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SYSTEMATIC STUDY OF ARID TERRITORIES

Landscape-Ecological Assessment of Dry Lands of the Russian-Kazakhstan Border Zone for Sustainable Land Use

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Abstract—An algorithm for the landscape-ecological assessment of drylands is developed and implemented based on the integration of geosystem, ecological-landscape, and agro-ecological scientific approaches, as well as landscape planning tools. The algorithm includes an analysis of the landscape structure of the territory and land-use dynamics; assessment of the potential natural resistance of landscapes to agricultural impact and their agricultural production quality; functional zoning; and the development of optimization measures for land use. The results of the study showed that 92% of the territory of the Russian-Kazakhstan border zone is represented by landscapes with poor or no resistance to agricultural impact. Landscapes with low values of agricultural production quality constitute 73% of agricultural land. Landscapes of good and medium agricultural production quality make up 19% and are located on flat interfluves. Recommendations for sustainable land use in the zone of dry steppes are proposed based on the identified landscape differentiation.

Keywords: dry-steppe landscapes, agricultural impact, ecologically acceptable land use, functional zoning

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INTRODUCTION

Dry-steppe landscapes occupy about 4% of the territory of Russia and almost 30% of Kazakhstan (Zolotokrylin, Cherenkova, 2009; Kazakh steppe..., 2018). Most of them are located along the joint border. Since the middle of the 20th century, these landscapes have been intensively plowed. At the same time, the natural features of these territories, which are characterized by a rather low agricultural potential, were not properly taken into account. Areas of degraded land (exposed to wind and water erosion, salinity, etc.) currently occupy a significant share in the land-fund structure on both sides of the state border, and this territory itself is included in the zone of deserted lands (Desertification ..., 2009). For example, in Kazakhstan, wind-eroded arable land accounts for 74% of Pavlodar oblast, which borders Russia, and 95% of the deflated arable land of the Altai Territory is located in the dry-steppe zone bordering Kazakhstan (National ..., 2017; Bunin et al., 2017).

Arid areas of agrarian specialization are very vulnerable and have poor resistance to various types of agricultural impacts; they require management from an ecological landscape point of view. In Russia and Kazakhstan, the section “landscape (or landscape-ecological) planning” is absent from the main territorial planning documents. The requirements of this section would allow the solution of such urgent problems as an accounting for the landscape structure of the territory and the resistance of geosystems to various anthropogenic influences, the creation of an environmentally optimal land-use structure, a balanced ratio of significantly and poorly transformed lands, the allocation of protected areas with particularly valuable natural landscapes, etc. (Orlova, 2014a).

It should be noted that problems of sustainable land use are currently being studied around the world in several directions: landscape or territorial planning, in which land use is considered as a spatial organization of a territory (Steinitz, 1995; Steiner, 2000); assessment of changes in land use and land cover with the use of remote sensing data and GIS (Lambin et al., 2001); the results of ecological landscape research based on the application of environmental laws to geographic processes and phenomena (Forman, 1995; Turner, 1998); and assessment of the impact of agricultural activities on geosystems and determination their sustainability (Hayati et al., 2010; De Luca et al., 2015).

In the search for methods of sustainable land use in arid areas, the most promising direction, in our opinion, is the integration of landscape-ecological and agro-ecological scientific approaches using the methods of landscape planning. This approach makes it possible to study the characteristics of geosystems for environmentally acceptable use in agriculture and to assess their ability to withstand loads without irreversible changes in their properties and structure.

The goal of the study was to develop the author's methodology of landscape-ecological assessment of arid lands for sustainable land use and to test it at the level of municipal districts of neighboring states with a long history of agricultural development.

MATERIALS AND METHODS

The methodical part of the study was based on the landscape (geosystem), ecological-landscape, and agro-ecological approaches and included the following main stages: (1) analysis of the landscape structure of the territory and land use dynamics, (2) assessment of the potential natural resistance of landscapes to agricultural impact, (3) assessment of the agricultural production quality of landscapes, and (4) functional zoning of the territory.

