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INTERPRETATION OF REMOTE SENSING DATA BASED ON THE ANALYSIS OF LANDSCAPE FORMING FACTORS

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Abstract: This article discusses the methodology for assessing the natural and recreational potential of landscapes in the Nura River basin. Based on this assessment, it is possible to make a component-by-component evaluation of the natural and recreational potential (relief, climate, water resources, vegetation, and specially protected natural areas). To calculate the potential, it is proposed to apply the balance method. With the help of the considered method, it is possible to conduct a comparative analysis of the prospective possibilities of the territory and natural and recreational resources. The results obtained in the article were ranked by groups. The interpretation of remote sensing data has become a critical tool in landscape analysis, allowing for the identification and evaluation of various landscape-forming factors such as topography, climate, vegetation, and human activities. This study investigates the use of remote sensing imagery to assess and interpret these factors, with a particular focus on their spatial and temporal relationships in shaping the landscape. By integrating high-resolution satellite data, digital elevation models (DEMs), and land use/land cover maps, we identify key patterns of landscape formation across diverse environments. Advanced image processing and machine learning algorithms are employed to analyze the interactions between natural and anthropogenic forces, revealing insights into landscape evolution and dynamics. The findings suggest that remote sensing not only enhances our understanding of landscape morphology but also provides a robust framework for monitoring land change over time. This approach offers valuable implications for land management, environmental monitoring, and conservation planning, contributing to sustainable landscape development and resilience in the face of climate change.

Keywords: landscape, wetlands of Central Asia, interpretation of remote sensing data, remote sensing of the Earth, Akmola region, Lake Teniz

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INTRODUCTION

Remote sensing of the Earth is a method of obtaining information about an object or phenomenon by analyzing data collected without direct contact with the studied object. The latest advancements in science, engineering, technology, and Earth studies have significantly influenced the development of remote sensing. An important methodological foundation for the interpretation of remote sensing data is demonstrated by research on the use of categorical maps for spatial modeling. For example, the development of the Maxent algorithm to predict soil types shows how categorical land characteristics can be transformed into spatially explicit models, greatly improving the precision of landscape factor analysis (Ahmer & Ostendorf, 2025). The use of remote sensing of the Earth in combination with GIS technologies and spatial modeling for archiving landmarks of landscape structures creates new opportunities for exploratory, scientific, and design work in landscape studies. An important area of application of remote aerospace sensing is the remote monitoring of the ecological situation and life safety in various landscape structures (Panasyuk, 2018). Remote sensing plays a vital role in ecological monitoring by providing valuable data for analyzing landscape structures, environmental conditions, and temporal

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changes. The integration of remote sensing data with Geographic Information Systems (GIS) technologies allows for effective mapping and management of landscape features, such as water bodies, vegetation, and land use (Ibrayev et al., 2013).

It is particularly useful in monitoring large-scale landscapes, including wetlands, where traditional ground-based methods might be difficult or impractical (Muthusamy & Ghosh, 2021). In the context of Central Kazakhstan, remote sensing can be employed to evaluate changes in land cover, vegetation health, and hydrological conditions (Lin et al., 2025).

This is crucial for understanding the dynamics of wetland ecosystems, which are sensitive to shifts in water levels, climate patterns, and human activities (Sargsyan & Bakiev, 2020). The application of satellite imagery, such as Landsat and Sentinel data, allows researchers to monitor changes in wetland habitats over time, offering insights into both natural and anthropogenic factors affecting these areas (Kim et al., 2019). The wetlands of Central Kazakhstan represent valuable ecosystems, as they play a crucial role in preserving biological diversity and maintaining the water balance of the environment. These wetlands of Central Kazakhstan are located in the central part — the Akmola region (Figure 1).

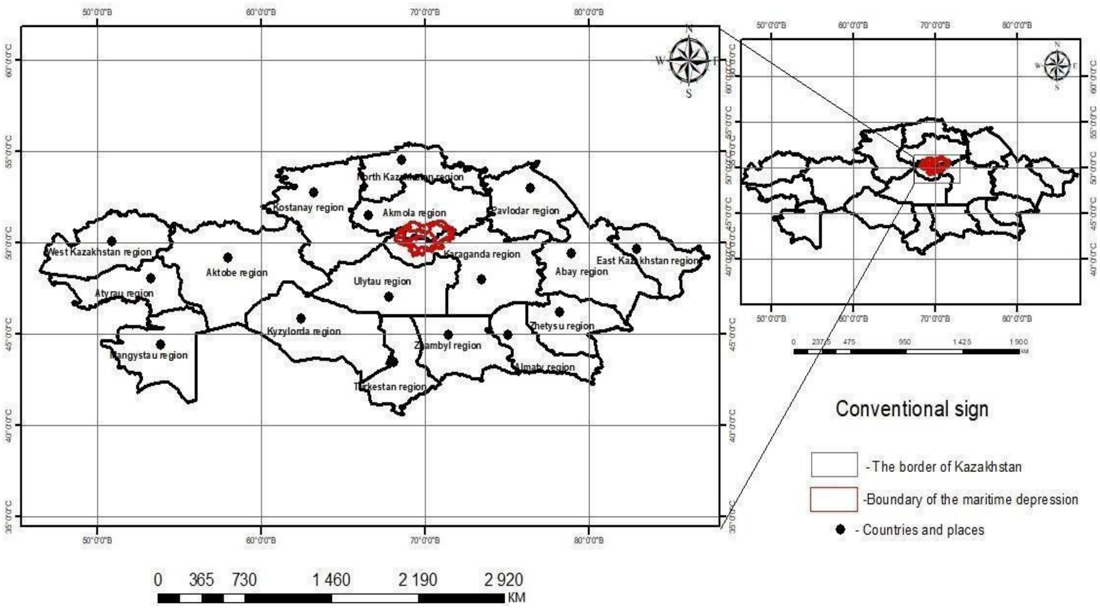

Figure 1. Geographical position of the Teniz-Korgalzhyn depression (Source: Sagatbayev et al., 2025)

Lake Teniz is located in the Akmola region, in the Korgalzhyn district of Central Kazakhstan, southwest of the country's capital, Astana. Its total area is 304 km².

The object of the study is the territory of Lake Teniz, located within the geographical coordinates from 68º00´ to 71º41´ east longitude and from 48º10´ to 51º43´ north latitude, and established in 1968 (Figure 2).

