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Assessment of the Status of Irrigated Lands in the Nukus District of the Republic of Karakalpakstan in the Geoinformation System

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Abstract—The results are given of a study of the status of irrigated lands in the Nukus district of the Republic of Karakalpakstan by geographic information systems (GIS). The urgency of this work is related to serious environmental problems caused by land degradation due to climate change and deterioration of water supply in the region. The composition of the soil cover and changes in the quality of irrigated lands for the period from 2012 to 2019 have been calculated and analyzed. The results obtained enable us to reveal the dynamics of degradation processes and may be used as a basis for developing measures to improve ecological conditions and soil fertility. This work proves the need for an integrated approach in agricultural management and in the use of irrigated land, which is especially important for the sustainable development of the region. The most noticeable structural changes in the use of soil resources are related to the expansion of cultivated areas of alluvial-meadow desert saline (solonchak) (old-tugai) soils by 7% of their total area and to the reduction of the area of cultivated meadow-marsh soils from 45 to 30%. Despite these changes, the parameter of the quality of irrigated lands remains at the same level. The quality structure of irrigated lands is predominated by medium-quality plots: the quality scores attributed to the lands are 40–50 for about half of the croplands, 30–40 for a third of the area, and higher than 50 for slightly more than a fifth of lands (the most productive ones). The composition of the soil cover of irrigated lands has also remained practically unchanged. The analysis shows that the basis of irrigated agriculture in the region consists of alluvial-meadow desert saline (solonchak) (old-tugai) soils, which occupy 60% of arable land with a similar rate of their development in the region.

Keywords: land use, soil cover, geospatial analysis, environmental monitoring, sustainable development

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INTRODUCTION

The problem of degradation of irrigated lands becomes particularly urgent in conditions of global climate change and increased anthropogenic impact, in arid regions such as Karakalpakstan in the Republic of Uzbekistan in particular. The Nukus district of Karakalpakstan located in the lower reaches of the Amu Darya faces a complex of environmental problems over the last 10-year periods due to lower water supply, soil salinization, and disturbance of irrigation infrastructure (Turmanova et al, 2022). The effects of the drying up Aral Sea and the deterioration of water quality have enhanced degradation processes, on irrigated lands in particular, which play a key role in food and social stability in the region.

Irrigated lands of the Nukus district remain the basis of agricultural production despite limited natural resources. However, their sustainable use is difficult due to increasing salinization, secondary waterlogging, and soil erosion, which cause lower yields, economic losses, and high environmental risks. Such conditions require the introduction of modern methods of monitoring and assessing the status of land resources.

Land salinization is one of the most serious ecological and economic problems in Karakalpakstan and in the Aral Sea Region in general. The salinity map (Fig. 1) shows that the central part of Karakalpakstan is most affected by this process (Alikhanov et al., 2008). This problem has significantly increased in the last few decades. Inefficient use of water resources, outdated irrigation technologies, and high evaporation in hot climate contribute to the salt accumulation in soils. Remote sensing monitoring

