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Spatial and temporal analysis of landscape dynamics in the Kostanay region under an- thropogenic impacts

Zhanar Ozgeldinova[1], Zhandos Mukayev[2], Altyn Zhanguzhina[1], Assel Bektemirova*[1], Meruyert Ulykpanova[1]

[1]L.N.Gumilyov Eurasian National University, Kazakhstan
[2]Shakarim University of Semey, Kazakhstan

*Corresponding author`s e-mail: asel.8.90@mail.ru

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Abstract: The aim of the work is to develop a method of landscape dynamics under anthropogenic impact. The developed methodology is tested on the territory of Kostanay region, which is one of the main regions of mining industry development, with a focus on iron ore mining and crop production. Space images and field survey results are used as input materials. In general, the work consists of the following six stages: the first stage includes the selection and processing of space images, the second stage includes the calculation of indices based on data from different channels of space images, the third stage includes field work aimed at collecting information for verification of the obtained results on the basis of RS data, the fourth stage includes the calculation of range values, the fifth stage comprises verification of the obtained indices, and the final sixth stage deals with calculation of the integral index of landscape degradation degree and analysis of landscape dynamics under anthropogenic impacts. The calculation of the integral indicator of the degree of degradation of the natural environment of the Kostanay region, based on the degradation of each indicator in the conditions of anthropogenic impact, allowed for identification of landscapes with different degrees of degradation (from weak to very strong). The research confirmed that landscapes with a high degree of degradation under anthropogenic impact are confined to semi-desert landscapes in the south of the study region. The degradation of these landscapes is associated not only with anthropogenic impacts but also with natural and climatic features that influence the development of landscape pollution processes. On the contrary, landscapes with a weak degree of degradation correspond to the forest-steppe and steppe zones, characterized by a high level of economic development and resistance to anthropogenic impacts. The verification of the obtained indicators by the values of the remaining 25% of field points determines the reliability of the obtained results, ranging from 87% to 92%, confirming the correct choice of methods and techniques for obtaining the results, especially the choice of field methods and vegetation and non-vegetation indices for assessing the selected indicators. Subsequently, based on the verified map of degradation of the natural environment, created through space monitoring for a certain period, it is possible to forecast the functioning of the natural environment in the conditions of anthropogenic impact.

Introduction

The world problem of finding universal criteria for diagnosing the landscape sphere under changing external factors and developing geographical forecasts is being solved in different aspects, including the International Program for the Study of the Biosphere, Lithosphere and Climate, the International Geosphere-Biosphere Program "Global Change" and others.

The understanding of landscape as an open dynamic spatial and temporal system, which meets the fundamental tasks and applied research of landscape-ecological content, determines the mandatory consideration of the time factor, which can be considered from both genetic (natural-historical) and experimental-transformative positions. The inventoried specificity of the structure, cognized regularities of functioning, and dynamics of landscapes open the way for justification of types of landscape use, and normative measures of loads.

The study of natural and anthropogenic dynamics of landscapes is one of the main directions of complex geography. The relationships between its components, which arise in the process of metabolism and as a result of various kinds of succession are the source of landscape dynamism. One of the most common ways of studying and modeling landscapes is to study one component in the landscape environment (against the background of other components). There are two main approaches to studying landscapes: biocentric and polycentric. The difference between the approaches is that in the first case, the researcher's view is biocentric - the main attention is paid to biota, and other components are considered by him only as the environment of dynamic processes. In the second case, the researcher's view is polycentric - equally focused on both biotic and abiotic components of landscapes (Petrov 2001).

Most landscape components, including biota, operate as subordinate open systems in relation to the entire landscape. More precisely, a landscape can be viewed as a combined system with feedback, incorporating biota (vegetation) as a distinct unit. The experience of their successful application in the development of an evolutionary-dynamic approach (Krauklis 1979, Sochava 1980, Belov and Sokolova 2014, Vladimirov et al., 2014, Nachtergaele et al., 2011) confirms the validity of the approach to modeling the dynamics of landscapes, in which the main attention is paid to vegetation, and all other components are considered as a medium of dynamic processes in the landscape.

The study of landscape dynamics in the conditions of anthropogenic impacts, exemplified by the Kostanay region, is prompted by the increasing anthropogenic impact on its natural environment. The Kostanay region possesses substantial reserves of various natural resources, including minerals, land, forests, and industries that are continually expanding, thereby giving rise to complex environmental problems. The manufacturing industry includes mechanical engineering, the metallurgical industry, and the production of building materials. It accounts for over 90% of the republic's iron ore products, 100% of iron ore pellets, and asbestos. These products are exported to various countries. As a consequence of this development, a wide variety of degrees and types of modifications to natural landscapes have emerged.

When solving problems related to environmental protection, environmental quality assessment and rational nature management, a large amount of spatially distributed information about the parameters of the natural environment is used. GIS-technologies in combination with mathematical modeling make it possible to make a forecast and estimate the scale of consequences of economic activity taking into account all aspects (Alam et al., 2022, Sówka et al., 2020).

Until today, vegetation often takes a leading role in the utilization space monitoring for calculating landscape dynamics, while soil cover is less frequently considered. For example, the Land Degradation Index (Formulas 3 and 4) exists in 2 variations: one based on NDVI and another based on the 'humidity' channel of the Tasseled Cap transformation, as seen in the TopSoil Grain Size Index (Myachina and Malakhov 2013). The research conducted by scientist

A.M. Fadhil (2009) focused on monitoring, mapping, and assessing land degradation. Additionally, Saaty, T.L. (2008) developed six indices characterizing LDV (land degradation vulnerability), specifically targeting the assessment of the sustainability indicators of the components of nature to degradation.

Knowledge of the mechanism of interrelations between landscape components, landscape and environment, the mode of functioning and dynamics will allow for providing an accurate forecast of the development and behavior of the landscape in certain conditions, scientifically substantiate the type of land use, provide for nature protection measures, and determine the maximum permissible loads on the landscape.

Thus, all the developed research methods characterize the degradation of agricultural land, but in no way characterize the dynamics of the natural system as a whole. In a landscape, all components are equal and all the relationships between them are subject to study. We believe that when studying the dynamics of landscapes in conditions of anthropogenic impact, it is necessary to take into account the indicators of all components of landscapes.

Materials and methods

As initial information for landscape mapping of Kostanay region we used the results of component studies of landscapes,

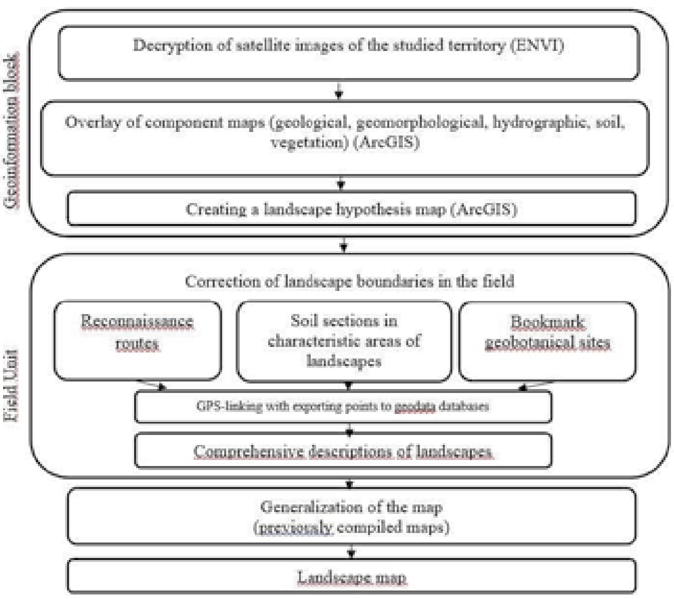

Fig. 1. Block diagram of geoinformation mapping of landscapes

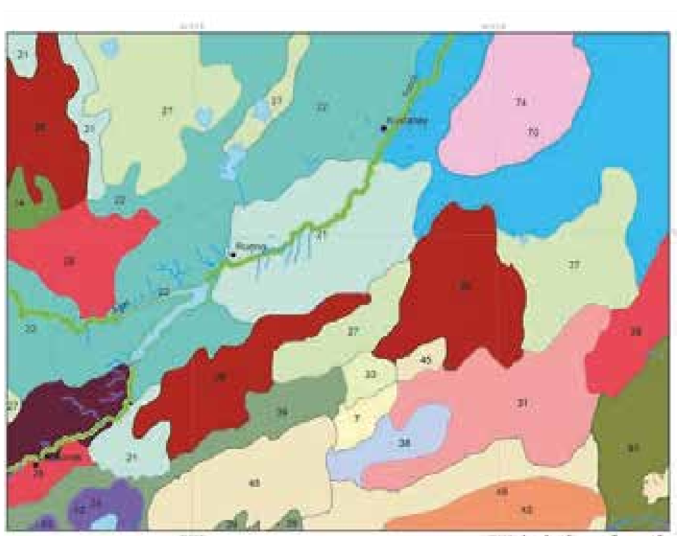

Figure 2. Fragment of the landscape map of the Kostanay region

three-dimensional relief model, Landsat 9 space images, materials obtained during the development of methods of territory surveying and image processing, data of Google Earth geoportal, materials of field studies with GPS-attachment, integrated in a single cartographic projection and coordinate system, topographic maps of 1:200 000, profiles characterizing lithology and structure of soil cover, as well as field descriptions of the landscape map of Kostanay region.

To generalize the landscape map of Kostanay region, a landscape map of Kazakhstan was used, compiled by Veselova L.K., Geldieva G.V. (National Atlas of the Republic of Kazakhstan, 2010). (Figure 1).