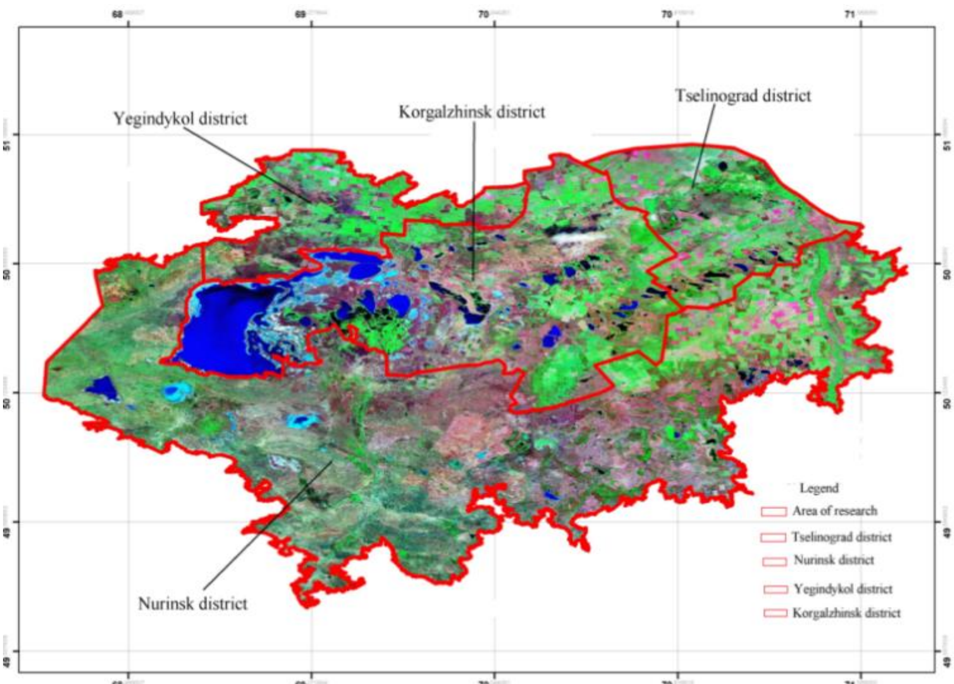

Figure 2. Teniz-Korgalzhyn depression (Source: Sagatbayev et al., 2025)

Monitoring the condition of this ecosystem will allow for the timely justification of conservation measures. The use of remote sensing data enables the application of modern, high-tech research methods and data interpretation, mathematical tools, and software, expanding the possibilities of monitoring studies of spatial-temporal changes in the natural environment (Bartalev et al., 1995).

JUSTIFICATION OF THE RESEARCH AREA

The Nura is a river in Kazakhstan. It is the largest river of the Nura-Sarys basin. The main flow of the Nura is directed to Lake Teniz, which belongs to the inland drainage basin.

The Nura River originates from the western spurs of the Kyzyltas Mountains and flows into Lake Teniz. The river is 978 km long, with a drainage area of 58.1 thousand km². It flows within the Kazakh Lowland. The main tributaries of the Nura River are the Sherubainura (right tributary), Ulkenkundyzdy, Ashysu, Matak (right tributaries), and Akbastau.

Lake Teniz is located in Central Kazakhstan. The Nura and Kulonotpes rivers flow into it (Figure 3).

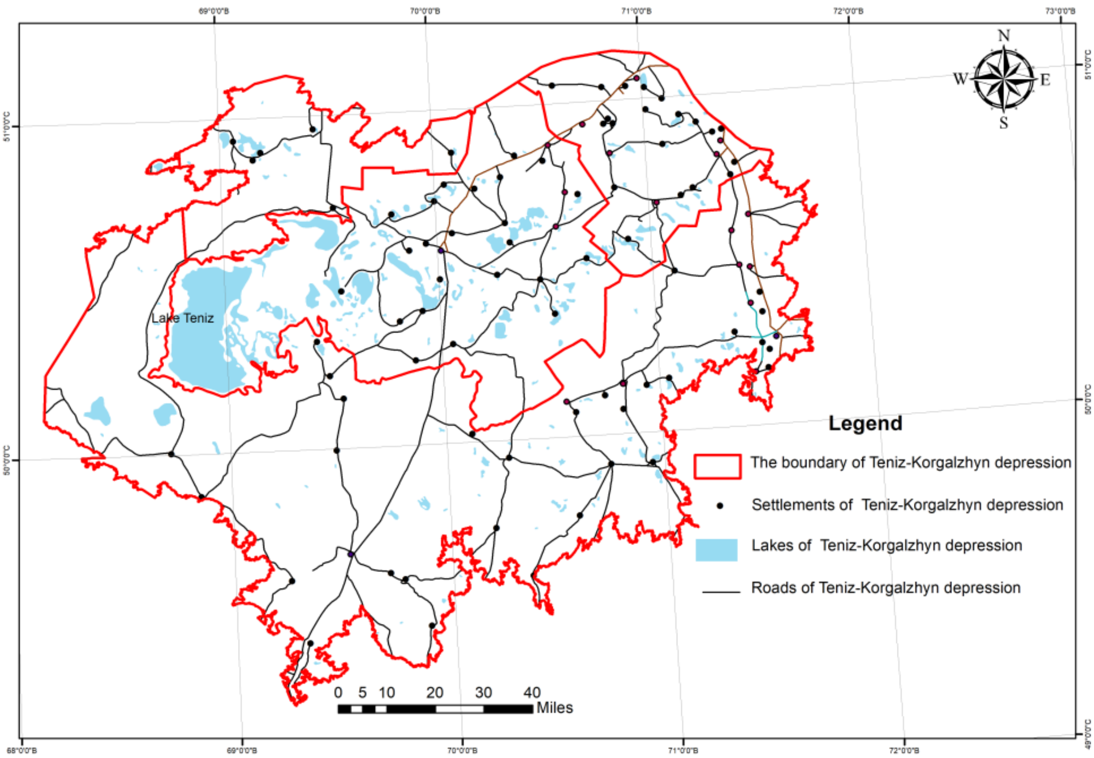

Figure 3. The location of river Nura (Source: Sagatbayev et al., 2025)

The catchment areas include significant sections of the Kazakh Lowland. The basin itself is located in the peripheral part of the Kazakh Lowland. Thus, the ecosystems of the Teniz-Korgalzhyn basin and the Kazakh Lowland are spatially and functionally interconnected (Sagatbayev et al., 2019a).