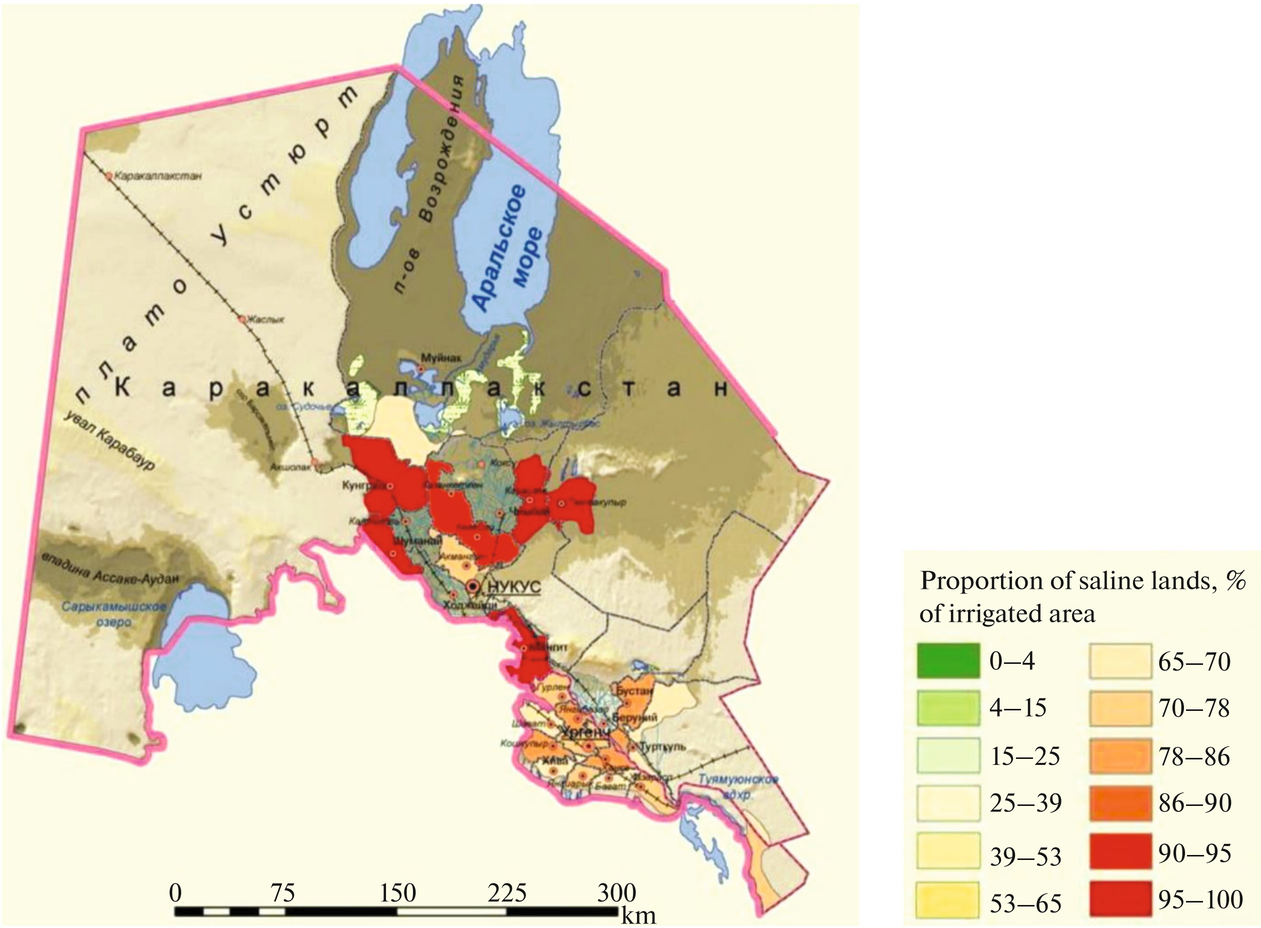

Fig. 1. Map of salinity in Karakalpakstan (Alikhanov et al., 2008).

of soil conditions confirms that almost half of irrigated lands in Uzbekistan undergo salinization (Abdullaev et al., 2023).

The temporal dynamics in some areas is important: soil status is improved (a decrease in salinity) due to application of land reclamation measures. However, degradation continues in the main area due to insufficient irrigation water, poor drainage, and violations of the groundwater regime. For example, the study in Fergana oblast has revealed an increase in the area of nonsaline soils from 4670 ha in 1993 to 10 533 ha in 2021. However, the areas of slightly saline soils have decreased, while moderately and strongly saline soils still represent a significant proportion (Khamraliev et al., 2023).

Soil salinity may be explained by several factors. Traditional irrigation methods result in moisture loss and increase the upward migration of salts to the surface. A drop in the groundwater level due to overuse also causes salt accumulation in the upper soil layers.

Saline soils significantly reduce agricultural production. This results in a decrease in yields of such important crops as wheat and cotton, which, in turn, affects the food security of the region and the economic well-being of the population. Local farmers encounter increasing difficulties in managing their farms, because they have to use additional resources to control salinization. The problem of land salinization in Karakalpakstan requires an integrated approach and the participation of all related parties to improve the situation and prevent further deterioration of the living conditions of local population.

