessing their role in sustainable land-use systems.

Uncertainty 3: Slow rates of recovery. In the mountain and desert ecosystems of Central Asia, the recovery of native climax plant communities following significant disturbance may take a prolonged period, even decades. The standard 15-year assessment interval adopted in the LDN methodology does not always make it possible to fully reflect positive changes associated with the introduction of less intensive grazing regimes. This is particularly relevant where recovery processes take place against a background of interannual climatic variability, which may mask or slow the manifestation of persistent positive trends in productivity indicators.

Ways forward: To improve the accuracy of pasture-condition assessment in Central Asia, it is advisable to apply more advanced methods of remote-sensing time-series analysis that minimise the influence of interannual climatic variability and smooth "climatic noise".

In addition to satellite data, the use of field verification mechanisms should be expanded, including the participation of local communities, pasture committees and local self-government bodies. Community-based pasture monitoring can constitute an important source of additional information on species structure, actual stocking pressure and the economic value of rangelands.

It is also appropriate to consider the application of regionally adapted NDVI thresholds, calculated for specific pasture types on the basis of long-term ground observations, rather than relying on universal global thresholds.

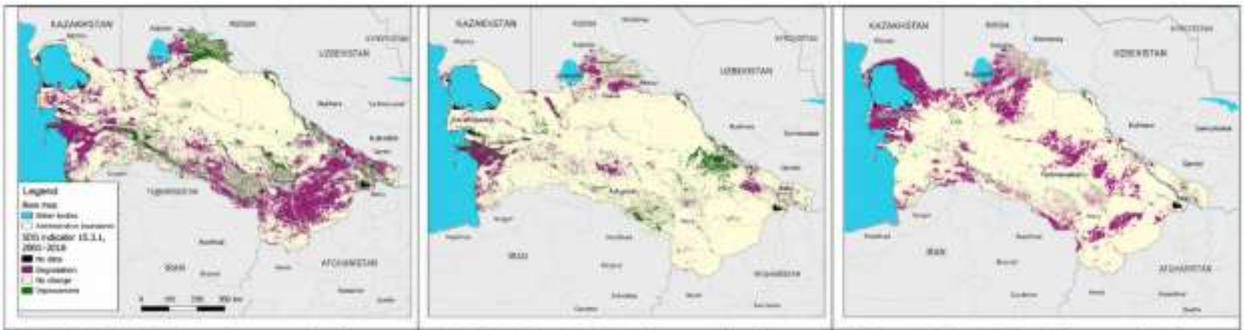
Figure 20. Comparison of two pastures with identical NDVI: the same NDVI, but different realities. The satellite records "greenness" but does not distinguish forage value. Only ground verification makes it possible to conduct a qualitative assessment of degradation processes.

8.4. The problem of selecting a representative baseline

According to the core UNCCD methodology, it is recommended that land condition be compared across two periods (for example, a "baseline" period of 2001-2015 and a comparison period of 2016-2020). For Central Asia, however, with its high interannual variability of climatic parameters and dynamic land use, this apparently straightforward approach gives rise to significant uncertainties that can substantially distort the results.

Uncertainty 1: High climatic variability within the period. The period 2000-2015 was characterised by substantial climatic variability in Central Asia. It included both relatively wet years and extremely dry years. Moreover, wet and dry periods manifested differently across the region. The selection of different periods for comparison (for example, 2000-2015 and 2005-2020) may produce entirely different, and often opposite, results depending on which phases of the climatic cycle (wet or dry) the selected years fall into. This makes the assessment highly sensitive to random fluctuations (Fig.21).

Uncertainty 2: Influence of socio-economic shifts. In Russia, Kazakhstan and other post-Soviet countries, the dissolution of the USSR was followed by fundamental changes in land use: large-scale abandonment of cropland in the 1990s and its partial return to production in the 2000s. These processes generated strong, multidirectional productivity dynamics: NDVI values on fallow lands increased steadily owing to natural revegetation, while on newly ploughed lands they often declined because of erosion and loss of organic matter. If the baseline period includes a phase of active land abandonment, subsequent dynamics may be interpreted as "improvement", even where they are driven by natural successional processes.



SDG 15.3.1. Baseline period 2001–2010, comparison period 2011–2018.	SDG 15.3.1. Baseline period 2001–2015, comparison period 2016–2020	SDG 15.3.1. Baseline period 2001–2017, comparison period 2018–2022

Figure 21. Differences in the assessment of trends in land-condition change when different baseline and comparison periods are selected (using the example of Turkmenistan) (based on materials from UNDP Turkmenistan [120]).

Uncertainty 3: Insufficiency of a 15-year period for slow processes. As noted above for pasture, forest and desert ecosystems, a 15-year interval may be insufficient to identify persistent long-term trends, given the slow pace of several degradation and restoration processes. The establishment of saxaul stands on the desiccated bed of the Aral Sea or the full development of steppe vegetation on fallow lands requires periods of 30-50 years or more. The use of a relatively short baseline period may result in lands at an intermediate stage of recovery being classified as stable or improving. Consequently, such territories may not be prioritised for additional measures, despite the fact that their condition remains substantially below a potentially attainable level of ecological and economic sustainability.

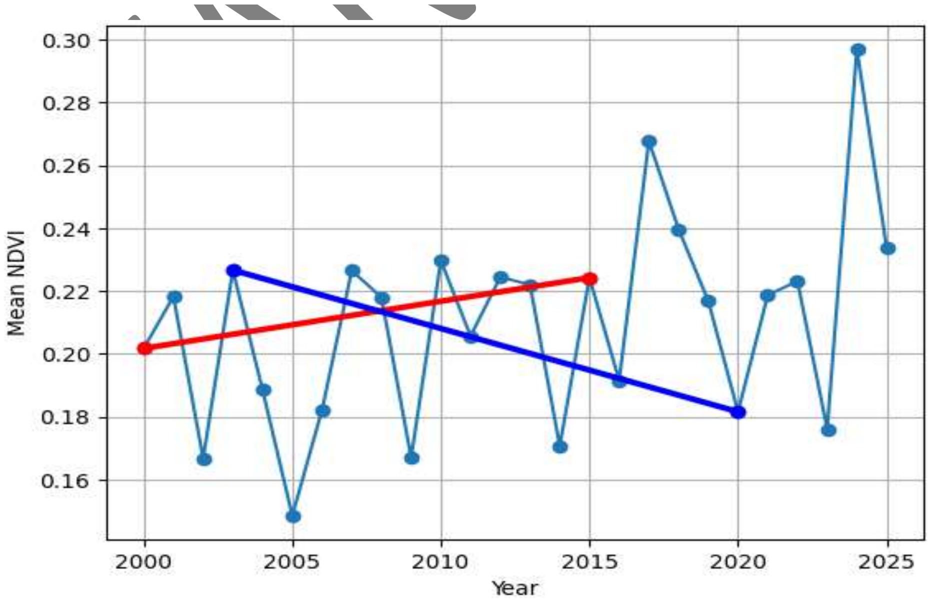


Figure 22. Sensitivity of trend assessments for semi-desert pasture degradation to the choice of baseline points: under high interannual climatic variability, the "two-date" method may produce opposite conclusions, with the result depending not on the real trend, but on which years are randomly selected as the baseline.

Ways forward: As a direction for methodological improvement, it appears appropriate to move from simplified comparison of two periods to analysis of long-term trends across the entire available period of satellite observations, from 2000 to the present. This approach makes it possible to account for interannual variability and enhances the robustness of conclusions to random fluctuations.

For practical land-resource management tasks, the use of a dynamic baseline may be justified, reflecting the long-term average productivity over an extended observation period. Under this approach, the current condition of a plot is assessed relative to its own long-term "norm", which facilitates a more accurate interpretation of deviations.

In addition, trend analysis should take into account the history of land use, including the distinction between fallow land and actively used cropland, in order to avoid conflating processes of different origin, such as ecological recovery and changes in the structure of land use.

8.5. The problem of accounting for historical legacy ("noise from the past" and accumulated risks)

The lands of Central Asia bear a heavy imprint of decisions taken decades, and sometimes centuries, ago. This creates powerful "historical noise" and generates "accumulated risks" that the global LDN methodology, focused on comparing two temporal snapshots, does not fully capture.

Uncertainty 1: Abandoned and "exhausted" lands. Large areas of irrigated land that underwent severe salinisation and depletion as a result of intensive use during the Soviet period were eventually abandoned. At present, such sites may be classified in satellite data as "other land" or may show a moderate increase in NDVI values owing to the development of salt-tolerant vegetation. An LDN assessment conducted using the standard methodology may show stability or even improvement on these sites, although in reality they are deeply degraded soils that have lost their potential and require enormous, often economically unviable, investment to be returned to agricultural use.

Uncertainty 2: "Genetic memory" of soils and accumulated risks. As already noted, contemporary degradation processes are often a continuation of long-term natural trends, such as climate aridisation, or the consequence of past anthropogenic impacts that altered the "memory" of the landscape itself. The long-term development of irrigation systems without corresponding development of drainage infrastructure contributed to the formation of zones with elevated groundwater mineralisation. Even if irrigation were discontinued today and anthropogenic pressure reduced, lenses of mineralised groundwater would continue to affect soils, cause capillary rise of salts and sustain degradation hotspots for decades. Hydrogeological and soil changes formed in the past create long-term risks that may manifest with a time lag. When applying the LDN methodology, which is based on comparing indicators within the established baseline period (2000-2015) and subsequent intervals, such accumulated factors are not always fully reflected. This may lead to underestimation of potential threats and complicate the correct prioritisation of actions within the "Avoid - Reduce - Reverse" hierarchy.

Uncertainty 3: Degraded infrastructure. The cause of continuing salinisation in fields that are still in use often lies not in the current mistakes of farmers, but in damaged or insufficient ameliorative infrastructure: dilapidated collectors, silted drainage canals and non-operational pumping stations. Global LDN indicators assess only the consequences - declining land productivity and the emergence of salinity patches - but do not identify the underlying infrastructural causes of the observed changes. The absence of analysis of historical factors and the condition of drainage systems may reduce the effectiveness of planned measures and limit their long-term impact.

Ways forward:

To improve the correctness of assessment, it is advisable to take account of the historical dynamics of land use. One possible direction is the creation of historical GIS layers based on the digitisation and georeferencing of archival materials from soil, ameliorative and land-management surveys, including soil maps and data on groundwater depth and salinity.

The comparison of such historical data with contemporary remote-sensing materials can contribute to a more accurate understanding of the scale of accumulated changes and to the distinction between ongoing degradation processes and long-term landscape transformations.

When formulating national LDN targets, it is advisable to consider not only the prevention of new losses of land resources, but also the possibility of addressing, in a phased manner, tasks related to the rehabilitation of previously disturbed areas, including recultivation and infrastructure restoration measures.

8.6. The problem of "grey zones" in mountains and foothills

In the mountain and foothill areas of the region, including the territories of Kyrgyzstan and Tajikistan as well as relevant zones of Kazakhstan, Turkmenistan and Uzbekistan, the characteristics of complex relief create additional constraints for the application of standard remote-sensing methods and may affect the accuracy of result interpretation.

Uncertainty 1: Unreliability and limitations of remote-sensing methods in mountains. Complex mountain relief creates a number of problems for remote-sensing assessment methods:

- **Shading:** deep shadows cast by mountain ranges make it impossible to obtain satellite information for significant areas of north-facing slopes.
- **Distortion of spectral characteristics:** differences in slope illumination (insolation) mean that the same vegetation type on south-facing and north-facing slopes may have entirely different spectral "signatures", disrupting automatic classification algorithms. The limitations of using vegetation indices to detect pasture degradation in the mountain systems of Central Asia are considered in [9].
- **Cloud cover:** high mountain areas are very often obscured by clouds, which further reduces the number of usable cloud-free images during the season. As a result, by some estimates, up to 20% of high mountain territory may remain a "grey zone" for reliable satellite monitoring.

Uncertainty 2: Specificity of degradation processes. In mountains, the principal degradation processes include water erosion (soil wash), mudflows, landslides and degradation of pastures on steep slopes, leading to the destruction of turf and formation of gullies. These processes are often local and "patchy" in character and may not be captured with sufficient sensitivity by global indicators with a resolution of 250-300 metres per pixel. This is particularly relevant where degradation is not accompanied by a change in land class; for example, a pasture may remain in the same category despite the formation of erosional landforms.

Case 4: The At-Bashy paradox: how an erroneous diagnosis could have channelled millions into restoring healthy pastures *(based on materials of the FAO/GEF PRAGA Project, Kyrgyzstan, 2022 [49]).*

Problem addressed: How can major investment errors be avoided when global data indicate degradation but local residents assert the opposite? If satellite data alone are trusted, limited resources may be directed towards "treating" a healthy ecosystem, while real problem hotspots are ignored.

Context: Under the PRAGA project, satellite analysis conducted according to the SDG 15.3.1 methodology clearly identified the southern part of At-Bashy district as one of the main degradation hotspots in Naryn region. Algorithms based on NDVI trends showed a persistent decline in land productivity over a significant area. This constituted a ready signal for international donors and national programmes: "these territories require priority attention and investment in restoration".

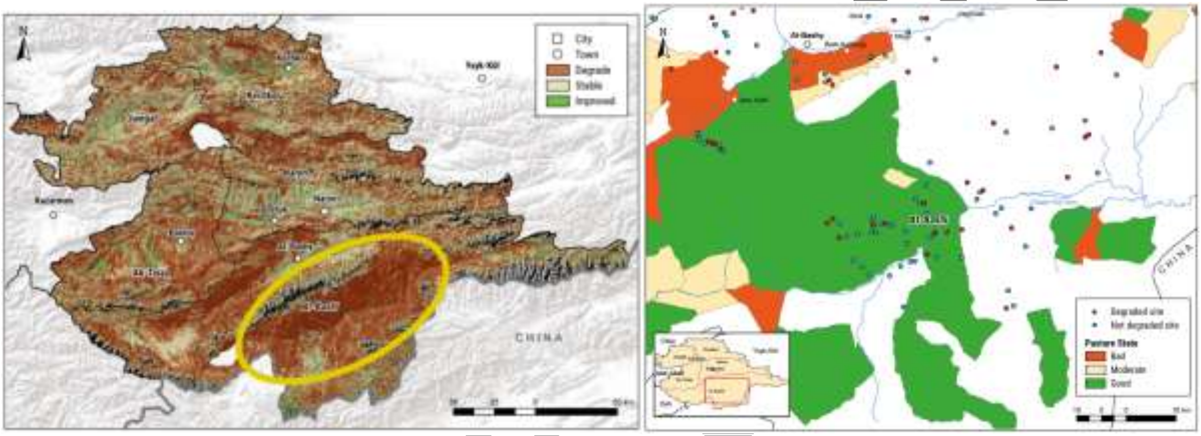


Figure 23. Assessment of the area of degraded land with emphasis on the territory of the southern part of At-Bashy district

However, local herders and members of pasture committees categorically disagreed with this conclusion during working seminars. They mapped the same territories and unanimously assessed them as "good" pastures that had always been, and remained, productive. A conflict of interpretation arose that had to be resolved before any measures could be planned.

Method applied (ground validation in the disputed zone): Focus on the "hotspot": researchers concentrated fieldwork precisely in the area south of At-Bashy where satellite data indicated degradation, while herders reported good condition.

Application of unified field indicators: Trial plots were established in the disputed territory, and the same five indicators were assessed: erosion, projected cover, share of edible plants, grass height and seed regeneration.

Integrated analysis: The results of field surveys were compared with the satellite degradation map and with data reflecting local herders' perceptions of pasture condition.

Result: Field data confirmed the view of local herders. Most trial plots in the southern part of the district were classified as "not degraded". It emerged that the NDVI decline recorded by the satellite was not caused by loss of biomass, but by the characteristics of the high-mountain landscape: at these altitudes, sparse vegetation cover (less than 70-80%) is the norm, not a consequence of overgrazing. In addition, in the same images, "degradation" encompassed steep south-facing slopes that have always been less productive owing to insolation and soil wash.

Interpretation: Had project decisions been made solely on the basis of satellite monitoring, funds would have been directed towards phytomelioration or changes in grazing regimes on healthy, well-functioning pastures. This would not only have caused direct financial losses, but also undermined community trust in any future initiatives ("attempts are being made to ‘improve’ what, from the perspective of local communities, is already functioning effectively”). Paradoxically, according to herders, the real problem was located nearby - on suburban pastures close to the settlement of At-Bashy, which they assessed as “poor” and where field data confirmed overgrazing. The satellite, by contrast, showed “improvement” there owing to the growth of ruderal vegetation on abandoned fields. The At-Bashy case became a classic example of how the integration of local knowledge does not merely correct, but can completely reverse, the diagnosis of degradation, making investments targeted and effective.

Ways forward: In mountain areas, the importance of ground verification increases substantially. Taking account of the knowledge of local communities and herders regarding the condition of specific slopes and sites can improve the accuracy of interpretation of remote-monitoring results. In this regard, it is advisable to consider participatory methodologies, such as PRAGA, developed for the conditions of Kyrgyzstan and adapted to regional circumstances [49].

The use of uncrewed aerial vehicles (UAVs) can serve as an effective tool for obtaining highly detailed images of representative sites and monitoring hard-to-access slopes.

When assessing degradation processes in mountain ecosystems, analysis of global land cover classes should be complemented with local, field-verifiable indicators, such as erosion-network density, the presence of fresh gullies, traces of mudflow processes and the condition of pasture turf on specific sites.

8.7. Institutional and terminological issues

The experience of countries in the region demonstrates that, even where advanced State monitoring systems exist, the implementation of the LDN concept encounters significant institutional barriers, which are often more difficult to overcome than technical challenges.

Uncertainty 1: Inconsistency of basic concepts. In the national legislation of countries in the region, the concepts and terms “land”, “land degradation” and “desertification” are often defined differently and, more importantly, do not always correspond to the definitions adopted under the UNCCD. For example, in some countries, the concept of “land degradation” is legally established only for agricultural land. This makes official accounting, and consequently targeted policy to combat degradation, impossible for forest areas, pastures (where they do not fall within the category of agricultural land), and land used for industry and transport. A gap exists between land, water and forest legislation, hindering the collection of comparable data for the calculation of the three subindicators.

Uncertainty 2: Fragmentation of agencies and monitoring systems. Monitoring of land condition in the region is undertaken by different agencies, each with its own history, mandates and budgets:

- Land-resource agencies maintain cadastres and account for land by category.
- Hydrometeorological services are responsible for drought and weather monitoring.
- Ministries of agriculture monitor yields and pasture productivity and, in some cases, soil fertility on arable land.
- Forestry ministries hold data on forests and, in some cases, pastures located on forest lands.

Their data are often incompatible, using different classifications, map scales, update frequencies and storage formats. The absence of a unified national monitoring system that integrates all these indicators into a single GIS platform makes automatic calculation of SDG indicator 15.3.1 impossible and requires substantial effort for “manual” processing and harmonisation.

Uncertainty 3: Absence of ecosystem-service-related concepts in legislation. The LDN concept employs contemporary economic terms such as “ecosystem services” and “natural capital”. These concepts are not yet present in the official legal frameworks of most countries in the region. As a result, it becomes more difficult to justify administrative and organisational decisions aimed at conserving these “intangible” values, and the practical applicability of progressive economic mechanisms, including payments for ecosystem services, is reduced.

Table 5. Comparative analysis of definitions of “land degradation” in legislation (hypothetical example)

Country	Legislative act	Definition / object of accounting	Problems for LDN application
Country A	Land Code	Degradation is the deterioration of soil properties on agricultural land.	Pastures on reserve lands, forest lands and land under infrastructure are not covered.
Country B	Law on Environmental Protection	Degradation is a general concept, without reference to categories.	Quantitative criteria and calculation methods are absent; monitoring is not undertaken.
Country C	No definition	The concept is used fragmentarily in by-laws.	Legal vacuum; sanctions or incentives cannot be applied.

Ways forward: A phased harmonisation of national legislation with UNCCD terminology and approaches is recommended. It is advisable to integrate into the legal framework concepts such as “land degradation”, “land degradation neutrality”, “soil organic carbon stocks”, “ecosystem services”, “sustainable land use” and other categories that ensure comparability and methodological coherence of LDN policy. A key step could be the establishment of inter-agency coordination committees or councils on LDN, with clearly assigned mandates for harmonising methodologies, aggregating data and coordinating budget priorities. To be effective, such structures should have institutional continuity and adequate resources.

Educational and professional programmes should be developed to train specialists proficient in GIS and remote sensing and familiar with the conceptual and methodological foundations of LDN. This will support the long-term sustainability of monitoring and planning.

Interstate cooperation should be pursued through regional coordination platforms or cooperation mechanisms with expert capacity, capable of ensuring data exchange, harmonisation of approaches and dissemination of best practices.

8.8. The problem of the applicability of global data and the need for verification

The fifth cluster of issues relates to the quality and applicability of the global datasets on which calculations for global-level assessment are based.

Uncertainty 1: Low accuracy of global data on soil carbon. Global datasets, such as SoilGrids [20], are constructed on the basis of machine learning and a limited number of soil sampling points (soil profiles). Their resolution and, more importantly, accuracy are in many cases insufficient for assessing changes at national or regional level over short periods of 15-20 years; they require additional calibration and comparison with ground data. In Russia, for example, discrepancies in comparison with ground data reached 1.5-3 times [78, 93]. In Central Asia, where soils are often saline, shallow and characterised by complex genesis, these errors may be even more substantial, limiting the use of global carbon data as the sole basis for management decisions.

Uncertainty 2: Mismatch between national and global classifications. National systems for assessing land productivity, such as soil bonitet scores or forest site-quality classes, and classifications of land according to economic use often cannot be directly and unambiguously matched to the classes used in global products, such as ESA CCI or MODIS Land Cover. Thus, there is a methodological mismatch between detailed local and national knowledge and universal global assessment schemes.

Uncertainty 3: Absence of systematic validation. In several countries of the region, systems of regular and sustainably financed ground surveys, required for validating satellite data and calibrating calculation models to local conditions, are still developing or function only to a limited extent. Under such circumstances, one-off scientific projects cannot always ensure the continuity and comparability of data required for systematic assessment.

Ways forward: Global indicators should be used as a baseline approach and as a tool for initial screening (Tier 1) [60]. To improve assessment accuracy, they should be supplemented with national statistical data and results from ground monitoring, with a phased transition towards more detailed Tier 2 and Tier 3 levels.

For the assessment of soil organic carbon, the use of data from national agrochemical services and soil surveys for verification and calibration of global models appears justified.

It is also advisable to consider the development of regionally adapted coefficients and recalculation algorithms that would allow national data to be integrated into a format consistent with reporting requirements for SDG indicator 15.3.1.

8.9. Summary of methodological uncertainties and directions for addressing them

The analysis undertaken makes it possible to systematise the key uncertainties that require due consideration and targeted action when assessing LDN in Central Asia. The findings should be synthesised in a summary table, which may serve as an indicative planning tool for national expert groups.

Table 6. Summary table of gaps and recommendations

Category	Key gap / uncertainty	Measures to reduce methodological limitations
Institutional	Terminological inconsistency; fragmentation of agencies; absence of a unified monitoring system; lack of human-resource capacity.	1. Harmonise legislation with UNCCD definitions. 2. Establish inter-agency LDN coordination committees. 3. Develop and implement educational programmes on GIS/remote sensing and LDN.
Land productivity	Difficulty in distinguishing climatic noise from trend; the "green desert" phenomenon; insufficient accounting for vegetation quality.	1. Move from point-in-time comparison to trend analysis. 2. Mandatorily use ground verification and data from pasture committees.
Land cover dynamics	Limited applicability of the global transition matrix under regional conditions.	Develop national, calibrated transition matrices for key land-use types, including irrigated lands, pastures and tugai forests.
Salinisation	Absence of a direct indicator; delayed effect;	1. Introduce additional national indicators, such as spectral salinity indices and electrical-

	insufficient consideration of the “genetic memory” of soils and accumulated risks.	conductivity data. 2. Create GIS layers of historical data, including soil maps and salinity maps, to analyse accumulated damage.
Baseline	Sensitivity of assessment to the choice of time period and the limitation of a 15-year interval for capturing slow dynamics.	1. Use moving-average methods and trend analysis for the entire observation period. 2. Establish a dynamic baseline. 3. Take account of land-use history, including fallow lands and virgin-land cultivation.
Spatial data	Limited accuracy of global data, particularly for soil carbon, and the presence of “grey zones” in mountain territories.	1. Use global data only as a framework and verify it with national data. 2. In mountains, apply UAVs and ground-monitoring methods for verification. 3. Calibrate global soil-carbon models using data from national surveys.

Chapter 9. Concluding recommendations on adapting the LDN methodology for the countries of Central Asia

1. **Harmonisation and coordination:** It is advisable to ensure alignment of national definitions and approaches with UNCCD terminology and methodological frameworks, and to consider establishing or strengthening permanent inter-agency coordination mechanisms on LDN.

2. **Transition to a multi-tiered system (Tier 1-2-3):** A phased expansion of the use of advanced analytical methods is recommended, including trend assessment, analysis of recurrence and signal persistence, with gradual transition to Tier 2 and Tier 3. Regular ground verification, including the participation of local communities and land-use practitioners, is an essential element of this transition.

3. **Development and approval of national indicators:** It appears justified to establish a list of additional nationally relevant indicators, such as salinisation indicators, erosion indices, characteristics of pasture species composition and the condition of ameliorative infrastructure, to be used for the refinement and verification of global data within the LDN framework.

4. **Calibration of tools:** It is advisable to adapt NDVI thresholds and land cover transition matrices with reference to the key landscape and ecosystem types of the region. Such work should be undertaken in a coordinated manner, including through interregional cooperation, for example by using the capacities of the UNCCD Interregional Group “Central Asia - Russia”.

5. **Integration of data into unified platforms:** A promising direction is the development of national GIS platforms that integrate satellite data, results of ground monitoring, digitised historical materials, cadastral information and data from local communities. Transparency and accessibility of verified information for scientific, educational and management institutions should be ensured, where possible.

6. **Consideration of historical legacy:** When formulating national voluntary LDN targets [71], it is advisable to consider tasks related to phased rehabilitation of territories with accumulated disturbances, including recultivation and restoration of drainage infrastructure.

7. **Institutionalisation of the approach:** It is recommended to integrate the results of adapted LDN assessment into strategic and spatial planning processes, including land-management schemes, regional development strategies and socio-economic support programmes.

Conclusion to Part II

The practical cases and methodological approaches presented in Part II demonstrate convincingly that a stage of critical analysis and systematic adaptation of the LDN methodology is an important condition for its effective application. Such an approach makes it possible to consider LDN not only as a reporting instrument, but also as a basis for the preparation of well-founded management decisions in the field of sustainable land use, taking due account of the specific natural and socio-economic conditions of Central Asia.

PART III. PRACTICAL SOLUTIONS FOR ADAPTING THE LDN METHODOLOGY: REGIONAL CASES AND METHODOLOGICAL APPROACHES

Introduction

Part II of this Handbook provided a detailed analysis of the uncertainties that arise when the global LDN methodology is applied directly in the conditions of Central Asia and the arid zones of the Russian Federation. The analysis indicates that universal algorithms developed for generalised global conditions may demonstrate limitations in a regional context characterised by high climatic variability, a complex land-use history, specific degradation processes, including secondary salinisation and the phenomenon of "green degradation" of rangelands, as well as institutional fragmentation of monitoring systems. However, diagnosis is only the starting point. Part III of this Handbook is devoted to the central issue: practical solutions, namely the transition from identifying problems to overcoming them in a systematic manner. Its purpose is to provide national experts, planning authorities and project teams with a practice-oriented, stepwise toolkit for adapting the LDN methodology to the national context. Such a tool is intended to support not only the identification of land degradation, but also a deeper understanding of its mechanisms, the assessment of possible development scenarios and the quantitative justification of priority measures and investments. The structure of this Part is organised as a sequential progression from the analysis of fundamental methodological elements, including baseline formation, to more complex composite approaches and, subsequently, to institutional mechanisms that ensure the sustainability of the system as a whole. Each section includes:

- a clear statement of the problem to be addressed, selected from those identified in Part II;
- a detailed description of the proposed methodological approach, or a combination of approaches;
- one or more country cases illustrating the application of the approach in practice, with quantitative results and conclusions;
- practical recommendations for implementation by countries of the region.

This section considers the application of methodological approaches on the basis of practical examples from Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, Uzbekistan and the Russian Federation (the Republic of Kalmykia, Volgograd Oblast and Samara Oblast), drawing on materials from UNDP-GEF, FAO and World Bank projects, as well as recent scientific publications. This approach is essential: it demonstrates that the discussion is not about hypothetical methodological improvements, but about practical tools that have already been successfully tested and verified in specific territories.

Chapter 10. From Static Assessment to a Dynamic Understanding of Land Degradation

10.1. The LDN Index as a decision-support tool

The contemporary international system for monitoring land degradation is based on SDG indicator 15.3.1, namely the proportion of land that is degraded over total land area. This indicator has played an important role in shaping the global sustainable development agenda and has provided the basis for comparable voluntary reporting by countries. However, as practical experience has accumulated, it has become apparent that the use of this indicator as a stand-alone measure does not always fully reflect the actual dynamics of land processes at the regional level or provide an adequate basis for subsequent management decisions.

The logic of the LDN concept presupposes the achievement of a balance between land losses and land restoration. In practice, however, indicator 15.3.1 captures only one side of that balance: degradation. Improvements in land resources remain outside the final indicator values and are accounted for only indirectly. In the arid and semi-arid conditions of the Central Asian region, this creates a paradoxical situation: territories in which substantial processes of both restoration and degradation are occurring simultaneously may demonstrate the same values of indicator 15.3.1 as regions where restoration is almost absent.

A response to this methodological limitation has been the proposal to use an integral measure: the LDN Index [3]. Unlike SDG indicator 15.3.1, it reflects the balance of processes and is calculated as the difference between the shares of improved and degraded land. This indicator places the key idea of neutrality at the centre of the analysis: the need to compensate losses through restoration.

Figure 24. Formula for calculating the LDN Index

The LDN Index should be regarded as an additional diagnostic instrument for analysing the balance between degradation, stability and improvement of land at the regional or subnational level. Its function is to support interpretation of the baseline assessment, identify priority territories for intervention and compare different land management scenarios.