The materials of the study were landscape maps on scale of 1 : 2500000 (*Landshaftnaya karta SSSR*, 1980) and 1 : 500000 (*Pochvennaya karta* ..., 2016); an agrolandscape map (*Atlas* ..., 1978); a soil map (*Pochvennaya karta* ..., 1986); satellite images that are freely available on the Internet (multispectral medium resolution satellite images from Landsat 7 ETM +, 8 OLI/TIRS); official data from the Federal Service of State Statistics, Federal Agency for State Registration, Cadastre, and Cartography, Altai Giprozem, the Kulundinsk Station of Agrochemical Service (for the Russian territory), the Statistics Committee of the Ministry for the National Economy of Kazakhstan, and the Land Management Committee of the Ministry of Agriculture (for Kazakhstan territory).

The Russian–Kazakhstan border regions have long been developed as a unified whole that is "complex by structure, but a single historical-geographical, ethnic, ecological, economic and informational space" (*Rossiisko-Kazakhstanskii* ..., 2011, p. 36). Therefore, they experienced similar anthropogenic impacts and environmental-management problems (Levykin et al., 2013; Chibilev, 2017; Spivak et al., 2017).

In 1991, a new state border of Russia with Kazakhstan appeared, and a single, naturally occurring territory began to develop in various institutional conditions. This was mainly due to the different vectors of agrarian policy, the outflow of the Russian population from northern Kazakhstan in the early 1990s, and the increase of abandoned arable land. Therefore, a parallel study of the functioning of land use systems on both sides of the state border is of undoubted scientific interest.

This study considered the municipal districts of two border regions located on the territory of the Kulunda plain of the Ob-Irtysh interfluve: the Altai Territory of the Russian Federation and the Pavlodar oblast of the Republic of Kazakhstan. According to the UN Convention to Combat Desertification, the study area belongs to dry, subhumid areas of desertification (The United Nations ..., 1994).

RESULTS AND DISCUSSION

Analysis of landscape structure, assessment of the structure and dynamics of land use. The landscapes of this territory belong to the steppe type of flat landscapes of the subboreal continental group, while the majority (80%) belongs to the dry steppe subtype. Landsat satellites (U.S. Geological Survey, 2017) were used to clarify the current land-use structure and landscape-use dynamics. The method of parametric classification with training was used for decoding. The results of the classification and generalization of objects are presented in Fig. 1.

The ploughing of areas of the Altai Territory is obvious, while a large area in Pavlodar oblast is occupied by pastures, hayfields, and deposits. According to the results of the interpretation of remote sensing data for the period 2000–2016, there was a reduction of plowed areas and an increase in the area occupied by grass, trees, and shrubs everywhere (Fig. 1), while the official statistics did not record these changes. The largest reduction, 10%, occurred in the Akkulinsk and Uspensk districts of Kazakhstan, Mikhailovsk, and Tabunsk districts of Russia.

Assessment of the potential natural sustainability of landscapes. The methodological approaches of Kochurov (1983), Snakina et al. (1993) and others were used to assess the state and stability of soils and natural complexes in order to assess landscape resistance to agricultural impact as the ability of geosystems to withstand external influences, as well as the ability to restore their properties after such impacts. These approaches are based on the rationing of individual indicators with their subsequent summing according to a point system, which allows landscapes to be grouped according to the degree of their overall stability (Orlova, 2014b).

Seventeen soil-landscape indices that, in our opinion, most comprehensively characterize landscape resistance to agricultural impact were selected. They were ranked based on the scale proposed by Orlova (2014b), and the calculation of points according to the formula

$$C = \frac{100 \times \sum_{g=1}^{n} C_g}{Q},$$

where C is the assessment of the potential natural resistance of the landscape to agricultural impact, in %; C_g is the score on the gth indicator; Q is the maximum possible amount of points; g is the numerical order of the index; and n is the number of indices (features).