The status of irrigated lands in Karakalpakstan in modern poor ecological conditions in the Aral Sea Region is of particular concern. The studies show that 56600 ha are saline, which is almost 10% of all irrigated lands in Karakalpakstan, and 171300 ha (34%) are moderately saline. The accumulation of pesticides and other pollutants in soils, secondary salinization of groundwater, and an imbalance in the hydrochemical regime cause a decrease in fertility and in yields of main crops in the Nukus district, which seriously damages the food security of the region (Nauryzbaeva, 2021).

GIS AS A TOOL FOR MONITORING THE STATUS OF LANDS

Comprehensive research based on an extensive information base, including meteorological, agrochemical, soil, and geomorphological data is necessary for sustainable environmental management. Such data may be most efficiently processed, analyzed, and visualized, using geographic information systems (GIS). Modern full-function GIS may be a key tool in the formation of national and regional environmental information systems.

High-precision methods of spatial analysis are also necessary for an adequate assessment and forecasting of the dynamics of degradation processes. Geoinformation systems are an effective tool for comprehensive assessment of degradation of irrigated lands. GIS technologies enable us to integrate remote sensing data, soil survey results, and spatial analytical data for quick identification of risk zones, monitoring of erosion and degradation processes, identification of the dynamics of changes, and development of scientifically based measures to restore land fertility (Kasyanov et al., 2021; Laozi, Topaz, 2021; Chen et al., 2019; Chashchin et al., 2024).

GIS are used to obtain digital models of the distribution of the particle-size composition, organic matter content, acidity, and salt regime of soils. Interpolation methods are applied to construct isopleths of soil properties at different depths for quick identification of areas with favorable and unfavorable conditions for agriculture (Goncharov, 2010; Gopp et al., 2023).

Soil maps at the regional level are compiled, using GIS tools, which simplifies agroecological zoning and specification of lands by fertility and vulnerability to degradation. For example, the SoilGrids project demonstrates the capabilities of global digital mapping of soils based on more than 240 thousand observations and machine learning with resulting maps of depth intervals with an accuracy of 250 m (Gopp et al., 2023).

Thus, GIS technologies applied for soil resource assessment provide highly precise, illustrative, and adaptable analysis and contribute to the creation of effective monitoring and decision support systems in the agricultural sector and to the development of strategies for adaptive management of agricultural landscapes in vulnerable regions such as the Republic of Karakalpakstan. Their use significantly improves the quality of soil information and helps to prevent land degradation.

Integrated approach to monitoring the reclamation status of irrigated lands based on the integration of balance-analytical and statistical methods with GIS technologies is proposed in a number of works. For example, a methodology for mapping salinization and waterlogging, taking into account groundwater depth and mineralization, tested in Karakalpakstan is proposed in (Nosirova, 2022). This approach enables us to identify strongly degraded areas and to provide recommendations for drainage and irrigation measures.

The engineering and geological assessment of the Nukus district performed by Iskenderov (2023) demonstrates the high efficiency of GIS for compiling schematic maps of changes in soil salinity and groundwater levels. Analysis of long-term satellite data and terrain survey with the use of GIS models shows a tendency tor the groundwater level rise, which is directly related to enhanced salinization and a decrease in vegetation stability (Nosirova, 2022).

Thus, the integration of GIS technologies into the monitoring system of irrigated lands in the Nukus district is a key tool for timely measures to adjust irrigation practices and prevent further soil degradation.

The purpose of this study is to assess changes in the status of irrigated lands in the Nukus district of the Republic of Karakalpakstan, using geoinformation systems, for identification of the spatial differentiation of degradation processes and substantiation of measures to improve ecological conditions and soil productivity.

MATERIALS AND METHODS

Cartographic materials for the area of the Nukus district used for the study include:

(1) a fragment of the State Soil Map of the USSR (sheet K-40) (*State Soil Map ...,* 1951);

(2) maps for assessing the quality of irrigated lands in the Nukus district (*Quality Estimation Maps ...*, 2012, 2019).

The composition of the soil cover of the Nukus district was calculated on the basis of a vectorized fragment of the soil map in GIS.

The maps used in the work to assess the quality of irrigated lands in 2012 and 2019 are the official archived materials of the State Committee of the Republic of Uzbekistan for Land Resources, Geodesy, Cartography, and State Cadaster compiled by the results of state soil surveys. The quality score in these maps was calculated by the approved methodology given in (*Metodicheskie rekomendatsii ...,* 2005).