The practical value of the LDN Index is particularly apparent when analysing the spatial heterogeneity of land degradation, as demonstrated by the data in Figure 25. The Index clearly reveals differences among the territories under analysis, thereby enabling more balanced decisions on the placement of priority measures at the subnational level: areas dominated by degradation may coexist within the same country alongside areas of sustained improvement. This result fundamentally changes the approach to planning interventions: instead of distributing resources evenly, it provides possibility for targeted action in priority regions.

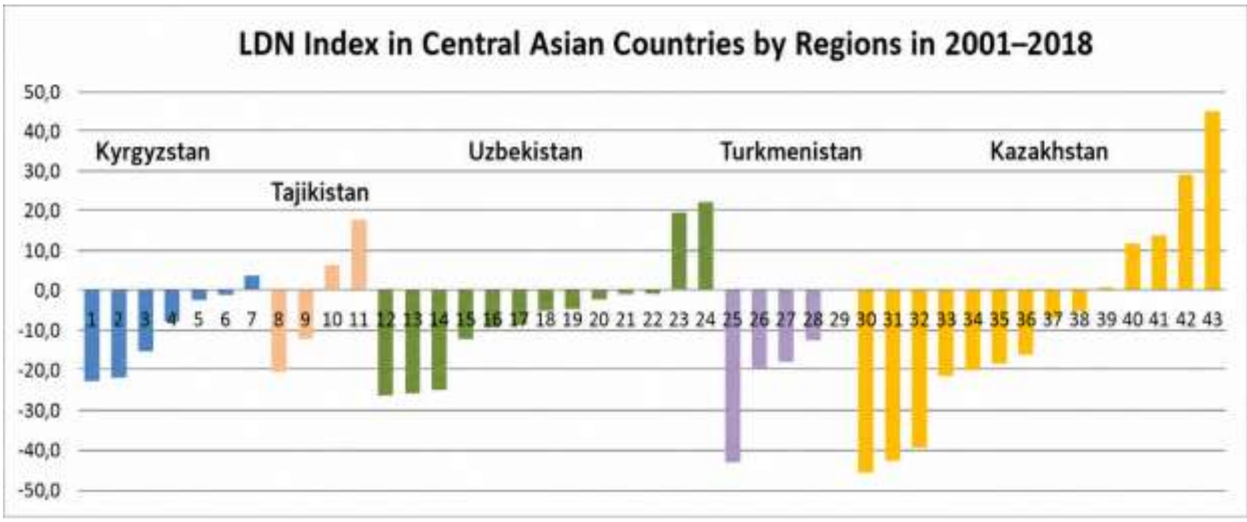


Figure 25. LDN Index in the countries of Central Asia by oblast, 2001-2018, with 2001-2005 as the baseline period (status as of 2019) [34].

Explanatory note to the figure:
Kyrgyzstan: 1 - Talas, 2 - Chuy, 3 - Naryn, 4 - Issyk-Kul, 5 - Jalal-Abad, 6 - Osh, 7 - Batken;
Tajikistan: 8 - Gorno-Badakhshan Autonomous Oblast, 9 - Sughd, 10 - Districts of Republican Subordination, 11 - Khatlon;
Uzbekistan: 12 - Jizzakh, 13 - Kashkadarya, 14 - Samarkand , 15 - Bukhara , 16 - Navoi, 17 - Andijan, 18 - Tashkent, 19 - Namangan, 20 - Republic of Karakalpakstan, 21 - Syrdarya, 22 - Surkhandarya, 23 - Fergana, 24 - Khorezm;
Turkmenistan: 25 - Mary, 26 - Lebap, 27 - Balkan, 28 - Ahal, 29 - Dashoguz;
Kazakhstan: 30 - West Kazakhstan Region, 31 - Aktobe, 32 - Kostanay, 33 - Akmola, 34 - Atyrau, 35 - Mangystau, 36 - Turkestan, 37 - North Kazakhstan, 38 - Kyzylorda, 39 - Pavlodar, 40 - Almaty, 41 - Zhambyl, 42 - Karaganda, 43 - East Kazakhstan Region.

As demonstrated below, the proposed LDN Index may provide additional analytical value when working with multi-year time series. Its application makes it possible to assess not only the current status of land, but also the direction of change. In addition, the use of the Index creates the basis for quantifying probable future trends, which is of considerable importance for planning practical measures to achieve LDN.

10.2. Addressing the baseline problem: transition to dynamic variability analysis for subnational and local use

One of the most debated elements of the global LDN methodology is the choice of the baseline period against which changes in land condition over time are assessed. International guidance establishes a fixed period at the beginning of the twenty-first century as the reference point for most assessments. This approach has proven useful at the global level, where a common point of reference is required to ensure data comparability. However, serious limitations become evident when this logic is transferred to regional and national levels.

Problem: Assessment results may demonstrate increased sensitivity to the choice of both the baseline period and the comparison period, particularly under conditions of high interannual climatic variability. Comparing two temporal snapshots may interpret short-term climatic fluctuations as persistent trends of degradation or recovery, thereby affecting the stability of conclusions and the comparability of reporting data. For Central Asia, the choice of a fixed baseline period has proven particularly problematic. The region underwent profound socio-economic transformations in land use after the dissolution of the Soviet Union, including widespread abandonment of agricultural land, changes in rangeland-use patterns and the restructuring of irrigation systems. As a result, many processes recorded in the early 2000s reflect not a stable landscape condition, but a phase of abrupt restructuring of the economic system.

Proposed solution. Recognition of this problem, compounded by high interannual climatic variability, led to the development of an approach based on the use of a **dynamic baseline and the transition to trend analysis** over the full time series. Instead of comparing two fixed periods, the entire available observation period, generally from 2000-2001 to the present, is proposed as the basis for comparison. Land condition in each particular period, for example a five-year interval, is assessed not against a particular period in the past, but against the long-term average "norm" for the relevant pixel or site. This approach helps to smooth the effects of extreme climatic events and provides a more robust assessment of long-term land condition.

Technically, this is implemented through the **moving average method**, whereby not one but a series of overlapping time intervals is analysed, for example 2001-2005, 2003-2007, 2005-2009, and so forth. The mean or median value for the whole period (at the time of preparation of this Handbook, 2001-2022) is adopted as the reference line (0), relative to which deviations in each temporal slice are measured.

Case 5: Calibration of the baseline for irrigated lands in Uzbekistan [36]

Context: In the Fergana Valley in Uzbekistan, large-scale works to rehabilitate irrigation and drainage systems have been undertaken in recent years, and their effectiveness has been confirmed by national statistical data. The standard approach based on a fixed baseline period (2001-2005) did not reflect these results, giving rise to doubts about the applicability of the method in principle.

Application of the method: As an alternative approach, long-term average NDVI values for 2001-2022 were calculated for each pixel and adopted as a conditional "0". Deviations from this median value were then calculated for consecutive five-year periods (2001-2005, 2003-2007, ..., 2016-2020). The resulting dynamics were visualised in the form of graphs and maps.

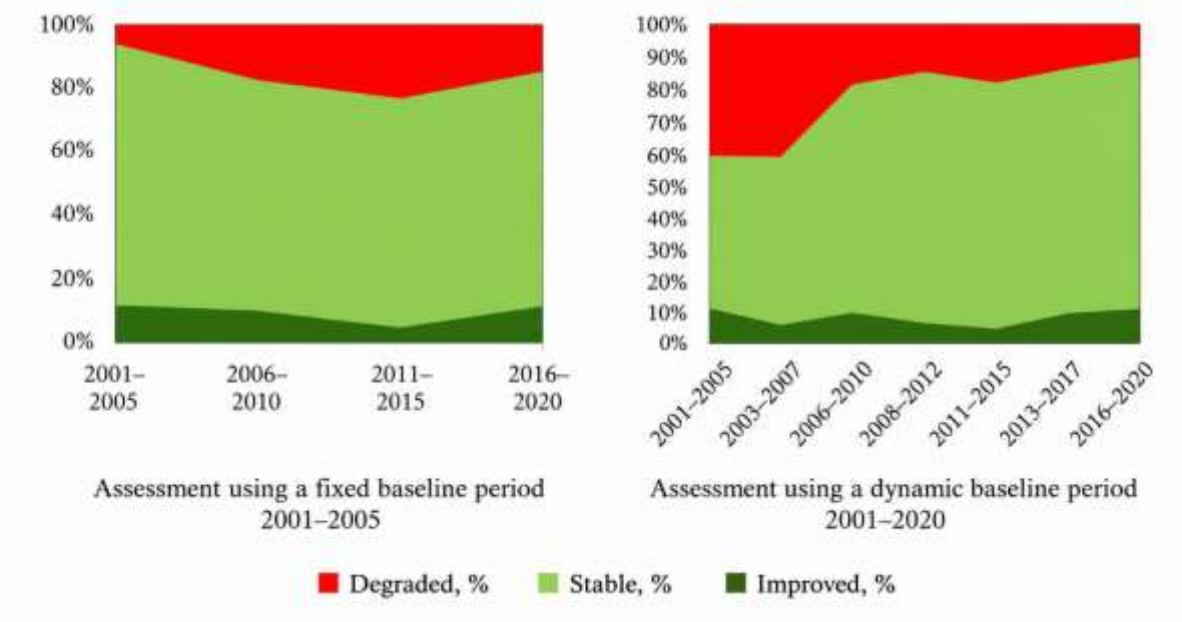


Figure 26. Differences in the assessment of land dynamics in Fergana Region, Uzbekistan, using different approaches to baseline definition

Result: The transition to a dynamic baseline made it possible to demonstrate clearly when conditions were better or worse than the average, and to record consistent land improvement in regions where substantial investments in improving the efficiency of irrigation systems had been made over the past 15-20 years.

Case 6: Calibration of the baseline for rangelands in Turkmenistan (based on materials of the UNDP-Turkmenistan project, 2025 [120])

Context: In Dashoguz and Lebap Velayats of Turkmenistan, where rangeland productivity varies considerably from year to year, the standard approach produced contradictory results and did not reliably indicate whether long-term degradation or temporary drought was being observed.

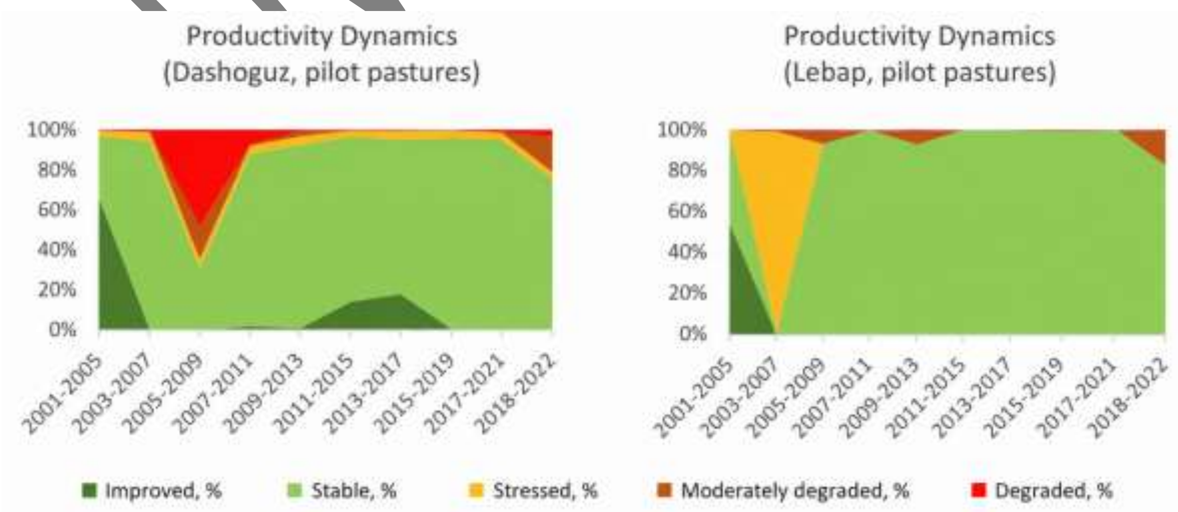


Figure 27. Dynamics of deviations in rangeland productivity from the long-term average in Dashoguz and Lebap Velayats, Turkmenistan

Application of the method: The calculation of long-term average NDVI values for 2001-2022 and the analysis of five-year dynamics for each pixel clearly indicated when conditions were better or worse than average. In addition to demonstrating differences in the dynamics of rangeland sites, this technique also made it possible to distinguish long-term trends from short-term fluctuations associated with dry or wet cycles.

The transition to a dynamic baseline can be regarded as a fundamental step in adapting the global methodology to regions characterised by high climatic and socio-economic variability. This approach has underpinned many subsequent tools for the analysis of trends, volatility, breakpoints and recurrence.

Chapter 11. New possibilities for using the dynamic baseline and time-series analysis

One of the most important implications of the transition to a dynamic baseline is the possibility of conducting a full time-series analysis of land condition indicators. Whereas the traditional UNCCD methodology effectively compares two fixed periods, the proposed logic treats land degradation or improvement as a continuous process that develops over time.

As noted above, the key instrument for this analysis is the moving average method. Its use enables a transition from simple monitoring to trend analysis: not only to record the fact of degradation, but also to assess the rate at which it develops. This approach creates the basis for more advanced analytical procedures, including the assessment of probable scenarios of future dynamics. The corresponding methodological opportunities are considered below.

Case 7: Quantitative assessment of reporting volatility in Kyrgyzstan and Tajikistan [12].

Problem addressed: Significant dependence of the final estimate of the share of degraded land on the choice of baseline period, rendering national and subnational reports vulnerable to criticism and manipulation.

Context: During preparation of national reports for the UNCCD, the question arose as to how reliable the estimates were if they changed so markedly when the baseline period was shifted.

Application of the method: Results for the share of degraded land in the same monitoring period (2016-2020) were compared using two approaches: (a) the fixed baseline period 2001-2015, recommended for PRAIS reporting; and (b) a dynamic moving-average approach, in which the entire period 2001-2020 was used as the reference base.

Result: The results revealed a substantial degree of discrepancy. Use of the 2001-2015 baseline period led to a considerable underestimation of the share of degraded land, by up to 70% for the LDN Index and up to 44% for the SDG 15.3.1 value, compared with the 2001-2020 baseline period. At the subnational level, discrepancies were even larger, masking both areas of degradation and areas of improvement, thereby preventing balanced land-use management decisions.

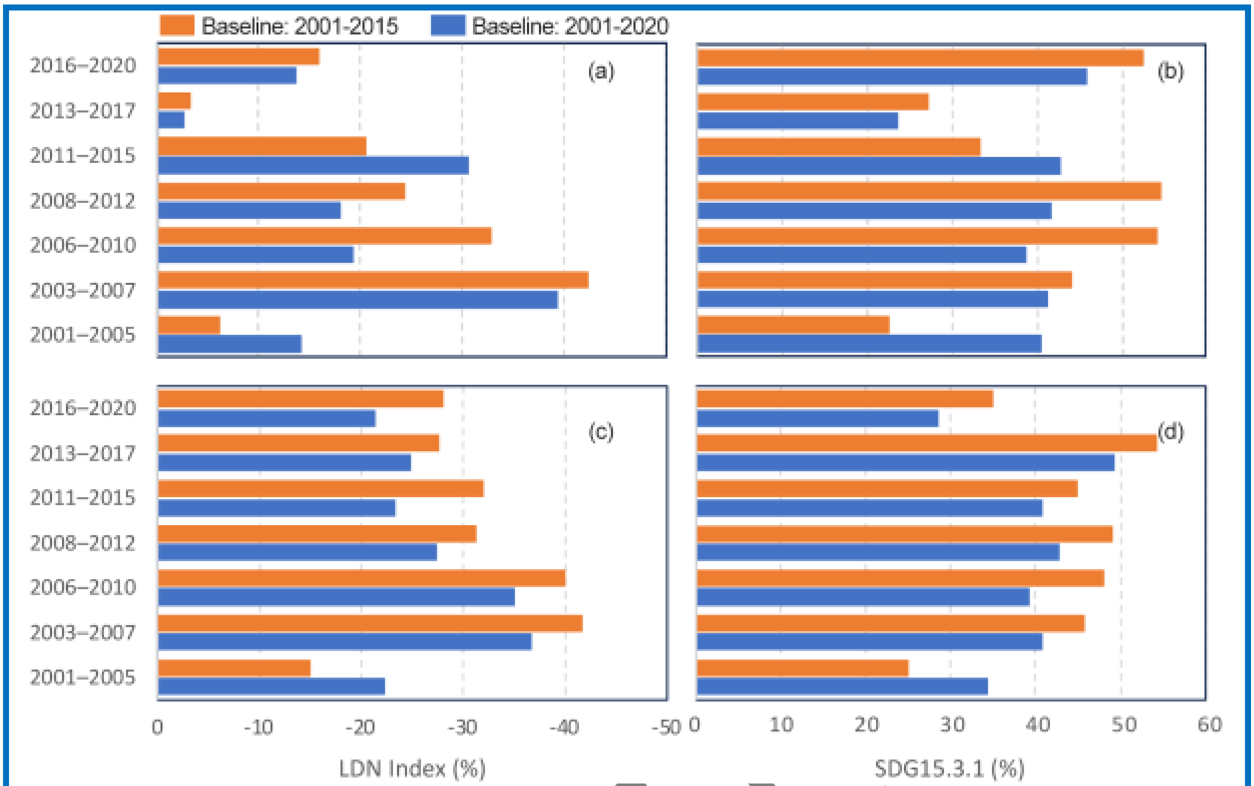


Figure 28. Comparison of national LDN Index values and SDG indicator 15.3.1 values for two baseline periods (2001-2020 and 2001-2015) for Kyrgyzstan (panels a and b) and Tajikistan (panels c and d)

These examples illustrate the fundamental dependence of LDN indicators on the choice of baseline period and, consequently, the instability of reporting. In other words, whereas estimates of degradation based on fixed baseline periods may change substantially with each data update, the use of a moving-window method based on a dynamic baseline stabilises results and increases confidence in the monitoring system.

Case 8: Assessment of the spatio-temporal dynamics of productivity trends in Karakalpakstan (based on materials of the UNDP-Uzbekistan project, 2025 [121]).

Context: To assess progress towards LDN targets at the subnational level, it is important to understand whether land productivity is increasing or decreasing in the long term, and where this is occurring.

Application of the method: On the basis of data series obtained in a semi-automated manner using Trends.Earth, map schemes are prepared that clearly demonstrate both the spatial distribution of five-year productivity trends and their pixel-level dynamics.

2001-2005 2003-2007

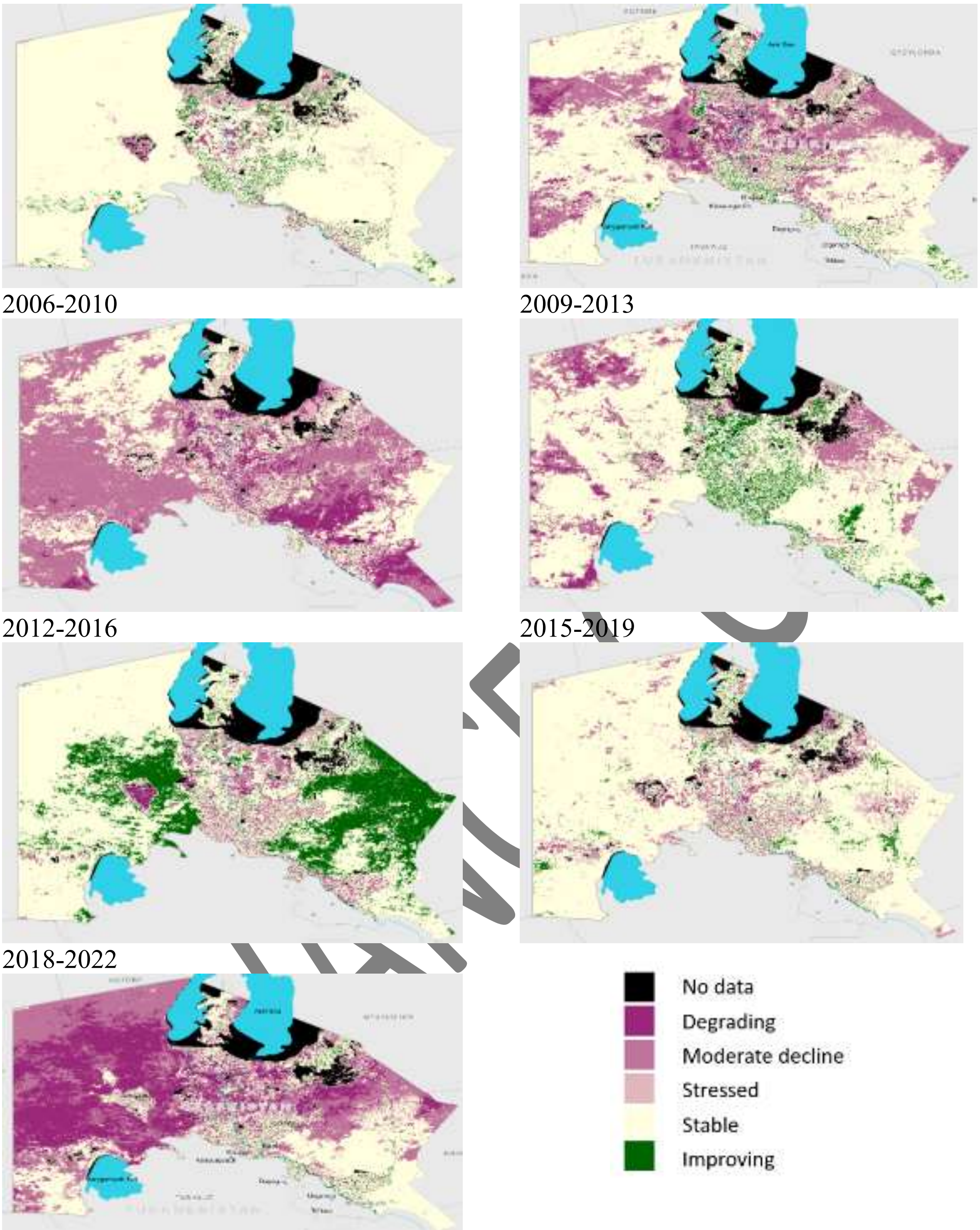


Figure 29. Dynamics of changes in land productivity trends in Karakalpakstan

Result: These cartographic materials are subsequently used for trend assessment, forecasting and refinement of the location of "hotspots" and areas of sustained improvement. This enables a transition from a binary "degraded/not degraded" assessment to an understanding of the spatio-temporal dynamics, reversibility and directionality of processes

Case 9: Identification of breakpoints in Tajikistan.

Time-series analysis proved to be of particular value in identifying so-called breakpoints: moments in time when the direction of a trend changes. Such points often coincide with major economic reforms, shifts in land-use systems or extreme climatic events. Their identification provides new opportunities for evaluating policy effectiveness and planning adaptation measures.

Problem addressed: The need to identify moments of fundamental trend reversal, when accumulated impacts or a climatic shock shift the system into a new, often irreversible state.

Context: Analysis of long-term dynamics of land productivity in Tajikistan demonstrated that the trend is not linear over the entire 20-year period.

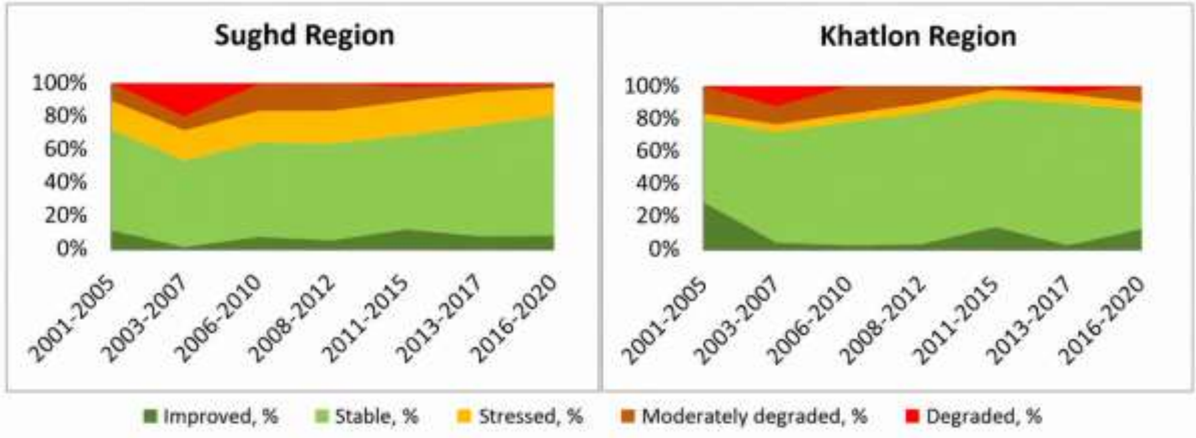


Figure 30. Dynamics of the land productivity indicator in Tajikistan

Application of the method: Using the non-parametric Pettitt test, time series for productivity dynamics and the LDN Index were analysed in order to identify a statistically significant moment of change in the mean value of the series.

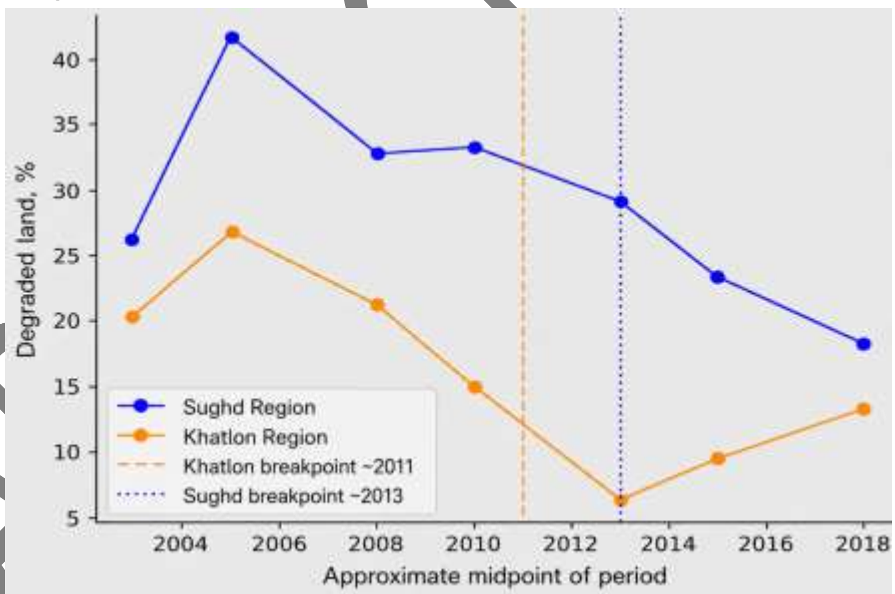


Figure 31. Dynamics of the share of degraded land for 2001-2020 with breakpoints

Result: A pronounced structural breakpoint is detected in both analysed oblasts. In Khatlon Oblast, a statistically significant regime shift is observed around 2010-2011, when the share of degraded land declined sharply from 20-27% in the earlier periods to 6-13% in subsequent years.

In Sughd Oblast, the breakpoint occurs somewhat later, around 2012-2013, with a transition from a higher level of degradation (on average 30-40%) to consistently lower values (18-23%). The Pettitt test confirms a change in the mean values of the time series and indicates the onset of sustained improvement in land productivity in the early 2010s, with the process beginning earlier and being more pronounced in Khatlon Oblast.

Understanding that land degradation responds to management decisions transforms the monitoring system from a passive observation tool into a feedback mechanism. This means that assessment results can be used not only for reporting, but also for real-time policy adjustment.

Chapter 12. Identification of land degradation hotspots and areas of sustained recovery

A further important step has been the development of methods for analysing the recurrence of land conditions. This approach is based on a simple but highly important idea: short-term changes may be random, whereas repeated changes indicate the presence of a persistent process.

The application of this method made it possible to identify territories where degradation occurs regularly and persistently. These areas were termed "hotspots". Areas of sustained improvement were identified in a similar way: territories where improvement occurs consistently over a long period (bright spots). It became apparent that these areas are of greatest interest from the perspective of land-use management.

One of the most unexpected results was that persistent hotspots generally occupy only a very small proportion of the territory. Yet they exert a disproportionately large influence on the overall dynamics of degradation. This finding has considerable applied significance, as it indicates the possibility of improving the effectiveness of LDN measures by concentrating them on a limited number of the most vulnerable or problematic zones. Such a transition from averaged assessments to spatially precise decisions may be considered one of the key achievements of the modern adaptation of the LDN methodology.

Cases 10 and 11: Recurrence analysis of trend frequency in Dashoguz Velayat, Turkmenistan (based on materials of the UNDP-Turkmenistan project, 2025 [120]), and in the Republic of Kalmykia (based on the IGRAS report, 2025 [118]).

Problem addressed: How can zones of chronic, persistent degradation be differentiated from zones where negative manifestations are random or episodic, associated with climatic fluctuations or temporary impacts? How can hotspots be reliably localised for investment purposes, so that resources are not expended on areas that may recover spontaneously in a wet year?

Context: In the Aral Sea region, with its extreme ecological and climatic variability, traditional methods did not allow priority restoration sites to be reliably located. Results varied depending on whether a dry or wet year was selected. Moreover, pixel-level analysis of series of maps indicated that, across most of the territory, recurring deterioration-improvement trends occurred in a very small share of cases, while most recurring conditions corresponded to the category of stability.

Application of the method: A recurrence analysis algorithm [122] was applied. For each pixel over the period 2001-2022, the number of ten five-year slices (2001-2005, 2003-2007, ..., 2018-2022) in which it was classified as "degraded" according to the integrated SDG 15.3.1 indicator was counted. The result is a raster in which each pixel value represents the frequency of degradation occurrence (from 0 to 100%). Similar calculations are carried out for stable conditions and improvement trends.