Within the Kostanay region, 85 individual landscapes were identified and shown on the map, which, as a result of their typological grouping and then structural and genetic classification, were ordered into hierarchical systematics (Figure 2, Table 1). The following classification categories are highlighted by headings and subheadings in the legend: classes (low-mountain and small-hill and plain landscapes), types (forest-steppe, forest, steppe, dry- steppe, semi-desert,

Table 1. Legend to the landscape map fragment (**Figure 2**)

No	Names of landscapes
	Low - mountain and small- hill landscapes
I	**Steppe** 1 – Erosion-denudation small hills, composed of sedimentary-igneous rocks and fixed by ancient weathering crust, with forb-oatmeal-feather grass steppes on solonetzic gravel-clayey chernozems in combination with steppe solonetzes.
II	**Semi – desert** 7 – Arid-denudation hills and hillocks, composed of sedimentary-igneous rocks, with white sagebrush-fescue-wheat grass vegetation on light chestnut normal alkaline soils.
	Plain landscapes
I	**Forest - steppe** **Extremely southern kolochno-steppe subtype** 21 – Flat-wavy sandy loam stratified plains composed of sedimentary-igneous rocks with lace basins, forb-feather-grass, and red-grass vegetation, with the participation of birch spikes on ordinary saline chernozems. 22 – Weakly undulating plains composed of sedimentary-igneous rocks, with mixed- grass and red-and-white vegetation, birch spikes on the chernozems of the southern normal, and solvents.
II	**Steppe** ***Northern subtype*** 26 – Undulating low-drained loamy ancient lake plain with mixed-grass-red-ash steppes on ordinary saline chernozems, in combination with steppe and meadow-steppe salt flats. Southern subtype 27 – Hilly and gently sloping basement plains, composed of sedimentary-effusive, less often intrusive rocks, overlain by thin gravel-clayey weathering crust, with forb-feather grass steppes on southern solonetzic chernozems, in combination with steppe solonetzes. 28 – Low-lying cover-loamy basement plains with mixed-grass-red-ash steppes on southern chernozems, often saline. 31 – Flat loamy bedded plains with forb-red feather-grass-feather grass steppes on southern carbonate chernozems. 33 – Gently sloping plains composed of clays, sandstones, gravel stones with fescue- feather grass, wheat grass-sagebrush vegetation on dark chestnut solonetzic soils with solvents. 38 – Flat-undulating poorly drained loamy ancient lacustrine plains with forb-feather grass steppes on southern solonetzic chernozems, in combination with steppe and meadow-steppe solonetzes. 39 – Flat-wavy sandy loam ancient alluvial plains with sandy grass-grass steppes on southern chernozems. 43 – Alluvial low-sloping plains composed of sands, and clays with wormwood-thyrsa, white-wormwood-fescue-granary vegetation on chestnut normal and underdeveloped soils. 45 – Diluvial-proluvial flat plains composed of clays, sandstones, and gravel stones, with fescue-feather grass vegetation on dark chestnut calcareous and alkaline soils with the participation of dark chestnut and meadow solonetzes.
III	**Dry steppe** ***Southern subtype*** 61 – Flat-undulating cover-loamy basement plains with fescue-feather grass and fescue- tyrsik steppes on chestnut-carbonate-alkaline soils. 62 – Gently sloping loamy bedded plains with fescue-feather grass and fescue-tyrsik steppes on chestnut-carbonate-alkaline soils.
IV	**Semi – desert** 70 – Slightly undulating plains, composed of sandy loams, sands, and clays, with kokpekovaya, chernopolynno-kokpekovaya, shvedkova-kokpekovaya, biyurgunovo- kokpekovaya vegetation on light chestnut normal and brown saline soils with salt flats and salt marshes. 74 – Bumpy-ridge sandy Aeolian plains with sagebrush-Tyrso-erkek desert steppes on light chestnut lightly formed soils and fixed sandstone.

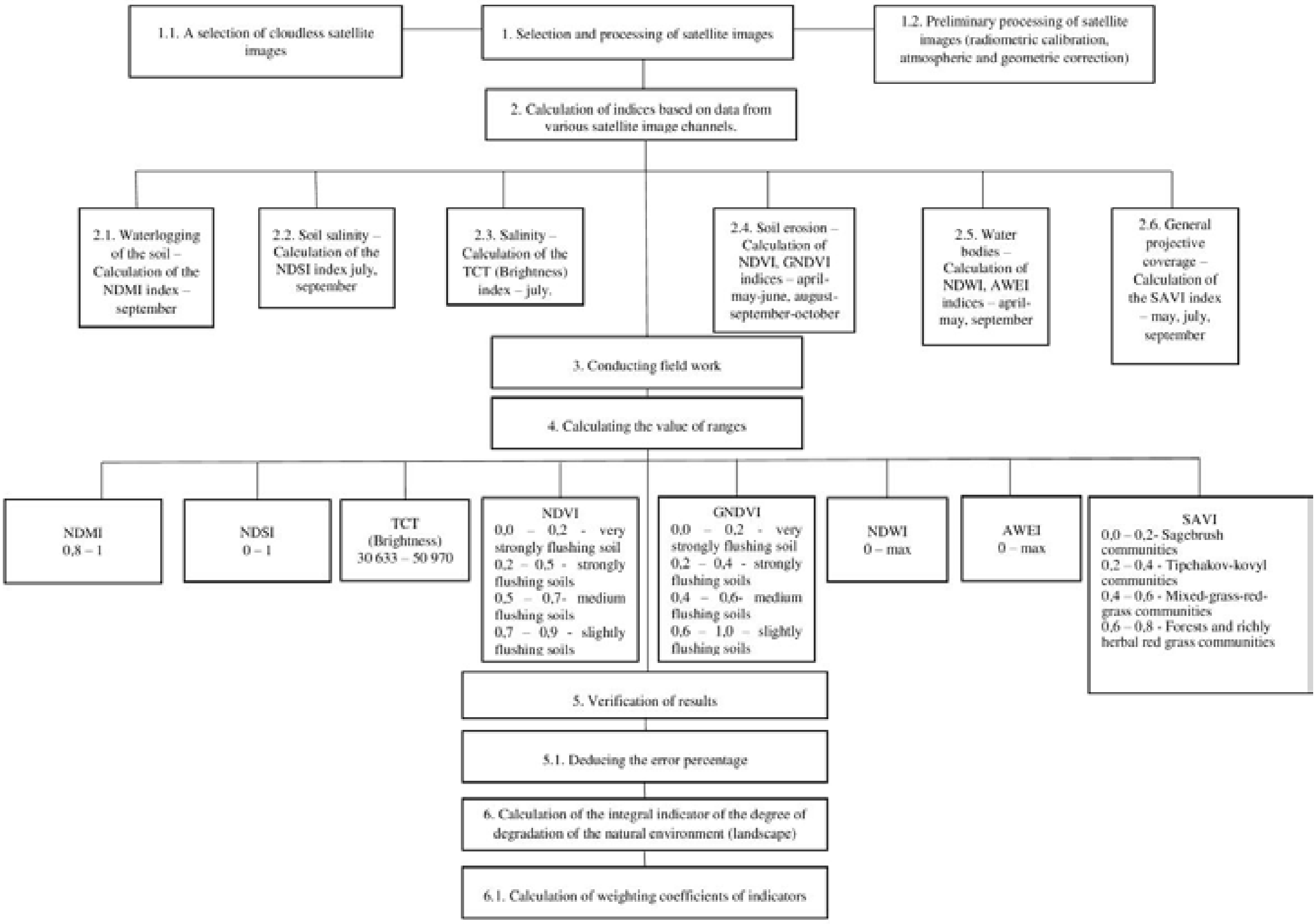

Figure 3. A flowchart of the proposed methodology in the current work

and desert landscapes), and subtypes (northern, southern landscapes).

The proposed method for assessing the dynamics of landscapes in conditions of anthropogenic impact makes it possible to differentiate and evaluate the dynamics in the context of individual components caused mainly by irrational economic activity (Figure 3).

After the selection of cloudless satellite images with a high spatial resolution (1.1.), it is necessary to pre-process satellite images that include radiometric calibration, and atmospheric and geometric correction (1.2.). To determine the selected indicators, Landsat satellite images 3, 5, 7, 8, and 9 of the territory of the Kostanay region for the established periods (1980-2022) were used.

The second stage includes the calculation of indices based on data from various satellite image channels. The indices with the highest reliability were determined when verifying the index values and field research data for mapping each indicator.