The maps for assessing the quality of irrigated lands were compiled within the boundaries of 11 administrative areas of the Nukus district on a scale of 1 : 10000. They contain the assessment of land quality expressed in quality points of the soil cover and information on a number of agrochemical parameters of the soil status for 2012 and 2019. According to the methodological recommendations, the quality score is calculated by data on the humus content, the thickness of the humus horizon, the particle-size composition, and soil salinity. Terrain surveys are performed within the contours of agricultural areas with sampling on agricultural plots representative for each soil type. The map reflects fertility classes (not soil areas), which are indicated by color. The main quality scale is based on

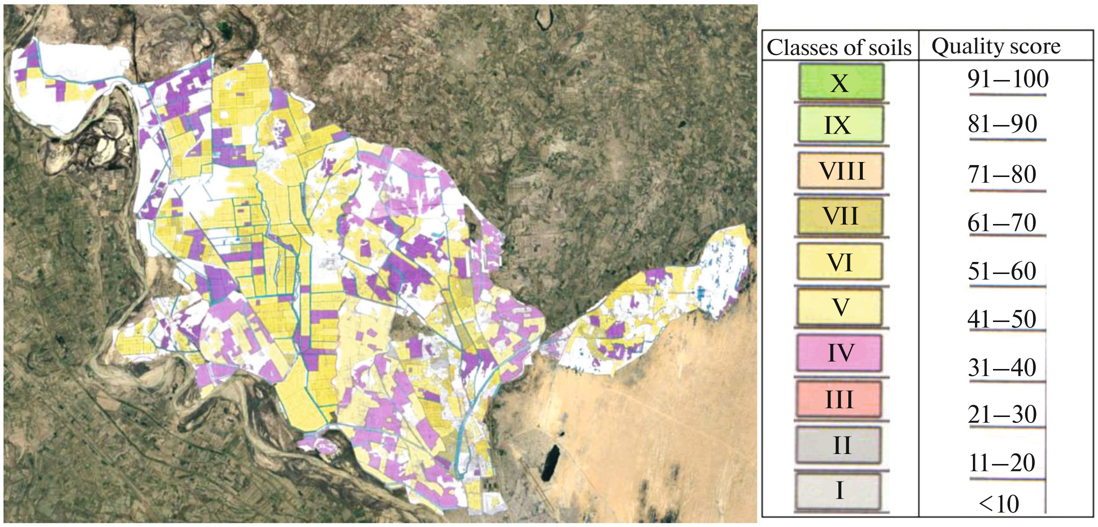

Fig. 2. Referenced maps for assessing the quality of irrigated lands in the Nukus district within administrative areas (2019).

the genetic group and the particle-size composition of soils, because many soil properties and processes of their formation and evolution are closely related to them (*Metodicheskie rekomendatsii ...,* 2005).

Maps of irrigated lands for 2012 and 2019 (Fig. 2) were referenced and vectorized, and agrochemical parameters and the quality score were added to the attribute table of the vector map.

The vectorization of materials and further work were performed in the MapInfo Professional v.17 program.

RESULTS

The composition of the soil cover was calculated in a GIS (Table 1) on the basis of the digital soil map (Fig. 3). The third part of the territory is occupied by blown sand among various soils. More than 35% of the area is represented by alluvial-meadow desert saline (solonchak) (old tugai) soils, which are formed on low watersheds. These soils are available for gravity-flow irrigation. They are used for wheat, barley, millet, and melon crops, and fallow lands are covered by weed vegetation (honeysweet) (Ibadullaeva, Tazhenova, 2019). The humus content in the upper soil horizon varies from 1.5 to 8%. The soil reaction is neutral or slightly alkaline, and the amount of absorbed bases reaches 40 mmol eq./100 g of soil. The soils may be widely used in agriculture, if their water regime is regulated. The second place (19.2%) is occupied by irrigated meadow saline soils formed under the effect of groundwater, the level of which is naturally or by artificial drainage maintained at a depth of 1.5–2.5 m. The humus amount varies widely from 1 to 3–4%. The content of carbonates in the humus horizon ranges from 3 to 9% of CO_2 and usually increases downward, sometimes very significantly. The common subtype distinguishing features of these soils include the thickness of the agroirrigation humus horizon (no more than 0.6 m) and various gleying of the subhumus horizon (Egorov et al., 1977). The soil cover of the Nukus district is saline (solonchak) and solonetzic in 88% of the area: these are soils and areas of blown sands among gray-brown solonetzic and saline (solonchak) soils (Fig. 3).

