https://doi.org/10.55764/2957-9856/2025-4-149-164.52

UDC 338.48:528.8
IRSTI 34.31.35

A. Sh. Shaken[1], K. T. Kyrgyzbay*[2], A. N. Abubakir[3]

[1] PhD, Acting Associate Professor
(Al Farabi Kazakh National University, Almaty, Kazakhstan; *shakenaiman1982@gmail.com*)
[2 *]PhD, Senior lecturer
(Al Farabi Kazakh National University, Almaty, Kazakhstan; ***kyrgyzbay.kudaibergen@gmail.com***)
[3] Master's student (Al Farabi Kazakh National University, Almaty, Kazakhstan; *aruzhana379@gmail.com*)

COMPLEX MONITORING OF THE ENVIRONMENTAL CONSEQUENCES OF ANTHROPOGENIC PRESSURE AT BURABAY NATIONAL PARK USING REMOTE SENSING DATA

Abstract. Overtourism has become a pressing issue in many protected natural areas, causing significant environmental degradation. This study focuses on the environmental consequences of overtourism in Burabay National Park by utilizing remote sensing data from 2020 to 2024. The research employs a multi-criteria approach using NDVI, NDWI, LST, NDBI, and BSI indices to assess changes in vegetation, water resources, land surface temperature, urbanization, and soil degradation. Satellite images were selected based on minimal cloud cover and peak tourist flow periods to ensure accurate monitoring of ecological conditions. The findings indicate substantial fluctuations in vegetation cover, with a temporary decline in NDVI values in 2021-2022, followed by a notable recovery in 2023-2024. NDWI analysis reveals a decline in water bodies until 2023, with signs of partial recovery in 2024. LST variations confirm the impact of land degradation, showing increased surface temperatures in 2021-2023, which later decreased as vegetation cover improved. The expansion of urbanized areas, reflected in NDBI growth, highlights the increasing anthropogenic impact. BSI trends indicate intensified soil degradation, particularly in 2024. Overlay analysis categorized the national park into three degradation levels, emphasizing areas requiring urgent conservation measures. These results provide valuable insights into sustainable management and mitigation strategies to balance tourism and environmental preservation in Burabay National Park.

Keywords: remote sensing, Landsat 8, ecological degradation, overtourism, monitoring, GIS.

Introduction. Tourism is one of the fastest-growing industries in the world. As the number of tourists increases, their negative impact on the environment is becoming more evident. Some destinations are exceeding their carrying capacity to accommodate visitors, effectively struggling with the phenomenon of overtourism. Overtourism places significant pressure on ecosystems, making it essential to develop new monitoring-based approaches to mitigate its consequences.

Overtourism became one of the main issue that have an impact on tourist destinations worlwide.This termin used to describe overindulgent number of visitors outreach reception capacityof the region causing negative consequences on habitat, local communities and incomparability of tourism experience.

Protected areas around the world work for crucial social purpose by providing area for recreational intentions.Especiallly, reachable places or top landmarks within specific Pas involve tourists causing overtourism. In the last decade large number of tourists in nature destinations caused the serious problem and needed to implement carrying capacity indicators accepted as the maximum number of people who can stay without harming environment.The problem of an increasing number of visitors in the environmentally valuable areas emerged in the last century and at that time, mainly out of concern for the state of the natural environment, carrying capacity [1].

In national parks especially the ones that have a huge number of visitors and in their nearby areas studies should be managed on the many-sided influences of tourism. This monitoring should contain effects on the environment and landscapes (to notify about resolution of the ecological carrying capacity) and the effectson people (to help specify the psychological and socio-cultural carrying capacity for tourism). It is vital to highlight that mass and immoderate tourism have not only negative impact on environment and landscape, but also on local communities. Moreover, the impacts of tourism come up with problem of littering, mostly with plastic waste and other non-biodegradable materials, the quantity of which has been growing in the last years [2].

It has long been known that the on-the-ground monitoring of PA ecosystems is high-priced, essentially due to the size and logistical limitations of national parks, appointed wilderness, wildlife refuges and other large PAs. Remote sensing monitoring can give information for the systematic, translucent, noteworthy and maintainable decision making in ecological systems.

Remotely sensed data are confirmed as priceless sources of information for natural resource managers. Rapid diversification in the application of remotely sensed data are promoting the collection of multi-decadal historical records, execution of new sensors, and developments in analytical techniques. To study landscape-scale changes in natural resources time series of photos are useful while data from high-resolution sensors can be used to distinguish and measure small changes in topography, map plant species or even individual plants, or quantify flows of nutriments and energy that alter plant growth and affect fire risk [3].

The primary task of the national park is to preserve and enhance the diversity of living organisms and natural landscapes, as well as to create conditions for scientific research and environmental education. Additionally, the park actively develops tourism infrastructure.

The concept of overtourism has attracted increasing academic attention due to its complex social and environmental consequences. According to UNWTO (2018), overtourism can be defined as “the impact of tourism on a destination, or parts thereof, that excessively influences the perceived quality of life of citizens and/or the quality of visitors’ experiences in a negative way.” This definition corresponds with Goodwin’s (2019) interpretation that overtourism occurs when “hosts or guests, locals or visitors, feel that there are too many visitors and that the quality of life in the area or the quality of the experience has deteriorated unacceptably” [4].

