ABSTRACT
of the dissertation for the degree of Doctor of Philosophy (Ph.D.)
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Development of scientific and applied foundations of landscape and agroecological zoning of the Turkestan region

This dissertation research addresses the challenge of sustainable agricultural land use in the Republic of Kazakhstan, aiming to restore and preserve the territory's agricultural resource potential.

Relevance of the research study. A key challenge for the socio-economic development of Kazakhstan specifically in desert regions such as the Turkistan Region is ensuring the environmentally safe and balanced development of agricultural production. The region ranks second in the republic for crop and livestock output, with agricultural land accounting for 86.4 % of its total area. Agricultural producers' pursuit of profit, without regard for the agro-resource potential of the landscapes being developed, leads to land degradation and a decline in both the volume and quality of crop production. A solution to this situation lies in basing the region's agricultural land use on the agro-resource and landscape-ecological components of the natural environment; this would, in turn, establish a spatial foundation for the region's agricultural development. Accordingly, this study develops scientific and methodological principles for landscape-agroecological zoning tailored to the natural conditions of the Turkistan Region based on ecological adaptability to landscape diversity.

Object of study – modern agricultural landscapes of the Turkistan Region.

Subject of study – patterns of agrolandscape differentiation and methods for their comprehensive agro-ecological assessment for zoning purposes.

Purpose of the study – To develop the scientific and applied foundations for the landscape-agroecological zoning of the Turkistan Region for the purposes of sustainable agricultural land use and the environmentally balanced development of the territory.

To achieve the stated goal, the following objectives were defined:

– to analyze the theoretical and methodological foundations of landscape-agroecological zoning and determine their significance in agricultural land use;

– to assess the structural organization of modern landscapes and their agro-resource potential;

– to identify spatial patterns regarding the extent of agricultural development, degradation, and resilience of landscapes to agricultural impact;

– to develop a scheme for detailed landscape-agroecological zoning, as well as measures and recommendations for balanced agricultural land use.

Research methodology. The methodological basis of the study comprises a combination of systemic, regulatory-legal, and landscape-ecological approaches utilizing GIS technologies. This framework integrates key principles and methods from landscape science, geoecology, natural-agricultural zoning, and land-use planning, enabling an assessment of the region's agro-resource potential, an evaluation of the ecological status of natural complexes, and a determination of landscape resilience to agricultural impact. On this basis, a detailed landscape-agroecological zoning of the Turkistan Region was conducted to promote balanced agricultural land use.

The research employed empirical, theoretical, and field methods, encompassing the following stages: problem definition; program development (including the formulation of core working hypotheses and priorities); selection and justification of the theoretical-methodological framework; data collection regarding the condition of landscapes under agricultural use; creation of assessment maps for the detailed landscape-agroecological zoning of the Turkistan Region; and the generation and validation of scientific results.

Sources of research materials – archival, cartographic, literary, and statistical data from the Land Resources Department and the Statistics Agency of the Turkistan Region (Republic of Kazakhstan); cartographic materials: a geomorphological map of Kazakhstan (scale 1:1,500,000; authors: A.V. Visloguzova, A.R. Medeu, et al.), a vegetation map of Kazakhstan and Central Asia (scale 1:2,500,000; authors: N.I. Akzhigitova, S.A. Arystangaliev, et al.), a topographic base map (scale 1:500,000), and a landscape map of Kazakhstan (scale 1:2,500,000; authors: V.M. Chupakhin, L.K. Veselova, G.V. Geldyeva); internal records from the JSC "Institute of Geography and Water Security" (Ministry of Science and Higher Education of the Republic of Kazakhstan); empirical data obtained during fieldwork conducted in 2022-2024; and remote sensing data, specifically multispectral Sentinel-2 satellite imagery from 2020-2024.

The scientific novelty of the research is determined by the following positions:

– criteria and assessment indicators for balanced agricultural land use in the Turkistan Region have been developed for the first time;

– a series of assessment maps for the Turkistan Region (at a scale of 1:1,000,000) has been developed for the first time utilizing proprietary methodologies, GIS technologies, and field research results covering: 1) contemporary landscapes; 2) the extent of agricultural landscape development; 3) water availability; 4) the agro-resource potential of landscapes; 5) landscape resilience to agricultural impact (crop cultivation and grazing); and 6) the degree of degradation of agricultural landscapes, including elements of their ecological status;

– an integrated spatial model for assessing the agro-resource potential of arid agricultural landscapes has been developed for the first time, based on a combined analysis of four groups of natural resource factors;

– a scheme for detailed landscape-agroecological zoning of the Turkistan Region, accompanied by a comprehensive explanatory legend, has been developed for the first time;

– a set of measures and scientifically grounded recommendations for balanced agricultural land use in the Turkistan Region has been developed for the first time; these are aimed at the region's ecological and socio-economic stabilization, taking into account the resilience of natural complexes to agricultural impact.