Table 1. Composition of the soil cover of the Nukus district (according to *State Soil Map* ..., sheet K-40, 1951)

Soils and nonsoil formations	Area, %
Gray-brown desert solonetzic	0.9
Takyr	2.0
Irrigated meadow saline (solonchak)	19.2
Meadow-swamp	7.3
Alluvial-meadow desert saline (solonchak) (old-tugai)	35.3
Alluvial-meadow desert washed (tugai)	0.8
Partially fixed hilly sands	1.1
Areas of blown sands among different soils	33.3

The coefficients that take into account the humus content, the thickness of the humus horizon, or the depth of the saline layer are used, when assessing the quality of soils to be irrigated in areas of gray-brown soils in the Republic of Uzbekistan (*Metodicheskie rekomendatsii ...,* 2005).

The general assessment of the quality of irrigated lands is shown by cartograms (Fig. 4). The soil quality score ranged from 29 to 62 in 2012 and from 24 to 65 in 2019. The main proportion of irrigated lands was represented by soils with the quality of 40–50 points.

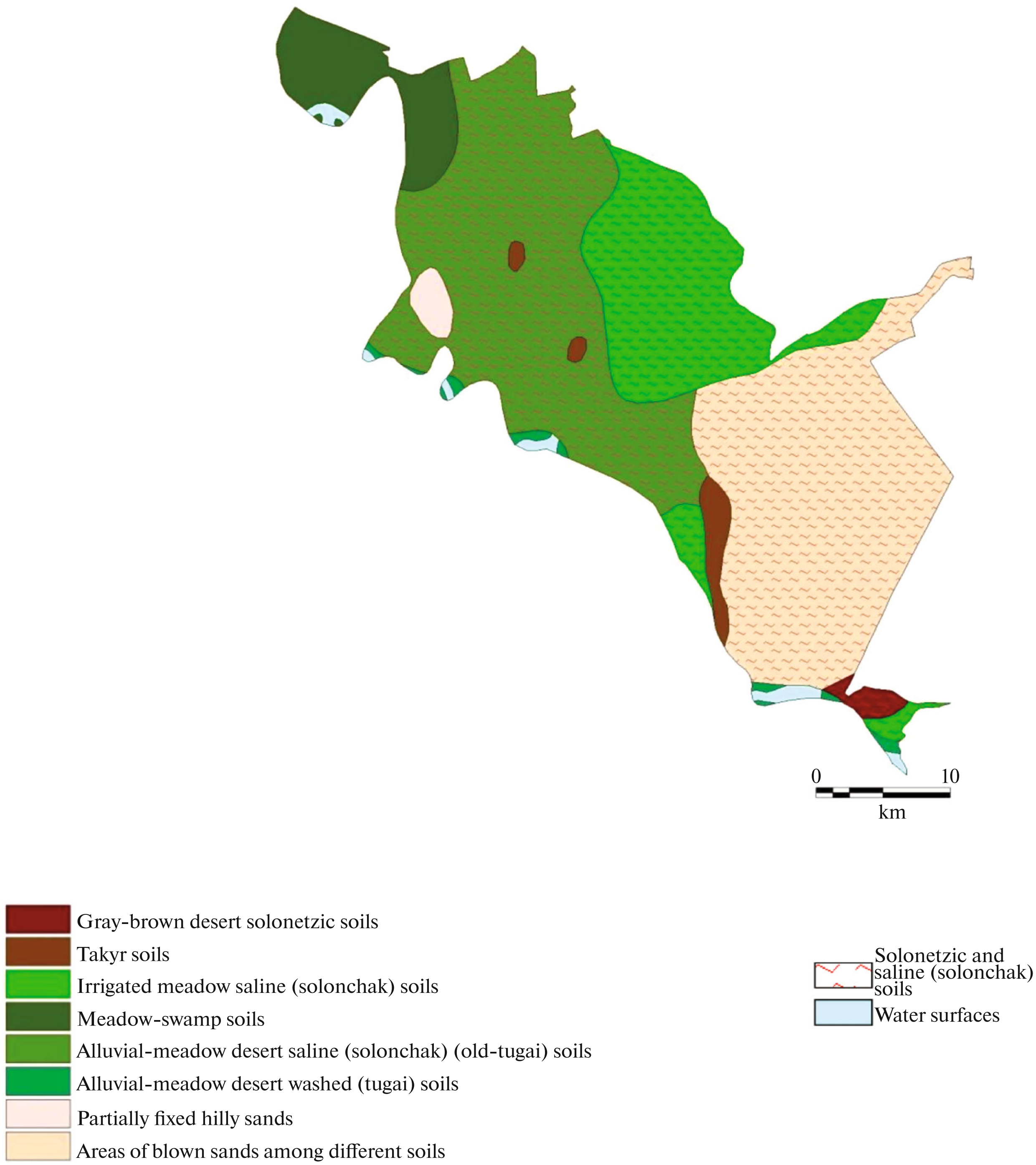

Fig. 3. Soil map of the Nukus district (according to the State Soil Map, sheet K-40, 1951).

The area of irrigated land in 2012 was 36000 ha or 34% of the area of the Nukus district and increased by 3000 ha by 2019 as compared to 2012, which was 3% of the entire district area. The quality score of irrigated lands in the Nukus district remained practically the same (Table 2). The composition of the soil cover of irrigated lands also remained unchanged (Table 