A significant body of research highlights the adverse social outcomes of overtourism for local residents. Increasing tourist flows lead to rising housing costs, crowding, commercialization of everyday life, and the displacement of local populations from central urban areas. Such changes often result in social tensions, the erosion of cultural identity, and loss of community cohesion. In destinations such as Venice, Barcelona, and Dubrovnik, residents have expressed discontent through protests and public movements against “tourism-phobia,” emphasizing the imbalance between the needs of locals and those of tourists [5]. Instances of overtourism have also been documented in several protected areas, including Saxon Switzerland National Park in Germany, Low Tatras National Park in Slovakia, the fjord regions of Norway, Iceland, Plitvice Lakes National Park in Croatia, and Stołowe Mountains National Park. Overtourism negatively affects not only residents but also visitors themselves. Excessive crowding in popular destinations and protected areas contributes to feelings of overpopulation, stress, and reduced satisfaction with travel experiences. Empirical studies demonstrate that visitor enjoyment declines when congestion reduces access to attractions and limits opportunities for meaningful engagement with nature and culture. Gretzel (2021) and Clark & Nyaupane (2020) also report that social dissatisfaction has become a defining feature of overtourism in numerous destinations worldwide [6]. The concept of overtourism reflects a threshold beyond which the disadvantages of tourism expansion outweigh its economic and cultural benefits. Overtourism leads to overpopulated areas, visitor misbehavior, local migration, and ecosystem overburdening. Protected areas serve not only as tourist attractions but also as spaces for local recreation, contributing to residents’ quality of life and mental well-being. While technological tools, including remote sensing, provide valuable data for monitoring environmental change, the human dimension remains central to overtourism management. Effective strategies require collaboration between local authorities, researchers, and communities to ensure that monitoring results inform socially sustainable tourism policies [7]. A people-centered approach focusing on equity, community empowerment, and cultural preservation is essential to mitigate the social impacts of overtourism.

The object of research. The Burabay State Scientific and Industrial Enterprise performs the functions of an environmental and scientific institution, and is also included in the list of specially protected natural territories created to preserve biological and landscape diversity. The purpose of the park is the rational use of unique natural complexes and objects of the state nature reserve fund, which have special ecological, scientific, historical, cultural and recreational value. The main objective of the national park is to preserve and increase the diversity of living organisms and natural landscapes, as well as to create conditions for scientific research and environmental education. In addition, the park is actively developing the tourist infrastructure [8].

The biosphere Reserve is organized on the basis of the Burabay State National Nature Park. In accordance with the Decree of the President of the Republic of Kazakhstan dated February 27, 1997 No. 3369 «On additional measures to strengthen the protection of the Borovsky mountain forest area», Decree of the Government of the Republic of Kazakhstan dated May 06, 1997. No. 787 Borovskoye Forestry of the Economic Department of the President and the Government of the Republic of Kazakhstan was transformed into the State Institution «Natural recreation Forest Complex «Burabay» of the Economic Department of the President and the Government of the Republic of Kazakhstan, on the basis of which, on the basis of the Decree of the President of the Republic of Kazakhstan dated July 16, 1999 No. 98, the State National Nature Park «Burabay» was established.

The total number of flora species for the territory of the Burabay, according to preliminary data, reaches 840 species of higher plants, while the largest number of species is concentrated in forests. Of these, 91 plant species are rare or relict, in need of special protection, including 11 species found here listed in the Red Book of Plants of Kazakhstan (2014). 37 species of mosses, 11 species of lichens and 17 species of ferns were identified in the flora of lower plants. Lichens are represented by 11 species and are divided into the following groups according to their proximity to the substrate: epigeal, epiphytic, and epilitic. Three species of the genus Cladonia are dominant – *C.sylvatica, C.alpestris* and *C.rangiferina*. Mosses are found in moist and moist habitats, the dominant species are *Pleurosium schreberi, Dicranum scoparium, Hylocomium palustre, Climaceum dendroides*, etc. The flora contains 81 relict species - representatives of the boreal flora of the northern taiga, which are located here on the southern border of their range.

The fauna of vertebrates includes 277 species belonging to 25 orders, including 15 species and subspecies of fish, 1 species of amphibians, 5 species of reptiles, 209 species of birds and 47 species of mammals (about 36% of the total vertebrate fauna of Kazakhstan). Of these, 1 species of mammals and 18 species of birds are listed in the Red Book of Kazakhstan, 2 species of fish, 12 species of birds, 8 species of mammals are included in the IUCN Red List.

The territory of the Burabay Natinonal park is administratively located within the Burabay and the Birzhan Sal districts of the Akmola region (figure 1). Both districts are grain-growing regions with great potential for agricultural development. There are 244 agricultural enterprises operating in Burabay district, including 43 LLP companies, 201 peasant farms, as well as 12 large and 60 medium-sized and small industrial enterprises, employing 2,152 people. About 320 agricultural enterprises operate in Birzhan Sal district, the mining industry accounts for 65.2%, the manufacturing industry for 32.1% and other sources for 2.7%.