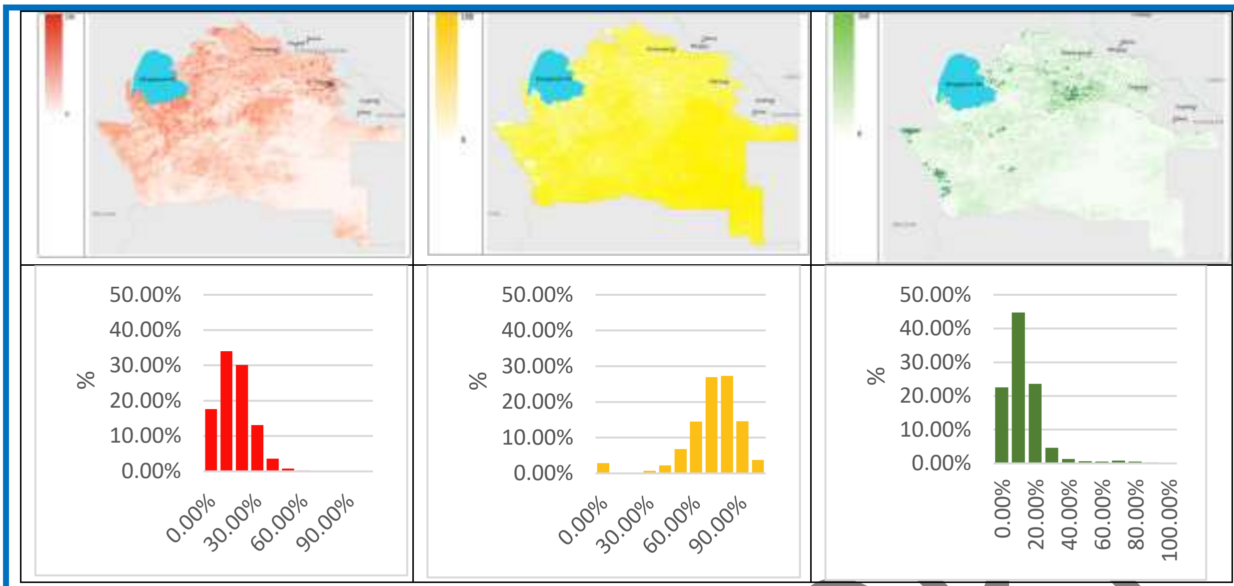


Figure 32. Recurrence analysis of deterioration - stability - improvement trends (right to left). Upper row: cartographic interpretation for Dashoguz Velayat; lower row: calculated histogram for Rukhybelent Etrap of the same velayat [120].

On the basis of these rasters, several categories of land are identified:

- Hotspots: degradation frequency > 70%. These are zones of chronic, persistent degradation requiring urgent restoration measures (the "Reverse" strategy).
- Bright spots: improvement frequency > 70%. These are zones of sustained recovery where successful practices should be studied and replicated.
- Permanently stable lands: stable conditions recur in 70% of cases or more. The priority here is to prevent degradation (the "Avoid" and "Reduce" strategies).
- Fluctuation zones: all other territories, where conditions vary in response to weather conditions or short-term impacts. Measures to prevent degradation are also a priority.

Result: Overlaying cartographic layers makes it possible to develop an informative map for selecting and calculating the required area of priority sites for land restoration in particular regions (hotspots), or sites for replicating so-called "good land-use practices".

This allows limited resources to be concentrated on clearly defined sites rather than dispersed across the whole region. An example of such a synthesis for the Republic of Kalmykia, Russian Federation, is provided below.

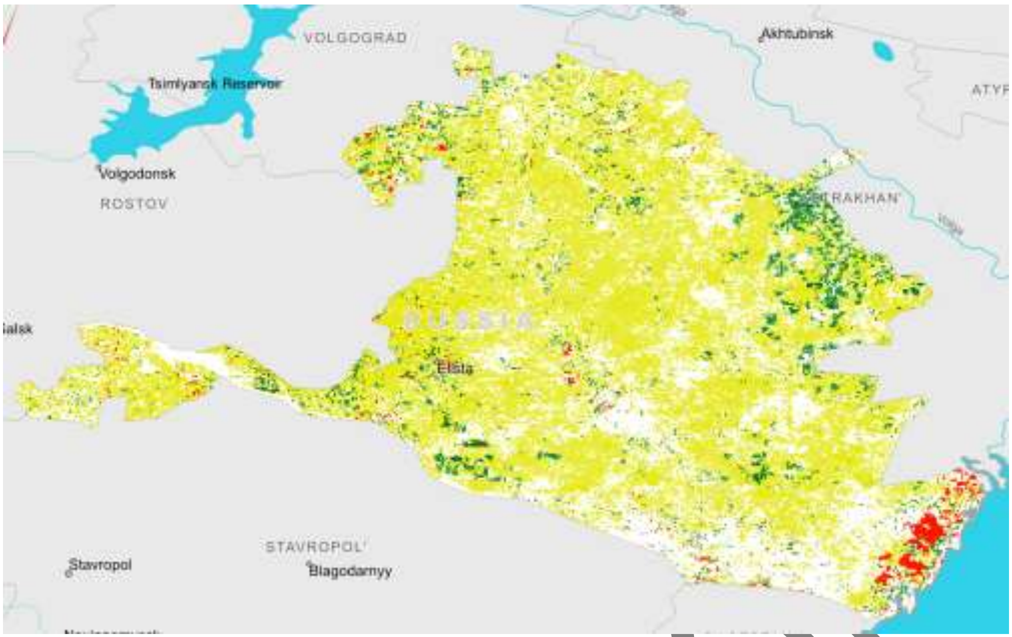


Figure 33. Cartographic synthesis of land improvement-stability-deterioration conditions with recurrence frequency above 70% (Republic of Kalmykia) [118].

Analysis of trend recurrence maps makes it possible to refine their practical application. In Kalmykia, for example, hotspots were further classified by intensity (70-80%, 80-90%, 90-100%), which made it possible to rank priorities for restoration measures even more precisely. Sites with a degradation frequency of 90-100%, the so-called critical hotspots, are regarded as zones of the highest priority and are also delineated using cartographic methods.

Table 7. Recurrence of land deterioration-improvement conditions (according to the integrated SDG 15.3.1 indicator) in Chernozemelsky District, Republic of Kalmykia.

	0%	10%	20%	30%	40%	50%	60%	70%	80%	90 %	100 %
Land deterioration (share of area, %)	1.74	8.9	23.3	36.8	21.1	6.1	0.9	0.2	0.1	0.1	0.53
Area, sq. km	190.6	979.3	2553.5	4036.0	2317.9	677.3	105.0	25.4	11.0	4.5	57.9
Stable condition (share, %)	12.8	0.0	0.1	0.7	4.1	11.9	22.6	26.9	15.2	5.1	0.4
Area, sq. km	1411.1	0.5	7.1	76.3	453.7	1312.3	2482.4	2943.7	1665.3	557.7	48.3
Land improvement (share of area, %)	46.6	32.2	8.57	1.1	0.8	2.7	3.5	2.5	1.2	0.5	0.1
Area, sq. km	5107.1	3538.8	939.0	129.2	92.8	295.91	383.5	273.45	138.5	53.2	6.8

The practical significance of the approach described above can hardly be overstated. Studies in Uzbekistan, Turkmenistan and the Russian Federation have demonstrated that persistent degradation foci occupy a relatively small proportion of the territory, yet exert a disproportionately large influence on overall dynamics. This means that measures to achieve LDN can be significantly more effective if they are directed to these localised zones.

Case 12: Digitisation and analysis of historical maps in the Hungry Steppe, Uzbekistan/Kazakhstan [94, 95, 107].

A specific example of the use of an approach close to that described above is provided by earlier comparisons of historical maps undertaken by a number of researchers.

Context: When planning large-scale land reclamation works in the Hungry Steppe, it was necessary to understand why, in some areas, leaching and drainage construction produced a lasting result, whereas in others the salts returned.

Application of the method: Detailed soil maps at a scale of 1:100,000, compiled in the 1960s and 1970s before the onset of intensive irrigation in many areas, were digitised and georeferenced. These maps reflected the "natural background": the initial condition of soils, including the presence of salts in the profile. The historical maps were overlaid with contemporary remote sensing data (salinity indices) and productivity maps.

Result: The analysis identified zones of ***"persistent" salinisation***, where salts had historically been present in soils (on ancient marine sediments) and where any attempts at leaching were inherently less effective. This made it possible to revise the reclamation programme, directing expensive chemical reclamation works and deep-drainage construction only to those sites where they could have a long-term effect. For areas of persistent salinisation, alternative strategies were proposed: cultivation of salt-tolerant crops, for example certain cotton varieties and fodder crops, or conservation with conversion to fallow land.

Chapter 13. Trend analysis: from monitoring to forecasting

The emergence of time-series analysis tools has effectively changed the very philosophy of land degradation assessment. Whereas monitoring was previously a series of "snapshots of condition", it can now be understood as observation of the development of a complex dynamic system. At first sight, this change may appear purely technical, yet its implications are much deeper.

For the first time, it becomes possible to consider land degradation as a process with its own rate, rhythm and phase transitions. This perspective is particularly important for the Central Asian region, where natural and socio-economic processes are intertwined and generate complex non-linear trajectories of change.

The development of time-series analysis methods naturally led to the next step: an attempt to look into the future. If land degradation is considered a process with its own dynamics, the question arises as to whether its further development can be predicted.

Until recently, such a question appeared premature. Monitoring systems were still being established, and the main task was to obtain reliable data on the current condition of land. However, the accumulation of time series and the development of analytical methods have made forecasting not only possible, but necessary.

13.1. Forecast modelling based on regression analysis

The first step towards forecasting was the application of regression analysis to time series of LDN indicators. This approach makes it possible to assess the rate of change in indicators and to extrapolate identified trends into the future.

The importance of this approach is difficult to overestimate. It shifts the discussion of land degradation from a qualitative to a quantitative plane. Instead of abstract statements about possible deterioration of land condition, future losses can be assessed in specific units of area and time.

This, in turn, opens the way to the formulation of realistic LDN targets. Countries and regions are able to assess the scale of restoration measures required to compensate for projected losses.

Case 13: Forecasting degradation-related losses in Iki-Burulsky District, Republic of Kalmykia (based on the IGRAS report, 2025 [118]).

Problem addressed: How can one move from recording the fact of degradation to a quantitative forecast of future losses in order to justify urgent investments in restoration? Under arid climatic conditions with high interannual variability, it is necessary to identify a persistent deterioration trend against a background of natural fluctuations and express it as a specific number of hectares that will be irreversibly lost for productive use by the target planning horizon (2030-2032) under a business-as-usual scenario.

Context: Iki-Burulsky District is identified in the study as an example of a territory following a "degradation advance" scenario. Analysis of dynamics for 2001-2022 demonstrated not only the presence of degradation, but also its persistent and aggressive growth. For planning measures under the regional programme to achieve LDN, it was necessary to answer the question: exactly how much land may be lost in the district by 2032 if no active measures are taken?

Application of the method: For the simplest quantitative assessment, the method of linear regression (trend analysis) is applied to the time series for the share of degraded land (D) over the period 2001-2022. The regression coefficient (b), reflecting the slope of the trend line, makes it possible to determine the annual rate of increase in degradation as a percentage of the total area. Using this coefficient, a general forecast of the absolute increase in degraded land over ten years (to 2032) can readily be produced. Similar calculations can also be undertaken for other trends: the share of improved land and the LDN Index.

Result: It was established that the b(D) coefficient for Iki-Burulsky District is +0.047% per year. This means that the share of degraded land is steadily increasing at this rate. With the district area of approximately 6,363 km^2, the annual increase in degraded land is about 299 ha per year. If the current trend continues, the area of degraded land in the district will increase by 2,990 ha by 2032. Taking into account the confidence interval shown in forecast graphs such as Figure 34, the range may be from 1,800 to 4,100 ha.

Interpretation: The projected loss of around 3,000 ha of productive land is comparable to the area of a medium-sized agricultural enterprise under Russian conditions. This figure becomes a key justification for budget requests and for planning phytomeliorative works, for example the planting of drought-resistant shrubs to stabilise sands, at a scale capable of compensating for expected losses, with an allowance for uncertainty. This translates planning from general aspirations into specific targets and financial calculations. In addition, such forecasts may provide the basis for setting LDN targets at national and subnational levels.

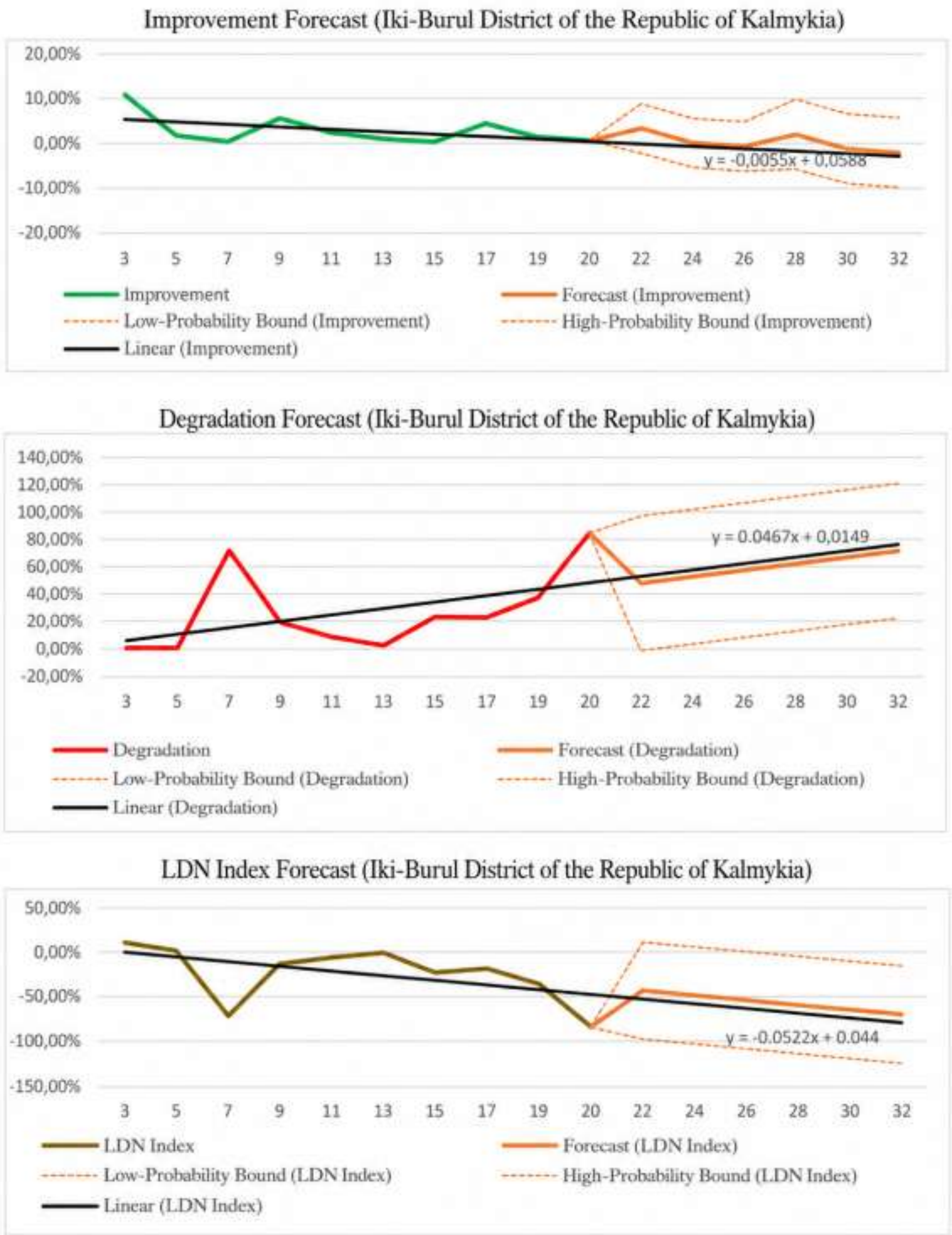


Figure 34. Forecast of the dynamics of land improvement-deterioration trends in Iki-Burulsky District

13.2. Analysis of trend dynamics for the formulation of land-use strategies

Traditional monitoring approaches embedded in international methodologies often produce distorted results in the region: natural climatic fluctuations may be erroneously interpreted as degradation, while real deterioration in land condition is masked if the comparison period includes favourable years. This leads to management strategies either being delayed or proving inadequate to real processes. For example, irrigated areas in the lower Amu Darya may degrade under a "depletion" scenario requiring one set of measures, while rangelands may enter a phase of active "degradation advance" requiring entirely different, urgent responses. To address this issue, [42] proposed a double-threshold method that differentiates priority LDN management strategies according to different land degradation scenarios in Central Asia.

Understanding which degradation mechanism has been triggered in a given territory becomes the key to the effective use of limited resources. The case below, using the velayats of Turkmenistan as an example, demonstrates how in-depth trend analysis makes it possible to move from uniform plans to a scientifically grounded portfolio of differentiated land-use strategies.

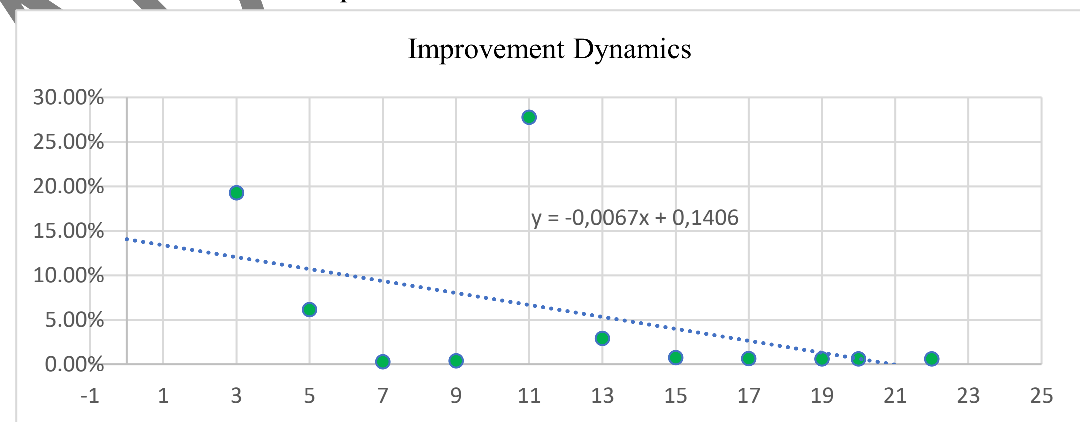
Case 14: Formulation of land-use strategies based on the analysis of degradation trends in Dashoguz and Lebap Velayats, Turkmenistan (based on materials of the UNDP-Turkmenistan project, 2025 [120]).

Problem addressed: Under conditions of high interannual variability in arid ecosystems, how can degradation be not merely recorded, but its underlying mechanisms diagnosed so that an adequate land management strategy can be selected? The use of fixed baseline periods produces contradictory results and does not enable short-term climatic fluctuations to be distinguished from persistent negative trends requiring intervention. It is necessary to move from uniform plans to differentiated strategies that reflect the specific development of the crisis in each territory.

Context: In the pilot regions of Turkmenistan (Dashoguz and Lebap Velayats), which are highly exposed to desertification in the Aral Sea basin, the standard SDG 15.3.1 assessment with different baseline periods produced non-comparable results. For planning activities under national LDN objectives, it was necessary to understand not only where degradation was occurring, but also how it was unfolding, so as to allocate limited resources between emergency restoration and preventive measures on a justified basis.

Application of the method: An approach was applied based on the use of a dynamic baseline (the median for 2001-2022) and the smoothing of short-term fluctuations using a five-year moving average. This made it possible to remove climatic "noise" from the data. Regression analysis was then applied to the resulting dynamic series in order to calculate two key coefficients:

- Coefficient "b" (rate of change,% per year), demonstrating the intensity of processes.
- Coefficient "a" (estimated condition at the beginning of the period), demonstrating accumulated resilience potential or the level of crisis..



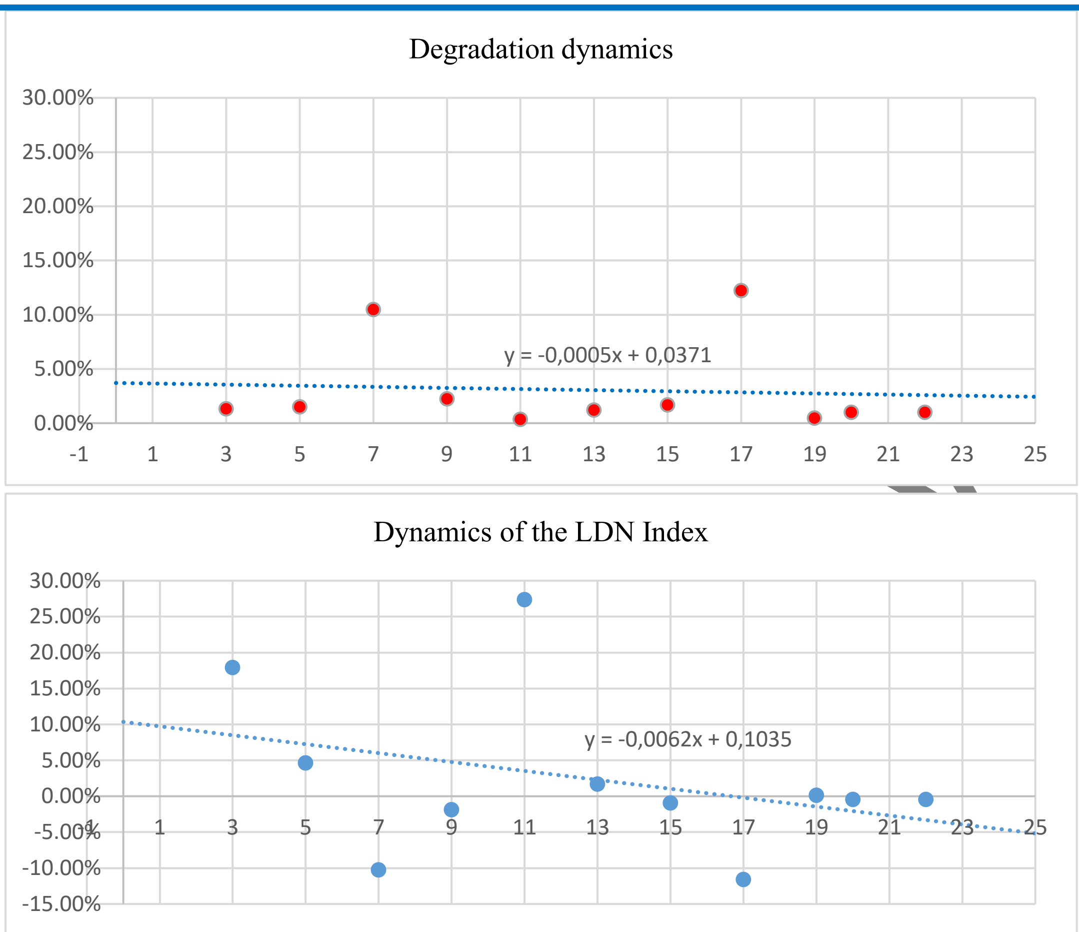


Figure 35. Example of analysis of the dynamics of land improvement and deterioration trends using regression analysis (Darganata Etrap, Lebap)

The joint analysis of these coefficients for the share of degraded land (D) and improved land (I) made it possible to diagnose the dominant mechanism, or scenario, of degradation.

Sub-case 14.1: Scenario modelling (based on materials of the UNDP-Turkmenistan project, 2025 [120]).

The next stage was the development of a scenario-based approach. Instead of a single forecast scenario, several possible development trajectories may be considered on the basis of coefficient combinations, reflecting different land management options.

Scenario analysis makes it possible to answer a key question: how will the dynamics of land degradation change if existing land-use practices are maintained, and how may they change if sustainable practices are introduced? This approach is particularly important for regions with high uncertainty regarding future climatic conditions. It enables a broad range of possible factors to be taken into account and enhances the robustness of decisions.

Result: Analysis of the trends described above revealed pronounced differentiation in degradation mechanisms across the territories studied, requiring fundamentally different management strategies:

"Degradation advance" scenario (Danev Etrap, Lebap): the most aggressive negative trend in the LDN Index was recorded here (b = -0.0181% per year), driven by the rapid expansion of degradation areas (b(D) = +0.015% per year). The initial condition (a = +4.8%) was good, but the crisis is developing in an avalanche-like manner. Strategy: crisis response.

"Depletion" scenario (Turkmenbashi Etrap, Dashoguz; Darganata Etrap, Lebap): the negative trend in the LDN Index (b = -0.0112 to -0.0062% per year) is formed mainly through a decline in the share of improving land (b(I) < 0) while degradation stagnates. In Turkmenbashi, the situation is aggravated by an extremely poor initial condition (a = -5.2%). Strategy: preventive strengthening and stabilisation - investment in maintaining the productivity of remaining viable land and phased rehabilitation.

Combined scenario (Rukhybelent Etrap, Dashoguz): simultaneous growth in degradation (b(D) = +0.005% per year) and a decline in improvement (b(I) = -0.0064% per year) indicate systemic failure. Strategy: an integrated plan combining urgent measures in hotspots and support for resilience across the rest of the territory.

Natural cyclicity (Gaplangyr Nature Reserve): a weak negative trend (b = -0.004% per year), low model predictability ($R^2 = 0.45$) and very limited improvement potential (a(I) = 7%) indicate an ecosystem existing in a fragile equilibrium. Strategy: conservation and adaptive management, protection from anthropogenic pressure rather than costly restoration.

Interpretation: Unlike a simple statement that degradation is occurring, diagnosis of mechanisms enables a transition to justified policy choices. Based on combinations of coefficients "a" (initial condition/potential) and "b" (rate and direction of change), the following typical land management strategies can be distinguished within the LDN concept:

1. Crisis response strategy. Characteristic of territories that initially had high potential ("a" high), but shifted into a phase of rapid deterioration ("b" sharply negative). Requires immediate capital-intensive measures to halt cascading degradation.

2. Preventive strengthening strategy. Applied where the current condition remains stable ("a" high), but a persistent though moderate deterioration is observed ("b" moderately negative). The aim is to invest in maintaining resilience, for example water saving and soil protection, in order to reverse the sign of the trend.

3. Stabilisation and phased restoration strategy. Required in territories already in crisis ("a" low) and continuing to deteriorate ("b" negative). Requires a combination of urgent suppression of active degradation foci and long-term rehabilitation programmes.

4. Conservation and adaptive management strategy. Suitable for ecosystems adapted to extreme conditions at a low level ("a" low) with a weak trend ("b" weak). The priority is protection from new anthropogenic threats, rather than costly restoration to historical states.

5. Maintaining positive dynamics strategy. Applicable where the initial condition was poor ("a" low), but management has turned the trend positive ("b" positive). The main task is to ensure long-term support for restoration processes.

Practical value: This approach enables a transition from uniform plans to a portfolio of differentiated measures, precisely tailoring sustainable land management strategies to the specific type of degradation crisis.

Chapter 14. Use of neural networks and machine learning

The development of forecasting methods inevitably led to the use of machine-learning tools. Land degradation is the result of interactions among a large number of factors: climatic, soil-related, hydrological and socio-economic. Traditional statistical methods are not always capable of accounting for such complexity.

The use of machine-learning algorithms opens the possibility of analysing large datasets and identifying hidden relationships among degradation drivers. This area is still at an early stage of development, but initial results demonstrate considerable potential. Machine learning and neural networks are becoming a powerful instrument for tasks in which traditional methods are constrained by the complexity and non-linearity of relationships between spectral characteristics and land condition.

Machine-learning models make it possible to identify the key drivers of degradation, assess their relative significance and construct more accurate forecasts. In the longer term, this may lead to the establishment of integrated decision-support systems for land use.

Case 15. Possibilities for forecast modelling of land-use change using alternative approaches (Nukus District, Uzbekistan [112]).

Context: Linear regression is not always capable of capturing complex non-linear patterns of change, especially when spatial distribution of future changes is at issue, rather than merely their total area. Tools capable of modelling spatial dynamics are required.

Application of the method: Researchers applied the CA-ANN approach (cellular automata - artificial neural network), a spatial model implemented in the MOLUSCE module for QGIS. The model is also "trained" on maps of changes over previous periods (2001-2010 and 2010-2022) and, taking into account factor maps (distance to roads, settlements and others), forecasts the land-use map for 2042, indicating where changes are most likely to occur.

Result: The model indicates a persistent reduction in cropland and rangeland areas, as well as desert lands, against a background of growth in the "artificial surfaces" category. It also provides a map of future change hotspots, indicating where conflict between built-up areas and agriculture is likely to be most acute. At the same time, the model does not account for transition rates.

Case 16. Digital mapping of soil salinity in Kalmykia using neural networks (based on [100-102]).

Context: In Kalmykia, where solonetzic complexes with subsurface salinity are widespread, traditional mapping methods require extensive fieldwork and are not always accurate. Linear models do not cope adequately with the non-linearity of relationships.

Application of the method: Field measurements of electrical conductivity (EC) and a broad set of spectral indices (NDVI, SAVI, EVI, salinity indices SI and others) derived from high-resolution SuperView-1 imagery (2 m) are used to train two models: multiple linear regression (MLR) and an artificial neural network (ANN). The objective is to predict soil salinity from satellite data.

Result: The neural network demonstrated substantially higher accuracy in salinity prediction (coefficient of determination R^2 up to 0.88) than linear regression (R^2 up to 0.70). The best predictors were NDVIt, TVI, EVI1 and Int1 indices. In other words, neural networks are capable of capturing complex non-linear relationships between spectral response and salinity, making them indispensable for the creation of accurate maps over large areas. This experience can be scaled up to irrigated areas of Uzbekistan and Turkmenistan.