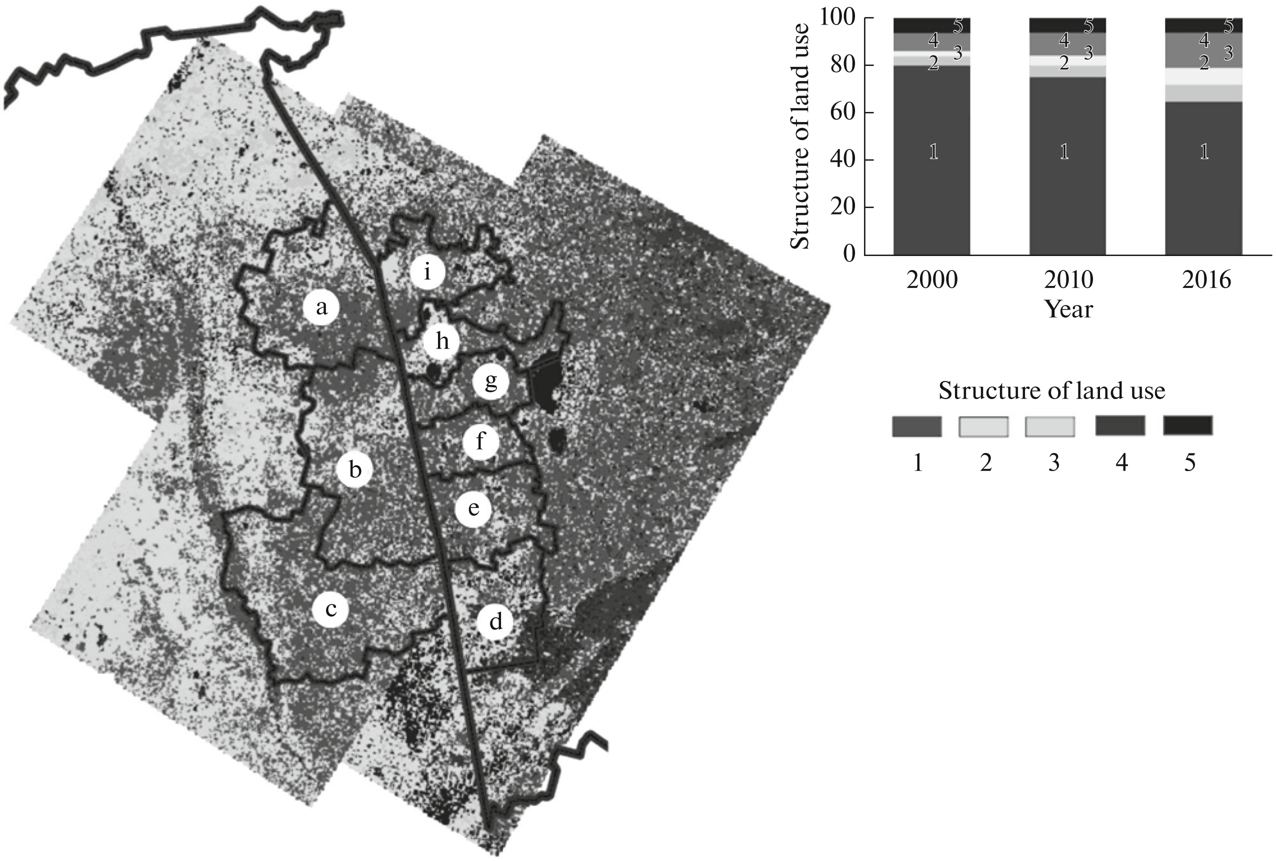

Fig. 1. Land structure in the Russian–Kazakhstan border zone according to a series of satellite imagery from 2000–2016. (1) Arable land, (2) pastures and hayfields, (3) trees and shrubs, (4) natural vegetation, (5) water bodies. Akimats of Pavlodar region of the Republic of Kazakhstan: (a) Uspenskii, (b) Scherbaktinskii, (c) Akkulinskii. Districts of the Altai Territory of the Russian Federation: (d) Mikhailovskii, (e) Klyuchevskii, (f) Kulundinskii, (g) Tabunskii, (h) Slavgorodskii, (i) Burlinskii.

An example calculation of the potential natural resistance to the agricultural impact of lacustrine accumulative landscapes (no. 269) according to the formula is $C = \frac{23 \times 100}{35} = 65.7$ points.