The Burabay Reserve consists of 10 cluster sites, the reserve also includes forest stakes interspersed with lands of other categories within the transboundary zone. The entire territory of the reserve is divided into 10 forestry districts: Akylbayskoye (10233 ha), Borovskoye (151217 ha), Barmashinskoye (9236 ha), Zolotoborskoye (11651 ha), Mirnoye (18394 ha), Priozernoye (9372 ha), Katarkolskoye (10515 ha), Bulandinskoye (12129 ha), Zhalayyrskoye (17387 ha), Temnoborskoye (15165 ha). The forestry departments combine forestry workshops and sites, which include 5 forest detours. In turn, the forest bypass is the lowest link in the planning structure of the park, its area, in accordance with established standards, averages 1.230 hectares.

There is very good access to the Burabay biosphere Reserve. A section of the Astana-Petropavlovsk expressway and the Almaty-Yekaterinburg railway runs from the southeast to the northwest through the territory of the reserve. The territory is crossed in different directions by asphalt roads connecting the cities. Makinsk, Stepnyak, Shchuchinsk, Stepnogorsk and smaller settlements located in the Birzhan Sal,

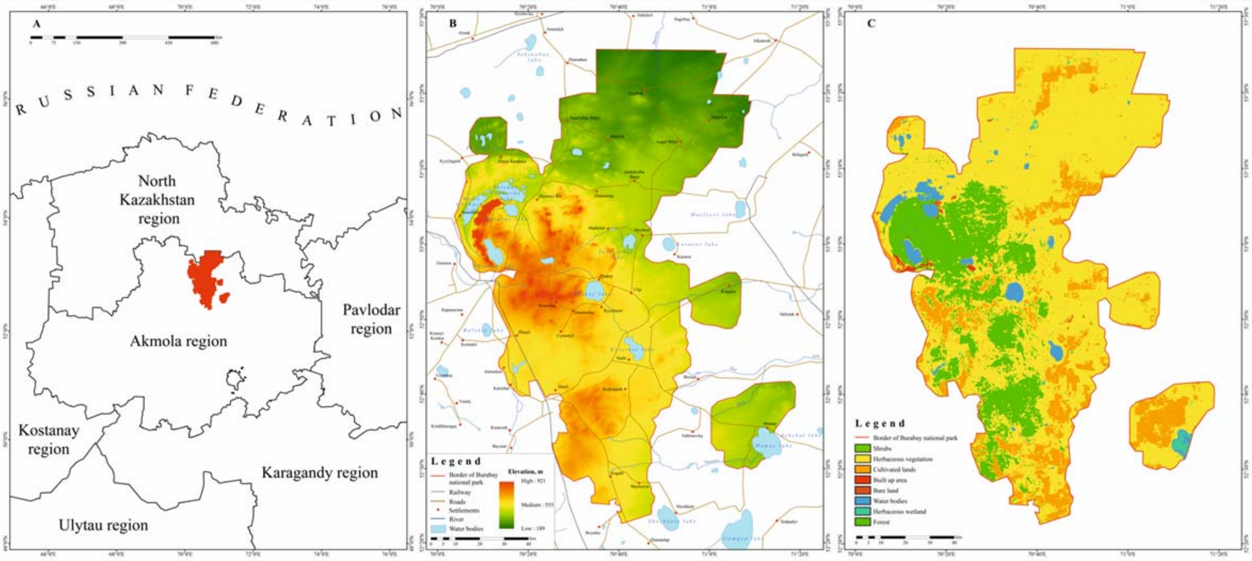

Figure 1 – Study area. (A) Location of Burabay National Park.
(B) Distribution of study area at the elevation scale. (C) Map of land use types

Burabaysky and neighboring districts. The road connection is open all year round, except for short periods during winter, when there are snowstorms and especially severe frosts, the Borovoe Resort Railway station is located 25 km from the village. Burabay (central estate of the BR «Burabay»), Makinsk station, 5 km from the estate of the Bulandinsky forestry. In addition, the regional center of Akmola region, the city of Kokshetau, has an airport capable of receiving international flights.

BR «Burabay» is part of the Shortandy-Burabay resort area. The region occupies an extremely convenient geographical location due to the proximity of densely populated industrial regions (including Russia) and the presence of trans-state air, rail and highways. Shchuchinsko-Borovskaya resort area is an ideal place for holding large prestigious and commercial events: congresses, forums, fairs, auctions, which allows for more active attraction of investment funds to development. Currently, from 5 to 10 tourist infrastructure facilities are being commissioned annually in the kurotny zone. Among them are the five-star Rixos hotel, the Kazakhstanskaya Lapland entertainment complex, the Park House Hotel, which has a multifunctional conference hall and rooms that meet high standards, the Terassa Park Pantotherapy Center, etc. To accommodate and serve tourists, there are hotels, hotels, tourist bases of various levels, more than 600 shops, catering establishments and organizations providing household services. A Republican ski base has been built with a ski jumping complex and a biathlon ground, which will become a center for high-level international competitions with the attraction of numerous tourists as spectators. The construction of a modern golf club has been completed. Currently, there are 29 tourist routes in the Burabai Biosphere Reserve: 15 of them are trails, 14 routes. Some of them are on foot (18), some are by bus (8), there are 1 equestrian, 1 bicycle and 1 water routes. The total length of all tourist routes is 503.5 km, while the total length of hiking routes is 246.5 km, bus routes – 226 km, cycling routes – 7 km, equestrian routes – 9 km, and water routes – 15 km.

The number of visitors to the national park is increasing every year. Thus, 526,620 people were registered in 2013, 615,644 in 2014, 631,615 in 2015, 644,541 in 2016, and 673,507 in 2017 [8].