For a more accurate interpretation of remote sensing data, key areas were identified within the study region, located in different landscape conditions. In Central Kazakhstan, the author has identified three key areas.

Brief description of the areas: The first key area is located in the Teniz Lake basin, which is the largest water body in the study region and represents the primary habitat for the flamingo population and other wildlife of the reserve. The second key area is located in the Nura River basin and includes watershed surfaces, valley slopes, and river floodplains. This selection allows for the inclusion of the full diversity of animal habitats in monitoring studies. The third key area is located in the eastern part of the Teniz-Korgalzhyn basin, influenced by the barrier effect of the Muzbel upland (Sagatbayev et al., 2019b). Thus, the selection of key areas covers the maximum diversity of the natural environment of the study region and ensures the representativeness of the sample through comprehensive studies within the 'keys' themselves.

For the study of lakes, three subsystems were selected:

1. Teniz Lakes (Large and Small);
2. Korgalzhyn Lakes – a protected biosystem reservoir, ecosystem;
3. Lakeside geosystems – 2nd and 3rd order. The boundaries of these areas are shown in Figure 4.

The geosystems are located within the subsystems of the Nura River. The area of 1) Teniz Lakes (Large and Small) polygon A is 11,480 km²; 2) Korgalzhyn Lakes, a biosystem reserve, polygon B is 55,591 km²; 3) Lakeside geosystems of 2nd and 3rd order, polygon C is 55,591 km². To determine the degree of landscape cultivation in the region, remote sensing data were used, including time-series satellite images obtained from the Landsat-7 and Landsat-8 satellites.

As is well known, the high efficiency of combining maps and satellite images has long been evident (Azbantayeva et al., 2022). To determine the dynamics of arable lands, mosaics of images taken in 1975, 1992, 2005, and 2024 were used.

For digitization, images from the United States Geological Survey (USGS) database were utilized. To obtain data on the area of arable lands for 1975, Landsat 5 images were used, which were processed using ArcGIS software to perform spectral decomposition into deciphering color channels. For example, by using a specific set of color channels, it is possible to directly isolate lands related to agricultural areas, arable lands, fallow lands, etc. A total of 320 satellite images were processed for the study region (Figure 5). Geographic location, absolute elevation above sea level, presence of aquatic systems, and other factors were used as criteria for identifying key areas. To determine structural changes within the selected key areas, it is suggested to use the profiling method by constructing complex profiles and plotting calculated indicators of soil-vegetation indices obtained from multizonal satellite imagery data spanning from 1975 to 2024.

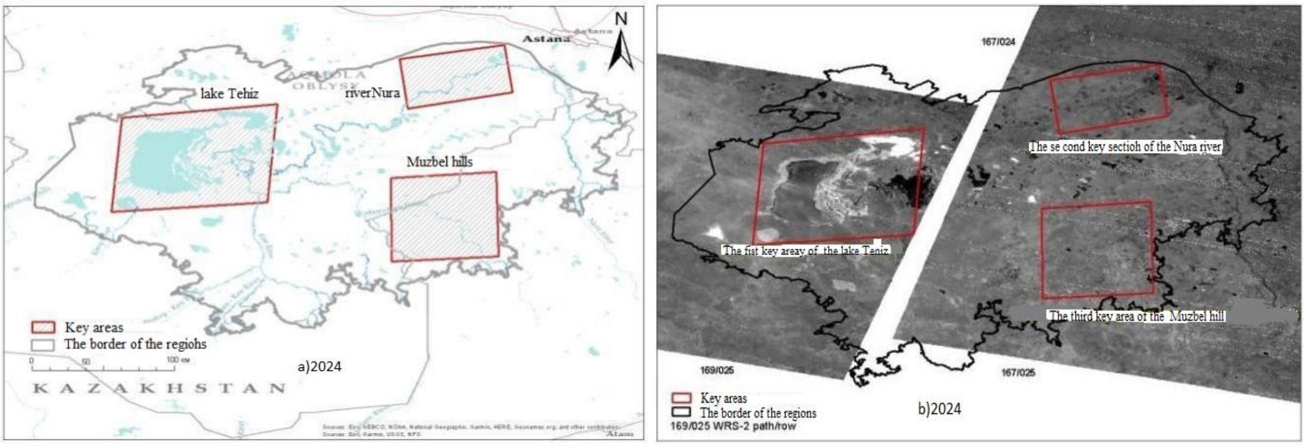

Figure 4. Map-scheme of the location of the key areas of the Teniz-Korgalzhyn depression A, B, and C (Source: Sagatbayev et al., 2025)

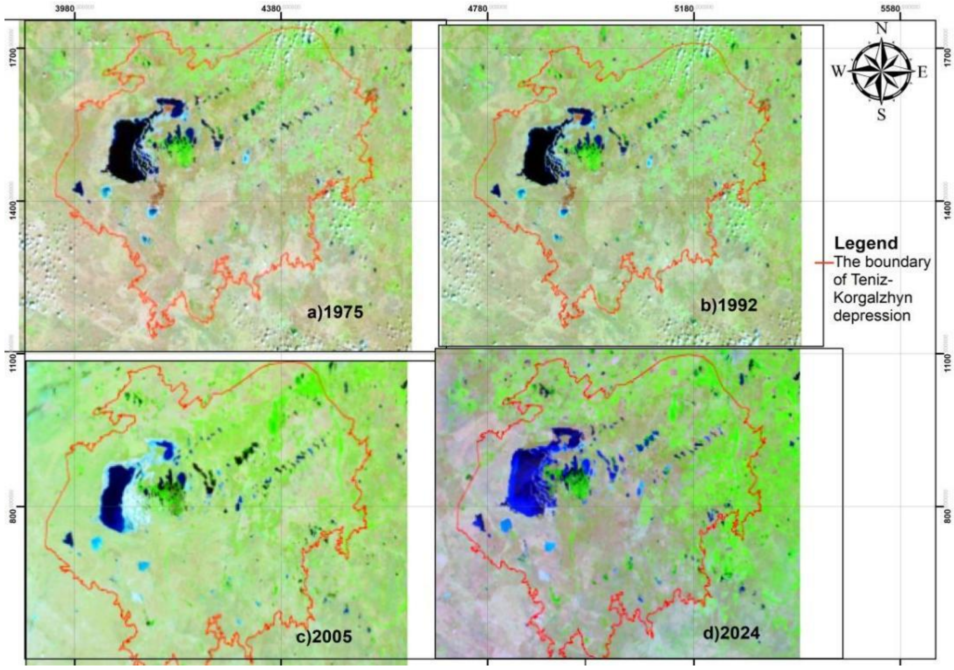

Figure 5. Images of 1975, 1992, 2005, 2024 Landsat scenes (Source: Sagatbayev et al., 2025)