(2.1.) Waterlogging of the soil. The causes of waterlogging are associated with both natural climatic changes and various types of anthropogenic human activity (irrigation, hydraulic engineering, industrial and municipal water consumption, agro technical methods of moisture accumulation in soils, and land management activities). To determine the waterlogging of soils, the NDMI index (Normalized Difference Moisture Index) is calculated using the formula 1:

$$NDMI = \frac{(NIR - SWIR)}{(NIR + SWIR)} \quad (1)$$

(2.2.) The salinity of soils. Soil salinization, both natural and secondary in conditions of irrigated agriculture, is one of the factors that enhances the degradation process. Secondary salinization of soils is almost always the result of improper irrigation regimes in crop production, which occurs as a result of excessive watering, which increases the level of salty groundwater or irrigation with highly mineralized water. To determine the degree of salinity, the salinity index (Normalized Difference Salinity Index) is calculated using the formula 2:

$$NDSI = \frac{(RED-NIR)}{(RED+NIR)} \quad (2)$$

(2.3.) Salinity. In irrigated and flooded areas, the formation of secondary salt marshes is possible when the level of saline groundwater rises and salts enter the soil in an amount exceeding their removal by irrigation waters. To determine the degree of salinity, the Tasseled Cap Transformation (Brightness) was used, calculated according to the formula 3:

Brightness = 0.3037 * Blue + 0.2793 * Green + 0.4743 * Red + 0.5585 * NIR + 0.5082 * SWIRI + 0.1863 * SWIRIIb (3)

(2.4.) Soil erosion. Anthropogenic factors of erosion include human activities, in particular organizational and economic ones, which lead to a violation of the balance between climate, soils, and vegetation. Types of organizational and economic activity contributing to erosion include plowing of land, tillage, grazing, deforestation, and construction. The best indicators of erosion among all the indices considered should be recognized as NDVI (Normalized Vegetation Difference Index) and GNDVI (Green Normalized Vegetation Difference Index) calculated by formulas 4 and 5, respectively:

$$NDVI = \frac{(NIR - RED)}{(NIR + RED)} \quad (4)$$

$$GNDVI = \frac{(NIR - GREEN)}{(NIR + GREEN)} \quad (5)$$

(2.5.) Water objects. The main direct anthropogenic impacts on water bodies are the construction of large reservoirs, irrigation channels, and water transfer systems, water intake of surface and groundwater for industrial production, irrigation of land, as well as for public utilities, and discharge of wastewater containing pollutants into rivers. Indirectly, the water balance of the territory and the state of natural waters are affected by deforestation and widespread plowing of land during agricultural development of the territory, the use of fertilizers and pesticides in agriculture, emissions of pollutants into the atmosphere leading pollution of precipitation, as well as surface and groundwater. NDWI (Normalized Difference Water Index) and AWEI (Automated Water Extraction Index) are the most effective water indices used for the detection of water objects from space multispectral images. They are calculated by formulas 6 and 7.

$$NDWI = \frac{Green - NIR}{Green + NIR} \quad (6)$$

(7)
AWEI = 4 * (Green – SWIR2) – (0.25 * NIR + 2.75 * SWIR1)

(2.6.) General projective coverage. Direct anthropogenic impact includes continuous deforestation, forest fires, and burning of vegetation, as well as the destruction of forests and vegetation during the creation of economic infrastructure (such as flooding during the creation of reservoirs and destruction near quarries and industrial complexes). The indirect impact is a change in living conditions resulting from anthropogenic pollution of air and water, and the use of pesticides and mineral fertilizers. The Soil Adjusted Vegetation Index (SAVI) is an indicator of the total projective cover (OPP) of vegetation. The value of L varies depending on the intensity of vegetation cover: in areas with very dense cover, L=0; in areas where vegetation cover is not developed, L=1. SAVI includes correction coefficients (0.25 for sparse vegetation of semi-deserts and deserts, 0.5 for normal vegetation, or used when the nature of vegetation cover is unknown) (formula 8).

$$SAVI = \frac{NIR - RED}{NIR + RED + L} * (1 + L) \quad (8)$$

The timing of monitoring indicators of environmental degradation depends on the seasonal nature of the manifestation of each indicator. Three periods were chosen for the general projective coverage: May, accounting for the maximum development of ephemeral vegetation; July, featuring the maximum development of meadow and sagebrush vegetation; and September, highlighting annual and perennial saltworts. Two periods, one with a spring maximum and another an autumn minimum of the areas of water bodies, were selected for the detection of water surfaces.

The third stage is fieldwork, the purpose of which is to collect information to verify the results obtained based on remote sensing data. To verify the vector map of environmental degradation developed in digital format according to remote sensing data, as well as to collect ground data, field studies are conducted on selected sites. Field research is carried out in terms similar to the terms of space photography. The received fieldwork data in the form of point shape files with GPS are stored in the geodata database. Observations are carried out in 3 seasons important for vegetation development, the period of maximum and minimum water levels, and these periods also cover the period of observation of other indicators (such as salt marshes, soil salinity, soil waterlogging, soil erosion, etc.): spring (from April 20 to May 20); summer (from June 20 to July 20); and autumn (from September 1 to October 1). These terms allow for covering all phenological groups, namely, ephemera and ephemeroids, summer- flowering (cereals and grasses), and late-flowering (wormwood, haze).

The points should be at a remote distance from each other, ranging from 100 to 1000 meters. There should be a minimum of 5 points on one demonstration site. All field research data are entered into the geodata database in the form of point shapefiles from a GPS receiver. All measurements and data from the forms are entered as attribute tables.

Full-profile soil sections were established at sites typical of the natural system of associated landscapes, considering the influence of anthropogenic sources. Soil samples were collected according to genetic horizons. When the soil samples were lumpy, large lumps were crushed, and all soil samples were evenly placed on paper. Any visually observed pebbles, insects, debris, and other foreign inclusions were removed. The purified soil samples were then crushed with a pestle in a mortar and sifted using a laboratory sieve.

A thermostatic-weight method was used to determine the waterlogging of soils. The thermostatic-weight method determines the soil moisture mass (W), which is expressed as % of the mass of absolutely dry soil and is calculated by the formula (9):

$$W(\%\ from\ the\ mass) = \frac{B - V}{V - a} * 100\% \quad (9)$$

where, a is the mass of the bux, g; b is the mass of the bux with wet soil, g; c is the mass bux with absolutely dry soil, g; (b – c) – the mass of water, g; (b – a) – the mass dry soil, g.

Subsequently, the obtained data on the gradation of waterlogging were verified with the data of the NDMI index (0.-8 – 1.0 waterlogging; 0.6 – 0.8 very high moisture level, etc.).

To verify the data obtained with the NDSI index and the results of field studies, laboratory investigations were carried out. These included the determination of the hydrogen index (pH), carbonate and bicarbonate ions, chloride and sulfate ions, calcium, magnesium in an aqueous extract, and the determination of the cation exchange capacity. The following test methods were employed for this purpose: the pH determination method using a pH meter (GOST 26423-85), the titrimetric method (GOST 26424-85), the argentometric method (GOST 26425-85), the turbidimetric method (GOST 26426-85), the atomic absorption method, the complexometric method (GOST 26428-85), a method for determining the capacity of cation exchange by photocolorimetry (GOST 17.4.4.01-84).

The degree of soil erosion was assessed through a morphological description of the profile at the key site. Field studies, based on the Sobolev classification, categorized eroded soils into slightly washed, medium-washed, strongly washed, and very strongly washed soils (Shcheglov and Gorbunova 2011). During the course of the study, eroded soil classes were correlated with values of the NDVI and GNDVI indices.

The vegetation cover of the territory was examined using traditional geographical research methods, specifically the route survey method. This involved describing plant communities at specific sites and recording the description points using a GPS device.

The fourth stage involves calculating the range values. To determine these ranges, we utilize information from literary sources (Resolution of the Government of the Republic of Kazakhstan 2013) and incorporate the results of their fieldwork. The index values are calculated ranges using the "Extract Multi Values to Points" tool in the ArcGIS 10 software. Point-shaped files from field research represent vector data, while the calculated indexes are represented as raster data. By employing this tool, the spectral index data for each pixel is recorded in the attribute table of the point shape file. The process includes determining both the maximum and minimum index values to establish the desired range.

Verification of the obtained indicators occurs through two methods: firstly, by comparing values with the remaining 25% of field points, and secondly, by cross-referencing with available historical cartographic material. This stage involves calculating the error percentage. The verification of selected points for individual indicators is carried out using field research data. A matrix of indicators is created for this purpose, where indicators determined by satellite images from the columns, reliable indicators determined on the ground form the rows. The matrix is filled in at all study points. Subsequently, the percentage of accuracy of determining each indicator is calculated (4.1.). Based on the results of field verification of the forecast map of environmental degradation in the Kostanay region, the reliability of the results ranged between 92% and 87%.

The calculation of the integral indicator of the degree of degradation of the natural environment (landscape) represents the concluding stage. During this stage, the integral value is computed based on the degradation of each indicator under anthropogenic impact. The digital map of natural environment degradation (landscapes) under anthropogenic impact, derived from the integral value, is calculated using the "Overlay toolset" group of tools in ArcGIS 10.5. Weight values for each indicator are input during this process (6.1.). Weighting coefficients are determined through an expert method, relying on the differentiation of indicators based on their contribution to the degradation of the natural environment under anthropogenic impact. Experts from various fields, including geographers, soil scientists, biologists, and ecologists from the Institute of Geography, Kazakh Research Institute of Soil Science and Agrochemistry, and U.

U. Uspanov of the National Company "Kazakhstan Garysh Sapary", were engaged for this purpose. The selection and collaboration with experts were followed generally accepted methodlogical recommendations (Samokhvalov, Naumenko 2007).

Results and discussion

Waterlogging of the soil.

The data obtained from the NDMI index enable the identification of areas on the Earth's surface with both minimum and maximum values of soil and vegetation moisture. The interpretation of NDMI values indicates a range from -1 to 1, wherein positive values greater than 0 correspond to the presence of water. Negative values are assigned in the presence of intense atmospheric and soil drought (Table 2) (https://eos.com/make-an-analysis/ndmi).

Based on the natural and climatic features of the studied region, it was observed that waterlogging of the soil cover decreases from north to south. This trend was established in 1980, where the study of soil waterlogging predominantly characterized landscapes in the forest-steppe and steppe zones, specifically, loamy stratified plains. Loamy soils, known for their high moisture retention capacity, are prevalent in these areas. The depth of groundwater in waterlogged landscapes ranges from 5 m to 6 m, and water-resistant strata are observed along the Turgay River, emerging on the surface of the earth (for example, landscape 53).