3). Over 58% of them are represented by alluvial-meadow desert saline (solonchak) (old-tugai) soils, and irrigated meadow saline (solonchak) soils occupy about 30%. The proportion of the rest irrigated soils ranges from 1 to 6%. The calculations show that irrigated soils include the areas given in the soil map on a scale of 1 : 1000000 as areas of blown sands among various soils, partially fixed hilly sands, and takyr soils. The methodological recommendations on the assessment

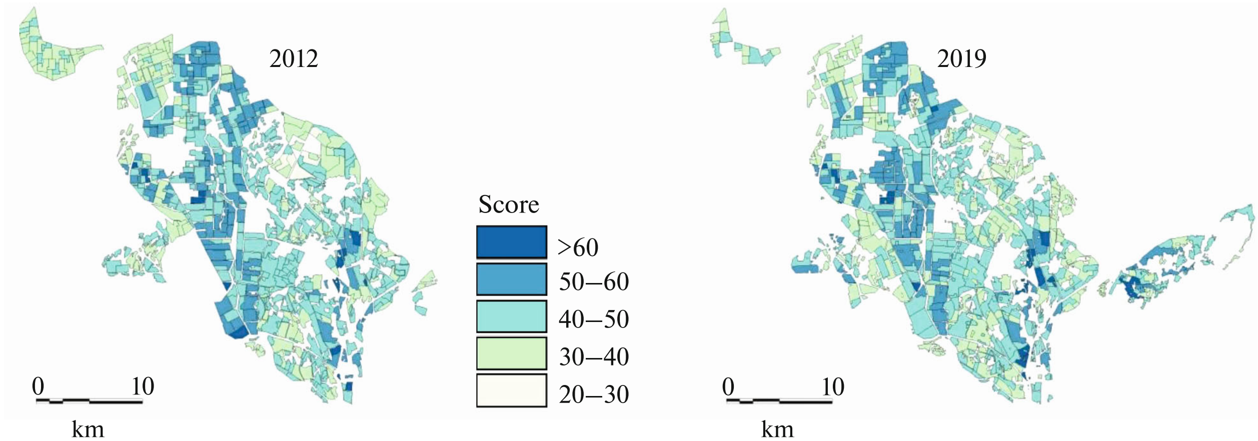

Fig. 4. Quality of irrigated lands in the Nukus district.

of soils to be irrigated in the Republic of Uzbekistan do not contain the results of their evaluation (*Metodicheskie rekomen-datsii …,* 2005). This may be related to the scale of the soil map used and requires clarification for the Nukus district.

Although the composition of the soil cover of irrigated lands remained in general the same, the proportion of used soils relative to their total area in the Nukus district significantly changed in some cases in the period from 2012 to 2019. The location of irrigated lands over the vector layer of the soil map is given in Fig. 5. The calculations show (Table 4) that the proportion of meadow-swamp soils used for irrigation in the region was 45% in 2012 and decreased to 30% by 2019. The proportion of the used alluvial meadow desert saline (solonchak) (old-tugai) soils increased, and addition 7% of these soils were involved in irrigation in the district by 2019.