Materials and methods. In this research, we employed a diverse array of metrics, encompassing the Normalized Difference Vegetation Index (NDVI), the Normalized Difference Water Index (NDWI), the Land Surface Temperature (LST), the Normalized Built-Up Difference Index (NDBI) and the Bare Soil Index (BSI) to conduct an in-depth environmental analysis of Burabay National Park [9].

Vegetation indices are a valuable tool for assessing the spatial distribution of vegetation coverage and soil characteristics by analyzing the unique patterns of light reflected by green plant life [10].

The Normalized Difference Vegetation Index (NDVI) is a quantitative measure used to determine the density of vegetation within a specific area. It can be employed to assess the vitality of plant life and track changes in its growth and uses near-infrared (NIR) and red (R) spectral bands. These two spectral bands are combined to form a single channel that contains normalized vegetation information. Digital numbers

(DN) obtained from each of these channels are then used to calculate NDVI, where each pixel contributes its corresponding DN value to the calculation.

NDVI is calculated using the Landsat Thermal Infrared (TM) sensor, which measures the amount of light that is absorbed by the earth's surface and atmosphere. The NDVI formula is:

$$NDVI = (NIR - Red)/(NIR + Red)\ , \quad (1)$$

where NIR – reflection in the near-infrared range; Red – reflection in the red spectrum [11-13].

The Normalized Difference Water Index (NDWI) was developed to identify water on the surface of wetland areas and quantify its presence. Initially designed for use with data acquired from the Landsat Multispectral Scanner (Landsat MSS), this index has since been adapted successfully for use with other imaging sensors when it is necessary to estimate the extent of water bodies. The NDWI is calculated using the following formula:

$$NDWI = (Green - NIR)/(Green + NIR)\ , \quad (2)$$

where Green – reflection in the red spectrum; NIR – reflection in the near-infrared range [14].

Land Surface Temperature (LST). The temperature of the earth's surface is influenced by various factors, including land use patterns, types of land cover, distribution of vegetation, and hydrological systems. These variations in temperature can have detrimental effects on the health of vegetation, availability of groundwater, and overall resilience of ecosystems. Urbanization and air pollution significantly contribute to fluctuations in the temperature of land surfaces. Additionally, the effects of climate change further exacerbate these fluctuations [14].

LST is calculated following 5 steps:

1. Conversion to Top of Atmoshere (TOA) Radiance:

$$L\lambda = ML * Q_{cal} + AL - O_i\ , \quad (3)$$

where Lλ – TOA spectral radiance (Watts/(m^2 * sr * μ)); ML – Radiance multiplicative Band (3.3420E-04 = 0.0003342); AL – Radiance Add Band (No.); Q_{cal} – Quantized and calibrated standart product pixel value; Q_i – correction value for band 10 is 0.29.

2. Conversion to Top of Atmoshere (TOA) Brightness Temperature (BT), Kelvin (K) to Celsius (0C) Degrees:

$$BT = \frac{K2}{Ln\left(\frac{k1}{L\lambda}+1\right)} - 273.15\ , \quad (4)$$

where BT – Top of Atmoshere Brightness (^{0}C); Lλ – TOA spectral radiance (Watts/ (m^2 * sr * μ)); k1 = = K1 constant band (No.); K2 = K2 constant band (No.). BT = (1321.0789/Ln (774.8853/TOA+1)) – – 273.15.

3. Proportion of Vegetation (PV):

$$PV = \left(\frac{NDVI - NDVImin}{NDVImax - NDVImin}\right)^2\ , \quad (5)$$

where PV – Proportion of Vegetation; NDVI – DN values from NDVI Image; $NDVI_{min}$ – Minimum DN values from NDVI Image; $NDVI_{max}$ – Maximum DN values from NDVI Image.

4. Land Surface Emissivity (E):

$$E = 0.004 * PV + 0.986\ , \quad (6)$$

where E – Land Surface Emissivity; PV – Proportion of Vegetation; 0.986 – corresponds to a correction value of the equation.

5. Land Surface Temperature (LST):

$$LST = BT/(1 + \left(\lambda * \frac{BT}{c2}\right) * Ln(E))\ , \quad (7)$$

where BT – Top of Atmoshere Brightness (^{0}C); λ – Wavelength of emitted radiance; E – Land Surface Emissivity; c2 = h*c/s = 14388 * 10^{-2} = 14388 mK; h – Planck's Constant = 1.38 * 10^{-23}JK; c – velocity of light = 2.998 * 10^8 m/s [15].

Normalized Difference Built-up Index (NDBI). The regions with plant life demonstrate a significant increase in the albedo between bands 4 and 5. Nonetheless, the vegetation exhibits a marginally higher or lower digital number (DN) value on band 5 in comparison to band 4, resulting in a discernible discrepancy between the two spectral bands. This characteristic allows for the identification of areas containing vegetation, which subsequently facilitates the calculation of the Normalized Difference Vegetation Index (NDBI):

$$NDBI = (SWIR - NIR)/(SWIR + NIR)\,, \quad (8)$$

where SWIR – Short-wave infrared spectrum; NIR – reflection in the near-infrared range.