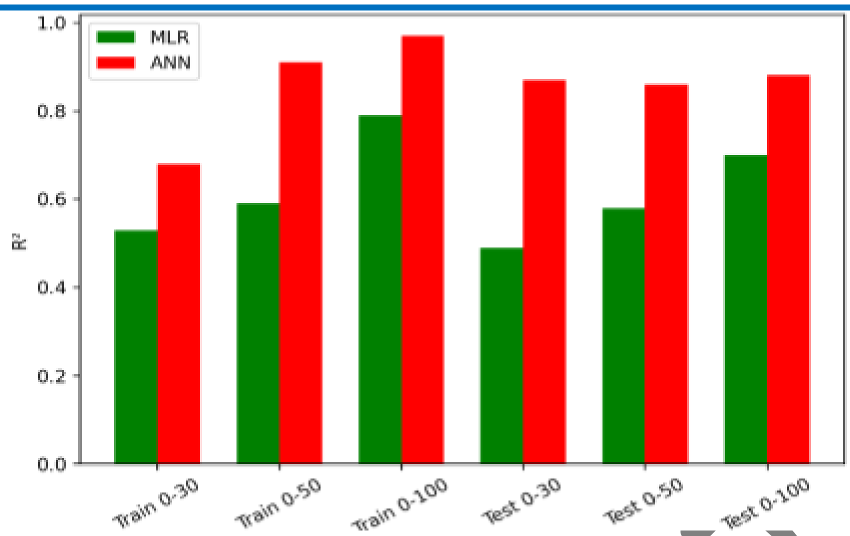


Figure 36. Comparison of the accuracy of MLR and ANN models for salinity prediction.

Case 17: Refinement of land-cover dynamics at the local level using neural networks (Prieltonye, Volgograd Oblast, Russian Federation) [108].

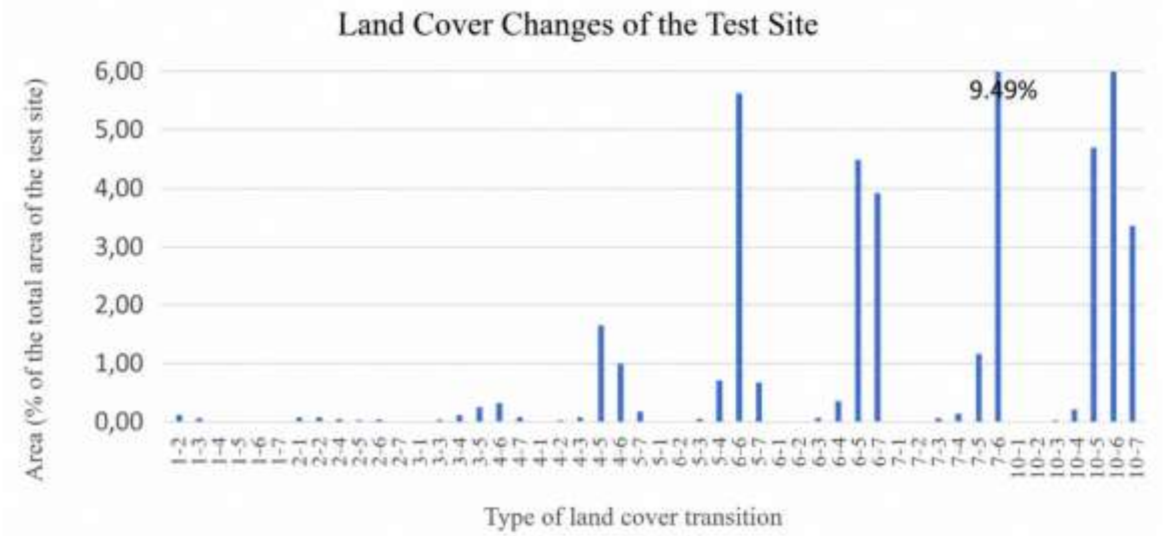
Problem addressed: How can one move from global aggregated degradation estimates to an accurate and reliable picture at the local level, required for planning specific measures to achieve LDN? The standard Trends.Earth approach, based on 300 m data and a limited set of land classes, cannot capture the complex mosaic of lands, divergent processes of recovery on abandoned lands and degradation on rangelands, and therefore provides a distorted picture of the actual balance. A method is needed that can reliably assess which processes, degradation or improvement, dominate in an area with high spatial heterogeneity.

Context: The territory consists of a mosaic of abandoned lands, rangelands under different grazing pressures, rainfed croplands and solonchaks. Previous studies demonstrated that global products, including Trends.Earth, incorrectly interpret dynamics in such territories, often concealing important local processes; for example, the recovery of steppe vegetation on abandoned land is masked by the general category "grassland communities". For correct reporting under SDG indicator 15.3.1 and for planning rotational grazing systems, a methodology operating at the level of individual fields and rangeland plots is required.

Application of the method: Self-organising Kohonen neural networks (implemented in ScanEx Image Processor software) were used as the main tool, applied to the analysis of a series of multi-temporal Landsat images (30 m resolution) for 2004 and 2014.

The standard approach is modified as follows:

- ***Detailing:*** instead of seven classes, an expanded classification adapted to local conditions is used. Rangeland subclasses are distinguished: conditionally non-degraded, slightly degraded, moderately degraded and strongly degraded rangelands, as well as vegetation of small depressions and solonchaks.
- ***Transition analysis:*** using the Change Detection module (SAGA GIS), a transition matrix was analysed not for seven, but for more than twelve classes. This made it possible to track the fate of each pixel, for example transitions from "cropland" to "slightly degraded rangeland" or from "strongly degraded rangeland" to "moderately degraded rangeland".
- ***Validation:*** classification results were compared with ground survey data from key sites established along a gradient of grazing pressure.



1 - Water bodies, 2 - Solonchaks, 3 - Vegetation of linear and closed liman depressions, 4 - Strongly degraded rangelands, 5 - Moderately degraded rangelands, 6 - Slightly degraded rangelands, 7 - Non-degraded rangelands, 10 - Cropland

Figure 37. Histogram of land-cover change types.

Result: The application of neural-network analysis with an expanded classification fundamentally changed the assessment of land-cover dynamics compared with the standard Trends.Earth method:

- ***Improved accuracy:*** the standard approach detected changes in only 27.5% of the territory (24.6% degradation and 2.9% improvement). The refined method demonstrated that changes affected 54% of the territory, with a different balance structure: degradation was identified on 40.6% and improvement on 13.4% of the area.
- ***Identification of hidden processes:*** divergent trends were quantitatively separated. The principal changes were associated with the withdrawal of cropland from production and its transition to rangelands. At the same time, recovery was recorded on the rangelands themselves: the share of strongly degraded areas declined from 5.3% to 2.6% owing to the redistribution of pressure onto new abandoned land areas.

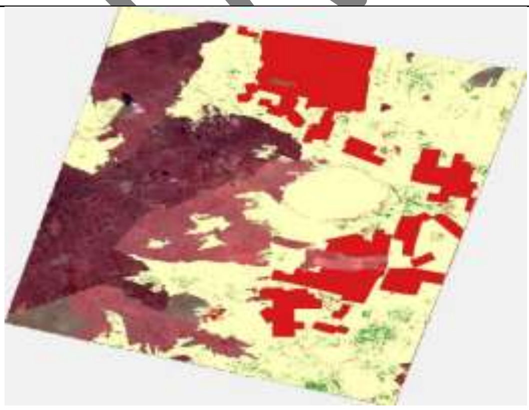
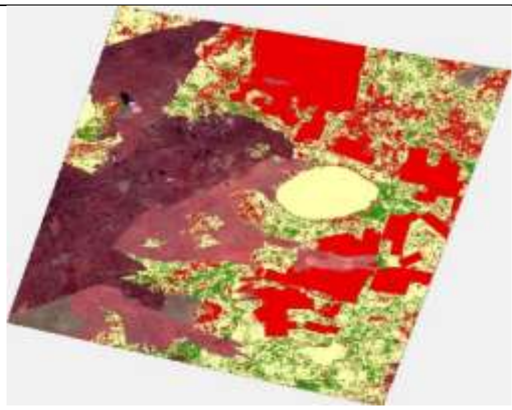
A. Using the Trends.Earth scoring matrix (default)	B. Using the extended stand classification and a scoring matrix adapted to local conditions
	

Figure 38. Assessment of land-cover degradation at the test site using different classifications and assessment matrices (the mask of steppe fires from different years, excluded from consideration, is shown in brown).

Management interpretation: The result demonstrated that a formal assessment of "degradation" over 40% of the area under the baseline methodology masks a complex process of post-agrogenic transformation, namely the revegetation of abandoned lands. For management purposes this means that the "red" zone on the LDN map requires not only measures to combat desertification, but also regulation of grazing pressure on newly available lands, in order to consolidate the positive recovery trend and prevent secondary degradation. The proposed approach identifies such nuances and supports more balanced recommendations than those generated using default data.

Chapter 15. Rethinking land-cover classification: modification of transition matrices

One of the important challenges in applying the global LDN methodology in Central Asian countries is the mismatch between global land-cover classifications and regional conditions. Global classifications were created to ensure comparability of data at the worldwide level. Yet detailed analysis reveals that they are overly generalised.

The previous case demonstrated how modification of land-class transition matrices may influence the results of land degradation assessment. Alongside baseline formation and indicator selection, this aspect is significant when applying the LDN methodology at national and subnational levels in the Central Asian region. This is because the standard class sets used in baseline UNCCD tools are universal in nature and may not fully account for the regional specificity of natural and production systems. It is therefore advisable to give attention to the formation of adapted land-class transition matrices that take into account both landscape diversity (forests, rangelands, cropland, desert areas and others) and differences in the character of land use (agriculture and forestry, protected areas, industrial lands and other categories). In post-Soviet countries, a unique land-use structure has formed as a result of historical, socio-economic and natural-climatic interconnections, including categories such as abandoned cropland, degraded rangelands and secondarily salinised lands. These categories play a key role in degradation dynamics, but are not always correctly represented in global classifications. The development of expanded regional classifications has become an important step towards increasing assessment accuracy. It makes it possible to account for land-use characteristics and improve interpretation of monitoring results.

Case 18: Adaptation of the transition matrix for irrigated lands and rangelands of Uzbekistan (with sign calibration), the Yashil Makon State Programme [109] (based on materials of the UNDP-Uzbekistan project, 2025 [120]).

Problem addressed: The global transition matrix embedded in Trends.Earth inadequately interprets land-cover class changes that are critically important for the region, for example "cropland -> fallow" and "saxaul woodland -> rangeland", resulting in systematic errors in degradation assessment.

Context: The transition "irrigated cropland -> fallow" is often interpreted in the global matrix as neutral or even positive because grass cover increases on fallow land. In reality, however, in the Central Asian region this is often the outcome of irreversible secondary salinisation and the loss of productive land; it is therefore an unequivocal sign of degradation.

Application of the method: A national expert group (soil scientists, agronomists and land-management specialists) redefined the sign of this transition as "negative" for all cases confirmed by salinity data (spectral indices, historical maps).

For another complex transition - "saxaul woodland (forest) -> ephemeral desert (grassland)" - clarifying conditions requiring verification were introduced:

- If thinning is caused by cutting and overgrazing - negative.
- If it is the result of natural dieback of old saxaul during a dry period within a natural cycle - neutral (temporary fluctuation).

Result: Application of the calibrated matrix made it possible to correctly assign areas of "irreversibly lost" irrigated land to the degraded category. This changed the priorities of the Yashil Makon State Programme, directing resources not only towards greening, but also towards land reclamation and investigation of the causes of land withdrawal from production.

Case 19: Adaptation of the transition matrix: from global classes to local types of irrigated lands and rangelands in the lower Amu Darya (detailing for district and local levels), based on UNDP-Turkmenistan 2025 and UNDP-Uzbekistan 2025 project materials [120, 121].

Problem addressed: How can the global LDN assessment methodology be adapted to obtain reliable results at district and local levels under arid-zone conditions? The use of standard global land-cover classifications and transition matrices in Uzbekistan and Turkmenistan leads to critical interpretation errors. Processes of "false greening", such as fields overgrown by sarsazan on solonchaks or the encroachment of low-value shrub species on rangelands, are automatically classified as "improvement" by satellite indices, although in reality they are signs of degradation, loss of economic value and salinisation. A "translator" from global language to local conditions is required to diagnose degradation accurately for the planning of preventive measures.

Context: Within UNDP projects in Uzbekistan and analogous initiatives in Turkmenistan, the task was not merely to assess land condition, but to provide specific management recommendations. Pilot districts in the lower Amu Darya are characterised by a highly mosaic land structure: irrigated fields, tugai forests, desert rangelands and drying lakes occur side by side. The standard set of classes - "forest", "rangeland", "cropland" - proved too coarse. It did not make it possible to trace critically important transitions, such as the replacement of valuable fodder saxaul by low-productivity saltwort communities, or the transition of irrigated cropland to the category of "bare solonchak".

Application of the method (adaptation of transition matrices): To address the problem, the LDN methodology was calibrated in two stages.

1. Detailing of land-cover classification: Instead of general classes, project experts developed hierarchical classifications that take into account the economic value and ecological functions of land. For example:

- For rangelands: the class "shrub rangelands" was divided into subtypes: saxaul, tamarisk, and transitional saxaul-tamarisk communities. The class "saltwort rangelands" was divided into ajrek, akbash, sarsazan and annual saltwort communities.
- For irrigated lands: a gradation was introduced not only by use ("irrigated/abandoned cropland"), but also by condition: "irrigated cropland without signs of salinity", "irrigated cropland with signs of salinity"; for abandoned lands, "shrub areas on solonchaks", "bare solonchaks" and "bare sands" were distinguished.

2. Development of regional transition matrices: Adapted transition matrices were prepared for these detailed lists, assigning each transition between subtypes the status of "improvement", "stable" or "degradation". The status was determined by experts on the basis of economic value. For example, the transition from "irrigated cropland without signs of salinity" to "abandoned cropland with shrubs on solonchaks" is unequivocally classified as degradation, even if the satellite NDVI increased (sarsazan produced "greenness"). Conversely, the transition from "bare solonchak" to "saxaul woodland" on rangeland is considered improvement.

Table 8. Assessment table for evaluating land-cover dynamics of rangelands at the level of rangeland units (with the addition of species-composition indicators).

Class of Pastures From:↓	Class of Pastures To →	Shrub			Semi-shrub-herbaceous					Saltworts				
		1	2	3	1	2	3	4	5	1	2	3	4	5
Shrub	1. Saxaul	=	-	-	+	-	=	-	-	-				
	2. Saxaul+Tamarix	+	=	-	+	+	+	-	-					
	3. Tamarix	+	+	=	+	+	+	=	-					
Semi-shrub-herbaceous	1. Teresken	-	-	-	=	-	-	-	-	-				
	2. Keyreuk	+	-	-	+	=	+	-	-					
	3. Wormwood	=	-	-	+	-	=	-	-					
	4. Dereza	+	+	=	+	+	+	=	-					
	5. Karabarak	+	+	+	+	+	+	+	=					
Saltworts	1. Annual saltworts	+			+					=	=	-	-	-
	2. Azhrek									=	=	-	-	-
	3. Quinoa (Atriplex)									+	+	=	-	-
	4. Akbash									+	+	+	=	-
	5. Sarsazan									+	+	+	+	=

* Improvement Stable Degradation

Bonitet Index To → From↓	I	II	III	IV	V	No forest stand
I						
II						
III						
IV						
V						
No forest stand						

Improvement Stable Degraded

Table 9. Assessment table for evaluating land-cover dynamics of forest areas.

Result: As a result of the adaptation, a practical tool for district and local levels was created.

- For rangelands: It became possible to map not simply "degradation", but its specific manifestations. For example, in Muynak District, Karakalpakstan, where global data recorded zones of "stress", the adapted matrix demonstrated that, over an area of approximately 1,500 km², saxaul communities were being replaced by low-productivity akbash and sarsazan communities (halophytisation). This made it possible to translate the problem from the general category of "instability" into a specific target for rangeland plans: restoration of fodder value through soil desalination and sowing of teresken.
- For irrigated lands: The updated transition matrix made it possible to quantify risks. In the area influenced by IWRM (integrated water resources management) projects in Amu Darya District, Karakalpakstan, it was established that at least 12% of lands recorded as

"irrigated" are in fact in a transitional stage towards "abandoned with signs of salinity". A forecast based on these matrices showed that, without improved drainage and water saving, by 2030 these lands would move into the category of "bare solonchaks", irreversibly lost for agriculture.

Interpretation: Adapted transition matrices may be described as a "traffic light" that precisely indicates where land is genuinely improving (green), where it is stable (yellow), and where it is degrading (red), while ignoring "false greening". This translates land management from a conceptual plane to the level of precise economic decisions: investors and farmers now have a tool that helps them understand that field overgrowth in this case is not ecosystem recovery, but a direct loss of cropland requiring urgent reclamation.

Chapter 16. Use of high-resolution remote sensing data and modern methods for their interpretation and the interpretation of results

The preceding sections have already addressed the effectiveness of using materials with higher resolution than those used to date in the Trends.Earth methodology. Higher-resolution data make it possible to identify local changes that remain invisible when global datasets are used. This is especially important at the subnational level, where specific management decisions are made. Low spatial resolution does not allow the small-contour nature of oasis landscapes, the patchiness of rangelands or the focal character of degradation to be identified. Averaging spectral characteristics within a pixel may limit the ability of remote-sensing algorithms to differentiate fundamentally different surface types, for example crusted solonchak and stabilised sand, leading to incorrect classification [113, 116].

The emergence of high-resolution satellite data has opened new opportunities for analysing the spatial structure of land degradation processes. The integration of satellite data with field observations has become an important step towards improving the reliability of assessments. It makes it possible not only to identify changes, but also to verify their interpretation [75, 114, 115].

Without attempting a comprehensive review of all developments currently available, this chapter considers some of the most interesting ones and presents them as short cases. Using specific examples from the five Central Asian countries and neighbouring regions with similar natural conditions, it demonstrates how these new methods and data help to address key LDN assessment tasks.

Case 20: Integration of radar and optical data with machine learning for mapping salinity of irrigated lands (Xinjiang, China - a model for Central Asia) [43].

Problem addressed: Secondary salinisation is the principal threat to the productivity of irrigated lands in Uzbekistan, Turkmenistan and Kazakhstan. However, traditional methods for assessing salinity using satellite data are constrained under vegetation cover (the "green degradation" phenomenon). Methods are needed that can "see" salts beneath the canopy of cultivated plants.

Context: The Xinjiang Uyghur Autonomous Region of China is almost identical in soil-climatic conditions and agricultural techniques to the irrigated areas of the Fergana Valley, the Hungry Steppe and the lower Amu Darya.

Methods applied: The Eighth Agricultural Division of Xinjiang was selected as a model territory. In combination with soil sampling under conditions of high vegetation cover, three types of predictors were used [43]:

- Radar information (Sentinel 1): polarisation indices sensitive to surface structure and moisture.
- Multispectral information (Sentinel 2): vegetation indices and spectral bands.
- Environmental variables: topographic factors (elevation, slope) and land surface temperature.

Four datasets (A, B, C, D) were generated with different combinations of these variables, and three machine-learning algorithms were applied: AdaBoost, gradient boosting (GBRT) and XGBoost.

Result: The best salinity mapping performance was achieved by the D-XGBoost model, which combined all three types of data: radar, optical and ground-based environmental variables. On the validation sample, it reached $R^2 = 0.72$ and RMSE = 2.40 g/kg [43]. Models that included topographic factors demonstrated higher accuracy than models based only on spectral indices. A particularly strong correlation was found between salinity and elevation ($r = 0.52$).

Conclusion for the region: The integration of radar data (Sentinel-1) with multispectral data (Sentinel 2) and topographic variables enables effective mapping of salinity even under vegetation cover, which is critically important for the early identification of "green degradation" on irrigated lands in Central Asia.

Case 21: Integrated monitoring of agricultural lands in the Aral Sea region using Landsat indices (Kazakhstan) [1].

Problem addressed: Degradation of irrigated lands in the Kazakh part of the Aral Sea region (Kyzylorda Region) is complex, combining reduced productivity, declining water availability and soil salinisation. The development of adaptation strategies requires simultaneous monitoring of all these parameters.

Context: Kazaly District of Kyzylorda Region is directly adjacent to the Aral Sea and experiences the full consequences of the ecological crisis.

Methods applied: Landsat-8 time-series images for 2014-2023 and three key spectral indices [1] were used: NDVI (Normalised Difference Vegetation Index) for analysing crop development dynamics and assessing productivity; NDWI (Normalised Difference Water Index) for assessing water availability; and NDSI (Normalised Difference Salinity Index) for mapping the degree of soil salinity.

Data processing was undertaken in EOSDA Land Viewer and QGIS, with the development of a series of thematic maps for the ten-year period.

Result: Detailed maps were produced, demonstrating the spatio-temporal dynamics of all three processes. This made it possible to identify areas where declining NDVI correlates with increasing NDSI, clearly indicating salinity as the cause of degradation, and areas where declining NDVI is associated with decreasing NDWI (water deficiency). The resulting maps provide a basis for ranking territories by priority for reclamation interventions and serve as a foundation for developing adaptation strategies under the continuing desiccation of the Aral Sea. The work demonstrated the effectiveness of using three indices jointly on the basis of medium-resolution Landsat imagery for operational monitoring of complex degradation processes in the region.

Case 22: Mapping water erosion risks using the RUSLE model and field validation (Uzbekistan) [24].

Problem addressed: In foothill and mountain areas, water erosion of soils is one of the principal degradation processes threatening the productivity of rainfed lands and rangelands. Quantitative risk assessment and identification of critical zones ("hotspots") are required.

Context: The study was conducted in Ugam-Chatkal National Park, where a combination of mountainous terrain, intensive land use and overgrazing creates high erosion risks.

Methods applied: The RUSLE model (Revised Universal Soil Loss Equation), integrated into a GIS environment, was used. The model accounts for five key factors: rainfall erosivity, soil erodibility, slope length and steepness, vegetation cover and land-use practices. Field survey data (georeferenced points with descriptions of erosion forms) were used to calibrate and verify the model. Validation was conducted through joint field visits by specialists from the Ministry of Emergency Situations, Uzhydromet and the Forestry Agency.

Result: Critical erosion hotspots were identified where predicted soil losses exceeded acceptable values. Field validation enabled model calibration, improved forecast accuracy and confirmed the presence of active erosion processes (rills, wash-off) at sites classified by the model as high-risk. The mapping results were used to develop recommendations for anti-erosion measures, including slope terracing and grazing regulation.

Case 23: Integrated analysis and forecasting of desertification processes using satellite data archives (Kazakhstan and Central Asia) [43].

Problem addressed: The need to establish long-term, comparable data series for analysing desertification trends across the whole of Central Asia and forecasting the further development of processes.

Context: The Kazakhstan-China Joint Laboratory "Technology and Application of Remote Sensing" at Al-Farabi Kazakh National University conducts integrated research on climatic and environmental changes in the region. At the same time, Chinese colleagues have developed a specialised dataset of desertification indices for the entire Central Asian region over a 40-year period [43].

Methods applied: On the basis of AVHRR GIMMS-3G+, GLASS and ESA CCI Land Cover data for 1982-2020, the Desertification Difference Index (DDI) was calculated within the albedo-NDVI feature-space concept. The DDI not only assesses the current condition, but also classifies land by degree of desertification, from slight to extremely severe. The index was validated using high-resolution Google Earth imagery and ESA CCI data; overall accuracy was 81.33% (kappa 76.60%).

Result: A unique open dataset (https://doi.org/10.57760/sciencedb.j00001.00975) has been created, containing annual rasters of albedo, NDVI and DDI for 39 years. This allows any researcher or decision-maker in the region to analyse long-term desertification trends without the need for primary processing of very large datasets. The analysis showed that DDI demonstrates a significant negative trend in degraded territories from 1992 to 2020, confirming the intensification of desertification processes in the region.

Case 24: Innovative approach to classifying the degree of sand stabilisation through the integration of radar coherence and optical indices (Kalmykia, Russian Federation) (based on the Sber Bank project, 2025 [122]).

Problem addressed: Areas with grazed-down above-ground phytomass that remain resistant to deflation are difficult to distinguish from open sands using vegetation indices. It is particularly important to identify sparsely vegetated sands, which may later transition either to open or to vegetated sands and constitute a critical zone for forecasting degradation dynamics. Yet their detection is the most difficult, because their optical characteristics differ only weakly from those of vegetated sands [117].

Context: The study was conducted in the desert zone of Kalmykia (Yashkulsky, Yustinsky, Lagansky and Chernozemelsky Districts), where herbaceous communities predominate and the problem of rangeland degradation and desertification is acute. From 1984 to 2020, areas affected by desertification increased almost fourfold, from 750 to 3,000 thousand ha [116].

Methods applied: An innovative approach was developed by adding to traditional vegetation indices the parameter of interferometric coherence calculated from Sentinel-1 radar images. The logic of the method is based on the physical properties of the surface: on open and sparsely vegetated sands, coherence is low because of mechanical variability of the sandy surface under the influence of wind and precipitation; on vegetated sands, coherence is high because soil bound by the root systems of herbaceous plants does not change substantially.

A four-element feature space was used for classification:

- Mean coherence (from 4-6 pairs of radar images over 2-3 months) - the key element.
- SAVI (Soil Adjusted Vegetation Index) [21] - minimises the influence of soil brightness.
- LAI (Leaf Area Index) [27] - effective in areas with dense vegetation.
- Short-wave albedo - total reflectance in the visible range.

Labelling points based on relative values of feature-space elements (135 in each class) enabled five surface types to be distinguished by combinations of elements: solonchaks, open sands, sparsely vegetated sands, vegetated sands and dense vegetation.

Result: The method made it possible, for the first time, to reliably separate sparsely vegetated and vegetated sands, which were almost indistinguishable by optical indices. Solonchaks, which are optically similar to open sands, differ fundamentally in coherence (high versus low), enabling them to be classified without ambiguity. Dense vegetation (shrubs), opaque to the C-band radar signal, has low coherence, like sands, but differs in optical indices (high SAVI/LAI and low albedo).

Regional relevance: This approach, combining radar coherence and optical indices, has substantial potential for monitoring desert rangelands in Turkmenistan, Uzbekistan and Kazakhstan, where the problem of distinguishing types of sands and solonchaks is equally acute. It is critically important for planning phytomeliorative works and forecasting degradation.

Case 25: Mapping and analysis of seasonal dynamics of desertification areas in Northern Dagestan using monthly Sentinel-2 composites [113].

Problem addressed: The need for operational and detailed mapping of areas affected by desertification, taking their seasonal dynamics into account. Traditional methods often provide a static picture and do not reflect intra-annual changes that are critical for understanding deflation and revegetation processes.

Context: Northern Dagestan (Nogai Steppe, Kizlyar rangelands and the Terek-Kuma Lowland) is one of the most arid and desertification-prone regions of the European part of the Russian Federation. Open and weakly stabilised sands, rangeland degradation and salinity are widespread.

Methods applied: The methodology is based on the use of monthly cloud-free Sentinel-2 image composites for 2022-2023, constructed from median pixel values, and comprises the following stages:

- Creation of a training sample based on visual interpretation of very-high-resolution imagery and field-visit data. Around 2,000 reference polygons were created, representing different types of underlying surface: open sands, sparsely vegetated sands, vegetated sands, solonchaks, croplands, water surfaces and others.

- Machine learning: the Random Forest algorithm, trained on the spectral signatures of reference sites, was used to classify the entire territory using 10 m composites.
- Seasonal dynamics analysis: the creation of a series of classifications for different months made it possible to assess how areas of open sands change during the year, for example increasing in early spring due to grazing of vegetation by livestock, or decreasing during the active vegetation period of ephemerals.

Result: Detailed maps of seasonal desertification dynamics with 10 m resolution were produced, allowing changes in the area of open sands to be tracked with an accuracy unavailable from global products. Key patterns were identified: open sands reach their maximum area in early spring (April), after the period of maximum grazing pressure, and their minimum in mid-summer (July), when ephemerals and ephemeroids develop. The method reliably separated primary sands (sites with persistent absence of vegetation) from seasonally dynamic sands, which is critical for planning phytomeliorative works: the former require active intervention, while the latter require grazing regulation.

Regional relevance: This approach can be directly adapted for monitoring desert rangelands in Turkmenistan, Uzbekistan and Kazakhstan. Monthly Sentinel-2 composites enable not only the creation of detailed maps, but also analysis of seasonal dynamics, identification of periods of greatest land vulnerability and assessment of the effectiveness of grazing regulation measures. Additional possibilities for using Sentinel-2 to assess evapotranspiration and monitor irrigation are presented in [73].

Conclusion

The cases presented convincingly demonstrate that the transition to higher-resolution data and the introduction of advanced analytical methods open new horizons for LDN assessment in the five countries of Central Asia:

- **Machine learning and the integration of heterogeneous data are becoming standard practice**: gradient boosting methods (XGBoost) and Random Forest demonstrate the best results for salinity modelling, landscape classification and desertification mapping, particularly when optical and radar data are combined with topographic variables. At the same time, the results obtained require expert interpretation, field verification and careful documentation of training data.

- **The need for a multi-index approach is confirmed by practice**: the use of a single vegetation index is insufficient. Cases from Kazakhstan and Turkmenistan demonstrate the effectiveness of the combined use of NDVI, NDSI and NDWI, as well as combinations of albedo, vegetation indices and spectral unmixing.

- **Radar imagery (SAR) and coherence analysis address tasks that optical data cannot solve**: SAR coherence is a unique and powerful descriptor for distinguishing surface types (sands with different degrees of stabilisation, solonchaks) and monitoring their dynamics. Adding coherence solves the problem of distinguishing sparsely vegetated sands from vegetated sands, as well as crusted solonchaks, which is critical for the desert zones of Central Asia.

- **Seasonal analysis and the creation of temporal composites improve accuracy**: the use of monthly cloud-free Sentinel-2 composites and seasonal dynamics analysis makes it possible not only to create more accurate maps, but also to identify critical periods of land vulnerability, which is necessary for adaptive rangeland management.
- **Field validation and long-term data series remain critically important**: even the most complex models require "ground truth" to improve accuracy, while long-term series (40 years) make it possible to identify real degradation trends against the background of climatic fluctuations.
- **The creation of open long-term datasets expands monitoring capacity**: the 40-year DDI archive for Central Asia provides the region with a ready-to-use tool for trend analysis and forecasting, which is critically important for transboundary issues such as desertification.

These methods and approaches, already tested in similar natural conditions, can be successfully adapted and scaled up to develop national LDN monitoring systems in Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan, enabling a transition from averaged global assessments to precise, locally relevant solutions.