Satellite imagery analysis has revealed significant changes in landscape cultivation across the study area, particularly in terms of agricultural expansion. Using multi-temporal satellite images from the USGS and the Landsat program, the study has mapped the transformation of arable lands and wetland areas over four decades. The application of ArcGIS software and spectral decomposition techniques allows for the identification and classification of different land types, including agricultural, fallow, and natural lands (Urazaliev, 2018). These analyses are instrumental in understanding how agricultural development impacts ecosystems within the Nura River basin and surrounding areas (Pueppke et al., 2018).

Several studies have demonstrated the efficacy of combining remote sensing data with field observations to monitor ecosystem dynamics (Tanton et al., 2001). The multi-spectral data from Landsat satellites allow for the assessment of vegetation indices and soil moisture levels, which are critical for understanding landscape cultivation and its subsequent effects on hydrological systems. These remote sensing technologies have enabled environmental scientists to monitor significant shifts in the hydrological and vegetative conditions of the Teniz-Korgalzhyn region over multiple decades.

The selection of key areas ensures that data can be gathered from regions with varying landscape conditions, which helps capture the full diversity of habitats found in the Teniz-Korgalzhyn basin. These regions serve as crucial testing grounds for understanding the effects of agriculture and land cultivation on local ecosystems, as well as how these processes influence water quality, biodiversity, and soil health. By utilizing multi-temporal satellite imagery, we can track structural changes and better understand the ecological transformations occurring across the region. In a similar vein, the application of GIS-based technologies in monitoring and managing the ecological and tourism resources of the Nura River basin can enhance landscape analysis, optimize habitat protection strategies, and improve the overall management of the area's natural resources, ensuring that both conservation and sustainable tourism efforts are aligned (Amangeldi et al., 2025).

METHODOLOGY

Application of Remote Sensing Method

At the initial stage of the work, remote sensing data (RS) were used as the primary source of information, as, according to Knizhnikov Yu.F. and Kravtsova V.I., reliable data on the dynamics of ecosystems can only be obtained through the analysis of time-series satellite images (Knizhnikov & Kravtsova, 1991). Time-series land cover maps were created by the authors based on the automated interpretation of Landsat images (resolution 15-30 m), and Sentinel-2 MSI (multi-spectral instrument, Level-1 C) fine spatial resolution (10 m-60 m) (Krishna et al., 2025). The choice of this series of satellites for solving the research tasks is determined by their spectral, spatial, and temporal coverage, resolution, and free access to the database. Three time-series of satellite images were used: taken on June 17, 1975, June 21, 1992, June 18, 2005, and June 20, 2024. A classification of the images based on remote sensing data from several temporal slices was then developed. This algorithm involved labeling all pixels in the image according to the characteristics of vegetation and soil cover for each time slice. By applying this technique, it is possible to detect changes in land cover over time and monitor the spatial distribution of various vegetation types and soil properties. Remote sensing technology allows for high-resolution temporal data to be captured, which is crucial for assessing land dynamics in regions with significant seasonal or environmental changes (Zhu et al., 2019).

After obtaining the cartographic basis for analyzing the spatial-temporal variability of vegetation index values, other landscape metrics were investigated, traditionally divided into two groups: composition metrics and configuration metrics. Composition metrics focus on the proportional distribution of different land cover types, providing an understanding of the variety and quantity of landscape components. Configuration metrics, on the other hand, assess the spatial arrangement of these components, revealing how landscape structure influences ecological processes. These metrics, when used in conjunction with remote sensing data, help to quantify the complexity of the landscape and can be particularly useful in identifying areas vulnerable to habitat fragmentation or land degradation (Turner, 1989; McGarigal et al., 2012).

At the stage of interpretation of remote sensing data, it was necessary to establish the patterns of spatial-temporal variability of vegetation index values. The landscape approach allowed the use of the potential of fundamental natural sciences, including landscape science, to establish such patterns. In particular, the integration of remote sensing data with landscape ecology principles allows for the exploration of how landscape patterns—such as fragmentation, connectivity, and edge effects—interact with environmental variables to influence vegetation dynamics and ecosystem health (Forman & Godron, 1986). In addition to vegetation indices, which provide insights into the greenness or productivity of vegetation, the analysis of other spectral indices, such as Normalized Difference Water Index (WNDWI) or Normalized Difference Vegetation Index (NDVI), further enhances the ability to assess the temporal evolution of wetland areas and their ecological health. These indices provide essential information about water availability and vegetation vigor, which are directly linked to the resilience of landscapes and ecosystems to environmental stressors, including climate change and human impacts (Xu, 2006; Zhang, 2021). The combination of these spatial-temporal analysis techniques and the landscape approach offers a powerful methodology for monitoring ecosystem dynamics (Wu, et al., 2025). This approach helps researchers and land managers to develop sustainable landscape management strategies that account for both ecological and anthropogenic factors influencing the region’s natural resources.

Assessment of Tourism and Recreational Potential

The overall economic value of the landscape services of wetlands was assessed based on the calculation of the following indicators: economic evaluation of natural resources, assessment of tourism and recreational potential, assessment of agricultural lands, evaluation of the filtration capacity of wetlands, and evaluation of carbon dioxide sequestration by forest and meadow vegetation. The overall economic assessment of natural resources, specifically the evaluation of key animal species, was conducted using standard methods. Calculations were carried out according to natural resource accounting data and annual reports from the Forestry and Hunting Committee of the Ministry of Agriculture of the Republic of Kazakhstan.