Bare Soil Index (BSI). The bare ground plays a critical role in the understanding of ecological systems and is an essential element in ecological processes. Its dynamic nature has significant implications for investigations related to soil desiccation, water balance quantification, dust deposition prediction, and urban development assessment. Due to the importance of bare ground, it is essential to improve current forecasting methods and leverage publicly available spatial data to generate dynamic maps of its distribution. This would enable a more precise assessment of its impact on ecological processes and provide valuable information for sustainable land management and is determined by the following formula:

$$BSI = ((Red + SWIR) - (NIR + Blue))\;/\;((Red + SWIR) + (NIR + Blue))\,, \quad (9)$$

where Red – reflection in the red spectrum; SWIR – Short-wave infrared spectrum; NIR – reflection in the near-infrared range; Blue – reflection in the blue spectrum [16,17].

Overlay Analysis. Overlay analysis was conducted to identify vulnerable areas of environmental degradation. Ecological Degradation (ED):

$$ED = DN_{NDVI} + DN_{NDWI} + DN_{LST} + DN_{NDBI} + DN_{BSI}\,, \quad (10)$$

where DN_{NDVI} – pixel value of NDVI nominative classes; DN_{NDWI} – pixel value of NDWI nominative classes; DN_{LST} – pixel value of LST nominative classes; DN_{NDBI} – pixel value of NDBI nominative classes; DN_{BSI} – pixel value of BSI nominative classes.

Datasets. This study utilized data obtained from the Landsat 8 satellite, comprising satellite imagery and related metadata. The Landsat-8 satellite, previously known as the Landsat Data Continuity Mission (LDCM), was successfully launched on 11th February 2013, aboard an Atlas V rocket from Vandenberg Air Force Base in California. The satellite is equipped with two key instruments: the Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS).

OLI captures images in three distinct spectral bands: visible, near-infrared, and short-wave infrared. TIRS utilizes a novel quantum physics-based approach to measure land surface temperatures. With a spatial resolution of 15m for panchromatic images and 30m for multispectral images, Landsat-8 can cover a swath width of up to 185km.

The Thermal Infrared Sensor (TIRS), developed by NASA's Goddard Space Flight Center, has a remarkable resolution of 100 centimeters. This sensor operates within the range of thermal infrared radiation and captures data in the wavelength range from 10.4 microns to 11.2 micrometers. Its primary purpose is to accurately detect and measure the heat radiation emitted by objects on Earth's surface.

The sensor produces 12-bit data, which is then converted into 16-bit integer values to create Level-1 products. These products can be further refined to provide a maximum resolution of 55,000 different shades of gray. The data can also be adjusted to reflect the radiance or reflectance at the top of the atmosphere, using specific radiometric scaling factors outlined in the metadata file known as the MTL.

TIRS has two distinct spectral bands: Band 10, which spans from 10.6 to 11.19 micrometers with a resolution of 100 centimeters, and Band 11, which ranges from 11.5 to 12.51 micrometers and also has a resolution of exactly 100 centimeters [18].

Results. Environmental monitoring was conducted between 2020 and 2024. Satellite images were selected based on criteria of cloud cover less than 10%, and during peak tourist flow periods. The dates of the images are: 09.11.2020, 08.13.2021, 06.05.2022, 07.10.2023, 07.06.2024.

Vegetation change detection. The Research presents the dynamics of vegetation changes in Burabay National Park for the period from 2020 to 2024 based on the NDVI. NDVI was calculated using (1) formula. Cartographic data (figure 2 and 3) and a table 1 reflecting quantitative changes in the areas of various vegetation classes were used for the analysis.

Figure 2 illustrates the spatial distribution of NDVI values for each year of the study (2020-2024).

Four classes are used:

1. Lower than 0 (negative values, barren territories) – marked in orange.
2. 0 – 0.1 (unproductive vegetation, degraded lands) – yellow.
3. 0.1 – 0.3 (sparse vegetation, shrubs, grassy vegetation) – light green.
4. More than 0.3 (dense vegetation, forests) – dark green.

There is a positive trend: an increase in areas with high NDVI (dark green areas), which indicates an increase in vegetation density.

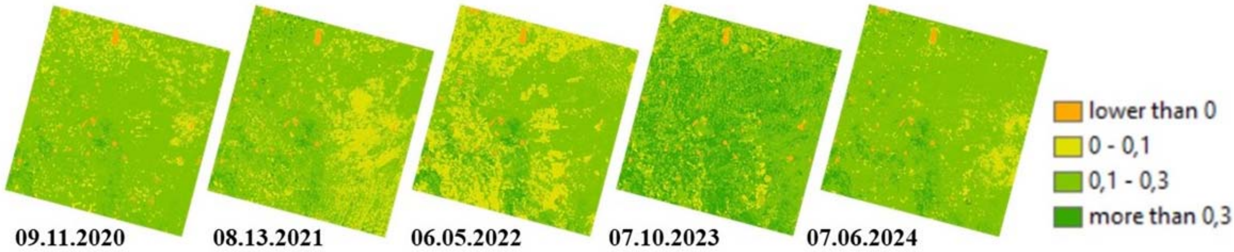

Figure 2 –Vegetation cover status based on satellite images

Between 2020 and 2022, a decline in NDVI was observed, indicating vegetation degradation likely associated with droughts, trampling, and increased tourist visitation. However, 2023–2024 demonstrated recovery dynamics, with an expansion of areas having NDVI > 0.3 (dense vegetation).