Main provisions submitted for defense:

1. Assessing the contemporary structural differentiation of landscapes in the Turkistan Region and their agro-resource potential forms the scientific basis for establishing a system of balanced agricultural land use in the region.

2. Comprehensive thematic mapping of agricultural landscapes in the Turkistan Region conducted using field surveys, remote sensing data, and modern GIS technologies ensures the reliability of the region's detailed landscape-agroecological zoning.

3. Detailed landscape-agroecological zoning of the Turkistan Region, based on the integrated analysis of natural-climatic, agro-resource, and landscape-ecological indicators, establishes the foundation for sustainable and environmentally safe agricultural land use in the region.

Theoretical and practical significance of the work. *Theoretical significance of the study.* The study's findings will contribute to the advancement of fundamental geography regarding the development of methodological and applied frameworks for landscape-agroecological research; they will also fill knowledge gaps in the theoretical and practical aspects of landscape science, agricultural land use, ecology, and applied mapping.

Practical value and significance of the study. The results of the dissertation research will serve as a tool for management bodies and agricultural entities in organizing balanced agricultural land use and restoring the agro-resource potential of the Turkistan Region; they will expand the international methodological framework for developing the conceptual foundations of landscape-agroecological research in desert regions; the practical recommendations developed for balanced regional land use amidst desertification processes can be adapted for desert territories in neighboring states; and the practical implementation of the landscape-agroecological zoning scheme will help improve agricultural land productivity and ensure environmentally safe and economically efficient operations.

The results of the dissertation research have been implemented by the Department of Land Relations (**Implementation Certificate No. 35/1838** dated September 30, 2024) and the Department of Agriculture (**Implementation Certificate No. 30/2599** dated September 30, 2024) of the Turkistan Region, Republic of Kazakhstan. Specifically, seven assessment maps at a scale of 1: 1,000,000 were provided, including the "Map of Contemporary Landscapes of the Turkistan Region," the "Map of Landscape Degradation in Agricultural Areas of the Turkistan Region (Including Ecological Status Indicators)" and others.

This series of assessment maps will be utilized to organize and manage agricultural land use and to formulate development plans for the agricultural sector, land-use systems, and land management in the Turkistan Region. The implementation of these research findings will yield economic, environmental, and social benefits for the region's sustainable development specifically by increasing the productivity of agricultural lands and the profitability of agricultural enterprises, as well as improving the well-being of the rural population.

The author's personal contribution to solving the objectives of the dissertation research is:

– assessing the structural organization of modern landscapes and their agro-resource potential, as well as the degree of degradation and landscape resilience to agricultural impact in the Turkistan Region;

– conducting field research on the land and water resources of the Turkistan Region;

– developing and creating a series of thematic assessment maps for the Turkistan Region;

– devising a detailed landscape-agroecological zoning scheme and a set of measures aimed at preserving and improving the ecological condition of the region's agricultural landscapes;

– preparing and publishing research findings in high-ranking scientific journals. The key findings from these articles are incorporated into the sections of the PhD dissertation.

The dissertation research is presented in the following sections:

1. Scientific-methodological and procedural foundations for landscape-agroecological zoning. The approaches and principles of landscape-agroecological zoning are analyzed. Methodological foundations have been developed for the evaluative mapping of landscapes used for agriculture in the Turkistan Region.

2. Assessment of the agro-resource potential of the Turkestan region as the basis for the sustainable development of agricultural environmental management. Based on comprehensive studies on agroclimatic, soil-land, agrobiological and water resources in various natural zones of the Turkestan region, a scientific and methodological approach of qualitative analysis to the construction of an additive qualimetric model was developed, on the basis of which an integral assessment of the agro-resource potential of landscapes (ARP) for agricultural use of the region was developed, taking into account 21 indicators of the state of the natural environment. An assessment of the ARP of landscapes for agricultural use (score assessment) showed that different values are observed, from a low level of 1.46 points in the desert flat lowland zone (landscapes of aeolian plains) to a high level of 5.70 points in the steppe mountain (mid-mountain) zone (landscapes of tectonic-denudation plains), which are strictly subject to the law of altitudinal zonation.

3. Assessment-oriented mapping support for the detailed landscape-agroecological zoning of the Turkistan Region. A map of the modern landscapes of the Turkistan Region (scale 1:1,000,000) has been developed. It reflects the patterns of regional structural organization and spatial differentiation of modern natural-territorial complexes (NTCs) and the specifics of their transformation; it also allows for an assessment of the territory's current agro-resource potential and serves as the foundation for the evaluative and thematic maps created as part of this study. An assessment of the Turkistan Region's modern landscape structure revealed that anthropogenically transformed NTCs play a significant role, appearing in virtually all identified landscape types. The largest areas of such complexes are concentrated within the natural complexes of piedmont plains (46.89 % of their total area) used for irrigated agricultureas well as within the NTCs of low-lying plains (22.68 % of their area), primarily in valley complexes and on ancient alluvial plains (used

as irrigated land and hayfields) and aeolian plains (used as pasture).