RESULTS AND DISCUSSION

During the automated decoding of Landsat images in the study area, differences in the quantitative indicators of vegetation indices were identified for different cover types: water surfaces of lakes and ponds; fallow lands; swamps; waterlogged meadows; typical steppe with feather grass; shrub-covered sagebrush-grass steppes, and bare soil surfaces. The results of image decoding obtained from the transformation of satellite data: images in the "false colors" and "natural colors" combination, the calculated tasseled cap value (moisture content of the area) for the studied area, as well as the vegetation index values NDVI, MNDWI, allowed refining the location and state of groundwater, which in the continental sector of Eurasia determines the potential for phytomass formation. Figure 6 presents a generalized diagram of the accuracy analysis of lake area measurements based on radar images from ERS-2, filtered by different methods implemented in ENVI 4.5.

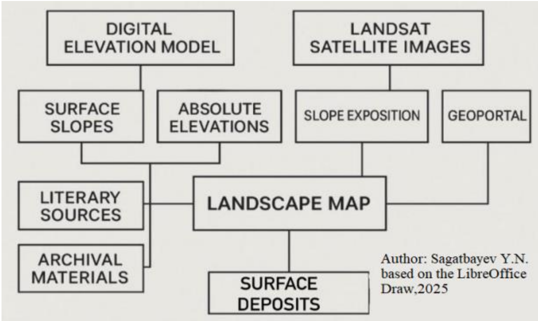

Figure 6. Generalized scheme for accuracy analysis of lake area measurements using ERS-2 radar images

The evaluation of vegetation indices (NDVI, MNDWI) and the accuracy of remote measurements of lake areas was carried out by comparing the lake area measurements from filtered radar images with measurements from the same lakes on Quick Bird images. The image filtering was done using Lee, Frost, Local Sigma, and Median methods implemented in ENVI 4.5 software. To define the boundaries of the lakes and study their dynamics, we used scenes from Landsat and Sentinel images. The images were selected from the summer, spring, and autumn seasons with the lowest possible cloud cover. In addition to the images, large-scale topographic maps of the region (1:500,000 - 1:200,000) were also used. However, there are certain specifics when working with these data.

This work utilized the concept of the most popular and frequently used index – NDVI (Normalized Difference Vegetation Index). The index is calculated using the following formula (1), (Xu, 2006; Zhou et al., 2020):

$$NDVI = \frac{L_2 - L_1}{L_2 + L_1}, \quad (1)$$

L2 is the reflectance coefficient in the near-infrared spectrum, and L1 is the reflectance coefficient in the red spectrum. The ratio of these values helps clearly separate and analyze vegetation from other natural objects. Using the normalized difference, instead of a simple ratio, increases measurement accuracy and reduces the influence of phenomena like lighting differences, cloud cover, haze, and atmospheric radiation absorption.

For green vegetation, reflectance in the red spectrum is always lower than in the near-infrared, so NDVI values for vegetation cannot be less than 0. The greater the green biomass, the higher the index. The index is also influenced by the plant species composition, density, condition, exposure, slope angle, and the color of the soil under sparse vegetation. NDVI is moderately sensitive to soil background changes, except when vegetation density is below 30%.

NDVI values range from -1 to 1. For green vegetation, the index typically ranges from 0.2 to 0.8. In the processing of satellite images, the ENVI software was used with a vegetation index calculator.

As a result of calculating the NDVI from satellite images of 1975 and 2024, index images of the Teniz-Korgalzhyn depression area were obtained, a fragment of which is shown in Figure 7.

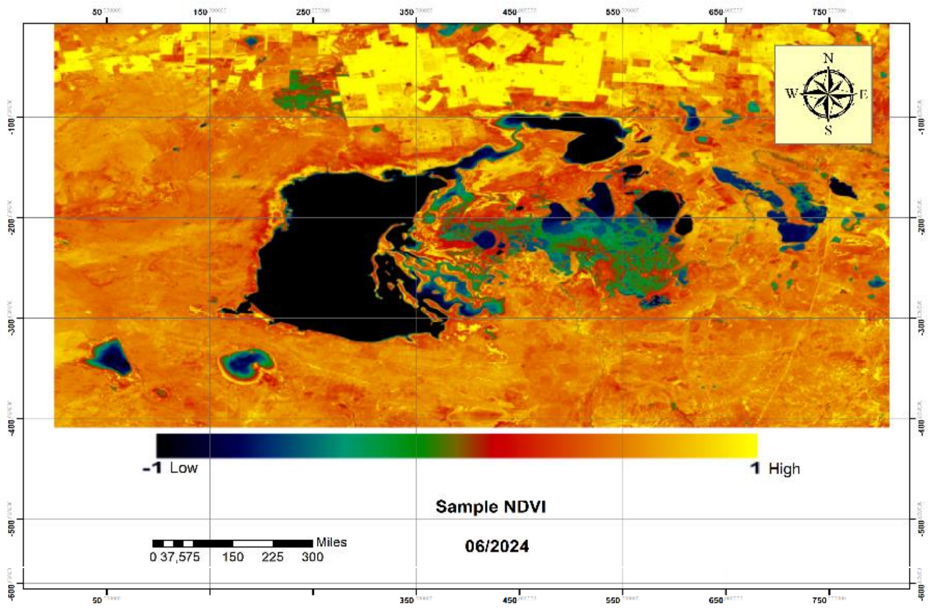

Figure 7. Fragment of the NDVI index calculation result based on the Landsat image from June 5, 2024 (Source: Sagatbayev et al., 2025)

NDVI has a good correlation with vegetation biomass. The relationship between these parameters is generally not linear and is influenced by the specific features of the studied area, its climatic and ecological characteristics. For instance, in this study, NDVI maps will be used to create masks for agricultural lands during land cover classification. When processing images, in addition to the vegetation index, the so-called water index is used to assess the moisture content in vegetation and soil. The index is calculated using the green (0.525–0.600 μm) and middle infrared (1.560–1.660 μm) ranges. The modified normalized difference water index (MNDWI) is calculated using the following formula (2), (Xu, 2006; Zhou et al., 2020):

$$MNDWI = \frac{L_2 - L_1}{L_2 + L_1}, \quad (2)$$

where L2 is the reflection coefficient in the green region of the spectrum;

L1 is the reflection coefficient in the middle infrared region of the spectrum. The MNDWI index is also effectively used for detecting water bodies on satellite images. This method of detecting water bodies based on multispectral data is based on the fact that water significantly absorbs radiation in the middle infrared range. This property will be used in this work to create water body masks during the verification of open water body classification (Li & Wu, 2004).