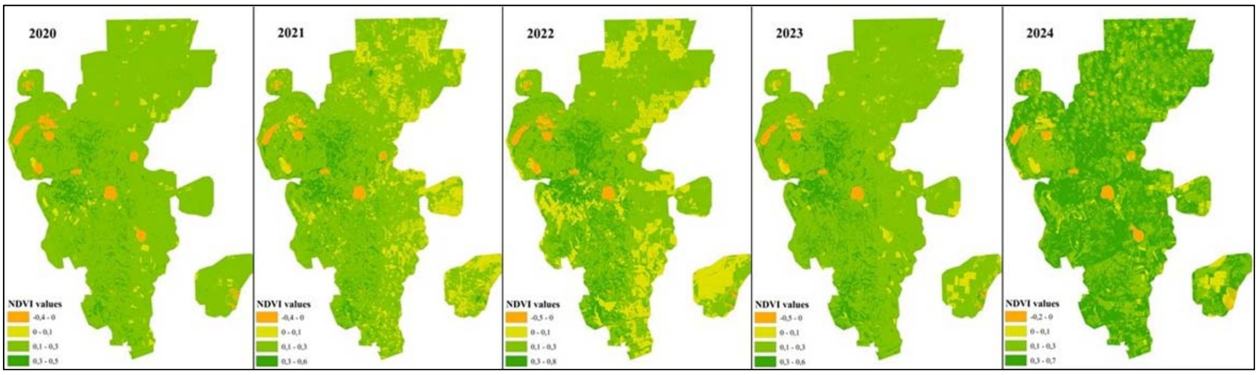

Figure 3 –Monitoring of the vegetation cover in Burabay Park

The table describes the density and health of vegetation, where higher values indicate a better growing season.

Vegetation categories are distributed into barren areas (rocks, sands, snow) with NDVI 0-0.1, sparse vegetation (shrubs, grassy landscapes) with NDVI 0.1–0.3 and temperate vegetation (forests and dense greenery) with NDVI more than 0.3.

Table 1 –Dynamics of changes in the area indicators of vegetation cover

Vegetation cover condition	NDVI values	Area by years, ha					
		2020	2021	2022	2023	2024	Average
Barren areas of rock, sand, or snow	0-0.1	14 363.37	87 275.7	107 683.02	23 277.33	27 358.02	51 991.49
Sparse vegetation (shrubs and grasslands)	0.1-0.3	436 797.63	360 087.03	317 863.08	409 642.29	216 594.09	348 196.82
Moderate vegetation	More than 0.3	31 036.86	38 742.75	59 143.41	53 415	235 911.87	83 649.98

The barren territories significantly increased their area in 2021 and 2022 (87,275.7 and 107,683.02 ha, respectively), but then decreased in 2023 and 2024. Sparse vegetation gradually decreased from 2020 to 2024, which may indicate degradation or a change in the type of vegetation cover.

Temperate vegetation is showing growth, especially in 2024 (235,911.87 ha), which indicates a possible improvement in the ecosystem or restoration of forests.

Average values for the period (2020-2024):

1. Barren territories occupied an average of 51,991.49 hectares.
2. Zones of rare vegetation – 348 196.82 ha.
3. Areas with moderate vegetation – 83,649.98 ha.

The results of the study indicate significant changes in the structure of the vegetation cover of the Burabay National Park. In particular, there is a decrease in areas of sparse vegetation and an increase in areas with moderate vegetation, which may indicate the process of ecosystem restoration. However, significant fluctuations in the area of barren territories require additional analysis of the causes of these changes. The data can be used to assess environmental changes, analyze trends in ecosystem degradation or restoration, and take environmental measures

Monitoring of the condition of water bodies. NDWI was calculated using (2) formula. The maps (figure 4 and 5) confirm a decrease in areas with positive NDWI values, especially in 2022-2023. In 2024, there is a slight increase in water bodies, which may indicate a restoration of the water balance. Thus, the study revealed a tendency to reduce wet areas with possible signs of recovery in 2024 [19].

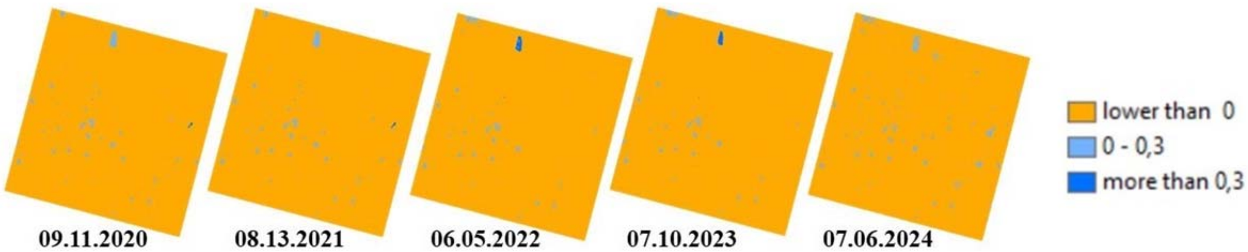

Figure 4 – Results of identification of water bodies from satellite images

A decrease in NDWI indicates a loss of water bodies or a decrease in soil moisture, which may be related to droughts, land-use changes, or environmental degradation.