Chapter 17. Land degradation indicators and levels of their applicability

The global methodology for assessing land degradation neutrality (LDN) provides only a general assessment algorithm under which national indicators may be considered and adapted either as analogue indicators (for the verification or supplementation of indicators of land productivity dynamics, land cover dynamics or soil organic carbon stocks) or as additional indicators. Adaptation of the assessment algorithm is particularly necessary for countries with extensive territories characterised by pronounced differences in natural and socio-economic conditions [31].

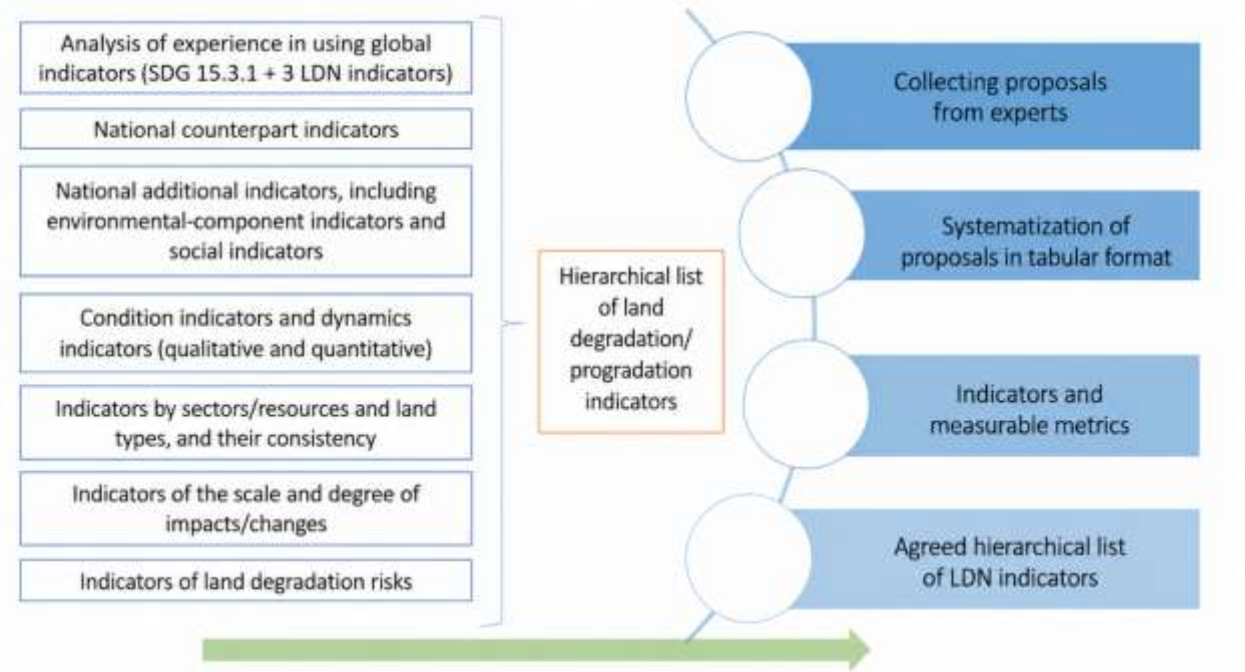


Figure 39. LDN indicators for different development priorities, land types and assessment scales.

Case 26. Possible national indicators for LDN assessment reflecting the regional specificities of Central Asian countries [92].

Issue addressed: This case considers the need for, and feasibility of, using different indicators that adequately and effectively substitute one or all of the three global LDN proxy indicators.

Context: Most Central Asian countries use land degradation assessment indicators developed during the Soviet period. Countries should take account of the experience gained in developing assessment methodologies, as well as indicators that capture specific local factors affecting land degradation. For example, in Uzbekistan, the mechanism for monitoring, assessment, preparation of reporting forms and publication of the results of measures to combat land degradation was introduced by Cabinet of Ministers Resolution No. 50 of 2 February 2023 [97].

Methods applied: The methodology is based on consideration of a wide range of baseline and regulatory indicators: dynamic indicators (reflecting processes and regimes), static indicators (reflecting condition) and target indicators (reflecting quality parameters), as used in different countries and in their regulatory guidelines and provisions. These indicators were compared with the global indicators using several criteria, including information value, reproducibility, equivalence, complementarity and others.

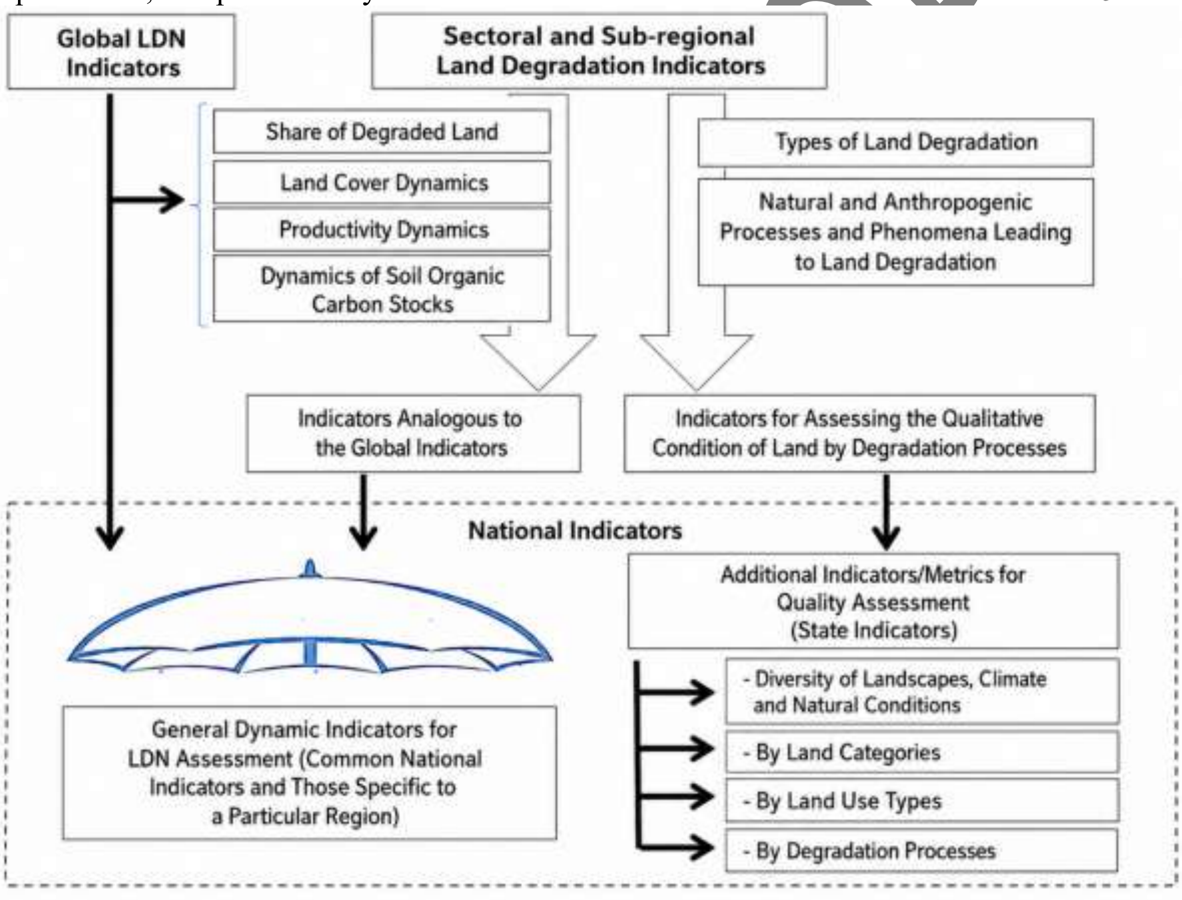


Figure 40. Conceptual scheme of the proposed expanded structure of the national LDN indicator system (for assessing dynamics and condition/quality) [91].

Result: An expanded framework of indicators has been compiled, showing indicators used by countries at different levels and potentially interchangeable depending on the objectives of the assessment.

Figure 41. Possible additional indicators for land degradation assessment

Case 27: The "iceberg effect": why global indicators do not "see" erosion and agricultural soil depletion (the case of Samara Oblast, Russian Federation), based on the IG RAS report, 2025 [118].

Issue addressed: How can the real scale of land degradation be assessed in an intensive agricultural region if global indicators (productivity and land cover) capture only the "tip of the iceberg" and fail to reflect processes critical for fertility, such as soil wash, loss of humus and depletion of nutrients? When planning measures to achieve land degradation neutrality (LDN)

in Samara Oblast, reliance solely on the standard set of indicators (for example, as calculated through the Trends.Earth module) leads to systematic underestimation of degraded areas. It remains unclear on which lands, and as a result of which processes, fertility is being lost; consequently, it is not possible to design targeted and economically sound restoration measures.
Context: The example is examined at three hierarchical levels: the oblast as a whole, a pilot municipal district and an agricultural enterprise. Samara Oblast is one of the key agrarian regions of the Russian Federation, with a predominance of chernozem soils.
However, many years of intensive use have led to the development of water erosion and agricultural soil depletion, manifested in declining humus content and reduced available forms of phosphorus and potassium. The standard LDN methodology, based on global datasets, proved "blind" to these processes, since such changes may occur without a change in land-use type and with a relatively stable NDVI.
Method applied (three-level system of additional indicators): To address the problem, a system for verifying and supplementing global indicators with regional and local data was developed and tested. The central idea was to use information that directly reflects processes leading to loss of fertility, but which is not captured by satellite sensors at standard resolution. The method included three blocks of additional indicators:

- ***Indicator of erosion hazard and actual soil wash:*** Since cartographic materials on erosion dynamics were not available, an indirect but robust indicator was proposed. Slopes steeper than 2 degrees were identified as "erosion-prone", and their areas were compared at the beginning and end of the period. In addition, for the agricultural enterprise, visual interpretation of very-high-resolution satellite imagery was carried out to calculate directly the increase in the length of gullies. Validation was also undertaken through visual interpretation of high-resolution satellite imagery at test sites.
- ***Indicators of agricultural soil depletion (dehumification and decline in nutrients):*** As a replacement for the poorly informative global indicator of soil organic carbon dynamics (which in Trends.Earth is "linked" to land-use change and always shows "0" in stable agricultural landscapes), data from state agrochemical monitoring were used. Changes in humus content, available phosphorus and exchangeable potassium in the plough layer were assessed over a period of 15-20 years. A change exceeding 10% (by analogy with the Trends.Earth threshold) was recorded as improvement or deterioration. In addition, to calculate degradation-related damage, national methodological scales of degradation severity were applied, comparing current values with reference values for chernozem soils.
- ***Economic indicators:*** To assess not only the ecological but also the economic significance of degradation, two calculated indicators were introduced: specific degradation damage (RUB/ha), calculated using an adapted methodology that accounts for loss of land value and foregone income due to declining fertility; and the profitability of investments in land restoration over different time horizons (6 and 20 years), expressed as the action/inaction cost ratio and calculated using the economics of land degradation methodology of J. von Braun.

Result: The introduction of additional indicators fundamentally changed the assessment of land condition and made it possible to quantify hidden processes.

- ***Erosion*** as the main "invisible" factor: Inclusion of the erosion hazard indicator demonstrated that, in the test district, 37% of the territory is at risk of soil wash or is already eroded. At the oblast level, this indicator amounted to 15.5%. At the local level, it was demonstrated that sustainable declines in productivity (NDVI) and humus content occur specifically on erosion-prone slopes. Without this indicator, the cause of degradation would have remained "climatic" or "undetermined".
- ***Phosphorus starvation:*** The principal degradation factor at all levels was not humus loss, but a sharp decline in available phosphorus. At the oblast level, deterioration in

phosphorus affected 13.7% of the territory; in the pilot farm, this indicator accounted for 63% of total damage. The standard "productivity" indicator did not reveal this, because yields were maintained in the short term through fertiliser application, while the long-term fertility potential was declining.

- ***Economic paradox:*** Calculations showed that, despite almost equal specific degradation damage at all three levels (approximately RUB 25,000-33,000/ha), the profitability of restoration differs radically. For the oblast and the district, investment in restoration proved profitable over a 20-year horizon (inaction-to-action ratio greater than 1), because current land productivity is low. For the pilot farm using no-till technologies, restoration proved unprofitable (ratio less than 1), notwithstanding the presence of erosion and phosphorus losses.

The paradox is explained by the fact that a high standard of agricultural management secures high current income, and the costs of additional "anti-degradation" measures do not pay off economically in the short and medium term, although they remain ecologically necessary.

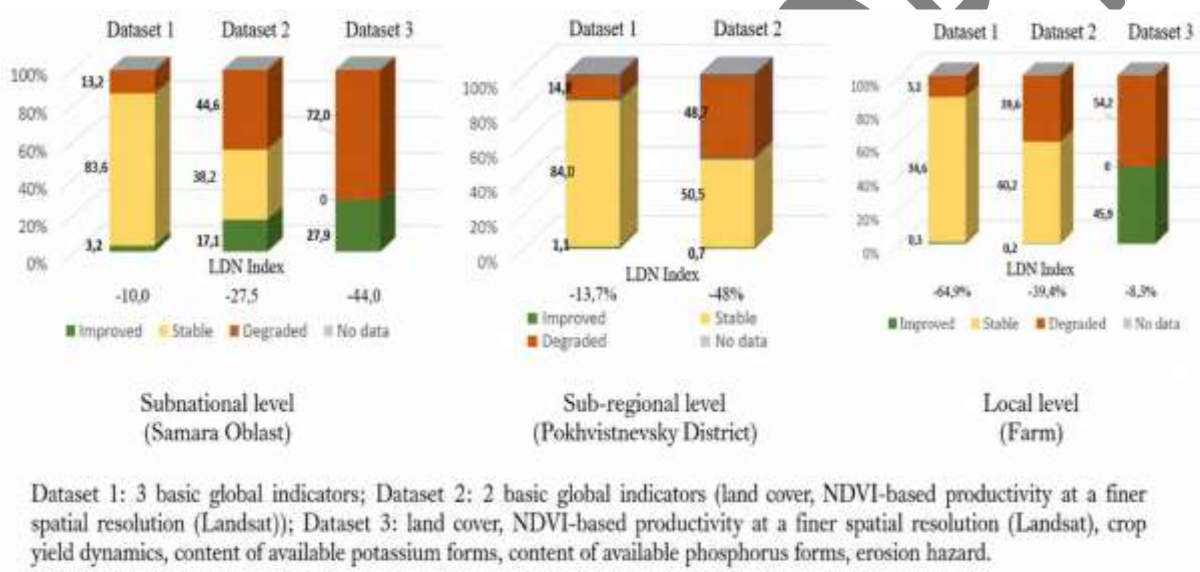


Figure 42. Changes in LDN assessment results when regional indicators are used.

Interpretation: The results made it possible to formulate a key conclusion for regional policy: global LDN indicators see only the visible tip of degradation. The real picture (the "underwater part of the iceberg") consists of erosion and agricultural soil depletion processes that require separate and more costly monitoring methods. SDG indicator 15.3.1, calculated using the adapted methodology (including erosion indicators and agrochemical data), showed an area of degradation 2-4 times larger than that obtained using the baseline methodology (for the oblast, 72% compared with 13%). This demonstrates that, without regional calibration and the introduction of additional indicators, LDN planning will be based on a false picture of well-being and will lead to inefficient expenditure on the wrong processes.

Case 28: The "distorting mirrors" effect: why global data show land improvement where local data indicate degradation (the case of Central Asia) [26].

Issue addressed: How can a reliable assessment of progress towards LDN be obtained in a region where official statistics and global satellite datasets speak different languages? When planning transboundary programmes to combat desertification in Central Asia, reliance solely on global land-cover datasets (for example, from open sources) results in systematic error. A "distorting mirrors" situation emerges: global data may show "improvement" or "stability", while local indicators and field studies record continuing degradation of valuable pastures and soils. Without calibration of data sources, it is impossible to apply correctly the "like-for-like" principle when accounting for offsetting measures.

Context: The objective was to assess progress towards LDN for the period 2000-2019. However, the standard methodology recommended by the UNCCD permits the use of different datasets. The analysis examined how the choice of a given global land-cover product (for example, CCI-LC or MCD12Q1) affects the final picture of degradation.

Method applied (multi-sensor analysis and consideration of soil quality):

1. ***Comparative analysis of datasets:*** The three principal global LDN indicators were calculated in parallel for the region using different databases.

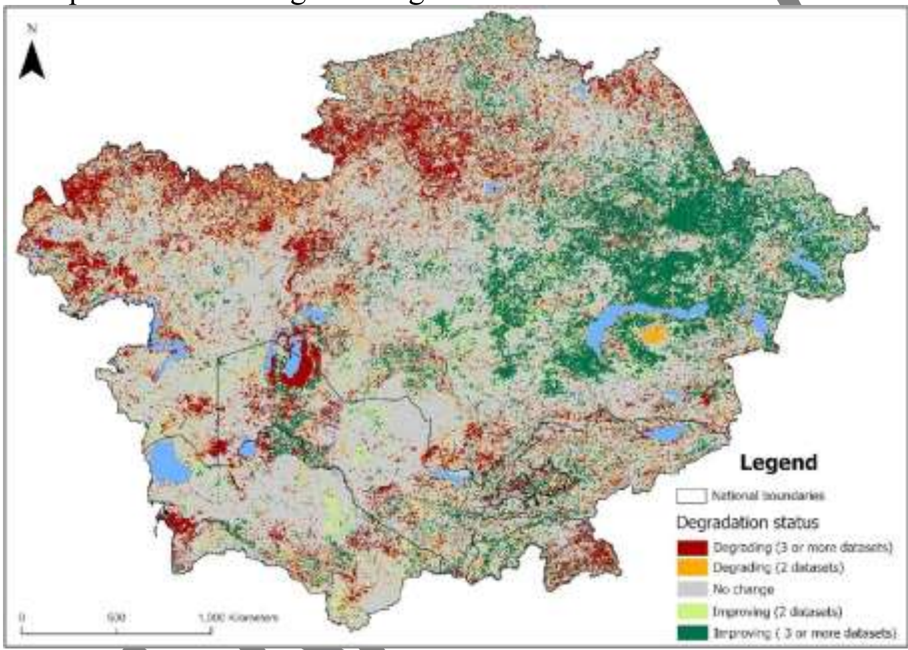


Figure 43. Map of agreement in degradation status between different land-use datasets. Areas where degradation or improvement is recorded on only one land-use map are considered areas with no change [26].

2. ***Incorporating the "like-for-like"*** principle with regional specificity: In addition to area calculations, data on land dynamics were overlaid with a soil-quality map developed specifically for Central Asian conditions (taking account of salinity, erosion and humus content). This made it possible, for the first time in the region, to answer the question: on what quality of soils is degradation occurring, and on what quality of soils is improvement taking place?

Result: A pronounced "distorting mirrors" effect was identified, and the risks of data misinterpretation were quantified.

- ***Range of uncertainty:*** Depending on the land-cover dataset selected, estimates of degraded land in Central Asia ranged from 15% to 34% of the total territory. A difference of more than a factor of two constitutes a critical uncertainty for investment planning at the state level.
- ***Losses on high-quality soils:*** The area of degradation on high-quality soils (those most valuable for agriculture) is more than twice the area of improvement on the same category of soils: 12% compared with 6%. This means that the region is losing its best natural resource capital. Improvements recorded by global data often occur on initially low-productivity or saline lands, and therefore do not compensate for the loss of "rich" pastures and arable land.
- ***Divergence of trends:*** Global productivity data may record positive trends (for example,

owing to an increase in green biomass), while local data on pasture structure and salinity indicate degradation. This confirmed the problem of “false greening” described above, but at the macro-regional level.

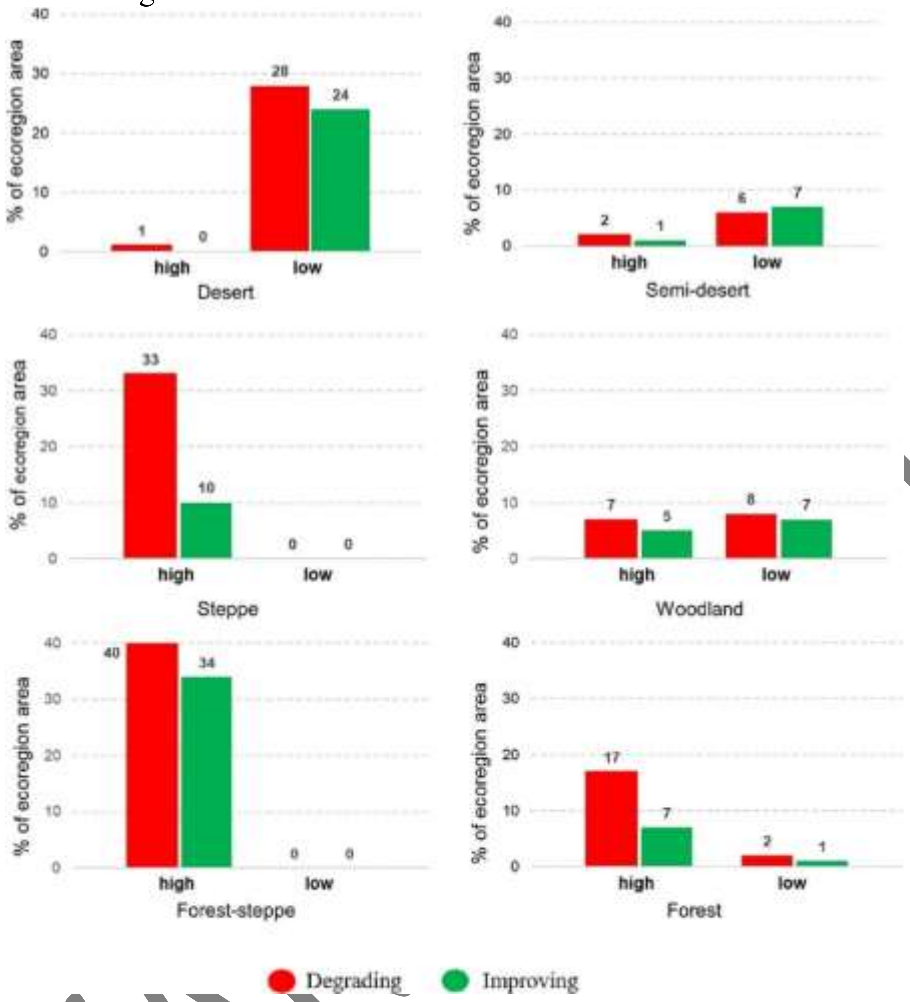


Figure 44. Land degradation trends for different soil-quality categories across the ecoregions of the assessed area.

Interpretation: These figures may provide a basis for revisiting approaches to SDG 15.3.1 reporting in Central Asian countries. Reliance on a single global dataset may create an illusion of progress where none exists. A “sensitivity analysis” tool implies that, before funds are allocated for offsetting measures, at least three different data sources should be cross-validated and necessarily overlaid with a soil-quality map. This is the only way to ensure that the “like-for-like” principle is respected.

Case 29: Data triangulation: combining the view from space, field measurements and local knowledge (based on the FAO/GEF PRAGA project, Kyrgyzstan, 2022 [49]).

Issue addressed: How can it be ensured that the data used to assess pasture condition - satellite imagery, field surveys and expert knowledge of local communities - are indeed reliable and do not contradict one another? In the mountain conditions of Kyrgyzstan, reliance on a single source (for example, global Trends.Earth data) may lead to serious errors: “green” slopes that satellites classify as improvement may in fact be overgrown with weeds, while high mountain areas classified by satellites as “degraded” may be in good condition, with naturally sparse vegetation cover. A triangulation mechanism is needed to reconcile these approaches, identify the reasons for discrepancies and develop a shared evidence base for decision-making.

Context: In 2019, within the PRAGA project, a large-scale pasture assessment was conducted in Naryn Oblast, Kyrgyzstan. The study covered three pasture types (winter, spring-autumn and summer pastures) and used three independent methods:

1. Analysis of satellite data (remote sensing): Degradation assessment using the SDG 15.3.1 methodology (land cover, NDVI-based productivity and carbon) over 15 years.
2. Field surveys: Assessment of 782 sample plots by professional expeditions using five key indicators (erosion, vegetation cover, proportion of edible plants, grass height and seed presence).
3. Pastoralists' perceptions (traditional knowledge): Members of pasture committees mapped pastures into three categories - "good", "moderate" and "poor" - on the basis of their long-term grazing experience.

The task was not to determine "who was right", but to understand the reasons for discrepancies and develop a reconciliation (validation) procedure that would serve as a reliability filter before any investment decisions were made.

Methods applied (data triangulation and validation):

1. Initial comparison: The results of the three approaches were overlaid. Agreement was found in only 39% of cases. This confirmed that the problem existed and required a mandatory verification procedure.

2. Analysis of discrepancies by pasture type: It became clear that the reliability of each method depends strongly on the landscape:

- ***Winter pastures*** (near villages): All three methods coincided in 100% of cases. The reason is that pastures are heavily degraded as a result of constant pressure, which is evident to the satellite, the field observer and the pastoralist alike. Here, satellite data can be trusted without additional verification.
- ***Summer pastures*** (high mountains): Agreement was 41.7%. Pastoralists often disagreed with remote-sensing data, arguing that open ground patches at these elevations are a natural norm rather than a sign of degradation, as classified by the satellite.
- ***Spring-autumn pastures*** (middle mountains): Agreement was the lowest, at only 11%. This is the most complex pasture type, combining high biodiversity, active vegetation and the presence of both edible and non-edible (weed) species.

3. Identification of "traps" for satellite data (sources of unreliability):

- ***The "arable land effect":*** On spring-autumn pastures, the satellite recorded a sharp increase in "greenness" (NDVI). Field data and pastoralists contradicted this. Validation revealed that the NDVI increase was driven not by pastures, but by patches of arable land (alfalfa and barley) that the satellite erroneously treated as part of the pasture area.
- ***The "weed effect":*** High biodiversity in the middle mountains, including many species not eaten by livestock (for example, Artemisia and Carex), also produces high NDVI values. Pastoralists perceive this as a "poor" condition (weeds), while the satellite interprets it as "good" (high biomass).

Result: the validation procedure as a guarantee of reliability

Validation workshops with pastoralists, during which satellite maps and field data were presented, made it possible to "reconcile" the approaches and achieve an impressive increase in agreement:

- Agreement between pastoralists' perceptions and field data increased from 80% to 86.7%.
- Agreement between pastoralists' perceptions and remote-sensing data increased from 46.4% to 89.3%.
- Agreement between field data and remote-sensing data increased from 46.4% to 96.4%.

Interpretation: The study demonstrated that no single method constitutes the "ultimate truth". Data reliability is context-dependent.

- Satellites work well in homogeneous and heavily modified landscapes (winter pastures), but become "blind" in complex mosaic ecosystems.
- Field surveys provide point information, but cannot cover large areas.
- Pastoralists possess invaluable contextual knowledge, but it is subjective.

Key policy and practical implication: investments in pasture restoration cannot be planned on the basis of satellite maps alone. Mandatory validation procedures involving local communities are required. Data triangulation is not an academic exercise, but a practical tool for filtering unreliable information, improving diagnostic accuracy and building a foundation for trust and joint management.

Chapter 18. Addressing institutional issues: data interoperability and coordination of forecasts

The experience of testing the LDN concept and its possible methods across Central Asia and the Russian Federation demonstrates that even the most advanced technical toolkit is of limited value unless embedded in a functioning institutional environment. Land data collected by different agencies (cadastral services, agricultural and forestry authorities, and hydrometeorological institutions) are generated within fragmented information systems and often rely on inconsistent classifications and formats. This prevents automated calculation of SDG indicator 15.3.1, requires labour-intensive manual processing and, even more importantly, precludes the development of reliable forecasts that require the integration of climate, soil and management data.

The absence of effective inter-agency coordination and integrated spatial data infrastructure can limit the potential of the LDN concept, reducing its application primarily to reporting rather than supporting regular management and strategic decisions. In addition, in the absence of agreed approaches to the use of forecasting models, there is a risk that different agencies will produce non-comparable assessments and scenarios, which may reduce planning coherence and complicate the formulation of shared development priorities. The importance of science-policy platforms for strengthening the scientific basis, coherence and practical applicability of decisions related to land degradation is considered in [44].

This chapter examines the transition from predominantly technical solutions to institutional implementation mechanisms. Examples from different countries demonstrate how the development of national GIS platforms, strengthening of the mandates of inter-agency coordination bodies, integration of forecasting modules into decision-support systems and investment in human-capacity development help transform fragmented data into a coherent land-resource management system.

Such a transition creates conditions for shifting the emphasis from responses to changes that have already occurred towards more proactive and strategically oriented land-resource management.

Case 30: Experience in establishing inter-agency coordination and data infrastructure in Uzbekistan

Context: Cabinet of Ministers Resolution No. 50 of 2 February 2023 [97] legally established a mechanism for land degradation monitoring in Uzbekistan and required several ministries and agencies (Ecology, Agriculture, Water Management and the Cadastral Agency) to provide data for this purpose.

Method applied: An LDN Coordination Council was established under the Ministry of Ecology, with the participation of all key agencies and scientific institutions (for example, the Soil Science Research Institute).

Technical platform: With the support of FAO projects, the development of a national GIS platform based on open-source software (GeoNode, QGIS Server) began. The platform integrates automatically updated layers of SDG 15.3.1 indicators (based on Trends.Earth); layers of national indicators (salinity and pasture condition); meteorological data from Uzhydromet; and digitised historical maps.
Standardisation: Unified data-exchange and classification standards were developed and approved for all participating agencies.
Result: According to national estimates, creation of the platform reduced the time required to prepare the national report on SDG 15.3.1 by a factor of two to three. More importantly, the emergence of a single validation source and transparent data enabled the Coordination Council, for the first time, to engage in a substantive discussion on LDN targets on the basis of agreed figures rather than institutional interests.

Case 31: Competency gaps as a major constraint on LDN: how Central Asian countries are addressing the shortage of geospatial skills

Issue addressed: Implementation of the LDN concept requires countries to calculate SDG indicator 15.3.1 regularly, which is impossible without qualified specialists proficient in GIS, remote sensing, time-series analysis and machine learning. All Central Asian countries face an acute shortage of such personnel. Without them, neither correct interpretation of satellite data, nor the establishment of national decision-support systems, nor verification of degradation "hotspots" on the ground is possible. International projects implemented in the region encounter a common problem: one-off training events have a punctual effect, but do not create sustainable institutional capacity.
The following analysis examines how Central Asian countries are addressing this problem and how human-capacity development is directly or indirectly linked to LDN objectives.