While processing satellite images in the ENVI software suite, a special calculator for spectral channel mathematics was used. As a result of calculating the MNDWI for satellite images from 1975 and 2024, index images of the Teniz-Korgalzhyn depression area were obtained, a fragment of which is shown in Figure 8.

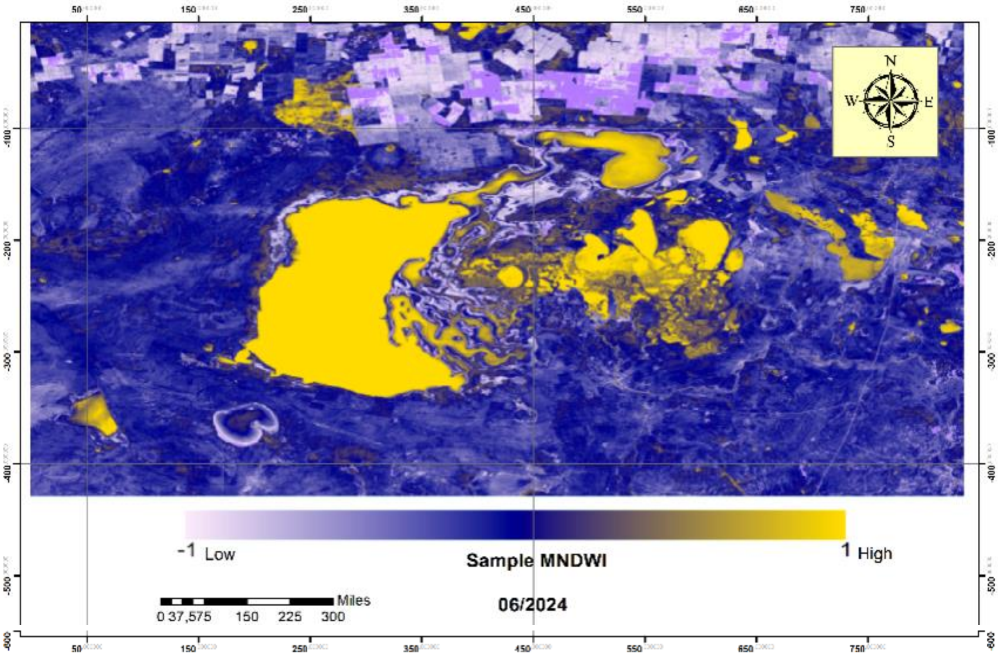

Figure 8. Fragment of the result of calculating the MNDWI index based on the Landsat image from June 5, 2024 (Sagatbayev et al., 2025)

For example, Landsat TM images are available in series from different years, from 1975 to 2024. However, there are certain differences in the structure of the data itself between these images.

Landsat 5 has a channel structure – VIS (3), NIR (1), SWIR (2), TIR (1); Landsat 7 – panchromatic, multispectral: VIS (3), NIR (1), SWIR (2), TIR (1) with a resolution of 15 m for the panchromatic channel and 30 m for the multispectral zone; Landsat 8 – panchromatic, multispectral: VNIR (6), SWIR (2), TIR (2) with a resolution of 15 m for the panchromatic channel, 30 m for the near and mid-spectral zones, and 100 m for the thermal zone (Li & Reynolds, 1993).

To delineate the boundaries and classify the components of the geosystems, all satellite data were converted into mosaic layers developed in the ENVI 5.0 program with a spatial resolution of 30 m (2008–2024). For collecting and processing the modern data slice (2014–2024), remote sensing data from Sentinel series satellites 1 and 2 were used.

The first radar satellite, Sentinel-1A, was launched into orbit on April 3, 2014, by the European Space Agency (ESA). It became the first in the satellite constellation for global environmental monitoring and security, Copernicus. Sentinel-1A was developed by Thales Alenia Space. It is equipped with a synthetic aperture radar (C-SAR), developed by Astrium, which ensures all-weather and round-the-clock delivery of satellite images (Xu et al., 2006).

Sentinel-2A and 2B satellites are equipped with an optical-electronic multispectral sensor for imaging with resolutions ranging from 10 to 60 m in the visible, near-infrared (VNIR), and shortwave infrared (SWIR) spectral zones, ensuring the display of vegetation state differences, including temporal changes, and minimizing atmospheric influences on image quality. Their capabilities correspond to those of Landsat-7 and SPOT-5 images. In the thematic processing of images, MNDWI and NDVI indices were calculated, and index maps were built for the entire Teniz-Korgalzhyn Depression.

NDWI represents the moisture content in the soil and leaves (Linke et al., 2009).This cartographic material was later used to describe and geographically characterize the studied area, as well as to create the landscape map of the Teniz-Korgalzhyn Depression. Using standard tools in the ArcGIS 10.4 program, we calculated all the indicators. Figure 9 shows the previously compiled medium-scale landscape map of the Teniz-Korgalzhyn Depression.