The waterlogging value of landscape 21, characterized by a flat–undulating sandy loam formation plain, ranges from 0.5

Table 2. Interpretation of NDMI index values

NDMI index value	Interpretation
-1 – -0.8	Bare Soil
-0.8 – -0.6	Very low humidity level
-0.6 – -0.4	Low humidity level
-0.4 – -0.2	Medium-low humidity level
-0.2 – 0.0	Intermediate humidity level
0.0 – 0.2	Average humidity level
0.2 – 0.4	Medium-high humidity level
0.4 – 0.6	High humidity level
0.6 – 0.8	Very high humidity level
0.-8 – 1.0	Overwatering

to 0.9. Areas with a waterlogging value of 0.9 in this landscape are attributed to the influence of the Zhelkuar reservoir. The reservoir's activity has adverse effects on the soil and vegetation cover, including the flooding of nearby territories and the creation of wetlands.

The waterlogging values in urban areas range from 0.5 to 0.8, a phenomenon linked to human-made waterlogging due to extensive construction of reservoirs, canals, pumping stations, water pipes, and wells. In the urbanized territories of cities such as Kostanay, Rudny, and Zhitikara, waterlogged areas are evident, with the NDMI index reaching 0.8. This heightened moisture content is a consequence of anthropogenic activities related to the extraction of iron ore and asbestos ores. It is worth noting that technogenic waterlogging of lands is also characterized by chemical contamination of the soil cover, indicating a negative impact on both soil and vegetation cover (Wilson and Sader 2002).

In addition to the impact of industrial facilities on the soil cover, agricultural activities also contribute to the challenges faced by the study region. For instance, the territory in the area of Fedorovka village exhibits a high NDMI index of 0.8, primarily due to extensive wheat cultivation, including fodder crops and cattle grazing. The adoption of irrigation technology in these areas has led to significant soil and vegetation cover degradation. This includes a reduction in the physical and chemical properties of the soil, a rise in groundwater levels, ultimately resulting in waterlogging of the soil cover.

It is noteworthy that in 1980, high values of the NDMI index (0.8) were characteristic of steppe landscapes in the northeastern part of the region. By 2000, waterlogging of the soil cover spread to steppe landscapes in the northwestern part of the study region. In 2022, the values of waterlogging (0.8 - 1) in the study region indicate a reduction in small moistened areas in the territory of steppe and semi-desert landscapes in the central part of the region. The increase in the moistened territories (0.6 - 0.8) in the steppe landscapes of the north-western part suggests a heightened economic burden in proximity to large industrial cities such as Kostanay, Rudny, Lisakovsk, and Zhitikara. The expansion of industrial facilities led to urbanized territories, an increase in the urban population, and the introduction of transport lines in the complex, all of the above conditions contributed to the moistening of the soil cover in the studied region (Figure 4).

To validate the data obtained with the NDMI index and field research results, the chosen method is the widely used and practical thermostatic-weight method (Official website of the All-Russian Research Institute of Vegetable Growing, a branch of the Federal State Budgetary Scientific Institution 'Federal Scientific Center of Vegetable Growing').

The field verification of the waterlogging forecast map for the Kostanay region yielded a reliability of 89%. In this case, the error can be attributed to the remote sensing temperature data. The alteration in the surface temperature of agricultural fields diminishes after watering and water absorption into the soil. Consequently, the variance in surface temperatures on different dates serves as an indicator of watering at specific times.

Salinity of soils.

In 1980, saline landscapes in the steppe zone exhibited a low NDSI index value ranging from

0.0 to 0.3, indicative of low-lying cover-loamy basement plains. The average NDSI index value, ranging from 0.3 to 0.5, characterized landscapes in the steppe zone represented by hilly and gently rolling basement plains composed of sedimentary-effusive rocks. High NDSI index values, ranging from 0.5 to 0.7, were observed in the semi-desert zone, featuring gently-framed sandy Aeolian plains composed of

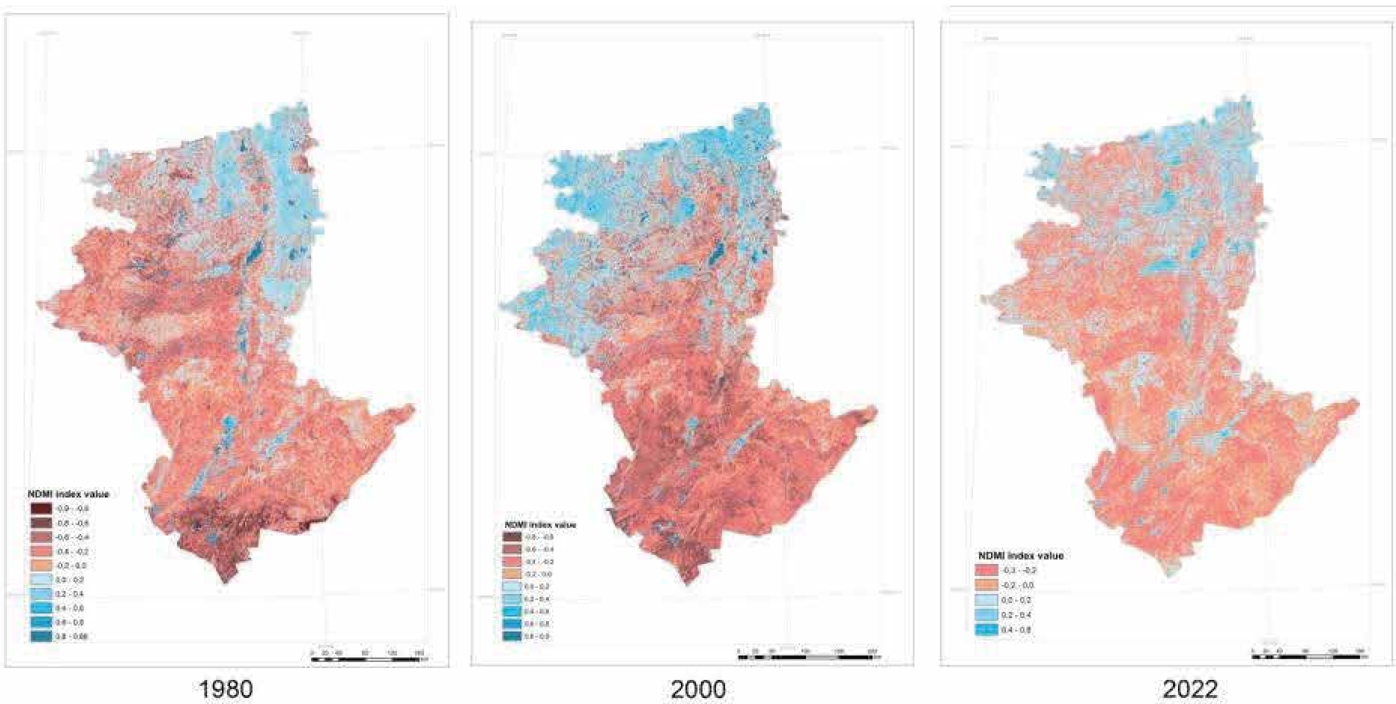

Figure 4. Normalized Difference Moisture Index

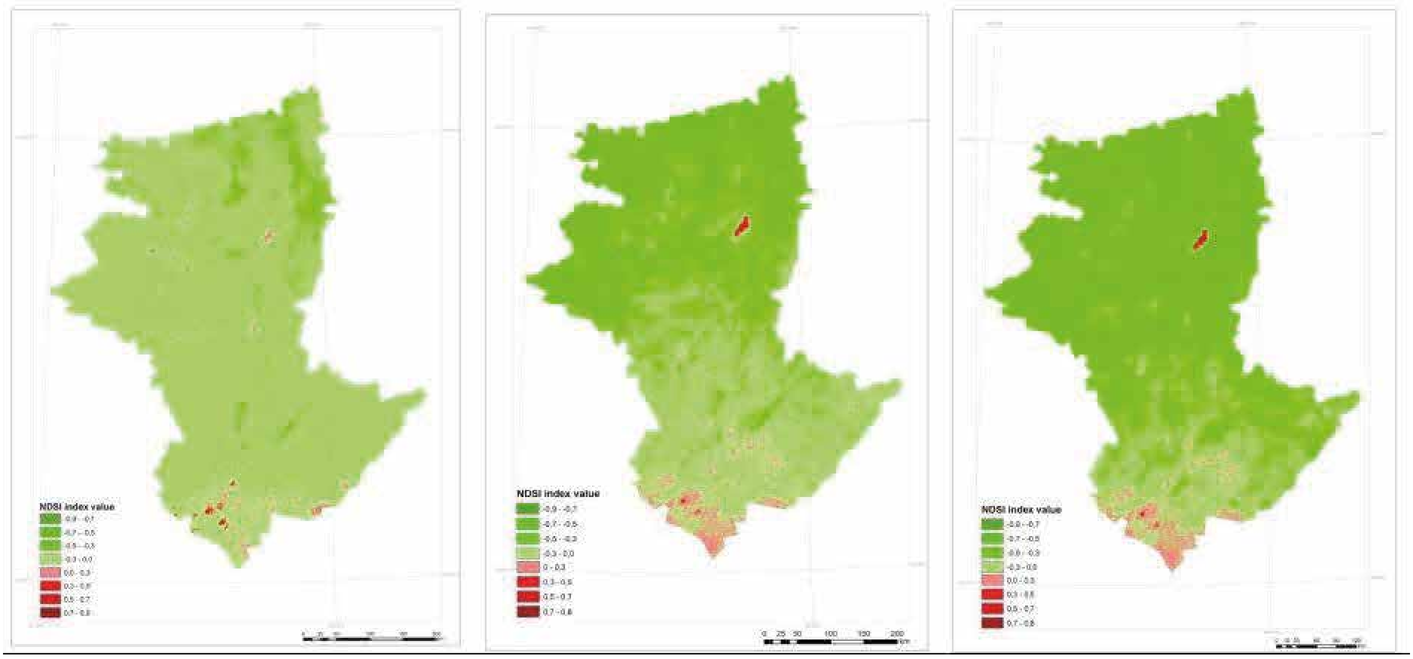

Figure 5. Normalized Difference Salinity Index

sandy loams and sands on light chestnut normal and brown saline soils with salt.