DISCUSSION

The obtained results of the study of the soil cover in irrigated areas in the Nukus district testify to specific conditions of formation and use of land resources in this arid zone of the Aral Sea Region. The domination of saline (solonchak) and solonetzic soils (more than 88% of the area) reflects the effect of arid climate and strong groundwater mineralization. Recent studies show that the area and intensity of salinization and degradation of soils in the Republic of Karakalpakstan and surrounding areas increase faster than it has been previously estimated. All the sampled soils in the Muinak and Chimbai districts and in the lower reaches of Amu Darya are saline, the salinity varying from moderate to very strong throughout the soil profile (Turmanova et al., 2022).

The domination of alluvial-meadow desert saline (solonchak) soils (35% of the area) is explained by geomorphological features of the area located in the Amu Darya delta. A significant proportion of blown sands among various soils (33% of the area) reflects intensive deflation typical for the Aral Sea Region under conditions of a drop in the Aral Sea level. This phenomenon is described in numerous works devoted to the environmental problems of the region (Pankova, 2016; Argaman et al., 2003; Stulina, Idirisov, 2024).

The expansion of the irrigated land area by 3000 ha over the period of 2012–2019 and the relative stability of soil quality (40–50 points) testify to a rational approach to involving the most productive lands in irrigation. The change in the structure of soil use—the decrease in the proportion of irrigated meadow-swamp soils from 45 to 30% of their area in the region and a rise in the area of irrigated alluvial meadow soils by 7%—reflects the adaptation of land use to local soil-climatic conditions.

The urgency of the results obtained is determined by the need to optimize the use of limited water and land resources in conditions of climate aridization in the Aral Sea Region. The compiled cartographic materials may be used for planning land reclamation measures and rational distribution of agricultural crops. The revealed differences between the compositions of the soil cover of fields calculated by the soil map and according to the methodological recommendations for the assessment of soils to be irrigated reflects the need for additional research to verify the contours of the soil map.

Table 2. Quality score of irrigated lands in the Nukus district

Quality score	Proportion, %	
	2012	2019
20–30	1.6	1.0
30–40	28.0	30.0
40–50	49.0	47.0
50–60 and higher	21.4	22.0

Table 3. Composition of the soil cover of irrigated lands in the Nukus district

Soils and nonsoil formations	Proportion, %	
	2012	2019
Takyr	1.1	1.1
Irrigated meadow saline (solonchak)	28.9	28.5
Meadow-swamp	5.1	6.0
Alluvial-meadow desert saline (solonchak) (old-tugai)	58.5	58.3
Partially fixed hilly sands	1.2	0.6
Areas of blown sands among different soils	5.3	5.5

CONCLUSIONS

The geoinformation analysis of the status of irrigated lands in the Nukus district based on data for 2012 and 2019 enables us to make the following conclusions. The area of irrigated land in the district increased by 3% over a 7-year period and is now more than 39 000 ha. Additional 7% of alluvial-meadow desert saline (solonchak) (old-tugai) soils were involved in the irrigation. Meadow-swamp soils were partially excluded from the use: only 30% of these soils were irrigated in the region in 2019 instead of 45% in 2012. The general qualitative assessment of irrigated lands (in quality points) remained almost the same.