Based on the results of field studies (2022-2024) and remote sensing data, a map of the agricultural development of landscapes in the Turkistan Region (scale 1:1,000,000) was developed and an assessment was conducted. This assessment showed that a high degree of agricultural development characterizes piedmont semi-desert alluvial-proluvial (39 % of the area), piedmont semi-desert low-hill (33 %), and bedded-structure (39 %) NTCs, as well as valley landscapes (53 %) used for regular irrigation.

An assessment of landscape degradation in agricultural areas determined the nature and extent of degradation processes affecting landscapes used for irrigated and rain-fed farming and livestock grazing, and established the optimal ratio of agricultural land areas across different landscape types. Based on this assessment, a map of agricultural landscape degradationincorporating data on ecological status was developed at a scale of 1:1,000,000. It was found that severely degraded landscapes cover 6.8 % of the territory; these consist primarily of overgrazed pastures located near settlements and wells within aeolian, piedmont (alluvial-proluvial and deluvial-proluvial), stratified, and low-hillock plain landscapes.

A map titled "Resilience of Turkistan Region Landscapes to Agricultural Impact" (scale 1:1,000,000) was also developed. Compiled based on identified landscape types, it illustrates the spatial patterns of landscape resilience to grazing and cultivation categorized into five resilience levels and serves as a foundation for determining regional agricultural specialization, setting load limits, and planning technological approaches to land resource management. The study found that landscapes exhibiting high or moderate resilience to grazing impact cover 66 % of the region's territory, while those resilient to cultivation impact cover 42.8 %.

4. A detailed landscape-agroecological zoning scheme for the Turkistan Region has been developed to support sustainable agricultural land use. A detailed landscape-agroecological zoning scheme for the Turkistan Region (scale 1:1,000,000) has been developed based on an adopted typological classification and is accompanied by a comprehensive legend. The smallest unit mapped in the scheme is the landscape-agroecological sub-region, defined by landscape boundaries. Within the plains area, the zoning scheme identifies 2 provinces, 3 districts, 6 sub-districts, and 11 landscape-agroecological sub-regions. Within the mountainous part of the region, 2 provinces, 2 districts, 14 sub-districts, and 18 landscape-agroecological sub-regions are identified and fully characterized.

The following have been developed: 1) a set of targeted environmental protection measures; 2) scientifically grounded criteria for balanced agricultural land use in pasture landscapes; and 3) criteria for the spatial organization of agricultural land structures within the landscapes of the Turkistan Region all aimed at maintaining a dynamic equilibrium between agro-resource potential and the economic use of the territory.

Based on the results obtained, the following conclusions were made:

1. A scientifically grounded scheme for the detailed landscape-agroecological zoning of the Turkistan Region reflects the territory's spatial differentiation based on an integrated analysis of natural-climatic, agro-resource, landscape, and environmental indicators; it serves as the foundation for establishing highly productive, sustainable, and environmentally safe agricultural land use, as well as for determining priority agricultural specializations for household farms adapted to local environmental conditions.

2. An integrated assessment of the agro-resource potential of landscapes incorporating agro-climatic, soil-land, agro-biological, and water indicators forms the basis for the spatial organization of agricultural land use in the Turkistan Region.

3. An integrated analysis of assessments regarding agro-resource potential, the degree of degradation, and landscape resilience to agricultural impact within the Turkistan Region has enabled the development of a set of targeted environmental protection measures aimed at the region's sustainable development.

4. The developed series of evaluative cartographic models for the Turkistan Region facilitates decision-making regarding the improvement of land-use systems and the region's

sustainable development.

Approbation of the study. The main results of the dissertation research were presented at:

– the International Scientific and Practical Conference "Anthropogenic Landscape Science: Research Methods, Modernization, and Sustainable Development" (Samarkand, Republic of Uzbekistan, May 17–18, 2024);

– the International Congress of Geographers of the Turkic World (Almaty, April 2025).

Based on the dissertation research materials, seven publications have been produced: three articles in journals indexed in Scopus, two in national scientific journals listed by the Committee for Quality Assurance in Science and Higher Education (Ministry of Science and Higher Education of the Republic of Kazakhstan), and two in international conference proceedings.

Structure of the dissertation. The dissertation spans 212 pages and comprises sections on normative references, definitions, notations and abbreviations, an introduction, four main chapters, a conclusion, and a bibliography of 299 sources (including 75 in foreign languages); it also contains 17 tables, 49 figures, and 9 appendices.