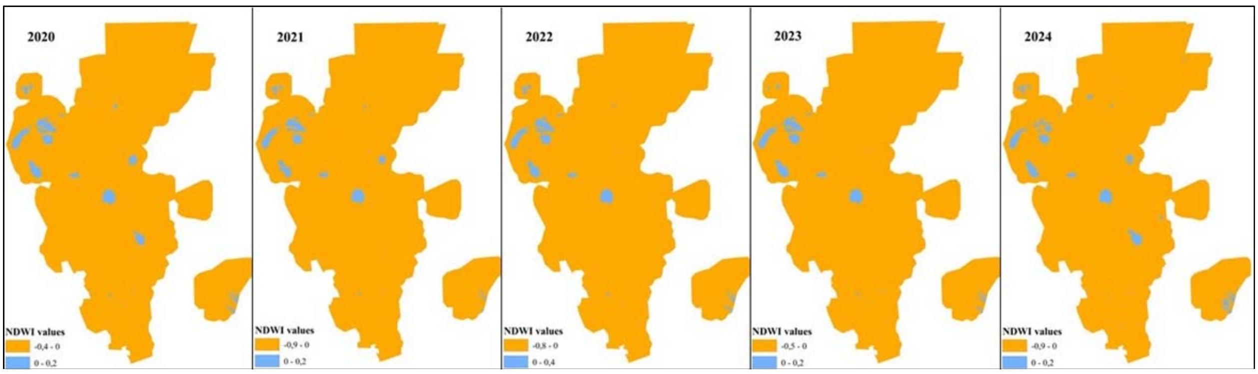

Figure 5 –Monitoring of water resources

In 2020, the area with NDWI > 0 was 123.61 km^2. In 2021 and 2022, it decreased to 98.80 km^2 and 96.87 km^2, respectively. The minimum area was recorded in 2023 – 82.89 km^2. In 2024, there was a partial recovery to 118.95 km^2. The average value for the entire period is 104.22 km^2 (table 2).

The recovery in 2024 may be attributed to changes in climatic conditions or water resource management measures. The fluctuations reflect the dual influence of climate variability and anthropogenic pressure near lakeshore tourist infrastructure.

Table 2 –Dynamics of changes in in water bodies

NDWI values	Area by years, km^2					
	2020	2021	2022	2023	2024	Average
More than 0	123.6087	98.7993	96.867	82.8855	118.9503	104,22

Surface temperature analysis. LST was calculated using (3-7) formulas. The spatial distribution of changes shows (figure 6 and 7) an increase in green areas in 2024, especially in the northern part of the territory, which confirms the restoration of vegetation or a decrease in surface temperature.

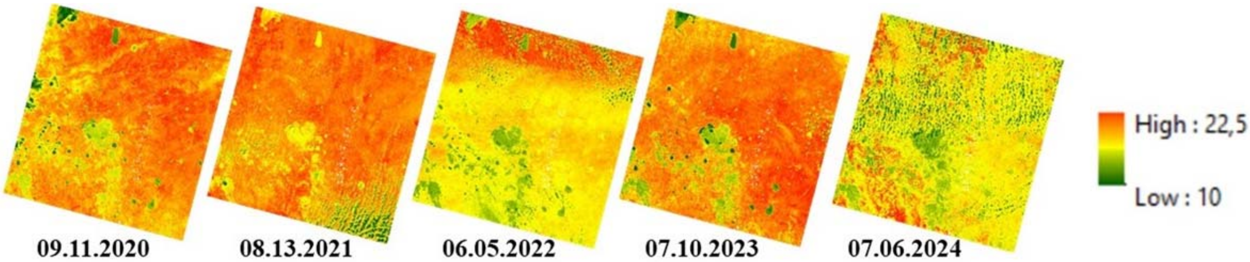

Figure 6 –Results of identification of LST from satellite images

In 2022-2023, an increase in red and orange hues is visible, which corresponds to an increase in LST and, probably, an increase in degradation processes. Based on the data, it can be assumed that the territory experienced a phase of degradation in 2021-2023, but in 2024, restoration processes began, leading to a decrease in surface temperature and an increase in vegetation cover.

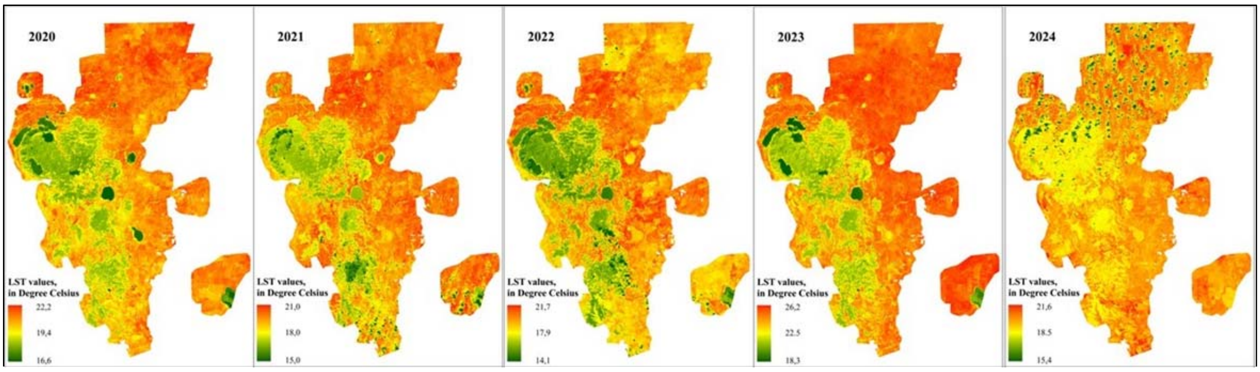

Figure 7 –Monitoring of land surface temperature

In different years, there is a significant variability in the distribution of temperature zones (table 3). In 2020, average temperatures prevailed (369 687.15 ha), while areas with high temperatures (32 097.96 ha) were relatively small. In 2022 and 2023, the high temperature zone increased (285 532.02 ha and 240,077.88 ha, respectively), indicating a possible increase in degradation processes or a decrease in vegetation cover. In 2024, there is again a reduction in high temperature zones (37 722.96 ha) and an increase in the average temperature zone (433 353.69 ha), which may indicate the restoration of vegetation or a change in climatic conditions.