Sub-case 31.1. Uzbekistan: targeted training in erosion assessment methodologies

In Uzbekistan, capacity development is focused on specific methodologies directly linked to LDN indicators. For example, in November 2025, ICARDA and the Environmental Protection Research Institute conducted a training course on "Soil Erosion Assessment and Application of RUSLE". The key feature was that the training was structured around a concrete tool (RUSLE) enabling assessment of one of the main degradation factors in foothill areas.
Link to LDN: Soil erosion is one of the processes leading to loss of productivity and reduced soil carbon stocks (two of the three global LDN indicators). Training national specialists in the use of erosion models enables a transition from theoretical reasoning to quantitative assessment of soil losses and planning of anti-erosion measures. Importantly, the training involved representatives of the Ministry of Emergency Situations, the Ministry of Ecology, Uzhydromet and the Forestry Agency - precisely the agencies that will later participate in inter-agency LDN reporting. Field validation, in which joint teams documented rills and gullies, made it possible to "connect modelling results with reality", which is critical for calibrating satellite data.
In parallel, the University of Geological Sciences hosted a remote-sensing and GIS training course with Korean partners (KIGAM), where participants learned to analyse satellite imagery and create digital elevation models. These skills are directly applicable to monitoring land-cover change, the first global LDN indicator. Within the NICOPA project, the National University of Uzbekistan is modernising curricula in precision agriculture, including GIS and big-data analysis, thereby creating a long-term basis for training professionals who understand the relationship between land productivity and management technologies.
Gaps: Despite this progress, the system remains fragmented: training is conducted within individual projects, and there is no single LDN competence centre that could coordinate staff development for all agencies involved.

Sub-case 31.2. Kyrgyzstan: a hybrid approach and institutionalisation through universities

Kyrgyzstan has developed the most comprehensive approach, combining targeted training for government bodies with systematic university education. In November 2025, within the KG RESILAND project (World Bank), supported by the European Space Agency (ESA), a training course was delivered in a distinctive hybrid format [74].

Link to LDN: The training was combined with field validation in Osh Oblast, where participants not only mastered algorithms for processing optical and radar data, but also visited target sites to verify identified "hotspots". This directly reproduces the PRAGA methodology (described above), in which local knowledge is integrated with satellite data for accurate diagnosis of degradation. The participation of representatives of the Ministry of Emergency Situations, the Water Protection Service and the State Agency for Land Resources creates a platform for inter-agency data exchange necessary for reporting on SDG 15.3.1.

In parallel, KSTU named after I. Razzakov implements the Digital Earth Qualification programme jointly with the University of Salzburg. The five course modules cover the full range of competencies, from the fundamentals of Digital Earth to spatial analysis and remote sensing. This is an example of systematic training of specialists who will in future be able to monitor degradation independently, without reliance on international experts. Importantly, the course is available not only to students, but also to practising specialists.

Gaps: GIS competency requirements have already been incorporated into qualification profiles for civil servants (for example, in the State Agency for Land Resources), indicating institutionalisation; however, the number of trained specialists does not yet meet the staffing needs of all regions.

Sub-case 31.3. Kazakhstan: fundamental university training

Kazakhstan relies on fundamental education as the basis for LDN human capacity. At Al-Farabi Kazakh National University, the Department of Cartography and Geoinformatics trains bachelor's, master's and doctoral students in Geoinformatics and Natural and Technogenic Risks.

Link to LDN: Curricula include ArcGIS, remote-sensing data processing, creation and analysis of digital maps, and programming languages for analytical automation. These are precisely the competencies needed to calculate SDG indicator 15.3.1, analyse NDVI time series and assess land-cover dynamics. Graduates of these programmes constitute a human-resource reserve for national land committees and research institutes involved in LDN reporting.

At M. Auezov South Kazakhstan University, the Cadastre programme trains specialists in land monitoring methods for detecting changes in condition, as well as aerospace surveying and remote-sensing data processing. Learning outcomes correlate directly with LDN tasks: graduates should be able to conduct monitoring to detect negative processes and develop recommendations.

Gaps: Strong fundamental training remains only weakly connected to the practical tasks of specific agencies. There is a noticeable shortage of regular targeted professional-development programmes for current ministry staff, similar to those being implemented in Uzbekistan and Kyrgyzstan.

Sub-case 31.4. Tajikistan: targeted training for emergency services and water management

Tajikistan, being highly vulnerable to natural hazards, focuses on training specialists for operational response. Under the same ICARDA/USFS project as in Uzbekistan, Tajik specialists mastered methods for erosion assessment and flood-risk analysis. Within the Degradation Prevention project, joint teams from the Committee for Emergency Situations and forest services documented erosion forms, which is directly linked to verification of LDN data.

Link to LDN: In mountain conditions, land degradation correlates directly with mudflow and landslide risks. Training specialists capable of assessing erosion processes and modelling their consequences provides a basis for incorporating land degradation into early-warning systems.

This is an example of how LDN tasks can be integrated into a broader risk-management context. With support from GIZ and the National Water Information System, training sessions were conducted for staff of basin administrations and Tajik Agrarian University on ArcGIS, web GIS and the GeoNode geoportal. These skills are necessary for land accounting, planning of pasture rotation and assessment of rangeland productivity, all key elements of LDN at the local level.
Gaps: Capacity development is carried out exclusively within project frameworks and remains highly dependent on external financing. A national university school of geoinformatics comparable to that of Kazakhstan is lacking.

Sub-case 31.5. Turkmenistan: an information vacuum

For Turkmenistan, open sources contain very little information on training programmes in GIS and remote sensing for land-monitoring tasks. This in itself is an indicator of a problem: the country is likely facing an acute shortage of personnel that is not being addressed either by international projects or by domestic education initiatives. Given that Turkmenistan, like other countries in the region, is a Party to the UNCCD and participates in reporting on SDG indicator 15.3.1, the absence of publicly available information on national capacity-development programmes highlights the importance of regional cooperation in this area. Exchange of experience and inclusion of Turkmen specialists in existing educational initiatives could be an important step towards strengthening the overall capacity of Central Asian countries in land monitoring.

Case 32: Scaling up local knowledge: how to turn the "five indicators" used by shepherds into a national pasture-monitoring system with the help of machine learning (based on the FAO/GEF PRAGA project, Kyrgyzstan, 2022 [49]).

Issue addressed: How can reliable local data collected by communities be used to create a pasture-monitoring system that works nationwide? Traditional methods are either too costly for regular application across vast territories (state expeditions) or provide a distorted picture (satellite NDVI, which does not distinguish edible plants from poisonous ones). A system is needed that is both economical and usable by communities themselves for operational management, while also enabling local knowledge to be scaled up to the national level for government decision-making and investment planning in the context of achieving LDN.
Context: Kyrgyzstan has a unique pasture-management system. Under the 2009 Law on Pastures, responsibility for pasture use and monitoring is assigned to local pasture committees, which bring together pasture users. Until recently, however, these committees lacked a simple and standardised tool for this work. In parallel, the state service Kyrgyzgiprozem maintained a network of 275 permanent monitoring points, but their data were updated infrequently and did not always reach the level of individual communities.
Method applied (integration of knowledge and technologies): A methodology was developed that combines three sources of knowledge: (1) pastoralists' traditional knowledge; (2) simplified field surveys; and (3) modern technologies (remote sensing and machine learning). The process included two stages:
Stage 1. Development of a "people's" monitoring protocol (the five indicators)
During a series of meetings with pastoralists and members of pasture committees (75 participants in total), they were asked to identify the signs they themselves use to determine pasture condition. It became clear that pastoralists intuitively use simple but informative vegetation indicators and rarely mention complex soil or water parameters.
On the basis of community proposals and scientific requirements, a simple questionnaire was developed and integrated into a mobile application (KoBo Toolbox). It included only five key visual indicators that any pastoralist could assess by eye: signs of soil erosion; percentage

vegetation cover; percentage of edible (grazed) plants; average grass height; and presence of seeds (an indicator of regeneration).

Using this protocol, teams of two to three people (including pasture committee members) were able to assess more than 780 sample plots across four pilot sites, covering about 2 million ha over two years, thereby demonstrating the speed and cost-effectiveness of the method.

Stage 2. Integration with machine learning and remote sensing for scaling up

Data collected by pasture committees through the mobile application (georeferenced photographs, dominant plant species classified as "forage", "weeds" or "poisonous", and vegetation cover) became not merely reports, but a training dataset.

Thousands of field points with coordinates were used to train a machine-learning algorithm (Random Forest). The algorithm analysed multi-year time series of Sentinel-2 satellite imagery and searched for relationships between spectral signatures and pasture-quality categories defined by pastoralists on the ground.

The trained algorithm made it possible to classify the entire pasture area, producing maps that show not simply "greenness" (NDVI), but the probability of occurrence of valuable forage grasses, weeds and poisonous plants.

The following year, the resulting maps were again presented to pasture committees for verification and correction, thereby closing the feedback loop and increasing model accuracy.

Result: The two-stage system created a synergistic effect that would not have been possible using any single approach alone.

- Validity of "people's" data: Comparison of simplified field data collected using the five indicators with detailed scientific assessments showed a high degree of correlation. Agreement between simple field data and pastoralists' perceptions after validation reached 86.7%.
- Tool for local management: The pasture committees received not merely a report, but a working instrument. The five indicators allow them to take reasoned decisions: for example, if grass height and the proportion of edible plants decline on a plot, pasture rotation should be introduced. Recording the same indicators one year later demonstrates the effectiveness of the measures taken.
- Technological breakthrough in scaling: Through machine learning, pastoralists' local knowledge was extrapolated to the entire territory. In pilot ayil aimaks of Naryn Oblast, maps were created showing areas with a high probability of weed occurrence. The accuracy of pasture-quality classification reached 85%, a level fundamentally unattainable using NDVI alone.
- Identification of "green deserts": The new maps made it possible, for the first time, to identify zones where high NDVI values (traditionally interpreted as "good") in fact concealed stands of non-edible or poisonous plants. These "green deserts" became targets for focused management interventions, such as regulating grazing periods or mechanically removing weeds.
- Differentiation of approaches by pasture type: Experience showed that different combinations of methods can be used for different pasture types:
    - Winter pastures (near villages): simple visual control by pasture committees is sufficient.
    - Summer pastures (high mountains): a combination of satellite monitoring and selective field checks is effective.
    - Spring-autumn pastures (middle mountains with high biodiversity): local knowledge remains indispensable, since pastoralists are best able to distinguish edible from non-edible species.

Interpretation: This case demonstrates an ideal model for countries seeking to establish a national LDN monitoring system that is at once scientific, economical and legitimate in the eyes of local communities. Rather than opposing "science" and "tradition", the project created a bridge between them. The five simple indicators became a common language in which pastoralists can speak with scientists. Machine learning became the tool that enabled this conversation to be scaled from the level of a single pasture to that of an entire country.

The key policy and practical implication is that:

1. Investments become targeted. Funds are directed not to abstract "degraded pastures" shown by satellites, but to specific areas where pastoralists confirm weed infestation and algorithms indicate a high probability of its occurrence.
2. Monitoring becomes continuous. The system transfers responsibility for annual data collection to communities (pasture committees), while the state (or large projects) is responsible for the technological platform, algorithm training and strategic planning.
3. "social licence" for management is achieved. Since decisions on grazing and restoration are based on data collected by the pastoralists themselves, the legitimacy of these decisions and willingness to implement them increase substantially.

Case 33: The "national LDN machine": how Kazakhstan's state land-survey system provides a basis for assessing degradation at national and subnational levels

Issue addressed: How can countries move from disparate and fragmentary assessments of land degradation to a sustainable, institutionalised national monitoring system capable of providing regular and reliable reporting on LDN indicators at all levels, from individual fields to the country as a whole? Global proxy indicators (land cover, productivity and soil carbon), calculated from satellite data, often suffer from insufficient accuracy, "false greening" and insensitivity to locally critical processes such as erosion, salinisation and pasture digression. Sound management decisions and planning of investments in land restoration require a reliable national system that integrates ground data, remote sensing and administrative resources. Kazakhstan, with its vast territory and critical dependence on pasture livestock production, has a particularly acute need for such a system.

Context: The Republic of Kazakhstan has an enormous land fund, more than 70% of which consists of agricultural land, predominantly pastures. Land degradation, including desertification, erosion and declining pasture productivity, represents one of the principal threats to economic security and the sustainability of rural territories. The country does not yet have a fully coherent system directed specifically towards achieving LDN. However, in response to the challenges of desertification, land degradation and drought and in line with international obligations, including SDG 15.3, a system of state organisations has historically emerged and continues to develop, with each institution responsible for a specific block of information necessary for comprehensive assessment of land condition. Together, these organisations - the Republican State Enterprise GISHAGI, the Republican State Enterprise on the right of economic management "State Institute for Land Survey Works" (GIPROZem), and the specialised KazNIIZhiK portal - form what may be described as a "national LDN machine", capable of supplying data for all three global indicators and offering more sensitive national supplements.

Method applied (integration of state monitoring systems): Kazakhstan has developed an effective division of labour among three key institutions. Their combined activity covers almost all LDN assessment needs, from primary data collection to the production of analytical products and decision-making.

1. Republican State Enterprise GISHAGI (https://gishagi.kz/) - the foundation: geodesy, cartography and spatial data infrastructure

Role in the LDN system: The institute is the sole provider of aerophotogeodetic survey services for agricultural mapping in the republic. It creates the digital spatial basis without which accurate referencing of all other data is impossible.

Methods and results for LDN: Geodetic and photogrammetric works provide highly accurate data on terrain and site conditions. This is critical for the correct interpretation of land-plot boundaries and land categories, which directly affects the accuracy of calculating the Land Cover Dynamics indicator. In addition, it provides a basis for modelling erosion processes and matter flows in the landscape, which is required for assessing degradation risks and, indirectly, for refining models of soil organic carbon stocks.

Digital cartography and the creation of digital terrain models provide the basis for overlaying all thematic layers, including soil, geobotanical and remote-sensing data. Without an accurate cartographic base, even the most detailed ground surveys lose spatial referencing and cannot be used to monitor changes over time.

2. Republican State Enterprise on the right of economic management “State Institute for Land Survey Works” (GIPROZem) (https://giprozem.kz/) - ground verification and accounting for land quality

Role in the LDN system: This is the central component of the system, responsible for direct instrumental measurement of parameters corresponding to all three global LDN indicators. With its extensive network of branches across all oblasts of Kazakhstan, the institute is the principal source of ground-verification information. Its activities are regulated by the Land Code of the Republic of Kazakhstan and a number of subordinate legal acts, including the Methodology for Soil Bonitet Assessment (as amended in 2024) and the Methodology for Land Monitoring (2022).

Methods and results for LDN: Soil survey and soil bonitet assessment correspond directly to the Soil Organic Carbon Stocks indicator and its national proxy. Soil surveys include the excavation of soil profiles, description of genetic horizons and sampling for laboratory analysis. The main parameters determined in laboratories include: humus content (%); humus stocks (t/ha) in the 0-20(30) cm layer; thickness of the humus horizon (A+B1) in cm; texture (physical clay content, %); carbonate content; degree of salinity (by dry residue and salt composition); alkalinity/solonetzicity; and physical properties such as bulk density and water-holding capacity.

Soil bonitet assessment is a comparative quantitative assessment of fertility expressed in points on a 100-point scale. The bonitet score is calculated on the basis of the above parameters relative to the reference soils of the region. Correction coefficients are applied to account for negative features, including erosion, salinity, stoniness and others. Changes in the bonitet score on the same plots during repeated surveys constitute a direct national indicator of degradation (a decrease in score) or restoration (an increase in score). Scheduled soil surveys are usually conducted every 15-20 years, although monitoring at control sites may be carried out more frequently.

Geobotanical surveys correspond directly to the Land Productivity indicator for pastures. They are conducted to determine the productivity of vegetation cover (forage yield in centners/ha) and the qualitative condition of pastures. Methods include field route surveys with sample plots, identification of the botanical composition of the sward (proportion of valuable, low-value and harmful species), and assessment of vegetation cover and condition (stages of pasture digression). Geobotanical maps at scales of 1:50,000 to 1:100,000 provide the basis for planning pasture rotation. These ground data serve as reference information for calibrating and validating satellite indices used to monitor vast pasture territories.

Agrochemical surveys correspond directly to the Soil Organic Carbon Stocks indicator and to control of agricultural soil depletion on arable land. They determine soil contents of humus; available forms of nitrogen, phosphorus and potassium; microelements (zinc, copper, cobalt and others); and acidity (pH). For agricultural lands, the established frequency is every 3-5 years on irrigated lands and every 5-7 years on rainfed lands. From 2026, agrochemical surveys (agrochemical cartograms) become mandatory for all land users, and their absence, or deterioration of soil quality by more than 10-15%, may entail withdrawal of land.

3. KazNIIZhiK portal (http://kazniizhik-pastures.kz/) - operational monitoring and decision-making

Role in the LDN system: This specialised resource demonstrates the transition from data collection to the creation of decision-support tools, especially in the critically important sector of pasture livestock production. The portal integrates remote-sensing and ground data to produce cartographic products.

Methods and results for LDN:

The MODIS NDVI data viewing and acquisition system (NDVI Greenness Maps) is a direct practical implementation of monitoring of the Land Productivity indicator using remote-sensing data in near-real time. The system enables tracking of pasture “greenness”, identification of trends in declining productivity (degradation) and improvement (restoration), and rapid response to drought events.

The forage resources map (scale 1:1,500,000) is a detailed “land cover” map for pastures, distinguishing types by vegetation composition (for example, feather grass-fescue-wormwood and saltwort-wormwood communities), which is important for assessing their economic value.

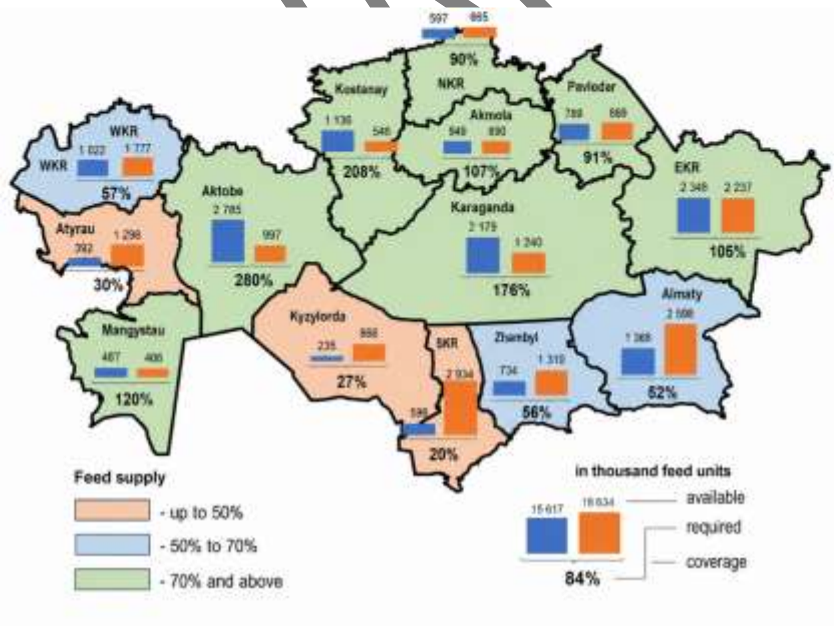


Figure 45. Map of pasture forage availability [77].

The pasture stocking-rate map is a key national indicator. It is calculated by comparing actual stocking pressure (number of livestock / pasture area) with the normative stocking rate approved by order of the Minister of Agriculture of the Republic of Kazakhstan. Norms are differentiated by natural zones and oblasts, pasture types (by dominant vegetation) and pasture condition (restored/degraded). For degraded pastures, the normative area per head is larger. Exceeding the actual stocking pressure over the norm signals overgrazing and high degradation risk. If actual stocking is less than 50% of the norm, the pasture is considered not to be used for its intended purpose, creating a risk of weed encroachment.

The pasture watering map contains information on the presence and condition of water sources (wells, boreholes and watering points). This is a critically important indirect indicator explaining the spatial distribution of pressure: degradation of infrastructure leads to overuse of pastures close to water and underuse of distant pastures, thereby generating local degradation hotspots.

Result: Establishment of a national LDN assessment system supported by data at all levels. Integration of the activities of the three institutions creates a strong synergistic effect, enabling Kazakhstan to build a fully-fledged system for assessing and achieving LDN.

For the global indicator “Land cover”: Contribution: GISHAGI provides an accurate cartographic base. GIPROZem prepares materials on soil bonitet assessment, soil and geobotanical maps, as well as land degradation maps. KazNIIZhiK details pasture classes by producing thematic maps of forage lands.

Result: Instead of coarse global classes (for example, “pastures”), the national system enables the use of detailed categories such as “feather grass-fescue-wormwood pastures on solonetz soils”, which is critical for assessing their condition and trends.

For the global indicator “Land productivity”: Contribution: GIPROZem conducts geobotanical surveys, producing ground data on yield (centners/ha) and botanical composition. KazNIIZhiK uses these data to calibrate and interpret satellite NDVI indices, producing operational productivity maps for vast territories.

Result: A two-level system emerges: ground reference data (“verification”) and operational satellite monitoring (“coverage”).

This makes it possible not only to record the fact of declining NDVI, but also to understand its causes, such as reduced forage yield, changes in species composition or climatic fluctuations.

For the global indicator “Soil organic carbon”:

Contribution: Through soil and agrochemical surveys, GIPROZem directly measures humus content and calculates the bonitet score, an integral fertility indicator that reflects soil quality on the basis of a comprehensive assessment rather than a single parameter.

Result: The global proxy calculated from transition tables is replaced by direct national measurements. This provides incomparably higher accuracy and enables monitoring of dehumification and nutrient loss even where land-use type remains stable. The soil bonitet score becomes a clear and useful indicator for agronomists and land planners, as it is directly linked to the economic valuation and cadastral value of land.

For the “like-for-like” principle and offsetting measures:

Contribution: GIPROZem data on soil types, bonitet scores and geobotanical characteristics make it possible to determine precisely on which lands degradation has occurred and where improvement has taken place. The pasture stocking indicator from KazNIIZhiK helps plan measures to reduce pressure (for example, watering of remote pastures) in order to compensate for degradation on nearby grazing areas.

Result: Compliance with the “like-for-like” principle becomes realistic. Degradation of highly productive floodplain pastures cannot be offset by improvement of low-productivity desert pastures, because national data make it possible to distinguish clearly between these categories.

Interpretation and the way forward:

Kazakhstan’s state land-survey system provides a unique example of an institutionalised monitoring approach that fits the LDN concept exceptionally well. Rather than relying exclusively on global satellite data, the country has created and maintains a “national machine”

that produces its own, more accurate and relevant data, underpinned by detailed methodologies and a regulatory framework.
The key policy and practical implication is that:

1. Degradation assessment becomes targeted and parametric. It becomes possible to state precisely that, in a given oblast, on particular soil types, humus content has declined by X% or the bonitet score has fallen by Y points owing to secondary salinisation; or that, in another oblast, on specific pasture types, actual stocking pressure exceeds the norm by a factor of Z, leading to productivity decline recorded by NDVI and confirmed by geobotanical data.
2. Restoration planning becomes economically justified. Knowing the bonitet score and actual productivity makes it possible to calculate foregone benefits from degradation and compare them with the cost of phytomelioration or construction of a watering point. Mandatory agrochemical surveys create a mechanism for controlling the effectiveness of investments.
3. Reporting on SDG 15.3.1 becomes reliable and transparent. Kazakhstan can report not on the basis of averaged global models, but using concrete national monitoring data collected according to unified standards (soil, geobotanical and agrochemical) and confirmed by ground observations from a network of control sites.

Thus, the system consisting of GISHAGI (the cartographic foundation), GIPROZem (ground verification and quality accounting with detailed bonitet and agrochemical parameters) and the KazNIIZhiK portal (operational monitoring and pasture analytics with stocking-rate norms) is a ready and functioning prototype of a national LDN monitoring system that could be replicated in Central Asian countries. Its further development - through digitisation of archival data, creation of a single national platform with open access to anonymised data, and integration with precision agriculture systems - will enable the country not only to report successfully on voluntary international commitments, but also to manage its land resources effectively, restoring already degraded lands and preventing further degradation.

Conclusion: from fragmented efforts to regional cooperation

The analysis undertaken demonstrates that Central Asian countries are at different stages in developing human and institutional capacity for LDN, with each country shaping its own priorities and areas of specialisation.

Kazakhstan has a well-developed academic base for training specialists in GIS, remote sensing and data analysis. The existing capacity creates favourable conditions for further expansion of the applied use of these competencies in LDN-related tasks.

Kyrgyzstan demonstrates a balanced model that combines training of civil servants, development of university programmes and the gradual institutionalisation of GIS competency requirements within public administration.

The Russian Federation has substantial scientific and methodological capacity in LDN, sustainable land management, soil science, landscape ecology, geoinformation analysis and remote sensing. A well-developed network of research institutes and universities supports the training of specialists and the development of methodological approaches to land degradation monitoring and sustainable land-resource management, including in the arid and semi-arid territories of Eurasia.

Tajikistan focuses on applied training for specialists working in areas of elevated natural risk, integrating LDN issues into the broader context of management of natural processes and territorial resilience.

Turkmenistan, drawing on its rich historical experience of regional cooperation in combating desertification, land degradation and drought (during the Soviet period, the country was a recognised centre for exchange of advanced practices), is progressively developing a national system for LDN capacity development. Further expansion of the country's participation in regional initiatives on skills development and knowledge exchange opens broad opportunities for mutually beneficial cooperation.

Uzbekistan is actively developing project-oriented training in specific methodologies, involving inter-agency teams and giving attention to field verification. This approach contributes to the formation of practical competencies and readiness for joint initiatives.

Conclusion to Part III

From diagnosis to action - building the national foundation for LDN

The practical cases and methodological approaches presented in Part III convincingly demonstrate that the knowledge gaps and uncertainties in the global methodology identified earlier are not insurmountable obstacles. On the contrary, they act as drivers for the development of a more advanced and adapted toolkit that takes into account the complex nature of the arid and high-mountain landscapes of Central Asia and the adjoining territories of the Russian Federation.

The process has moved from rethinking the fundamentals of assessment - replacing a static "reference point" with a dynamic baseline and analysis of complete time series - to the creation of sophisticated predictive models. The key to understanding real processes lies in moving beyond the flat dichotomy of "degradation/improvement" towards a multidimensional diagnosis: identifying hidden mechanisms ("advance" versus "depletion"), localising "hotspots" of chronic degradation and bright spots of sustained restoration, and quantitatively forecasting possible future losses.

However, the principal lesson from the analysis of regional experience goes beyond technical improvements. It is institutional in nature. Numerous examples from Uzbekistan, Kazakhstan, Kyrgyzstan and Tajikistan demonstrate that even the most accurate satellite data and sophisticated machine-learning algorithms remain an unrealised potential unless they are embedded in a functioning governance system. The creation of fragmented pilots is necessary, but only a first step.

Institutions and data infrastructure

Sustained success is achieved where technical solutions are supported by the creation of a unified spatial data infrastructure. Experience from Uzbekistan, Kazakhstan and Kyrgyzstan shows that national geoportals address a fundamental task: overcoming institutional fragmentation. A single platform ensures transparency, reproducibility of assessments and the engagement of science and society.

The integration of modern technologies with traditional knowledge is of particular value. The Kyrgyz experience has demonstrated that involving local pasture communities in data collection through mobile applications and training algorithms on these data can achieve a level of accuracy that is unattainable using only "global" products.

From indicators to diagnosis and strategy

Adaptation of the methodology required a refinement of approaches to indicator use. The global set of three sub indicators provides the overall assessment framework; however, correct interpretation of results under regional conditions requires the application of additional data-processing procedures considered in the practical cases presented above. At the same time, management decisions require more detailed diagnosis focused on specific land types and degradation mechanisms.

In this regard, the Handbook presents a set of additional tested indicators that make it possible to adapt monitoring to the specificities of the main land-use types in the region: pastures, irrigated lands, desert and tugai forests, and mountain and foothill zones. For pasture areas, indicators of sward quality are important (vegetation cover, proportion of forage and undesirable species), as are selected remote-sensing parameters, including radar characteristics such as coherence, for clarifying surface types and the condition of sandy massifs. For irrigated areas, key roles are played by salinity indicators (for example, SI), data on the condition of collector-drainage networks and measurements of soil electrical conductivity (EC) for model calibration and validation. For mountain and foothill zones, priority indicators include erosion hazard and actual soil wash, as well as the use of UAV data for detailed monitoring of vulnerable areas, including terraced slopes.

The application of these indicators in combination with analysis of long-term trends creates a basis for differentiated management strategies, ranging from response to zones of pronounced degradation to preventive measures aimed at strengthening resilience and conserving land resources.

This approach expands the functional potential of the LDN concept, making it possible to use it not only for voluntary international reporting, but also as a tool for evidence-based investment planning and for identifying priority areas for restoration and sustainable management.

Human capacity and regional cooperation

Limited human resources in GIS and remote sensing remain a pressing issue for most countries of the region. At the same time, the analysis conducted makes it possible to identify national areas of specialisation: the developed academic base in Kazakhstan, experience in institutionalising competencies in Kyrgyzstan, and practical experience in field validation in Uzbekistan and Tajikistan.

This differentiation creates prerequisites for the establishment of a regional system of knowledge exchange and capacity development based on the mutual complementarity of competencies and the development of agreed standards for professional training.

From pilots to a national system and forecasting

The region has developed the basic prerequisites for implementing LDN approaches. The next stage should be the transition from individual pilot initiatives to sustainable national monitoring systems based on inter-agency coordination, developed spatial data infrastructure and systematic human-capacity development. Such a transition creates conditions for shifting the focus from recording the consequences of degradation towards more proactive and strategically oriented land-resource management. A detailed analysis of the relevant directions and mechanisms is presented in the concluding Part IV of the Handbook.