The maximum NDSI index value (0.7 to 0.9) was typical of landscapes in the semi-desert zone, represented by flat-wavy sandy loam stratified plains composed of sandy loams, sands on brown saline soils with salt flats and salt marshes. These territories serve as pastures, and arable lands, primarily cultivated with wheat and millet, supplemented with fodder crops (15-40%) (Figure 5).

In 2000, salinity levels ranging from 0.0 to 0.3 extended to landscapes in the steppe zone, characterized by diluvial-pluvial flat plains composed of clays and sandstones with tipchak-kovylkov Stipa lessingiana vegetation on dark chestnut saline soils. By 2022, salinity had expanded into landscapes of the steppe zone, now represented by gently wooded cover-loamy plains with mixed-grass-red-grass steppes on the chernozems of the southern. Sionce 1980, these territories have been used for arable land cultivation, primarily sown with wheat. The substantial increase in soil salinity is attributed to the disruption of irrigation process, negatively impacting soil fertility. Between 2000 and 2022, the anthropogenic impact of industrial facilities on the region's soil cover intensified, with observable saline areas near industrial cities such as Kostanay, Rudny, Lisakovsk, and Zhitikara. The study revealed that salinity degree reached a high value of 0.9 in 1980 and 2000. In 2022, there was a notable expansion in the distribution of saline territories compared to previous measurement periods.

To verify the data obtained with the NDSI index and the result of field research conducted at Econus LLP, the degree soil cover salinity was determined through several laboratory studies. These included the determination of the hydrogen index (pH), carbonate and bicarbonate ions, chloride and sulfate ions, calcium, magnesium in aqueous extract, and determination of the cation exchange capacity. The field verification of the forecast map of soil cover salinity in the Kostanay region yielded a reliability rate of 87%.

Salinity.

Upon analyzing the 1980 index results, it is evident that salt marshes are a distinctive feature of the flat-undulating and slightly undulating semi-desert landscapes in the south, where animal husbandry is the main anthropogenic activity. Within this range, the values of the Tasseled Cap, ranging from 35 497 to 50 970 in 2022 year, correspond to the presence of salt marshes.

Since 2000, there has been a graduał increase in territories with the spread of salt marshes, expanding from north to south, where animal husbandry is the primary anthropogenic activity. These territories function as pasture lands where continuous livestock grazing takes place. The persistent grazing has a direct impact on the reduction of projective vegetation cover, leading to an effluent water regime occurs. Consequently, the attraction of salt solutions occurs within these areas.

In 2000, the prevalence of salt marshes expanded significantly in the dry-steppe low- undulating plain landscapes. This expansion is likely attributed to the irrigation practices implemented in these territories. Notably, these landscapes are dedicated to the cultivation of grain and leguminous crops, including seed production. are grown in these landscapes.

In general, there has been an increase in the area of arable land in the study area. For instance, in 2000, the arable land area in the Kostanay region was 5 605.0 thousand hectares, and by 2021, it had expanded to 6 293.5 thousand hectares (26.6 million hectares at the national level). Estuary irrigation, primarily relying on the spring runoff of the Torgai and Tobol rivers, has been a key factor in the expansion. However, constant and excessive irrigation of the land has led to moisture penetrating into the soil, where it combines with saline groundwater. This, in turn, causes the rise of salts through capillaries to the surface, ultimately contributing to the formation of salt marshes (Figure 6).

Thus, with the expansion of agricultural land use, there is an increase in the spread of salt marshes from north to south.

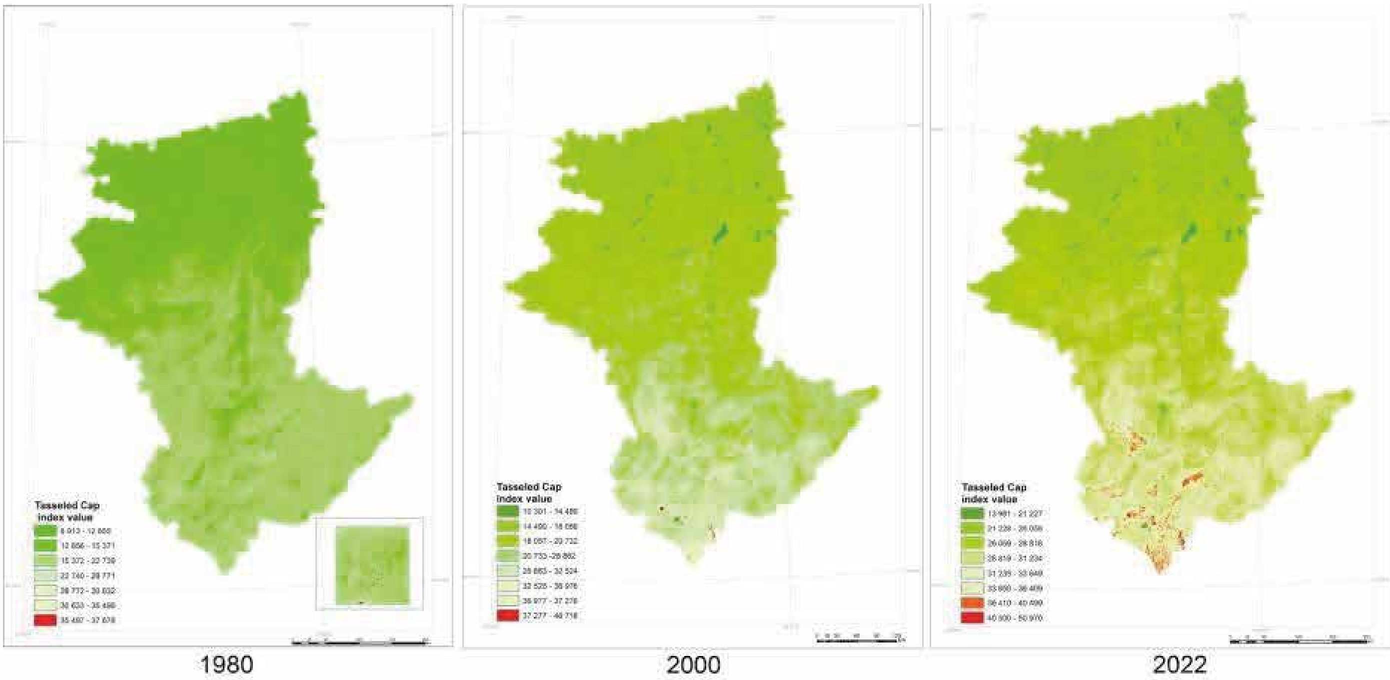

Figure 6. Tasseled Cap Transformation

According to the results of field verification of the forecast map of salt marshes in the Kostanay region, the reliability rate of the results was 88%. However, it is important to note that error were identified, particularly in landscapes with sparse grassy vegetation on malt. This specific condition led to the formation of a mixed signal from two classes.

Soil erosion.

Among all the indices considered, the best indicators of soil erosion, according to our study and sources (Gusev et al. 2020), are NDVI and GDVI, determined using the non-parametric Mann- Whitney criterion. The degree of soil erosion in the field was assessed through a morphological description of the profile of the key site (Shcheglov and Gorbunova 2011, Huang et al. 2021). This classification resulted in soil erosion into slightly washed, medium washed, strongly washed, and very strongly washed soils (Table 3, 4).

The comparison using the Mann-Whitney criterion showed that there is no significant difference between highly eroded and medium-eroded soils, as well as between slightly eroded and non-eroded soils. However, significant differences ($p<0.01$) were observed when grouping key sites into 3 categories: sites without soil (open ground); strongly and moderately eroded soils; and weakly eroded and non-eroded soils.

In the course of the study, it is evident that soil erosion affects the productivity of vegetation cover. Specifically, higher the erosion levels are associated with lower humus and nitrogen content, increased acidity, and reduced bio productivity. These changes in soil properties influence the spectral-reflective properties of the Earth's surface, i.e. NDVI, GNDVI (Vian et al. 2018, Govaerts, and Verhulst 2010).

In 1980, steppe zone landscapes were characterized by slightly washed soils with NDVI values ranging from 0.7 to 0.9 and GNDVI values from 0.6 to 1.0. These landscapes,

Table 3. Classification according to Sobolev

Classificatio n according to Sobolev	Description	NDVI index value	GNDVI index value
Very strongly flushing soil	These include soils in which the horizon of the sun is completely washed away, the parent rock of C. The arable layer of brown color is characterized by a lumpy structure.	0.0 – 0.2	0.0 – 0.2
Strongly flushing soils	These include soils in which the AB horizon is washed away, the BC horizon is opened, and the arable layer is underlain by the lower part of the BC horizon transitional to the parent rock. The arable land has a brown color.	0.2 – 0.5	0.2 – 0.4
Medium flushing soils	These include soils in which horizon A is partially (more than half) or completely washed away; horizon AB is plowed or opened. The surface of the arable land has a brownish tint.	0.5 – 0.7	0.4 – 0.6
Slightly flushing soils	These include soils that have no more than ½ horizon A washed away. At the same time, the lower part of horizon A opens up. According to the color of the arable layer, the soil does not differ from the unwashed one.	0.7 – 0.9	0.6 – 1.0

Table 4. Interpretation of the SAVI index for 2022

Name of classification	SAVI value	Projective cover	Projective cover of 100%
Absence of vegetation	-0,6 - 0,0	1,1	
Sagebrush communities	0,0 - 0,2	<50	33,2
Tipchak-kovyl communities	0,2 - 0,4	>50	41,3
Mixed-grass-red-grass communities	0,4 - 0,6	<70	18,9
Forests and richly herbal red grass communities	0,6 - 0,8	>70	5,6

represented by flat-wavy loamy plains, exhibited specific spectral properties. The average washed soils, characterized by NDVI values ranging from 0.5 to 0.7 and GNDVI values from

0.4 to 0.6, are indicative of the steppe zone landscapes. These landscapes are represented by flat sandy-sandy loam ancient alluvial plains. Strongly washed soils with NDVI values from

0.2 to 0.5 and GNDVI values from 0.2 to 0.4 are typical for landscapes in the semi-desert zone, represented by undulating clay bed plains. Very strongly washed-away soils with NDVI values from 0.0 to 0.2 and GNDVI values from 0.0 to 0.2 characterize a significant part of the landscape in the steppe and semi-desert zones of the region. These territories include gently undulating and gently sloping plains composed of clays and sandstones. These territories are erosive and pose a danger for cultivation, with a substantial portion having a light mechanical composition of the soil. The main cause of soil erosion is improper use of land, specifically continuous plowing of arrays of light soils, the use of improper agricultural techniques, and excessive grazing of livestock. In 1980, part of these territories was used for grazing on natural forage lands, as well as stall-feed – hay from natural hayfields and field products. The other part was used for arable land, which was sown with wheat, with a slight participation of fodder crops (15-30%), using steam and non-fallow soil treatment (Yengoh et al. 2014).