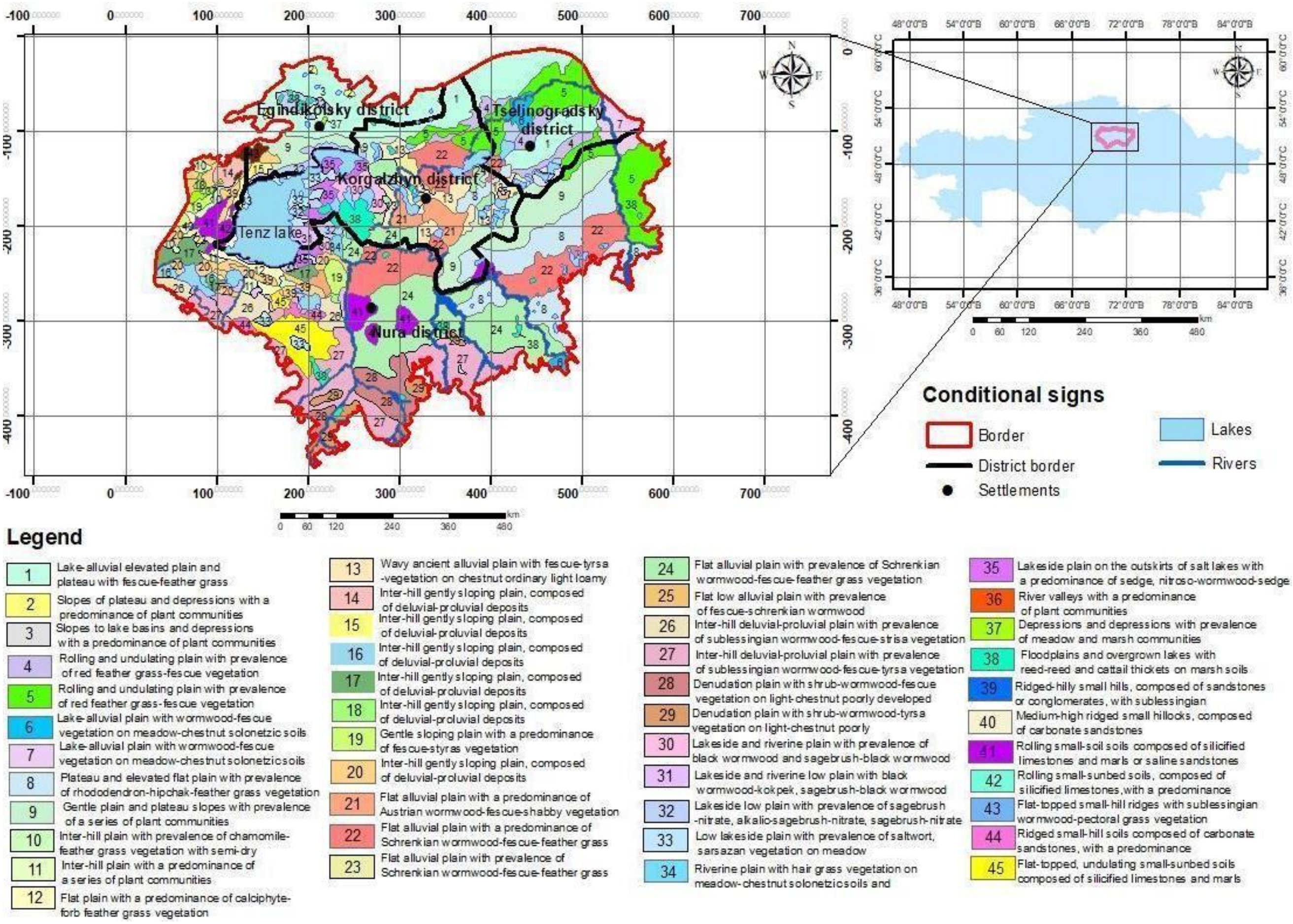

Figure 9. Landscape map of the Teniz-Korgalzhyn Depression (Source: Sagatbayev et al., 2025)

The landscape map of the Teniz-Korgalzhyn Depression shows a variety of landscape zones that represent the territorial distribution of natural complexes, including steppe, forest-steppe, and lake ecosystems (Sagatbayev et al., 2025). Different types of landscapes, such as plains steppes, floodplain areas, and zones with water bodies, are highlighted according to the color scale and symbols. The boundaries of the studied area are also marked, making it easy to navigate its geographical limits. This cartographic material is crucial for understanding the natural diversity of the Teniz-Korgalzhyn Depression and serves as the basis for assessing its recreational potential (Alipbeki et al., 2024)

Assessment of Tourism and Recreation Potential

The value of direct land use for tourism was calculated by estimating the annual income generated from organizing excursions, exhibitions, and other events in the buffer zones of the Korgalzhyn Reserve (Table 1). The total cost of services provided includes tourists' transportation costs, access to observation decks, provision of camping areas, visits to the Nature Museum, availability of food services, and accommodation expenses. It is worth noting that more than 80-85% of the costs are related to accommodation, while only 3-4% are spent on transportation. The income data were taken from official development programs of the Akmola region for the years 2018-2024.

Table 1. Assessment of the Recreational Potential of Major Wetlands Visited by Tourists (According to Regional Development Programs for 2018–2024)

Name of the Site	Infrastructure	Transport accessibility to major administrative centers	Average tourist flow, people/year	Cost, USD
Korgalzhyn State Nature Reserve (village of Korgalzhyn)	Six guest houses, three hotels, five cafes, home-style cuisine, two restaurants, nature museum, hunting grounds, etc.	130 km from Astana, 2-hour drive	3000	766700

As seen from Table 1, the Korgalzhyn Nature Reserve is visited by an average of 3,000 people annually, contributing to the growth of tourism-related income. Considering that the total number of visitors to the Teniz-Korgalzhyn Depression region in 2024 exceeded 28,000, there is potential for further growth in tourism income. Therefore, it can be concluded that most tourists do not utilize the services of tourism organizations and, most likely, unorganized tourism predominates in this area. The main type of tourism in protected areas is related to the scientific and educational interest of visitors. The administrative center of the reserve in the village of Korgalzhyn hosts visitors and promotes ecotourism. The most significant development of tourism is observed in the Korgalzhyn district, which is due not only to its rich tourist and recreational potential but also to substantial funding from Astana.

As a result of the cartometric measurements conducted, the following data on the sizes of the largest lakes in Central Kazakhstan were obtained (Table 2).

As a result of topographic and bathymetric surveys, the most reliable morphometric data have been obtained, as presented in the articles by G.G. Muravlev, A.G. Popolzin, E.A. Kazanskaya, and T.M. Trifonova.

Table 2. Morphometric Characteristics of the Largest Lakes in Kazakhstan

Lake	Watershed area, thousand km²	Absolute elevation, m	Lake area, km^2	Length, km	Width, km	Maximum depth, m	Water volume km^3
Teniz	94.9	304	1161	74	40	8	0.6

Lake basins belong to various genetic groups, which leads to a wide diversity of lakes in terms of size, shape, depth, hydrological regime, and hydrochemical characteristics. The differences in the genesis of the basins are influenced by both endogenous factors—such as recent tectonic movements, seismic activity, and the lithology of the rocks - and exogenous factors, including river erosion, wind, ice, karst, suffusion, and gravitational processes.

It is also important to consider the changes induced by human activity and climate fluctuations. For the Teniz-Korgalzhyn depression, where wetlands play an important role in maintaining the migratory routes of waterfowl, NDVI, MNDWI provides important information about the state of the ecosystem and its response to external influences such as climate change and anthropogenic impact. NDVI, MNDWI data obtained using Landsat satellite imagery over the past fifty years allows us to analyze long-term trends and identify areas with reduced productivity (Table 3).