As a result of the assessments, the following gradations were distinguished: the landscapes are unstable or low-stability and relatively stable, requiring special care during economic activity. There are no stable landscapes capable of withstanding a large agricultural load in this area (Fig. 2).

Lacustrine-alluvial, accumulative-denudation, and loess-accumulative types of steppe landscapes (8% of the territory) composed the *relatively stable* group. They were characterized by their accumulative geochemical position, a flat terrain with slopes less than 1°. The soils were mainly sandy with a nonflushing water regime and were not saline (the salt content in the upper horizon was lower than 0.15%). They had good water-physical properties, and the acidity of the soil solution was close to neutral. Low-humus soil (the humus content in the 0- to 20-cm layer was 4.1–6%). The territory is used for arable land; the main factor changing the structure of the soil cover is wind erosion.

Low-stability landscapes were represented by aeolian-accumulative and denudation-stratified types of steppe landscapes, as well as alluvial accumulative and loess accumulative types of dry-steppe landscapes (75% of the territory). The soils were predominantly sandy with a nonflushing water regime and a low degree of salinity (the salt content in the upper horizon was more than 0.21–0.3%), satisfactory water-physical properties, and a slightly acidic or weakly alkaline acidity of the soil solution. The soils were weakly humous (the humus content in the 0- to 20-cm layer varied from 2 to 4%). The territory was almost completely plowed (76%), and the main ecologically significant factor changing the structure of the soil cover is wind erosion, with salinization and pasture digression to a lesser extent.

Agriculturally *unstable* steppe landscapes included lacustrine accumulative and lacustrine accumulative-denudation landscapes; dry-steppe landscapes included lacustrine-alluvial accumulative and denudation reservoirs (17% of the territory). They are dis-