PART IV. SYNTHESIS OF THE METHODOLOGY: AN ENHANCED ALGORITHM FOR LDN ASSESSMENT AND A ROAD MAP FOR CENTRAL ASIA

Introduction: From adaptation to an integrated system

The preceding parts have sequentially examined the fundamental provisions of the global LDN methodology (Part I), analysed its application under the specific conditions of Central Asia (Part II), and presented practical solutions and regional case studies (Part III).

The analysis demonstrates that the mechanical replication of global approaches without due consideration of the regional context may constrain both the accuracy and the practical applicability of the results. High interannual climatic variability, historically shaped land-use patterns, specific degradation processes (including the phenomenon of 'green degradation'), and the institutional fragmentation of monitoring systems all make the systematic adaptation of the methodology necessary.

The concluding part of the Handbook is devoted to synthesis. Its purpose is to present not a set of separate methodological elements, but an integrated and enhanced algorithm for LDN assessment which is grounded in the global methodology while taking into account the particular natural and socio-economic conditions of Central Asia.

A key element of the proposed approach is the transition to a dynamic baseline, which broadens the analytical possibilities of the assessment, including the analysis of persistent trends, the identification of hidden degradation factors, and the development of substantiated forecast scenarios.

This part examines in detail the stages of the proposed algorithm, as well as the specific features of its application according to the scale of assessment (national, subnational and local) and sectoral context (irrigated and rainfed arable land, rangelands and forest ecosystems). It systematises proposals for selecting indicators applicable at each analytical level. The section concludes with an indicative road map for the further development of the LDN methodology, including areas requiring additional elaboration and in-depth joint research by the countries of the region. It is important to note that the proposed algorithm should be regarded as an instrument for additional interpretation and regional planning, rather than as a replacement for official reporting submitted by countries at the international level.

Chapter 19. A stepwise algorithm for the regionally adapted interpretation of LDN assessment results for Central Asia

The proposed algorithm is based on four key principles arising from the analysis presented in Parts II and III:

1. **Complementing the fixed baseline** with time-series dynamics analysis: the official baseline period is retained as the reference point for reporting, while longer time series are used to identify territorial norms, climatic fluctuations, the recurrence of processes, and persistent degradation trends.

2. **A tiered approach:** from global screening (Tier 1) to in-depth diagnostics using national data (Tier 2) and precise field measurements (Tier 3).

3. **Data integration:** bringing together remote-sensing data, field surveys, historical maps and traditional knowledge.

4. **Diagnosis of mechanisms,** rather than merely recording the fact of degradation, in order to select an appropriate management strategy.

The general flow chart of the algorithm is presented in Figure 45; a detailed description of each stage follows below.

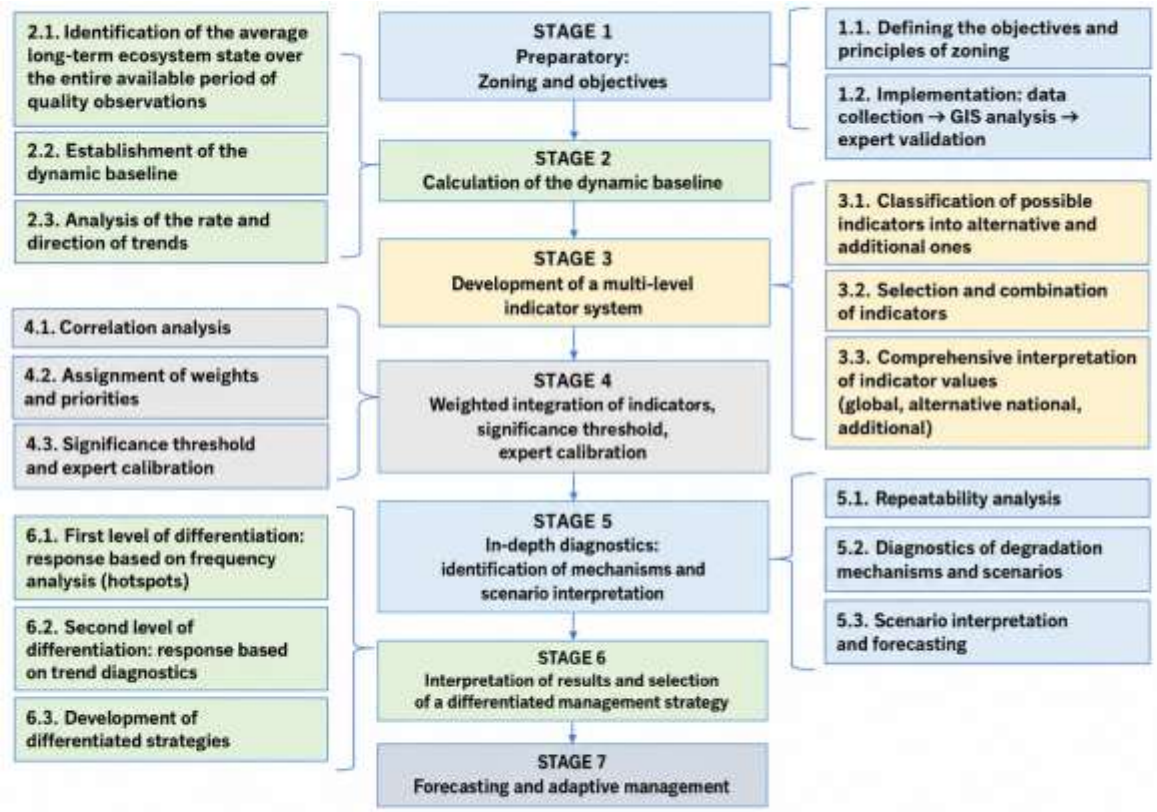


Figure 46. Enhanced algorithm for assessing and achieving LDN under the conditions of Central Asia

Stage 1. Preparatory stage: territorial zoning and definition of assessment objectives

The first stage is of key methodological importance, even though it does not involve the direct calculation of indicators. It concerns the conceptual calibration of the assessment system.

Before applying the algorithms, it is necessary to define the scale and object of the assessment (national level, an individual region, a river basin or a production unit) and to formulate clearly the assessment objectives, for example the preparation of reporting under SDG indicator 15.3.1, the justification of investments in restoration measures, or the adjustment of management practices, including pasture rotation.

In Central Asia, with its immense landscape diversity - from the high-mountain meadows of the Pamirs to the sandy deserts of the Karakum and the densely populated oases of the Fergana Valley - the application of uniform, standardised degradation criteria should be regarded as a serious methodological error. What is a ‘norm’ for a desert (a low NDVI value and sparse vegetation cover) would be a ‘catastrophe’ for an irrigated field. What constitutes a sign of degradation for a pasture (a shift in species composition) may not be captured by the global algorithm if the formal land-cover class remains unchanged. The key action is therefore to undertake territorial zoning.

1.1. Purpose and principles of territorial zoning

The purpose of zoning is to divide the territory into relatively homogeneous units (zones/regions) within which natural conditions, dominant land-use types and, consequently, limiting degradation factors are similar (for example, 'desert rangelands', 'foothill dry steppes', 'irrigated oases' or 'mountain meadows'). This makes it possible to establish specific 'rules of the game' for each zone: its own indicator thresholds, its own transition matrix and its own set of priority national indicators.

Zoning should be carried out on the basis of two complementary groups of criteria, considered in conjunction:

1. **Natural (landscape-ecological) criteria:**

- Bioclimatic potential: first and foremost, this refers to the aridity/moisture index (for example, the Vysotsky-Ivanov moisture coefficient, Selyaninov's hydrothermal coefficient or the De Martonne aridity index). It is this parameter that determines the 'normal' productivity range for a given area.
- Soil conditions: soil type, texture, the presence of 'genetic memory' features (for example, salinity of parent materials), and the degree of drainage.
- Relief: plains, foothills or mountains, and slope steepness (a critical factor for erosion).

2. **Anthropogenic (economic) criteria:**

- Dominant land-use type: irrigated arable land, rainfed arable land, transhumant rangeland, village-adjacent pasture, forest fund land (including saxaul stands), reserve lands, and other land categories or land-cover classes that are important for the territory under analysis.
- Institutional conditions: prevailing forms of land tenure (private ownership, leasehold, communal use), the presence of pasture committees, and proximity to large settlements (a pressure factor).

The overlay of these criteria results in a territorial zoning map, in which each delineated unit (region) has its own distinct 'profile'.

1.2. Why is a correct LDN assessment impossible without zoning?

The need for this stage is determined by three key problems identified in Part II:

1. The problem of 'different norms' (productivity calibration). The global land productivity indicator uses uniform algorithms to calculate NDVI trends. However, a 10% decline in NDVI in a dry-steppe zone may constitute a catastrophic trend indicating pasture degradation, whereas the same decline in a desert zone may fall within the range of natural long-term cyclicity. Zoning makes it possible to establish reference values and significance thresholds for each natural region; without this, trend analysis (Stage 5) loses its meaning.

2. The problem of interpreting transitions (matrix calibration). The global matrix of land-cover transitions (for example, in Trends.Earth) assigns the same assessment to a given type of land-cover change worldwide, which may be inappropriate for specific territories. As demonstrated in the case studies, the transition 'irrigated arable land → fallow land' cannot be assessed in the same way in the foothills (where it may be a temporary phenomenon) and in the lower Amu Darya (where it is often the result of irreversible salinisation). Zoning allows nationally adapted and calibrated transition matrices to be linked to specific territories. For a zone of 'irrigated lands at high risk of salinisation', the transition cited above would be classified as 'degradation', whereas for a 'foothill rainfed farming' zone it may be assessed as 'neutral'.

3. The problem of selecting priority indicators. The three global proxy indicators are mandatory, but insufficient for diagnosing the mechanisms of land degradation at the regional level. The set of additional indicators must be 'zone-specific'.

- For irrigated agriculture zones, priority additional indicators may include the Salinity Index (SI), groundwater depth and the condition of collector-drainage systems.
- For desert rangelands, they may include vegetation cover, the proportion of palatable species, and radar coherence data to assess sand stabilisation.
- For mountain zones, they may include erosion indices (RUSLE) and UAV data on the condition of terraces.

1.3. Practical implementation

1. **The development of a territorial zoning map** should be regarded not as a one-off research initiative, but as the foundation for a sustainable regulatory and methodological framework. Its formal approval by the competent public authority (for example, the Ministry of Agriculture or the relevant land agency) would be justified, with subsequent use as a baseline document for national LDN reporting. The zoning map should be developed in an inter-agency format with the participation of scientific and sectoral experts, ensuring the harmonisation of approaches and data.

2. **Data collection:** agrometeorological reference materials, large-scale soil maps (held in the archives of design institutes such as GIPROZem in Kazakhstan or Uzgiprozem), land cadastre data and maps from geobotanical surveys.

3. **GIS analysis and digitisation:** modern GIS tools make it possible to overlay these disparate layers and delineate the boundaries of relatively homogeneous territories.

4. **Expert validation:** the resulting map should subsequently be discussed with regional experts - soil scientists, agronomists, rangeland specialists and representatives of local communities. Their knowledge of local specificities is invaluable for refining boundaries determined by automated methods.

Conclusion: territorial zoning is not a bureaucratic formality, but the creation of a 'coordinate system' for all subsequent work. It makes it possible to move from a uniform global template to a flexible, landscape-adapted assessment system. Without this stage, the use of a dynamic baseline (Stage 2) and trend analysis (Stage 5) will operate with figures detached from the actual natural and economic context, inevitably leading to erroneous management decisions.

Stage 2. Transition to a dynamic baseline: establishing the 'territorial norm' and moving towards trend analysis

The second stage is an important component of the proposed regionally adapted methodology, as it makes it possible to complement the fixed baseline with the analysis of longer time series. This approach does not replace the established baseline period used for official reporting, but expands the possibilities for interpreting results by taking into account the long-term dynamics of land condition. As shown in Part II and illustrated by the case studies in Part III, under the high interannual climatic variability of Central Asia, the analysis of longer time series reduces the sensitivity of results to the selection of particular assessment periods and better accounts for the influence of dry and wet years, while also distinguishing short-term climatic fluctuations from persistent long-term trends of land degradation or restoration. 2.1. What is a dynamic baseline?

In addition to comparing land condition between two fixed periods (for example, a 'baseline' period of 2001-2015 and a comparison period of 2018-2022), it is proposed to use the long-term average condition of the ecosystem over the entire available observation period as the reference line. This condition is regarded as the 'territorial norm' or 'historical range of variability' for each individual pixel or homogeneous land unit.

The key distinction is that a dynamic baseline:

- **Has no single calendar date.** It is not a 'point' or 'period' in the past, but a statistical characteristic (mean or median).
- **Is individual for each pixel.** It takes into account the natural potential of a specific land unit: the NDVI norm for a desert pasture will differ from that of a foothill meadow.
- **Is 'flexible'.** As new data accumulate (for example, every five years), the long-term average norm may be recalculated, allowing long-term climate trends (such as secular aridisation) to be taken into account.

2.2. Method of establishment: from smoothing to the norm

The procedure for determining a dynamic baseline includes several mandatory steps.

Step 1. Constructing the full time series. The analysis uses all available cloud-free satellite data over the longest possible observation period. For regional and national levels, these may be MODIS data series (from 2000, 250 m resolution) or AVHRR (from the 1980s). At the local level, Landsat data (from the 1980s, 30 m) and Sentinel data (from 2015, 10 m) may be used.

Step 2. Smoothing and filtering climatic noise. Annual NDVI data and other indices contain strong fluctuations associated with droughts and wet periods. Smoothing methods are recommended to separate this 'noise' from the signal.

- Main method: calculation of a moving average using overlapping windows, for example of 3-5 years. This makes it possible to obtain a smoothed curve reflecting medium-term dynamics.
- Additional method: use of smoothing filters (for example, the Hodrick-Prescott filter), which make it possible to separate trend and cyclical components in the time series.

Step 3. Calculating the 'territorial norm'. The reference line (conditional '0') is taken as the arithmetic mean (or median) of the smoothed series over the entire observation period. For example, for a region with data from 2000 to 2025, the norm would be the average value of the smoothed NDVI over these 26 years. This value represents the long-term production potential of the ecosystem under current climatic conditions.

Step 4. Assessing deviations for reporting periods. At this step, land condition is assessed not 'relative to 2015', but relative to this long-term norm. For each reporting period (for example, the five-year period 2021-2025), the average smoothed value for those years is calculated and its deviation (in percentages/fractions) from the established norm is determined.

2.3. A new indicator: the trend as a measure of degradation

Using the full time series opens the way to the most important step - quantitative trend analysis. It is at this point that the principal indicator changes.

Under a static approach, the principal indicator is the ratio of areas: how many hectares have moved into the 'degraded' category and how many into the 'improved' category. However, this indicator says nothing about the speed or persistence of the process.

In the updated system, the principal indicator of land degradation becomes not area, but the rate and direction of change, expressed through the coefficients of a regression equation.

How it works:

For each pixel (or for each zone or polygon), a trend line is constructed for the smoothed time series of the key indicator (for example, deviation of NDVI from the norm, the share of degraded or improved land, or the LDN Index). Linear regression is used, where:

$$\mathbf{Y = a + b * X}$$

- Y is the value of the indicator (for example, the share of degraded land, in %);
- X is time (year or sequence number in the observation series);
- b is the regression coefficient, or slope of the trend line.

The interpretation of coefficient b is provided for the trend in the share of degraded land; for the trend in the share of improved land, the interpretation is reversed.

- b (degradation trend) > 0: the share of degraded land is systematically increasing. The rate of increase (in % of area per year) is numerically equal to the coefficient. This is the principal indicator of advancing degradation. The higher the value of b, the more aggressive the process.
- b (improvement trend) > 0: the share of improved land is systematically increasing. This is an indicator of sustained restoration.
- b ≈ 0: the system is in a state of dynamic equilibrium (stability), despite possible interannual fluctuations.
- A negative b for the LDN Index indicates that the balance is shifting towards degradation, and that this is occurring at a measurable rate.

2.4. Why is the trend more important than the area?

Consider two hypothetical districts (A and B). In both, the assessment for 2015-2025 shows that the share of degraded land increased by 5%. A standard static approach would conclude that they require equal attention.

However, trend analysis may demonstrate a fundamental difference:

- District A: degradation occurred abruptly during the first two years as a result of an extreme drought and then stabilised. The coefficient b for the entire 10-year period will be small, and the future forecast stable.

- District B: the area of degradation is increasing steadily every year by 0.5%. Here, coefficient b will be positive and statistically significant. This is a signal of a chronic, ongoing process requiring urgent intervention.

Conclusion: under the high natural variability of Central Asia, it is the persistent trend (a significant coefficient ***b***), rather than a one-off change in area, that represents a reliable indicator of anthropogenic or long-term natural degradation. Establishing a dynamic baseline and subsequently analysing trends enables us to move from the question 'how much has degraded?' to the far more important management question: 'at what rate and in which direction is the process developing?' This, in turn, makes it possible to justify forecasts quantitatively and to calculate the necessary scale of compensatory measures.

Stage 3. A tiered system of indicators: from global screening to local diagnostics

The third stage is the technical core of the entire assessment. At this stage, not only the three mandatory global LDN sub-indicators are calculated, but, crucially for Central Asia, they are also verified and complemented using national and local data. The key principle here is the Tiered Approach and sectoral specificity.

Accordingly, it is appropriate to complement the unified set of global indicators with specialised indicators, particularly at the local level or for smaller districts. For each level of governance and for each land-use type, it is proposed to use its own optimal set of measurable indicators.

3.1. Classification of indicators: alternative and additional

Before turning to the lists, it is important to distinguish indicators according to their function in relation to the global methodology.

Alternative indicators (replacing global proxies): national indicators that directly measure the same process as the global sub-indicator, but with greater accuracy and relevance, since global data (for example, SoilGrids for carbon) often have an unacceptable level of uncertainty at the national level.

- Example: instead of calculating soil carbon stocks from global tables and land-cover classes (Tier 1), data from agrochemical surveys of arable lands, with direct measurement of humus content, may be used (Tier 2/3).

Additional indicators (expanding diagnostics): indicators that are not included in the triad of global indicators but are critical for understanding the mechanisms of degradation under specific regional conditions. Global indicators may demonstrate that something is happening (for example, productivity is declining), but they do not explain why (salinisation, erosion, a shift in species composition). Additional indicators answer the question 'why?' by reflecting processes and regimes.

- Example: the Salinity Index (SI), calculated from Sentinel-2 data, is an additional indicator to productivity (NDVI). It explains the cause of yield decline in an irrigated field.

3.2. Detailed set of indicators for different assessment levels

Table 10 presents an expanded and systematised list of indicators, grouped by assessment level (Tier 1, 2 and 3) and by land-use type. The list is not exhaustive, but covers the indicators that are most tested and recommended for the region.

Table 10. Expanded system of possible LDN indicators for Central Asia

Level / Land-use type	Global sub-indicators (mandatory)	Examples of alternative indicators (additional regional)	Examples of additional indicators (local diagnostic)	Data sources / Methods of acquisition
Tier 1 (National)	Baseline sub-indicators of SDG 15.3.1: 1. Productivity (NDVI trend/state) 2. Land cover (LCCS classes) 3. Soil carbon (IPCC Tier 1)	• Yield of major crops (centners/ha) according to statistical reporting • Livestock numbers (conditional head) • Share of irrigated land in the total land fund	• Aridity index (droughts) • LDN Index (balance of improvements/degradation) • Frequency of dust storms (number of days)	Trends.Earth, FAOSTAT, national statistical yearbooks, hydrometeorological data
Tier 2 (Subnational: oblast/district)	Verified and calibrated using national data			
All types	• Productivity (NDVI based on Landsat/Sentinel) • Land cover (refined classes based on cadastre data)	• Soil bonitet score (integrated fertility assessment) • Rangeland productivity (fodder units/ha based on geobotanical maps)	• Regression coefficient (b) for the share of degraded land (process rate) • Recurrence maps of degradation (frequency analysis)	Landsat/Sentinel-2, land cadastre data, geobotanical maps, agrochemical surveys (every 5-10 years)
Irrigated arable land		• Humus content (%) in the arable layer (alternative to carbon)	• Spectral salinity indices (SI, NDSI) • Groundwater depth (m) • Groundwater mineralisation (g/l) • Share of drained areas (%)	Sentinel-2, field conductivity meters, melioration cadastre data
Rainfed arable land		• Productive soil moisture reserves (mm)	• Erosion index (RUSLE) - estimated soil loss (t/ha per year) • Share of erosion-prone slopes (>2°) • Content of mobile phosphorus and potassium (mg/kg)	Digital elevation models (SRTM, ALOS), field surveys, agrochemical service data
Rangelands (plain and desert)		• Above-ground biomass productivity (centners/ha)	• Vegetation cover of the soil (%) • Share of valuable forage species (%)	Field transects, data from pasture committees,

Level / Land-use type	Global sub-indicators (mandatory)	Examples of alternative indicators (additional regional)	Examples of additional indicators (local diagnostic)	Data sources / Methods of acquisition
			(field-based) • Pasture-load index (actual/normative) • Share of open/weakly stabilised sands (based on radar coherence data)	Sentinel (coherence), MODIS NDVI
Rangelands (mountain and high-mountain)		• Productivity (based on harvest cuts at key sites)	• Sward height (cm) • Presence of erosion forms (rills, washout) - score-based assessment • Share of areas with disturbed turf (%)	UAVs, field verification (PRAGA method), data from pasture committees
Forest lands (saxaul stands, tugai forests)		• Forest cover (%) • Timber stock (m^3/ha)	• Canopy closure/vegetation cover (%) • Species composition (share of native species) • Presence and condition of shelterbelts (per hectare/linear features)	Forest cadastre data, Sentinel-2, UAVs
Tier 3 (Local: farm, pasture committee)	Precise measurements, direct decision support			
All types	All of the above indicators, but with maximum detail and linkage to specific land plots.	• Yield (centners/ha) of a specific field	• Salinity maps (based on SI) at 10 m resolution • Maps of rangeland species composition (based on UAV/neural-network data) • Soil electrical conductivity (EC), dS/m (field measurements) • Groundwater depth in observation wells (m)	UAVs (orthophotos, multispectral imagery), field soil profiles, mobile applications (KoboToolbox, ODK) for data collection, data from pasture committees

3.3. How to select and combine indicators: practical examples

The table above may appear complex at first glance; the examples below demonstrate how an 'indicator package' can be developed in practice for specific situations.

Example 1: National reporting under SDG indicator 15.3.1 for Kazakhstan

- Level: Tier 1
- Indicators: the three global sub-indicators (Trends.Earth) + alternative indicators (statistical data on yields and livestock numbers) + additional indicators (the LDN Index by oblast and the pasture-load map from the KazNIIZhiK portal).
- Purpose: to provide official data for voluntary reporting to the UNCCD, while demonstrating that the country uses not only global proxy indicators but also its own national monitoring systems.

Example 2: Developing a programme to combat salinisation on irrigated lands in Bukhara Province (Uzbekistan)

- Level: Tier 2
- Indicators:
  - Global (productivity): NDVI trends based on Landsat data over 25 years (identification of productivity decline zones).
  - Alternative (carbon/fertility): agrochemical survey data on humus content and mobile mineral nutrition elements, providing evidence of agricultural depletion.
  - Additional (diagnostic): the Salinity Index (SI) from Sentinel-2, overlaid with groundwater-depth maps from the melioration cadastre.
- Result: identification of areas where declining productivity (low NDVI) correlates with high salinity indices and shallow groundwater. This justifies investments not simply in 'increasing yields', but in specific melioration measures (drainage repair, leaching and gypsum application).

Example 3: Rangeland management in Naryn Province (Kyrgyzstan)

- Level: Tier 3
- Indicators (PRAGA method):
  - Simple field indicators: vegetation cover (%), grass height (cm), proportion of palatable plants (%), seed presence (yes/no), and signs of erosion (yes/no).
  - Satellite-based (verified): maps generated by a neural network on the basis of field data, showing the probability of the spread of non-palatable species by pasture unit.
- Result: the pasture committee receives a map where the areas marked in red are not simply 'degraded' areas, but areas overgrown with poisonous grasses. The management response is to alter grazing periods or reseed valuable grasses not across the entire pasture, but in specific locations.

3.4. Principle of integration: from indicators to decisions

The key conclusion from this stage is that an indicator has value not on its own, but through its interpretation in conjunction with others. The priority is to develop a system in which:

1. **Global indicators** provide the initial signal (where is instability occurring?).
2. **Alternative national indicators** confirm and refine this signal, replacing coarse proxies with precise measurements.
3. **Additional indicators** explain the cause (why is this happening?) and help to select the correct instrument from the Avoid-Reduce-Reverse hierarchy.

Such an integrated approach makes it possible to move from establishing the fact of degradation to the substantiated planning of measures to prevent it and restore land, which is the ultimate objective of the entire LDN concept.

Stage 4. Additional interpretation of the integrated assessment: analysing indicator redundancy, result sensitivity and prioritisation of measures without replacing the 1OAO principle

The fourth stage is devoted to a critically important procedure: bringing together heterogeneous information from numerous indicators (the three global indicators and a range of additional indicators) into a single decision on the status of a land unit - whether it is degraded, improved or stable. The global methodology proposes a simple and conservative principle for this purpose: **One-Out, All-Out (1OAO).** However, experience in Central Asia demonstrates that the technical application of the 1OAO principle to an expanded set of additional indicators may increase the risk of double-counting the same processes.

4.1. The One-Out, All-Out (1OAO) principle: a conservative approach

The 1OAO principle described in the Good Practice Guidance [66] and discussed in the first part of the Handbook, remains the basic rule for integrating the three main sub-indicators of SDG indicator 15.3.1. At this stage it is used as the starting point for the subsequent interpretation of results, analysis of the causes of degradation, and selection of priority management measures.

4.2. The problem of redundancy and the unjustified overestimation of degraded area

However, when moving to national and subnational levels, where an expanded set of additional indicators is used (see Stage 3), the 1OAO principle begins to produce distortions. The more indicators are included in the assessment, the higher the probability that at least one of them will show a 'signal', even if no real or substantial degradation exists. This leads to the effect of ***unjustifiably inflating the calculated share of degraded land***.

The root of the problem lies in the correlation or redundancy of indicators. Many are not independent, but describe the same processes from different perspectives. Under Central Asian conditions, this is particularly evident:

- Example 1 (rangelands): the global indicator 'land productivity dynamics' (NDVI trend) and the additional indicator 'proportion of valuable forage species' are often closely related. In 95% of cases, a decline in NDVI on a pasture is accompanied by a deterioration in species composition. Including both indicators in an assessment under the 1OAO rule provides no new information, but formally doubles the 'weight' of the problem, even though in essence the same degradation process is being counted twice.

- Example 2 (irrigated lands): the Salinity Index (SI) and declining productivity (NDVI) are also correlated, but with a time lag. Salinity may already be high while a high NDVI value is still maintained through fertiliser application. In this case, the indicators provide different but complementary information, and neither should be excluded. At the same time, in this context the Salinity Index (SI) should primarily be regarded as an additional early-warning and risk diagnostic indicator. It may indicate a degradation process before it manifests itself in declining NDVI; however, its use to change the official status of a land unit under SDG indicator 15.3.1 requires a separate national methodological decision, documentation of threshold values, data sources and verification procedures. Otherwise, SI should be used for interpretation and prioritisation of measures, but not as an automatic standalone criterion of official degradation.

Key conclusion from regional studies: as described in a number of works [29, 35, 36], for arable land and rangelands in Central Asia the global indicator 'land productivity dynamics' determines the final status of the integrated SDG 15.3.1 indicator for a land unit under the 1OAO rule in 95% of cases. This may mean that, in many cases, it largely determines the final assessment. Adding other indicators without taking their interrelationships into account may create a risk of overestimating the degraded area due to the inclusion of statistically unstable or interdependent signals.

4.3. Proposed solution: analysis of 'weights' and the introduction of significance thresholds

In order to preserve the sensitivity of the method while avoiding unjustified overestimation, it is proposed to use a modified integration procedure at national and subnational levels by introducing elements of mathematical weighting of indicators. This is not a rejection of the 1OAO principle, but rather its additional analytical calibration, and an additional weighted assessment for prioritisation and sensitivity analysis which does not replace 1OAO.

The weighted integration procedure includes the following steps:

Step 1. Correlation analysis. During system calibration for a specific region or land-use type, a pairwise correlation analysis should be conducted for all indicators used (global and additional). This makes it possible to identify groups of strongly correlated indicators which, in effect, measure similar parameters or processes.

Step 2. Assignment of weights and priorities. For each group of correlated indicators, a 'leading' indicator is identified, with the highest diagnostic value and the lowest uncertainty. Other indicators in the same group are regarded as confirmatory, but do not have an independent 'veto' right under the 1OAO rule. For example:

- For rangelands: the leading indicator is the productivity trend (NDVI), while the proportion of valuable species and vegetation cover are confirmatory. If NDVI is stable but species composition deteriorates, a risk or initial stage of degradation is recorded, but the land unit is not included in the final statistics of degraded land without additional confirmation in the next cycle.

- For irrigated lands: the leading indicator may be the Salinity Index (SI) as an early indicator, while the NDVI trend is confirmatory. A high SI with stable NDVI is an alarm signal requiring intervention, but the land unit may not yet formally be considered degraded according to the productivity criterion.

Step 3. Introduction of a significance threshold for additional indicators. In order for an additional indicator to 'outweigh' the global indicators and independently classify a land unit as degraded, the change in that indicator should exceed a stricter threshold than that used for global indicators. For instance, if a 10% threshold may be sufficient for a global indicator, a threshold of 20-30% may be established for a specialised additional indicator to filter out random fluctuations.

Step 4. Expert calibration. Final weights and threshold values cannot be determined statistically alone. They should be approved by national expert groups involving sectoral specialists (soil scientists, agronomists, foresters and rangeland specialists), on the basis of an understanding of the significance of a given process for the relevant land-use type.

4.4. Illustration of the 'weighted' approach

Table 11. Hypothetical irrigated arable plot in the lower Amu Darya.