Table 3. Values of vegetation indices obtained after processing satellite images of Central Kazakhstan

Name of the key section	Values of vegetation indices			
	NDVI	MNDWI	NDVI	MNDWI
	1975	1975	2024	2024
Plot including lake basins and terraces	1158.48	1160.07	1154.09	1157.68
Plot located in the valley of the Nura River	1154.67	1155.87	1152.47	1148.98
A plot located on a watershed surface	1.1	1.2	0.8	1.0
The site located in the barrier conditions of Teniz-Korgalzhyn depression	33	34	32.7	33.9

The data in the table illustrate the spatial variation in the values of vegetation indices NDVI and NDWI. The highest index values, indicating moisture, are observed in hydromorphic and semi-hydromorphic conditions, where the groundwater table is close to the surface. This relationship allows the identification of the most humid habitats in the study area based on the NDVI and NDWI index values. These areas are typically associated with the valleys of small rivers and streams with well-developed bottoms covered by diverse herbaceous and sedge-grass meadows on meadow and marsh-meadow alluvial soils, as well as low lake terraces with grass-herb, bushy, and sedge-grass swamp meadows on meadow-marsh and primitive-layered soils. Semi-hydromorphic geosystems in flat plains form under conditions of relatively close groundwater levels, with periodic rises (usually in the spring), creating conditions for additional moisture. Groundwater is mineralized and lies at depths of 3 to 5 meters. Semi-hydromorphic conditions are also found in the basins and depressions of watersheds, which exist under conditions of abundant additional moisture in the spring. In semi-hydromorphic conditions, halophytic-shrubby communities have formed on meadow-steppe solonchaks (desert and desert-steppe complexes dominated by Kochia), and bush thickets on meadow-chestnut soils.

The most valuable habitats in the study area are hydromorphic ecosystems, which are inhabited by waterfowl and shorebirds. Together with the surface area of the lakes, these ecosystems account for approximately 22.7% of the territory. The depth of the groundwater table in hydromorphic habitats ranges from 1 to 3 meters, which plays a crucial role in the formation of biomass in the continental climate. In conditions of intense evaporation, hydromorphic environments form succulent saline communities on meadow solonchaks, as well as meadow, tree-shrub communities on meadow soils or swamps and meadows on marsh and meadow-marsh soils.

The least humid areas are the watershed surfaces, used for plowing or occupied by sagebrush-thistle plant groups and xerophytic-mixed-grass steppe ecosystems on chestnut and dark-chestnut soils. Previously, A.T. Akhmetov and others identified three zonal classes of automorphic geosystems on the watershed surfaces (Akhmetov et al., 2006)

- Moderately dry steppes on dark-chestnut soils (northern and northeastern parts of the site);
- Dry steppes on chestnut soils (the majority of the territory);
- Desertified steppes on light-chestnut soils (small southern part of the territory).

Dry steppes form 32 flatland and 9 small-hill ecosystems and are easily recognizable on satellite images as speckled elements of their patterns. Moderately dry steppes form 5 ecosystem types, while desertified steppes consist of 3 types of flatland and 3 types of small-hill ecosystems, all of which can be decoded on satellite images.

The application of remote sensing data allowed the precise division of terrestrial ecosystems into automorphic, semi-hydromorphic, and hydromorphic categories. Furthermore, the analysis of a series of temporally different Landsat satellite images enabled the identification of spatial differences in the intensity of biomass accumulation in areas located in various landscape conditions (Table 2). The largest biomass accumulation occurs in lowland areas associated with lake basins and floodplains. On watershed surfaces, the most productive areas are located in the barrier conditions of the Kazakh small-hill upland, which represents an incomplete barrier according to the classification, where air masses humidify the windward slopes, traverse the front hills, and provide moisture to the upper and higher slope microzones of the leeward side.

Minimal values of NDVI and NDWI indices are observed within the watershed surfaces of interfluves, beyond the influence of the small-hill barriers. The analysis of the factors differentiating the landscape sphere on the study area allowed us to explain the spatial distribution of vegetation index values and establish the patterns of their dynamics, offering a more accurate evaluation of the ecological potential and ecological capacity of landscapes in Central Kazakhstan. These landscapes represent valuable ecosystems for many animal species.

Based on the remote sensing data, it was established that windward slopes of the Kazakh small-hill upland receive more precipitation than leeward slopes and lowland plains. The barrier effect is noticeable across the entire territory of Teniz-Korgalzhyn depression, shaping the unique properties of its geosystems. The accumulation of air masses before the barrier of the Kazakh small-hill upland starts about 100 km away from it; as a result, precipitation increases on the windward side of this uplift over an extensive area of Central Kazakhstan. In the landscapes of the rain shadow, on the other hand, the signs of aridization are intensified, which are manifested in the decrease of NDVI values on leeward slopes.

CONCLUSIONS

As a result of the conducted study, the interpretation of Earth remote sensing data based on the analysis of landscape-forming factors led to the following conclusions. The use of Earth remote sensing (ERS) methods made it possible to effectively identify and map key landscape-forming factors that influence the formation of natural and anthropogenic landscapes of the Teniz-Korgalzhyn Depression. The analysis of satellite imagery data and their interpretation ensured high accuracy in determining the boundaries and characteristics of various types of landscapes.

Based on the analysis of spatio-temporal data, the main trends in changes in landscape complexes in the depression were established. Areas with the greatest variability were identified, indicating their high sensitivity to natural and anthropogenic impacts. The study demonstrated the possibility of using ERS data for environmental monitoring and tourism development. Areas with high tourist attractiveness were identified, as well as zones requiring increased attention from the point of view of natural resource protection. The main landscape types of the Teniz-Korgalzhyn Depression, including wetlands, steppe areas and anthropogenically modified territories, have been identified, which allows taking their features into account when planning tourist routes and nature conservation measures. The key factors influencing the formation of landscapes in the study area, including climatic conditions, hydrological regime and anthropogenic impacts, have been identified, which allows more accurate forecasting of possible changes in the future.

The developed methodology for analyzing landscape-forming factors based on remote sensing data can be used for further studies of similar natural areas, as well as for monitoring the state of the environment in a changing climate.

Thus, the results of the study are of practical importance and can be applied in the field of nature conservation, environmental monitoring and planning of sustainable tourism development in the Teniz-Korgalzhyn Depression.

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