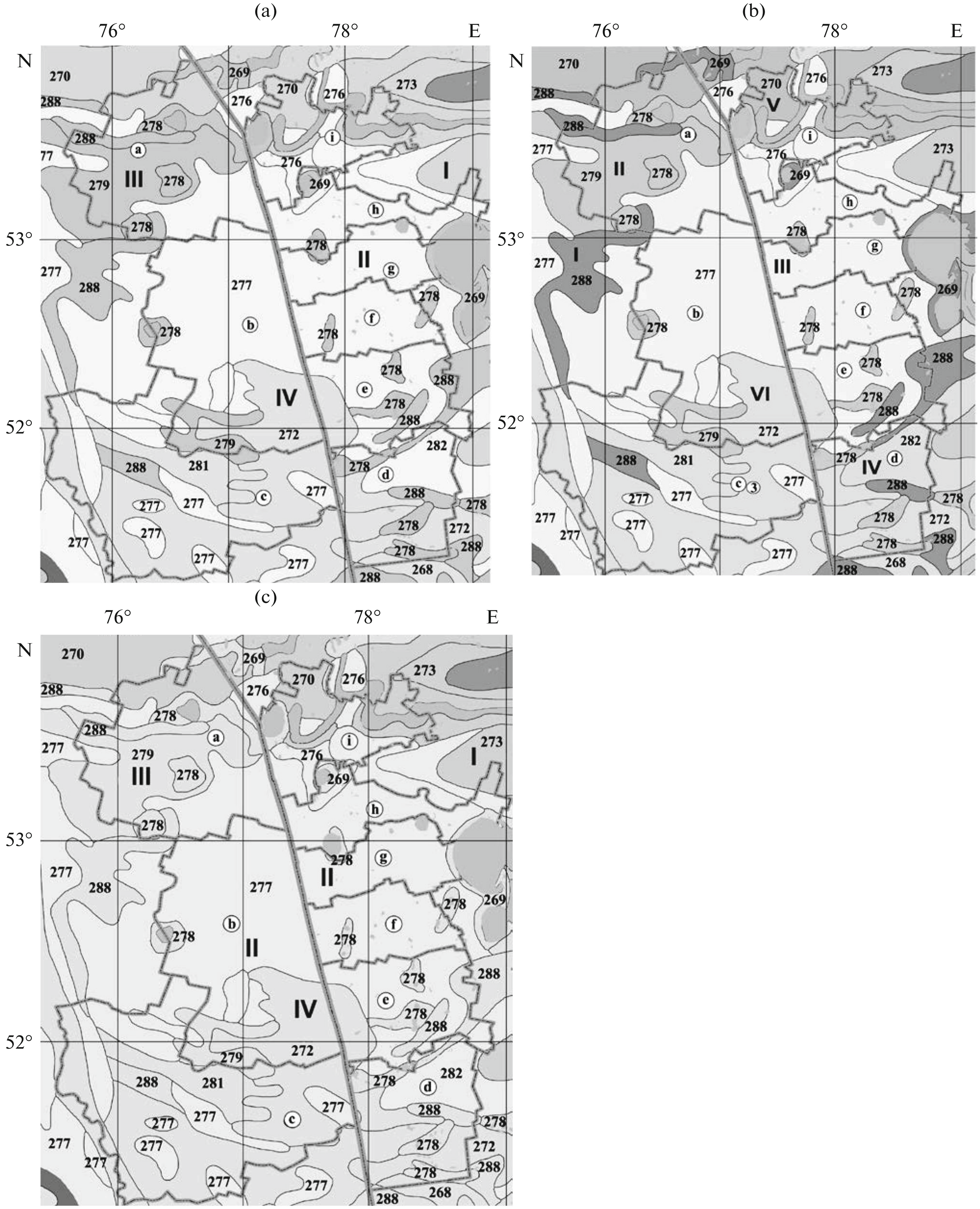

Fig. 2. Potential natural resistance of landscapes to agricultural impact (a), agroproductive quality of landscapes (b), and functional zoning of the territory (c) of the Russian–Kazakhstan border zone. (a) I—relatively stable, II—low-stability, III—unstable, IV—not used in agriculture; (b) I—very low, II—low, III—below average, IV—medium, V—good, VI—not used in agriculture; (c) landscape use zones: I—economically viable, II—ecologically adaptive, III—in conservation mode, IV—not used in agriculture. Landscapes. Typical steppes (real steppes): 269—lacustrine accumulative, 270—lacustrine-alluvial accumulative-denudation, 272—aeolian accumulative, 273—loess accumulative, 276—denudation reservoir. Dry-steppe: 277—alluvial accumulative, 278—lacustrine accumulative, 279—lacustrine-alluvial accumulative, 281—aeolian accumulative, 282—loess accumulative, 288—denudation layered.

Table 1. Criteria for assessment of the quality of agricultural production of landscapes in the dry-steppe zone (fragment)

Criterion	Good and medium quality	Below average quality	Low and very low quality
	suitable for tillage and all other agricultural land uses	suitable for hay lands and pastures	suitable for pastures
Relief pattern	Flat, smooth, gently undulating	Flat undulating	Undulating steeply sloping, undulating
Degree of horizontal dissection of relief, km/km^2	0.6–0.9	1.0–2.5	>2.6–3.0
Humus content in soil layer 0–20 cm, %	4.1–6	2–4	<2
Water-physical properties of soil	Good	Satisfactory	Unsatisfactory

tinguished from the group of unstable landscapes by a high degree of salinization (the salt content in the upper horizon is more than 0.6%) and by poor water-physical properties. In agriculture, they are used for pastures that are highly susceptible to salinization and deflation.

Assessment of agricultural production quality. The quality of agricultural production was assessed based on criteria developed by the authors (Table 1) in order to determine landscape suitability for agricultural use. Among the criteria were such significant indices for agricultural lands as the geochemical position, degree of natural drainage, slope steepness, groundwater depth, soil humus content, humus horizon thickness, nutrient content in the soil, etc. These indices were ranked according to scientifically based standards and criteria for their agricultural-production quality.

According to the assessment (Fig. 2), a significant proportion of agricultural land (73%) was occupied by landscapes with low values of agro-industrial quality. In addition, very poor quality (8%) lands were involved in agricultural use: coastal areas of lakes with a high degree of salinization (the salt content in the upper horizon was higher than 0.6%). Landscapes of good and average agro-industrial quality composed 19% of the study area and were located on flat interfluves.