Indicator	Value	Interpretation under the 1OAO rule	Interpretation under the weighted approach
Productivity (NDVI trend)	Stable (+1%)	No degradation	Leading indicator. Stable.
Land cover	'Arable land' (unchanged)	No degradation	Confirmatory. No change.
Soil carbon (agrochemistry)	Decrease of 5%	No degradation (<10% threshold)	Confirmatory. Minor decline.
Salinity Index (SI)	Increased by 25%	Degradation (under 1OAO)	Confirmatory, but exceeds the threshold (25% > 20%). Included as a high-risk signal.

Result under standard 1OAO: the plot is degraded (because of SI). The degradation area is counted.

Result under the weighted approach: the leading indicator (productivity) is stable. The additional indicator (SI) shows a strong increase exceeding the higher significance threshold.

Hence, the plot cannot be recognised as degraded to the moment, but it is identified as an area of 'critical risk' with a forecast of imminent degradation. This calls not for inclusion in loss statistics, but for immediate preventive measures (improved drainage and leaching). This is a more nuanced and management-relevant decision.

Conclusion. The One-Out, All-Out principle remains the foundation of the integrated assessment, but at national and subnational levels it should be applied with due consideration of correlations among indicators. Moving to a weighted assessment that distinguishes leading and confirmatory indicators and introduces differentiated significance thresholds makes it possible to:

1. Avoid unjustified inflation of the degraded area as a result of including redundant or weakly significant signals.
2. Maintain the high sensitivity of the method to real threats.
3. Produce not merely statistics (‘degradation yes/no’), but a diagnostic map distinguishing areas that are already degraded from areas at risk, which is critical for planning anticipatory, rather than only compensatory, measures.

Stage 5. In-depth diagnostics: recurrence analysis, identification of mechanisms and scenario interpretation

The fifth stage is the analytical core of the entire enhanced methodology. If the previous stages answered the questions *‘where?’ and ‘how strongly has the situation changed?’*, this stage must answer the key management questions: *‘is the problem chronic?’, ‘what is the dominant degradation mechanism?’ and ‘what scenario of development can be expected?’*. The answers make it possible to move from standardised measures to the differentiated strategies described in Stage 6.

Diagnostics consist of three consecutive analytical procedures, each providing a distinct information layer. The first of these - trend analysis - was discussed in detail in Stage 2.

5.1. Trend analysis: rate and direction of change

As described in detail in Stage 2, the use of a dynamic baseline makes it possible to construct a trend line for each pixel or polygon based on a smoothed time series of key indicators (for example, the share of degraded land D, the share of improved land I, or the integrated LDN Index). The linear trend equation

Y = a + b * X provides two key parameters:

- **Coefficient b -** the rate and direction of change (the slope of the trend). A positive b for D indicates steady expansion of degradation; a negative value indicates its reduction.
- **Coefficient a -** the estimated value of the indicator at the beginning of the observation period, interpreted as the initial potential of the territory or its ‘historical baggage’.

These coefficients serve as the basis for the subsequent diagnosis of mechanisms. Before proceeding to that diagnosis, however, persistent chronic processes must be separated from temporary climate-driven fluctuations.

5.2. Recurrence (frequency) analysis: separating chronic problems from climatic noise

The first specialised procedure answers the question: *‘Is degradation on this land unit a persistent, recurring phenomenon, or is it the result of a one-off climatic anomaly?’*

Methodology of analysis:

1. Constructing a series of temporal snapshots. The entire available observation period is divided into a set of overlapping or consecutive time intervals. For Central Asian conditions, the use of five-year moving windows has been found to be optimal (for example, 2001-2005, 2003-2007, 2005-2009, ..., 2018-2022). A five-year window smooths annual climatic variability while retaining sensitivity to medium-term trends.

2. Classifying status within each ‘window’. For each pixel or polygon in each five-year period, the status is determined using the integrated SDG 15.3.1 indicator (taking account of verified and additional indicators): ‘degradation’, ‘improvement’ or ‘stability’.
3. Calculating frequency. For each pixel, the number of time windows in which it was classified as ‘degraded’ is counted (as a percentage of the total number of windows). Similar calculations are carried out for the statuses ‘improved’ and ‘stable’.

Interpretation of frequency-analysis results:

- *‘Hotspots’: degradation frequency > 70%.* These are areas of chronic, persistent degradation. Negative processes dominate here regardless of climatic fluctuations. Such areas require immediate and, as a rule, capital-intensive restoration measures (the ‘Reverse’ strategy).
- *‘Bright spots’: improvement frequency > 70%.* Here it is important to study and replicate successful land-use practices, creating demonstration and learning areas.
- *Permanently stable lands: stable states recur in 70% of cases or more.* The priority here is preventive measures to avoid degradation (the ‘Avoid’ and ‘Reduce’ strategies).
- *Fluctuation zones:* all other territories (where degradation and improvement frequencies are below 70%, and stability also does not dominate). These are areas where land condition fluctuates in response to weather conditions or short-term anthropogenic impacts. They require particular attention, since temporary deterioration may become chronic degradation under inappropriate management. The priority is prevention (Avoid) and adaptive management.

Practical significance: experience described in the case studies shows that persistent degradation centres (‘hotspots’) occupy a relatively small share of the territory (often less than 5-10%), but exert a disproportionate influence on overall dynamics and serve as sources of dust storms and biodiversity loss. Concentrating resources on these areas provides the maximum effect.

5.3. Diagnosis of degradation mechanisms and scenarios (based on the joint analysis of coefficients a and b)

The second procedure answers the question: *‘How exactly is the process unfolding? What is its dominant mechanism and on what initial basis is it developing?’* For this purpose, the regression coefficients obtained in Stage 2 should be used, but considered systemically, taking into account both the rate of change (***b***) and the initial condition (***a***).

Coefficient ***a*** may be considered as a characteristic of the initial potential of the territory; its interpretation should take account of the specific land type concerned and may differ for arable land, rangelands, forest land and other categories:

- **A high value of a<D> (for example, > 20-30%):** the territory already had a significant ‘historical tail’ of degradation at the start of the period. This is a zone of accumulated damage requiring long-term restoration programmes.
- **A low value of a<D> (for example, < 5-10%):** the initial condition was favourable and degradation was minimal. This is a high-potential zone where the primary task is to prevent losses.

- **A high value of a<I>:** the territory has good self-recovery capacity or has already been subject to successful measures.
- **A low value of a<I>:** restoration potential is low; even if pressure is removed, the system will recover slowly.

Combining these four parameters (a<D>, a<I>, b<D>, b<I>) provides a more nuanced diagnosis than analysing trends alone. An expanded typology of scenarios based on the practical case studies is presented below.

Table 12. Expanded diagnosis of degradation mechanisms taking into account initial potential *(I - improvement; D - degradation)*

Scenario	Diagnostic features (combination of a and b)	Interpretation of mechanism and outcome	Management strategy
1. Crisis Onset	a<D> is low (initially favourable), b<D> >> 0 (rapid increase). a<I> may be high, but b<I> is declining.	A territory with high potential suddenly comes under strong degradation pressure. The crisis develops on a ‘healthy’ base. Immediate response is required before the potential is irreversibly lost.	Emergency Reverse, aimed at reducing aggressive degradation in order to preserve initially high potential.
2. Chronic Exhaustion	a<D> is medium or high (problems already exist), b<D> > 0 (slow increase). a<I> is low, b<I> < 0 (recovery capacity is declining).	The system is slowly but steadily losing the remnants of its resilience. Positive processes are shrinking. This is typical of territories with a long history of overgrazing or inappropriate melioration.	Stabilisation and phased restoration (Reduce + Targeted Reverse), aimed both at improving the poor initial condition (negative a) and reducing the negative trends that have exacerbated it.
3. Systemic Collapse	a<D> is high, b<D> > 0 (degradation is expanding). a<I> is low, b<I> < 0 (restoration is declining).	The worst-case scenario. The territory is problematic from the outset; degradation and declining potential continue, with no resources for recovery.	Comprehensive Reverse. Heavy investments are required, combining urgent and long-term measures in a combined scenario.
4. Potentially Stable Equilibrium	a<D> is low, b<D> ≈ 0 (degradation is absent and does	The territory is in equilibrium and has good potential. The main task is	Preventive protection (Avoid). Sustainable management and

Scenario	Diagnostic features (combination of a and b)	Interpretation of mechanism and outcome	Management strategy
	not emerge). a<I> may vary, b<I> ≈ 0.	to prevent negative trends from emerging.	monitoring for early detection of threats.
5. Fragile Low-Level Equilibrium	a<D> is high, b<D> ≈ 0. a<I> is low, b<I> ≈ 0.	The ecosystem has adapted to conditions of chronic degradation. There are no active trends, but no recovery is occurring either. This is an ‘ecological dead end’.	Conservation and protection from new threats (Avoid). Costly restoration is not advisable. Improvement potential is extremely low.
6. Recovery from High Base	a<D> is low, b<D> < 0 (degradation is declining). a<I> is high, b<I> > 0 (improvement is expanding).	An ideal scenario. A territory with good potential is recovering successfully. The task is to support the process.	Maintain & Upscale success.
7. Recovery from Low Base	a<D> is high, b<D> < 0 (degradation is declining). a<I> is low, b<I> > 0 (improvement is increasing from zero).	A territory that had been in deep crisis has begun to emerge from it. The process is under way, but requires continuous support because self-recovery potential was initially low.	Sustained Reverse.

5.4. Scenario forecasting

The concluding part of diagnostics is the use of identified trends and mechanisms to develop forecasts. The method of linear extrapolation based on coefficient b (calculation of future losses) was described in detail in Stage 2. It is important to emphasise here that forecasting should be scenario-based.

Instead of a single forecast, several trajectories should be constructed, reflecting different possible futures:

- **The Business-as-Usual (BAU) scenario:** extrapolation of current trends (coefficients b). It demonstrates what will happen if nothing changes.
- **The Climate Scenario:** adjustment of trends taking into account projected climate models (for example, increasing aridisation). This requires integration with hydrometeorological data.

- **The Management Scenario:** modelling how trends (b) will change when specific measures are implemented (for example, a 20% reduction in livestock numbers or construction of drainage on 1,000 ha). This makes it possible to substantiate the effectiveness of planned investments quantitatively.

Summary.

In-depth diagnostics transform raw monitoring data into structured information for decision-making.

1. **Recurrence analysis** localises zones of chronic problems ('hotspots'), where investments will have the greatest effect, as well as zones of sustained restoration ('bright spots'), whose experience should be replicated.
2. **Diagnosis of mechanisms** (based on the joint analysis of coefficients a and b for degradation and improvement trends) makes it possible to understand the nature of the crisis, assess the initial potential of the territory, and select an appropriate strategy from the Avoid-Reduce-Reverse hierarchy.
3. **Scenario forecasting** makes it possible to assess the consequences of inaction and substantiate the cost-effectiveness of planned measures, shifting the discussion from 'something must be done' to 'this should be done because it will save X billion by 2030'.

Stage 6. Interpretation of results and selection of a differentiated management strategy

This stage forms the bridge between analysis and action. At this stage, the full body of diagnostic information obtained in previous steps is translated into a concrete, scientifically grounded action plan. We move from answering the question 'what is happening?' to answering the central management question: 'what should be done, and where?'

The key principle here is ***differentiation***. It is neither possible nor efficient to apply identical measures across the entire territory. A successful strategy for achieving LDN should be a portfolio of solutions 'stitched together' from different approaches for different zones, depending on their diagnosis. This portfolio is developed on the basis of two complementary diagnostic inputs obtained in Stage 5: (1) the results of frequency analysis and (2) the typology of scenarios identified through the joint analysis of coefficients a and b.

6.1. First level of differentiation: response based on frequency analysis

The first, broadest level of dividing the territory into zones with different degrees of problem persistence is provided by frequency analysis (section 5.2). It answers the question: 'where has the problem already become chronic, and where is it temporary?'

- **'Hotspots' (degradation frequency > 70%):** areas of chronic, persistent degradation. Negative processes dominate here irrespective of climatic fluctuations. A 'Reverse' strategy is required. These are zones for immediate and, as a rule, capital-intensive investments: phytomelioration, reclamation, construction of drainage systems, and changes in land-use type.
- **'Bright spots' (improvement frequency > 70%):** here, natural processes or sound management are already producing positive results. The strategy is to 'Maintain &

Upscale'. Successful practices should be studied and documented so that they can be used as examples for learning and transfer to other territories.

- **Permanently stable lands (stability > 70%):** zones where land condition is stable. The main task is to prevent degradation from emerging. The strategy is 'Avoid'. This implies the introduction of preventive sustainable land management measures: regulation of pressure, protective afforestation and observance of crop rotations.
- **Fluctuation zones** (all other territories): the most difficult category to manage. Here, land condition fluctuates in line with climatic cycles or short-term impacts. In favourable years they may appear healthy; in dry years they may issue warning signals. It is precisely here that temporary deterioration may turn into chronic degradation if management is inappropriate. The strategy is adaptive management and monitoring, with emphasis on preventive measures (Avoid) and rapid response to the first signs of a persistent negative trend.

6.2. Second level of differentiation: response based on trend diagnostics

The first level tells us where the problem is chronic and where it is not. It does not, however, explain how exactly the degradation process is unfolding. For this purpose, the results of mechanism diagnostics, based on the joint analysis of coefficients a and b for established dynamic trends (section 5.3), are used. This diagnosis makes it possible to select the appropriate intervention instrument.

Recall that coefficient a reflects the initial potential of the territory ('proximity to the edge of the precipice'), while coefficient b reflects the rate and direction of the process ('the speed of decline'). Combinations of these coefficients for degradation (D) and improvement (I) indicators yield different scenarios, each requiring its own strategy. The expanded interpretation of these scenarios, directly linked to the choice of management decisions, is presented in Table 13.

Table 13. Selection of a management strategy based on the diagnosis of mechanisms

Scenario	**Diagnostic features**	**Interpretation of the mechanism**	**Management strategy (LDN hierarchy) and specific examples of measures**
1. Crisis Onset	a<D> is low (initially favourable), b<D> >> 0 (rapid growth of degradation). a<I> may be high, but b<I> is declining.	A territory with high potential suddenly comes under powerful and acute degradation pressure. Urgent measures are required.	Emergency Reverse. Measures should aim at immediately addressing the cause: sharp reduction of livestock numbers, closure of the site to grazing, emergency construction of protective structures, and prohibition of ploughing.
2. Chronic Exhaustion	a<D> is medium or high (problems already exist), b<D> > 0 (slow	The system is slowly but steadily losing the remnants of its resilience.	Stabilisation and phased restoration (Reduce + Targeted Reverse). Priority measures are to halt the

Scenario	Diagnostic features	Interpretation of the mechanism	Management strategy (LDN hierarchy) and specific examples of measures
	increase). a<I> is low, b<I> < 0 (recovery capacity is declining).	Positive processes are shrinking. This is typical of territories with a long history of overgrazing or inappropriate melioration.	decline in recovery potential (Reduce): infrastructure improvement (watering points to disperse pressure), support for natural regeneration. In parallel, targeted restoration (Reverse) should be implemented on the most valuable sites.
3. Systemic Collapse	a<D> is high, b<D> > 0. a<I> is low, b<I> < 0.	The worst-case scenario. The territory is initially problematic and negative processes continue to develop; recovery resources are exhausted.	Comprehensive Reverse. Heavy long-term investments are required, combining urgent and long-term measures: phytomelioration, radical pasture improvement, and reconstruction of drainage systems. The strategy should be designed over decades.
4. Potentially Stable Equilibrium	a<D> is low, b<D> ≈ 0. a<I> may vary, b<I> ≈ 0.	The territory is in equilibrium and has good potential. The main task is to prevent negative trends from emerging.	Preventive protection (Avoid). Sustainable management and monitoring for early detection of threats. Introduction of good practices that prevent overload and erosion.
5. Fragile Low-Level Equilibrium	a<D> is high, b<D> ≈ 0. a<I> is low, b<I> ≈ 0.	The ecosystem has adapted to life under conditions of chronic degradation. There are no active trends, but there is also no recovery. This is an ‘ecological dead end’.	Conservation and protection from new threats (Avoid). Costly restoration is not appropriate here and may disrupt the fragile equilibrium. The priority is protection from new anthropogenic pressures and maintenance of the existing regime. Example: protected areas on degraded lands.
6. Recovery from High Base	a<D> is low, b<D> < 0. a<I> is high, b<I> > 0.	An ideal scenario. A territory with good potential is recovering successfully.	Maintain & Upscale. The task is to ensure long-term support for restoration processes (maintaining pasture-rotation regimes, fire protection). The experience should be

Scenario	Diagnostic features	Interpretation of the mechanism	Management strategy (LDN hierarchy) and specific examples of measures
			documented for transfer to other territories.
7. Recovery from Low Base	a<D> is high, b<D> < 0. a<I> is low, b<I> > 0.	A territory that had been in deep crisis has begun to emerge from it. The process is under way, but self-recovery potential was initially low.	Sustained Reverse. The process requires continuous support and investment. Without support, it may easily reverse. Measures include reseeding valuable grasses, regulating grazing, and controlling weeds.

6.3. Integration of the two approaches: from diagnosis to action in a specific case

The two diagnostic levels do not operate instead of each other, but together. Frequency analysis (hotspots) tells us where to concentrate efforts. Mechanism diagnostics (a and b scenarios) tells us which specific efforts should be applied there. Incorporating coefficient a into the diagnostic analysis makes it possible to answer not only the question 'how fast are we sliding into the abyss?' (trend b), but also 'how close are we already to the edge?' (initial state a). This provides a more three-dimensional picture for strategic decision-making and helps avoid serious errors when identical measures are applied to territories that differ fundamentally in the mechanism of their crisis.

Thus, at the sixth stage, diagnostic data are transformed into a targeted action plan:

1. Frequency analysis serves spatial prioritisation by identifying zones of chronic problems ('hotspots') where intervention is needed first.
2. Mechanism diagnostics (based on coefficients a and b) determines the type of intervention required for each zone, making it possible to select an appropriate strategy from the expanded Avoid-Reduce-Reverse hierarchy.
3. Integrating these two approaches makes it possible to develop a portfolio of differentiated strategies for the entire region, where each management unit (from a national park to a pasture committee) has a clear, scientifically grounded prescription: 'here - rescue immediately; here - restore patiently; and here - simply protect and avoid interference'. This is the essence of the transition from passive monitoring to active land-resource management on the pathway to land degradation neutrality.

Stage 7. Forecasting and adaptive management

The final stage shifts the system from passive reporting to active planning. Forecasts of future dynamics are constructed on the basis of identified trends. For example, it is estimated how many hectares of rangeland will be lost by 2030 if current trends continue (the BAU scenario), and what volume of compensatory measures will be required to achieve neutrality. These forecasts are reviewed and refined in each new monitoring cycle, implementing the principle of adaptive management.

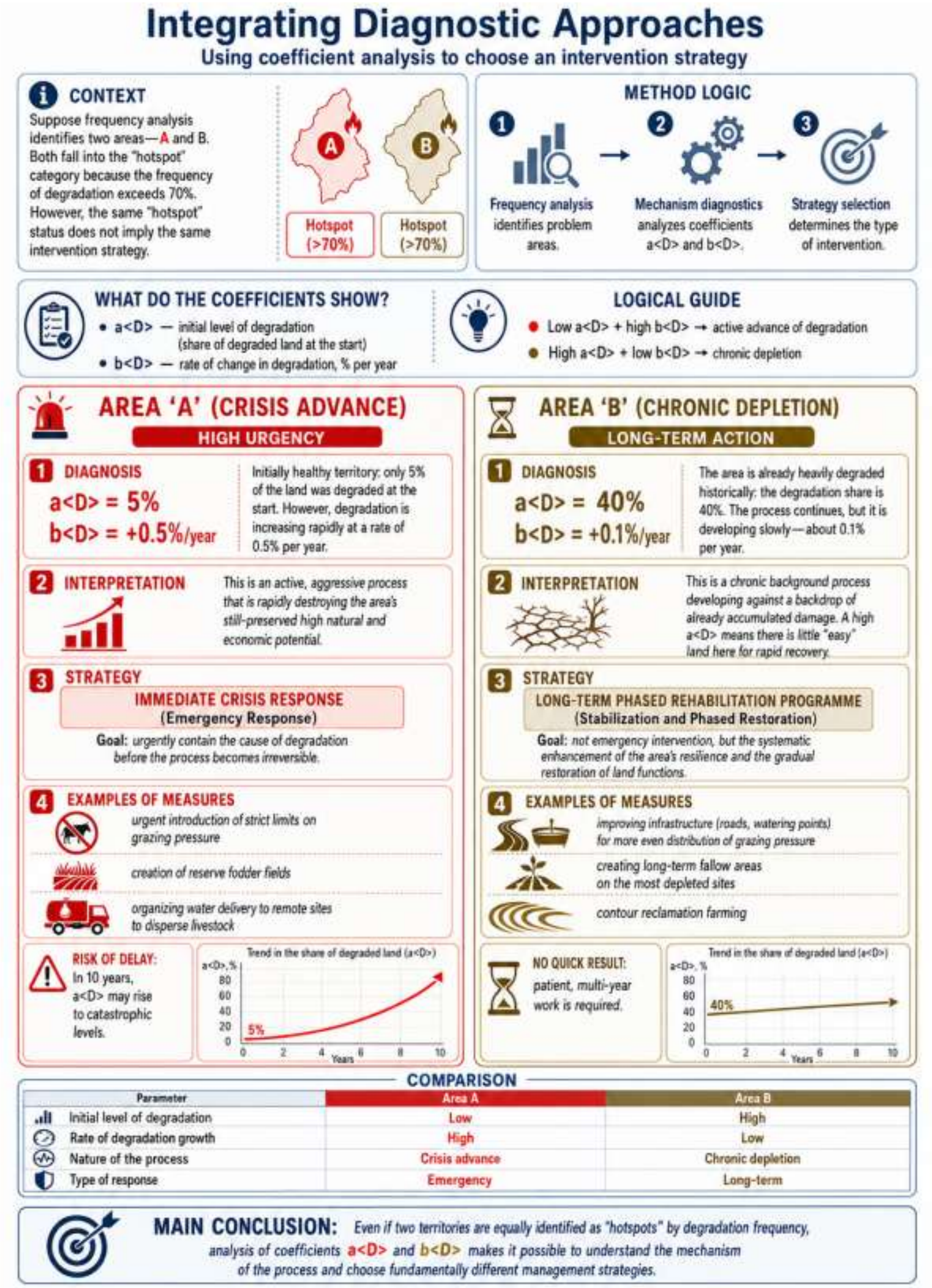


Figure 47. Schematic diagram for selecting a land-use strategy taking account of trend analysis

Chapter 20. Scaling the algorithm: from the national level to the individual field

The proposed algorithm is universal in its logic, but its tools and indicators change fundamentally depending on the scale of assessment. Table 14 systematises these differences.

Table 14. Application of the enhanced LDN algorithm at different scales

Stage / Characteristic	National level (Tier 1)	Subnational level (Tier 2)	Local level (Tier 3)
Main purpose	International reporting (SDG 15.3.1), identification of national hotspots, strategic planning.	Regional planning, budget allocation, development programmes, refinement of LDN targets.	Design of specific measures, monitoring of their effectiveness, resolution of land disputes.
Spatial resolution	Coarse (250 m - 1 km).	Medium (10-30 m).	High and very high (less than 10 m, UAVs, field measurements).
Main data sources	MODIS, AVHRR, global ESA CCI products, SoilGrids, national statistics (yields, livestock numbers).	Landsat, Sentinel-2, national maps (soil, geobotanical), cadastre data, agrochemical survey results.	Sentinel-2, commercial satellites (SuperView, Planet), UAVs, field transects, soil profiles, electrical conductivity sensors, data from pasture committees.
Verification	Expert assessment and comparison with limited national data.	Validation across a network of representative key sites with the involvement of scientific organisations.	Full or sample-based ground verification with the participation of land users and field measurements.
Key indicators (in addition to the three global indicators)	Integrated indices (LDN Index), forest share, share of irrigated land, livestock numbers.	Salinity indices (SI), share of erosion-prone land, pasture productivity (centners/fodder units), condition of shelterbelts.	Vegetation cover, species composition (share of palatable/poisonous plants), sward height, groundwater depth, mineralisation, thickness of the humus horizon.

Stage / Characteristic	National level (Tier 1)	Subnational level (Tier 2)	Local level (Tier 3)
Methods	Spatial analysis in Trends.Earth, statistical processing.	Time-series analysis (Landsat), calculation of spectral indices, regression analysis to identify trends.	Classification based on neural networks (Kohonen, Random Forest), SAR coherence analysis, erosion models (RUSLE), field mapping.

Chapter 21. Sectoral specificity: arable land, rangelands and forests

The general algorithm also requires ‘sectoral calibration’. The key features for the three main land-use types in the region are presented below as an example for further methodological development and specification.

21.1. Irrigated and rainfed arable lands

Main threats: secondary salinisation, dehumification, water erosion (on rainfed land), and irrigation erosion.

Key indicators (in addition to the baseline indicators):

- Spectral salinity indices (SI) for early detection of the problem while NDVI remains high (the phenomenon of ‘green degradation’).
- Groundwater level and mineralisation (a critical salinisation factor).
- Agrochemical monitoring data: dynamics of humus content, mobile phosphorus and potassium.
- Soil bonitet score.
- Condition of the collector-drainage network (an infrastructure indicator).

Specificity of interpretation: the transition ‘irrigated arable land’ -> ‘fallow land’ in the region should be interpreted not as a neutral change, but as degradation if it is caused by irreversible salinisation.

21.2. Rangelands

Main threats: overgrazing (pasture breakdown and erosion), undergrazing (weed encroachment and ‘green deserts’), desertification and deflation.

Key indicators:

- Vegetation quality indicators: vegetation cover, proportion of valuable forage species, proportion of weed/poisonous plants, sward height and seed presence.
- Pressure indicators: actual stocking rate (head/ha) compared with the norm.
- Deflation indicators: share of open and weakly stabilised sands, identified through a combination of optical and radar data.
- Water-supply indicators: availability and condition of watering points.

Specificity of interpretation: an increase in NDVI on rangeland requires mandatory verification. It may indicate either recovery or a 'green desert' (expansion of non-palatable plants). A pasture with high NDVI but dominated by wormwood or poisonous grasses is a degraded pasture.

21.3. Forest lands (including saxaul stands and tugai forests)

Main threats: cutting, degradation under grazing pressure, fires, declining groundwater levels (in tugai forests), and desiccation.

Key indicators:

- Forest cover (forest-covered area) and its dynamics.
- Canopy closure/stand vegetation cover.
- Species composition and age structure (to assess natural regeneration).
- Presence and condition of shelterbelts (as linear features).
- Area affected by fires and clear-cutting.

Specificity of interpretation: transitions involving saxaul stands require careful interpretation. Natural thinning during drought is a temporary fluctuation, not degradation. Anthropogenic degradation (cutting, grazing) requires intervention.

Chapter 22. Road map for future research and further development of the LDN methodology in Central Asia

The synthesis presented in the Handbook is not an end point, but an important milestone on the path towards a fully adapted and functioning regional monitoring system. Several key areas for future research and institutional efforts are proposed.

22.1. Technical and methodological directions

1. **Development of regional spectral libraries and calibration coefficients:** coordinated work is needed to collect field spectral data for the main soil and vegetation types in the region. This will substantially improve the accuracy of machine-learning algorithms for mapping salinity, rangeland species composition and types of desertification.
2. **Integration of radar data into regular monitoring:** experience from different countries demonstrates the considerable potential of radar coherence for monitoring sand dynamics, soil moisture and vegetation structure. Regional protocols for processing Sentinel data should be developed so that these data can be incorporated into national systems.
3. **Improvement of forecasting methods:** moving from simple linear extrapolation of trends to more complex models that take account of climate scenarios, socio-economic drivers and scenario planning ('what if...'). This will make it possible to justify long-term investments in restoration.
4. **Assessment of accumulated historical damage:** a methodology is needed that can quantify irreversible land losses from previous periods (for example, the Soviet period) and incorporate tasks for addressing them into long-term national LDN **targets, while distinguishing them from the prevention of current degradation.**

22.2. Institutional and organisational directions

1. **Establishment of a regional LDN centre of excellence** (for example, within the framework of the UNCCD Interregional Group 'Central Asia - Russia'): such a centre

could harmonise methodologies, organise joint training programmes, validate regional products and coordinate transboundary monitoring.

2. **Institutionalisation of community-based monitoring:** the role of pasture committees, village assemblies and other local communities in data collection for LDN verification should be formalised in legislation. This would help enhance the legitimacy of decisions and reduce monitoring costs.
3. **Development of financing mechanisms for compensatory measures:** how can pilot projects be scaled up into large programmes? Existing mechanisms should be studied and adapted for the region, including payments for ecosystem services, green bonds and carbon credits (through carbon sequestration resulting from the restoration of degraded lands). The economic rationale for such mechanisms can be based on data from enhanced LDN monitoring.

Conclusion

The proposed approach marks a transition from a uniform, 'copied' model of land degradation assessment to a flexible, ***landscape-adapted and problem-oriented system***. It has been demonstrated that successful application of the LDN concept in Central Asia requires more than merely calculating the three global indicators. It is important to emphasise that the proposed approaches are intended to improve the quality of interpretation and practical applicability of results, while maintaining consistency with the global methodological framework. The following is proposed:

1. **Change the assessment philosophy -** move from static comparison to the analysis of dynamic processes based on a dynamic baseline.
2. **Deepen diagnostics -** go beyond establishing facts to identifying mechanisms ('onset', 'exhaustion', 'green degradation' - a situation in which high vegetation activity masks the deterioration of soil properties) and localising chronic hotspots.
3. **Differentiate the toolkit -** use different datasets and indicators depending on scale (national, regional, local) and land-use type (arable land, rangeland, forest).
4. **Institutionalise the process -** establish inter-agency coordination mechanisms and unified spatial data infrastructures, and, critically, include local communities in the verification and monitoring system.

The enhanced algorithm described in detail in this Handbook, together with the road map for future research, is intended to help national expert groups, planning authorities and project teams not only report against SDG indicator 15.3.1, but also use the LDN methodology as a powerful, scientifically grounded instrument for managing the future of their lands. By following this pathway, the countries of the region will be able to move from the passive recording of damage to proactive, effective and equitable management of their most important natural capital.

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