In 2000, steppe plain landscapes, composed of clays, sandstones, sands, and featuring erosion-denudation slopes, were classified within the category of poorly washed soils, with NDVI values ranging from 0.7 to 0.9 and GNDVI values from 0.6 to 1.0. Transitioning from the category of medium-washed to strongly washed, semi-desert landscapes with slightly undulating terrain, composed of granites, limestones, and sandstones, exhibited NDVI values from 0.2 to 0.5 and GNDVI values from 0.2 to 0.4. The extensive plowing, insufficient afforestation, waterlogging of arable lands, neglect of care for hayfields and pastures, and low farming culture on the land led to the loss of the soil's inherent self-regulation properties. This, in turn, resulted in the widespread occurrence of flushing, erosion, and blowing away of the fertile layer over significant areas due to wind and water erosion. In regions where virgin and fallow lands were developed, particularly on chernozems and chestnut soils, long-term cultivation of monoculture cereals caused dehumidification and loss of soil fertility. According to the Institute of Soil Science of the Ministry of Education and Science of the Republic of Kazakhstan, the morphological, physical, and biological properties of chernozems have significantly changed over 50 years of development. There is a real danger of erosion and soil degradation in the study region. In the top layer of 0-20 cm of chernozems, the humus content decreased by 27%, in the 20-50 cm layer by 23%, and in the 50-100 cm layer by 16% (Figure 7).

In the Kostanay region, soil erosion is primarily influenced by mining enterprises, in addition to agricultural activities. The areas with very strongly washed-away soils are characterized by flat-undulating plains composed of clays, and sandstones. The Sarbay quarry and Kazogneupor LLP (a production complex for aluminosilicate refractories) significantly contribute to this impact. As a consequence of such activities, substantial land areas are seized, rendering them unsuitable for use in the national economy, and unsuitable territories such as quarries, dumps, tailings dumps, storage sites for mine and household water also appear.

After conducting field verification of the soil erosion forecast map in the Kostanay region, it was determined that the results achieved a reliability rate of 92%.

Water objects.

The NDWI index values range from -1 to 1, where the values from 0.2 to 1 indicate water surfaces, values from 0.0 to 0.2 suggest flooding and humidity, values from -0.3 to 0.0 represent moderate drought and partially non-water surfaces, and values from -1 to -0.3 correspond to non-water surfaces (The official website of EOS Data Analytics).

The analysis of acquired images reveals significant changes in water resources in the Kostanay region from 1980 to 2022. Situated in an arid zone with considerable fluctuations in the amount of precipitation, the region experiences an average annual precipitation ranging from 250 to 390 mm/year around the largest mineral deposits. The amount of precipitation directly affects the amount of water runoff in rivers leading to substantial variations in the flow rates in the Kostanay region over the years. The region's hydrography exhibits unique characteristics, characterized by a poorly developed network with numerous drainless lakes and closed depressions. The waters from these features do not contribute to the rivers but instead evaporate on the spot. Consequently, the Kostanay region demonstrates an exceptionally low average annual runoff from its surface, expressed in a value close to 0.5 liters per second per square kilometer.

The world's largest water consumers include thermal energy, agriculture, and the chemical and metallurgical industries. Agriculture alone uses over 70 percent of water, much of which is used almost irrevocably. In the future, the volume of agricultural water consumption in the studied area will increase to 348 million m3. Over time, there has been an increase in evaporation losses from estuaries and ponds, coupled with a decrease in water arrivals. In the 1980s and

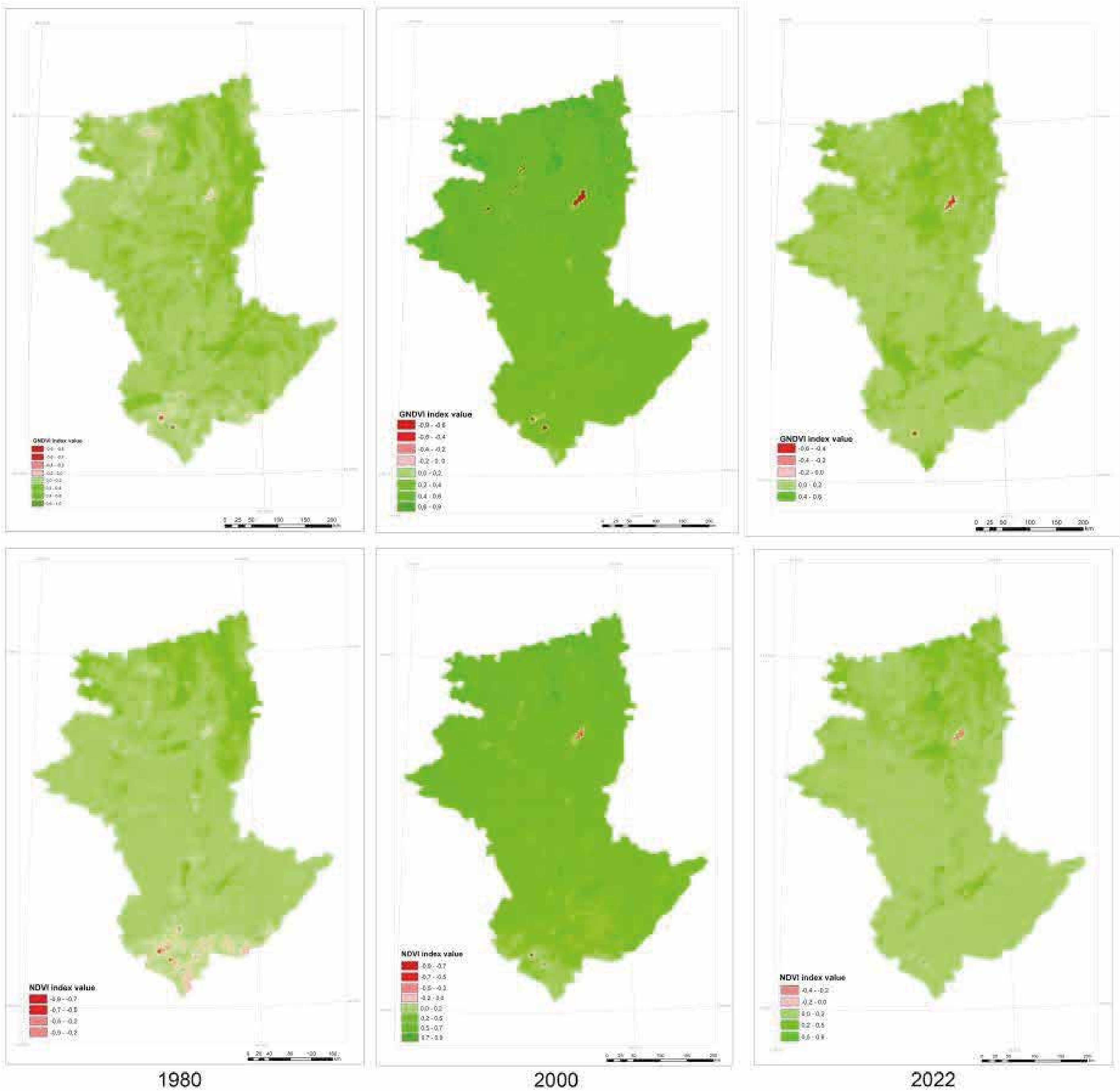

Figure 7. Normalized Difference Vegetation Index, Green Normalized Difference Vegetation Index

2000, there was a small amount of spring runoff, with water predominantly lingering on arable land and in reservoirs. Water entering the lake basins due to snow melting was insufficient to compensate for evaporation losses (Figure 8).

On the territory of one of the largest industrial areas of the Kostanay region (Kostanay, Rudny, Zhitikara), there are changes in the NDWI index, with values decreasing from 0.1 to

One of the reasons for this change is industrial and municipal wastewater from industrial enterprises and residential areas, along with surface drainage from polluted territories and industrial waste landfills. The increase in the population of Kostanay city, from 164 500 people in 1980 to 251 825 people in 2022, further amplifies the demand for water resources for municipal and industrial purposes. Another factor contributing to increased water consumption is the technical water supply infrastructure, reliant on a reservoir constructed on the Tobol river. This reservoir serves the dual purpose of supplying electric and thermal energy to the iron ore enterprises, including the Sokolov and Sarbay mines, ore processing plant, repair plant.

General projective coverage.