Functional zoning. The evaluation of agricultural production quality, integrated with the results of the assessment of landscape sustainability to agricultural impact, allowed the identification of functional areas with different modes of agricultural use. For this, the matrix for the allocation of functional zones was used (Orlova, 2014b).

According to the functional zoning of the Russian–Kazakhstan border zone (Fig. 2), the smallest proportion is occupied by territories with economically feasible use. These are alluvial-accumulative types of dry-steppe landscapes that are relatively resistant to agricultural impact, with good or medium quality of agricultural production. It is recommended that these areas be used for tillage in arable rotation with a grain-tillage conservation cropping system (feed and coarse grain crops predominate in seedings).

Low-stability landscapes of medium or lower quality formed an area of environmentally adaptive use of landscapes and occupied most of the studied territory. They require the introduction of restrictions on the forms and intensity of land exploitation to reduce the negative agricultural impact. These landscapes are recommended for arable rotation with a high proportion of forage crops (perennial grasses) and for natural forage lands as agro-technical and reclamation measures.

The landscape-use zone in conservation mode combines unstable landscapes with low and very low agricultural production quality. It includes lakeside areas with alkali soils and salt marshes, as well as areas with soil-protective forest belts and ribbon forests. These landscapes are not advisable for agricultural use due to their unsuitability for intensive use, as well as their value as environmental, water protection, and soil protection functions. The use of separate sites for selective haymaking is allowed.

CONCLUSIONS

The results of the study revealed certain features of modern land use on the territory of the Russian–Kazakh border.

1. Agriculture has remained the main use of the land since the middle of the XX century for most of the territory. Grain crops prevail in the acreage structure (55–69% in Kazakhstan and 62–70% in Russian parts), while a more environmentally acceptable (soil-protective) use would be an increase in the share of forage crops in arable rotation or use of the territory as haymaking and pasture with a regulated cattle load.

2. The low agro-industrial quality of dry-steppe landscapes, together with their lack of resistance to agricultural impact, require the use of soil-saving technologies, adaptive-landscape farming systems, and the implementation of a whole range of measures to restore soil fertility. In fact, their neglect, together with the critically low amounts of fertilizer application, leads to a progressive decrease in soil fertility and

productivity of agricultural land (The data on agricultural land fertility ..., 2018).

3. There are differences in the structure of land use in the Russian and Kazakhstan regions. For example, in the border areas of Kazakhstan, the levels of agricultural development and ploughing of the territory are much lower. Here, the majority of agricultural products are produced by farms engaged mainly in animal husbandry. In the Russian regions, farmers are mainly engaged in crop production, and agricultural production is distributed almost equally between agricultural enterprises, farms, and the household (33, 37, and 30%, respectively).

In general, it is necessary to note the similarity of the main problems of land use (irrational structure of crops, dehumification, deflation, and decline in agrocenose productivity) in the border areas of these countries, which are united by a common development history and environmental-geographical conditions of land use.

The following measures based on these results to optimize the agricultural use of drysteppe landscapes have been proposed: (1) changes to the structure of farmland in the study area via a reduction of degraded and unproductive arable land and its transformation into forage lands; a reduction of the proportion of acreage with grain crops and industrial crops (which are soil destructive crops); an increase in perennial grasses and pasture area; (2) reduction of livestock loading on pastures; (3) the widespread introduction of soil-saving farming systems; (4) the development of land reclamation systems; (5) compensation for the lack of soil nutrients by treatment with the necessary doses of fertilizers and the planting of perennial grasses; (6) the creation of afforestation belts; (7) the formation of an ecological frame and natural barriers of desertification.

The proposed algorithm for the landscape-ecological assessment of dry lands adapted to the dry-steppe landscapes of the Russian–Kazakhstan border zone makes it possible to take into account the natural and agro-productive qualities of landscapes and to differentiate their use and preservation.

COMPLIANCE WITH ETHICAL STANDARDS

Conflict of interest. The authors declare that they have no conflict of interest. *Statement of the welfare of animals*. This article does not contain any studies involving animals or human participants performed by any of the authors.

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