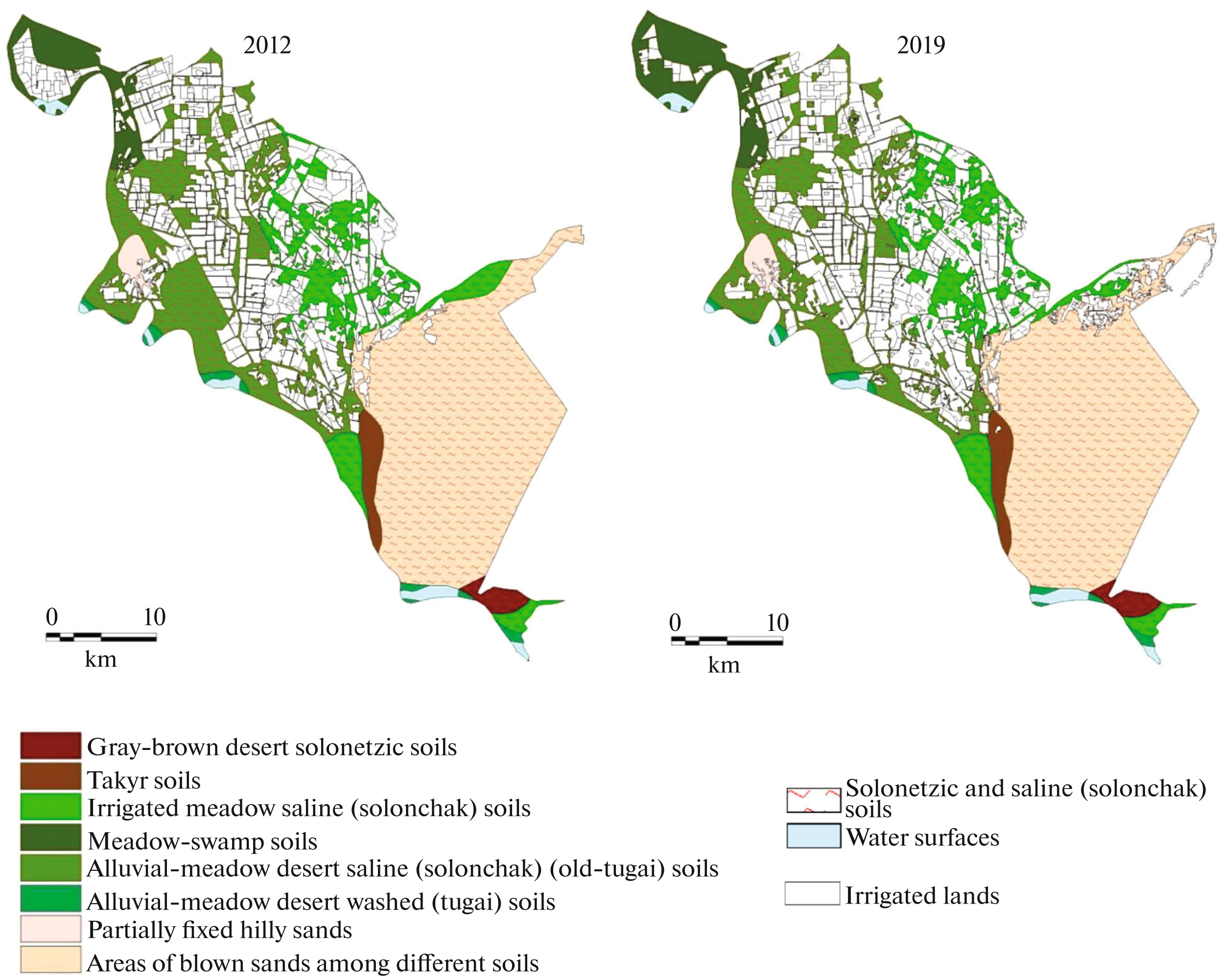

Fig. 5. Location of fields in the Nukus district.

Table 4. Proportion of irrigated soils relative to their total area in the Nukus district

Soils and nonsoil formations	Proportion, %	
	2012	2019
Takyr	18.0	19.9
Irrigated meadow saline (solonchak)	54.3	56.1
Meadow-swamp	44.7	30.0
Alluvial-meadow desert saline (solonchak) (old-tugai)	53.5	60.3
Partially fixed hilly sands	23.8	18.4
Areas of blown sands among different soils	2.4	6.1

The use in irrigation is maximal (almost half of the cultivated lands) for lands with a score of 40–50 points, is about 30% for lands with a score of 30–40 points, and is a little higher than 20% for the most fertile lands with a quality score greater than 50 points. The calculations for 2019 show that alluvial-meadow desert saline (solonchak) (old-tugai) soils are the most used for irrigation: their proportion in the plowed area is 60%, and the share of their development in the area is also 60%.

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ETHICS APPROVAL AND CONSENT TO PARTICIPATE

This work does not contain any studies involving human and animal subjects.

CONFLICT OF INTEREST

The authors of this work declare that they have no conflicts of interest.

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