In 2022, the SAVI index value in the study area range from -0.6 to 0.8 (Table 4), with the maximum values from 0.4 to 0.8, occupying 5.6% of the territory of the region. These areas predominantly belong to the forest-steppe zone, characterized by flat loamy and flat-wavy sandy loam plains with pine, pine-birch dead-cover, and settled grassy forests, including

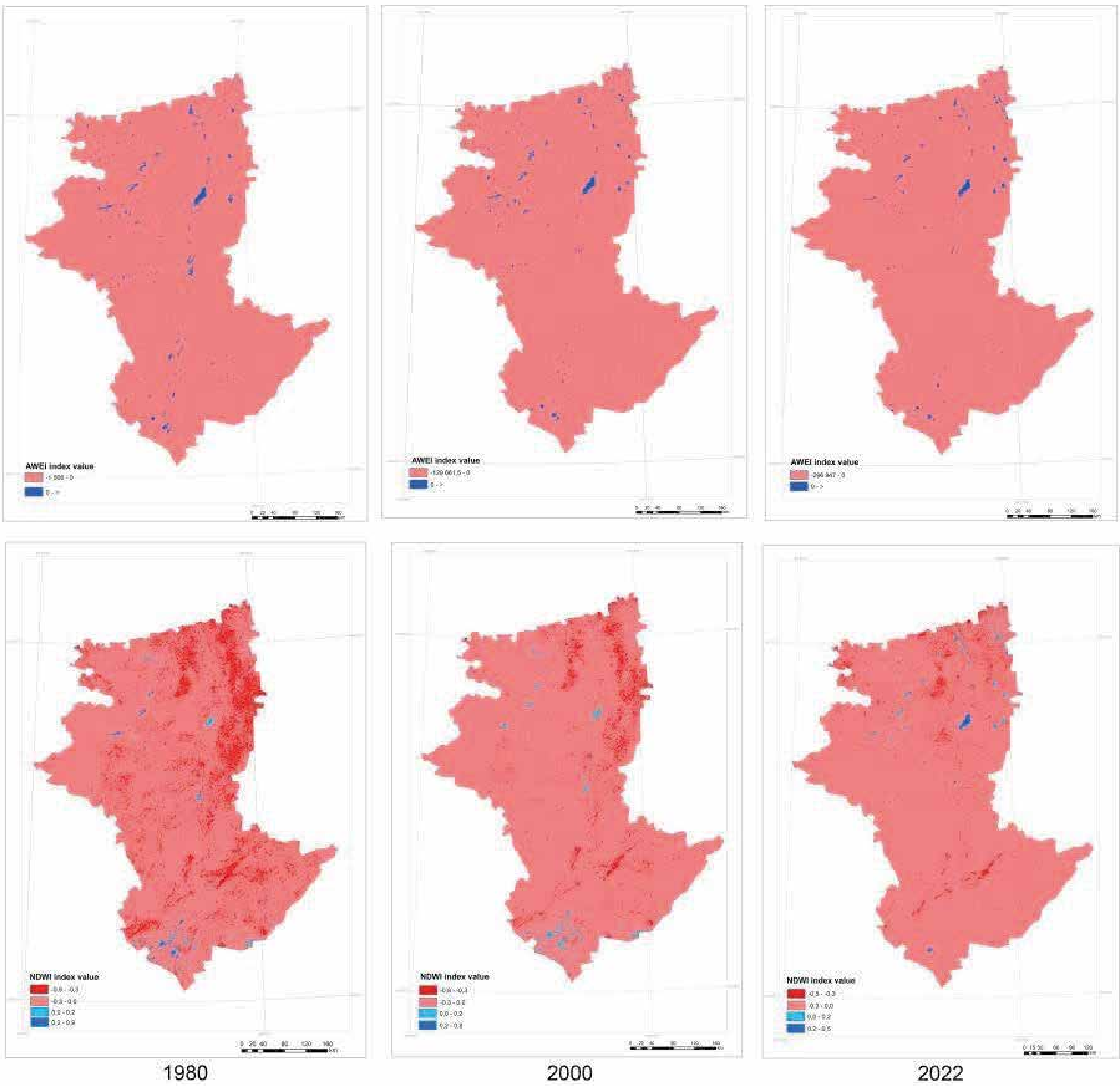

Figure 8. Normalized Difference Water Index, Automated Water Extraction Index

territories such as Arakaragai, Kazanbasy, and Amankaragai forests.

The majority of the studied area, accounting for 41.3%, corresponds to the values of the SAVI index ranging from 0.2 to 0.4. This region is characterized by hilly-heeled basement and flat-framed sandy Aeolian plains within dry-steppe landscapes with typical grass-grass vegetation.

As a result of the development of new arable territories, there has been a change in the values of the SAVI index, for example, in 2000, the area was covered by sandy-grass communities, whereas in 2022, it was used for cultivating a variety of crops, including spring wheat, spring barley, spring oats, corn, spring hard wheat, buckwheat, potatoes, spring rapeseed, and others (Figure 9).

Across the study area, there is a trend of gradual decrease in the SAVI index values from 1980 to 2022. In 1980, most of the territory (averaging 50%) was dominated by plots with high SAVI values (above 0.4). However, from 2000 to 2022, there was a tendency to increase landscapes with the lowest index values (below 0.4). On average, areas with a low index value constituted 66.5% of the total study area. The areas of plots with medium and high SAVI values averaged 27%. Anthropogenic activities, particularly agriculture (livestock) and industry, are identified as contributing factors to the reduction in projective vegetation coverage of the region.

The minimum values of SAVI are associated with pastures, where there has been a shift in land use. For example, in 1980, the flat-bed plains with chestnut soil were cultivated with

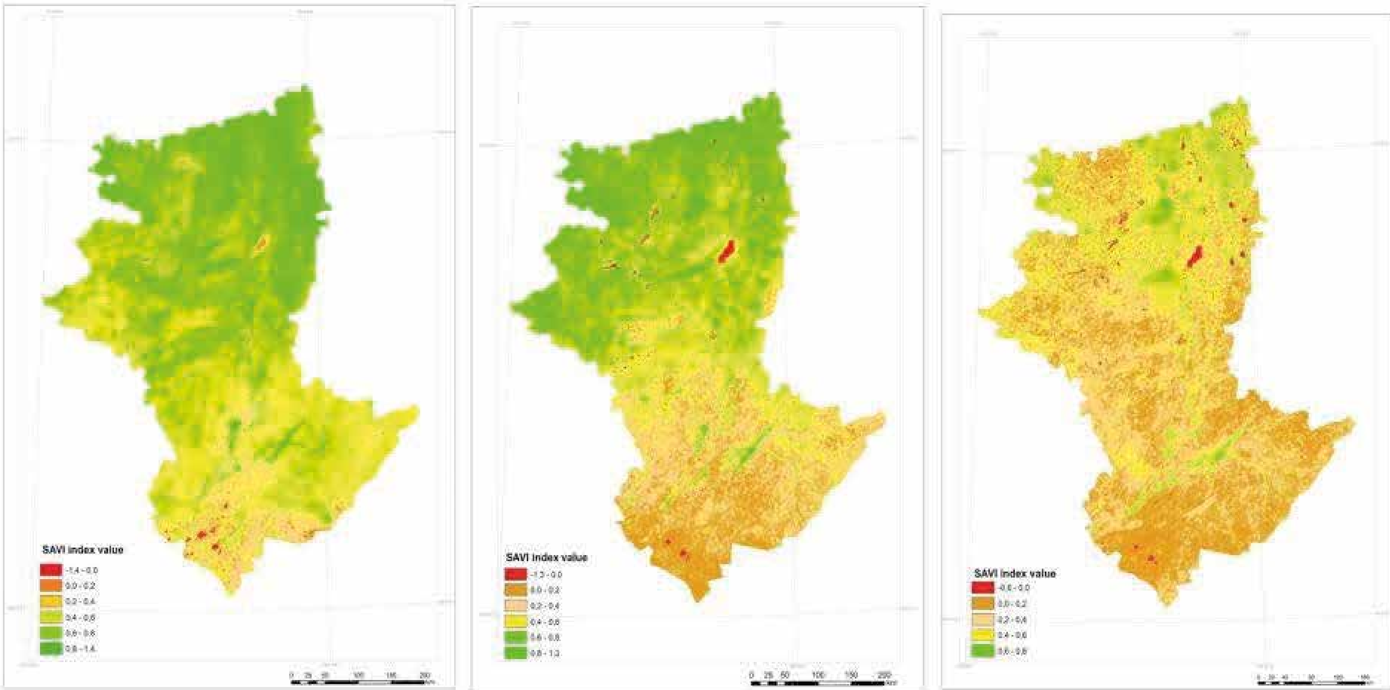

Figure 9. Soil Adjusted Vegetation Index

grain crops. However, by 2000, these territories began to be used for pastures, leading to the representation of minimum SAVI values. Additionally. waste from industrial production during mining and motor transport has a determinant effect on plant communities. Vegetation in proximity to industrial cities such as Kostanay, Rudny, Lisakovsk, and Zhitikara undergoes various changes due to gaseous and pulverized emissions (El Garouani et al. 2017).

Following the field verification of the forecast map for the projective vegetation coverage of the Kostanay region, the obtained results demonstrate a reliability of 89%. The error occurs on sandy landscapes and landscapes with sparse grassy vegetation cover, resulting in the formation of a mixed combining two classes.

The parameters used to characterize these indicators served as the basis for the zoning (ranking) the territory of the Kostanay region based on the degree of degradation under anthropogenic impact conditions. The derived integral indicator resulted in classification ranging from absence, weak, medium, strong, to very strong degradation (Figure 10).

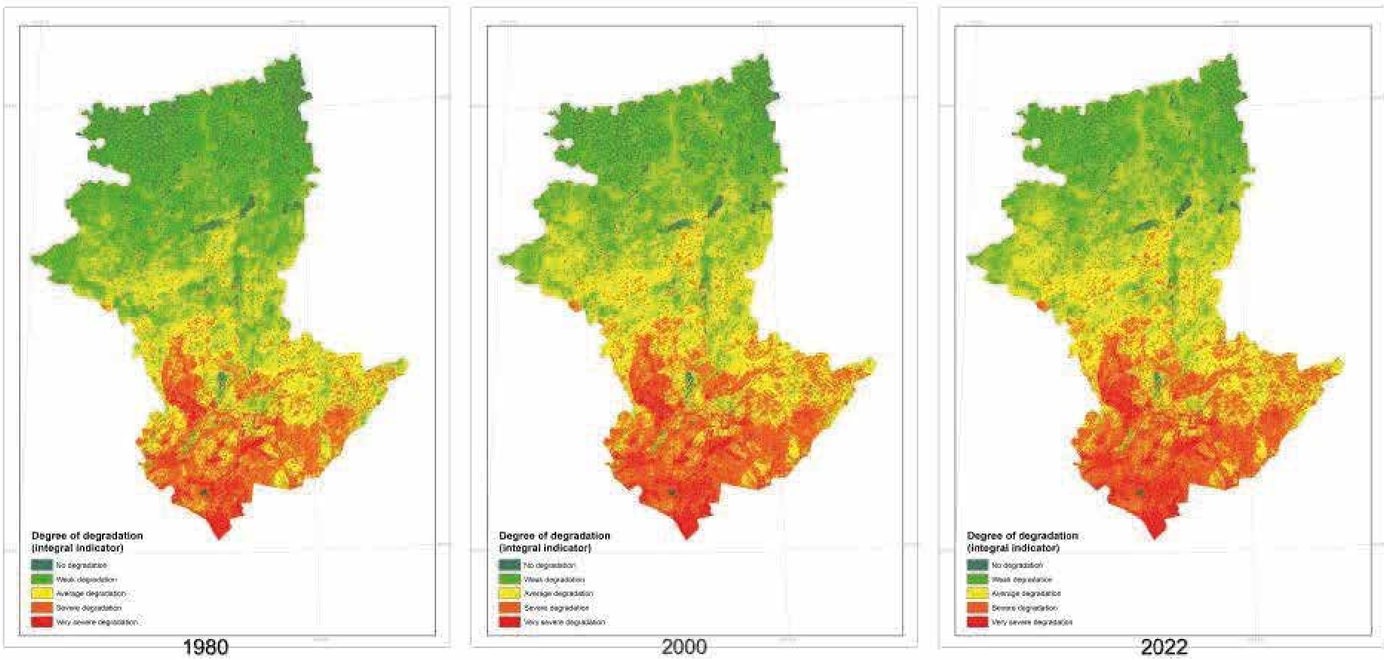

Figure 10. Zoning of the territory of Kostanay region according to the degree of degradation under conditions of anthropogenic impact

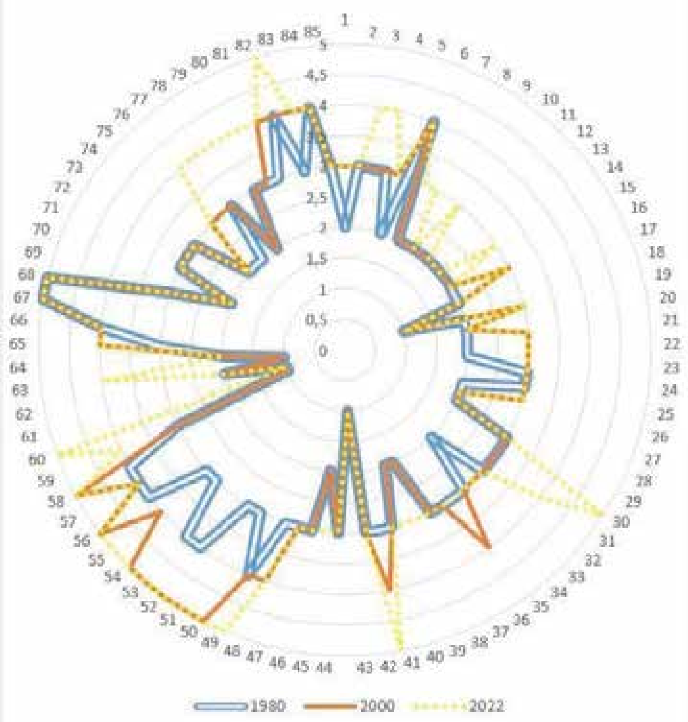

Figure 11. Graph of changes in the degree of degradation for the landscapes of the Kostanay region

According to the assessment and ranking of the Kostanay region's territory, weak anthropogenic degradation is characteristic of forest-steppe and steppe landscapes in the northern part of the study region. These regions primarily consist of hilly-undulating plains with beds of temporary watercourses, composed of loam. They are characterized by a high degree of resistance to anthropogenic influences and a relatively high degree of development, hosting major settlements such as Kostanay and Rudny. These natural complexes have been experiencing high anthropogenic pressure for a long time. All types of anthropogenic impacts are presented here. The management structure here is both intensive and extensive, with the mining industry dominating, however their high resistance to anthropogenic influences is attributed to the natural factors of their formation. The evaluation results indicate maximum values of the total projective coverage and water bodies for this region, with the SAVI values ranging from 0.6 to 0.9 and the NDWI values from 0.2 to 0.9.

The vast majority of geosystems with an average degree of degradation cover 37.2% of the Kostanay region. These territories are primarily characterized by steppe landscapes, featuring gently rolling cover-loamy plains with beds of temporary watercourses, composed of loam. The nature management structure in these regions is extensive-intensive, with dominance from agriculture and mining industries. The evaluation results indicate average values for total projective coverage and water bodies are characteristic of this region, with SAVI values ranging from 0.4 to 0.6 and NDWI values from 0.0 to 0.2.

Natural complexes classified as severely degraded are mainly dry-steppe landscapes, characterized by flat and steep loamy stratified plains. These are mainly rural areas, with a predominant focus on animal husbandry and transport in the nature management structure. The evaluation results indicate high values in specific indicators for this region, particularly salinity (Tasseled Cap) ranging from 30 633 to 50 970 and erosion (NDVI) from 0.2 to 0.5.

The category of very severe degradation is attributed to semi-desert landscapes, characterized by flat-wavy loamy stratified plains. These landscapes, due to their lack of population, experience a relatively minimal anthropogenic load but exhibit a weak resistance to anthropogenic influences due to natural factors of formation. These are mainly areas of agricultural development, with an abundance of small populated areas. The evaluation results reveal that this particular region exhibits the maximum values of salinity (Tasseled Cap), ranging from 30,633 to 50,970, and erosion (NDVI) from 0.0 to 0.2. (Figure 11).

In general, as indicated in Figures 10 and 11, the degradation of landscapes under anthropogenic impact demonstrates an increasing trend from north to south, which is associated with the increasing activity of economic development of the natural environment of the Kostanay region. The forest-steppe and steppe landscapes in the northern part of the study zone are characterized by a high level of resistance to anthropogenic influences, depending on the physical and geographical conditions. However, the growing anthropogenic activity inevitably leads to the degradation of the natural environment in these territories. This northern section is the most densely populated and industrially developed part of the region.

Conclusion

1. The proposed method for assessing the dynamics of landscapes under anthropogenic impact enables differentiation and evaluation of changes in individual landscape components caused mainly by irrational economic activity. The indices with the highest reliability were determined through the verification of index values and field survey data, facilitating the mapping of each indicator, including soil overwatering, soil salinity, salinity, soil erodibility, water bodies, and total projective cover).
2. The verification of the obtained indicators using the values from the remaining 25% of field points determines the reliability of the results, ranging from 87% to 92%. This confirms the correct choice of methods and techniques for obtaining results, especially the choice of field methods and vegetation and non-vegetation indices for evaluating the selected indicators.
3. The computation of the integral indicator for assessing the degree of degradation of the natural environment of the Kostanay region, based on the degradation of each indicator under anthropogenic impact, enabled the identification of landscapes exhibiting varying degrees of degradation, ranging from weak to very strong. Studies have confirmed that landscapes with a high degree of degradation under anthropogenic impact are predominantly found in the semi-desert landscapes in the southern part of the study region. The degradation of these landscapes is associated not only with anthropogenic impacts but also with natural and climatic features that affect the development of landscape pollution processes. Conversely, landscapes with a low degree of degradation correspond to the forest-steppe and steppe zones, characterized by a high level of economic development and high resistance to anthropogenic influences.

4. Studies have confirmed that landscapes with a high degree of degradation under anthropogenic impact are predominantly situated in the semi-desert landscapes located in the southern part of the study region. The degradation of these landscapes is associated not only with anthropogenic impacts but also with natural and climatic features that affect the development of landscape pollution processes. In contrast, landscapes with a low degree of degradation correspond to the forest-steppe and steppe zones, characterized by a high level of economic development and high resistance to anthropogenic impacts.
5. The forest-steppe and steppe landscapes in the northern part of the study zone exhibit a high level of resistance to anthropogenic influences, determined by the physical and geographical conditions, but the growing anthropogenic activity inevitably leads to the degradation of the natural environment of these territories.
6. All the research methods developed so far focus on characterizing the degradation of agricultural land, but they do not characterize the dynamics of the entire natural system. In the landscape, all components are equal and all the relationships between them are subject to study. We believe that when examining the dynamics of landscapes under anthropogenic impact, it is necessary to take into account the indicators of all landscape components. Subsequently, based on a verified map of the natural environment degradation generated through space monitoring and field research results, it is possible to predict the functioning of the natural environment under anthropogenic impact conditions.

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