Dynamics of areas of temperature classes

1. Low temperatures: Their area fluctuated significantly, with a sharp decrease in 2021-2022 and a recovery in 2023-2024.
2. Average temperatures: Stability is observed with small changes, but in 2024 they will reach the largest area (433 353.69 hectares).
3. High temperatures: They reached their maximum in 2022 (285 532.02 ha), but then began to decline, especially in 2024 (37 722.96 ha). This may be due to climate change, restoration measures, or natural cycles.

Table 3 –Dynamics of changes land surface temperature

Temperature ranges	Area by years, ha					
	2020	2021	2022	2023	2024	Average
Low	90705.06	8191.71	2294.19	60220.8	21419.19	36566.19
Middle	369687.15	306197.19	204665.58	192192.21	433353.69	301219.16
High	32097.96	178103.97	285532.02	240077.88	37722.96	154706.96

This dynamic indicates that managing visitor density and introducing seasonal restrictions can reduce surface heating effects associated with soil compaction and vegetation loss.

Identification of anthropogenic impact. NDBI was calculated using (8) formula. Based on the maps (figure 8 and 9) of the NDBI index and the table of dynamics of changes, the following conclusions can be drawn:

1. The general trend of anthropogenic impact

In 2020-2023, the average and high degree of anthropogenic impact prevailed, indicating intensive urbanization processes or soil degradation.

2. In 2024, there is a sharp reduction in areas with high and medium levels of NDBI, as well as a significant increase in the area of low levels of anthropogenic impact.

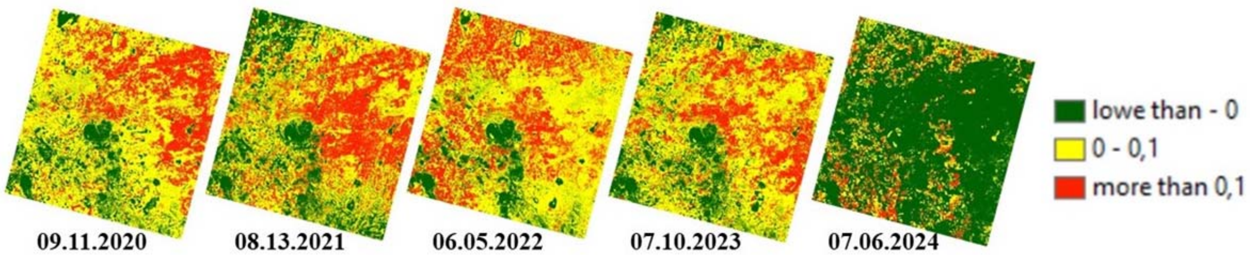

Figure 8 –Results of identification of antropogenic impacts from satellite images

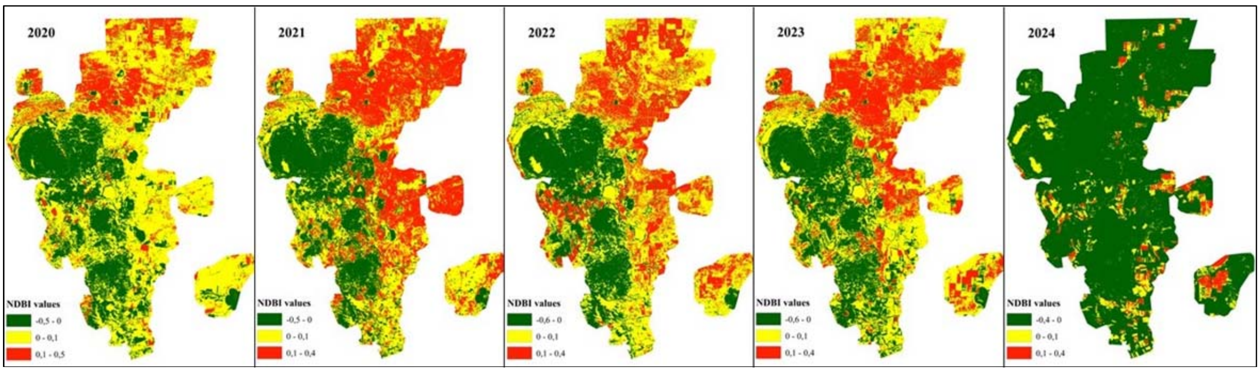

Figure 9 –Monitoring of NDBI values

Dynamics of the areas of anthropogenic impact classes

1. Low level (NDBI < 0). In 2020, it was 79,631.19 ha, then increased to 175,961.79 ha (2021). In 2022-2023, its area remained relatively stable (~135,000 ha). In 2024, there was a sharp reduction to 22,670.28 hectares, which may indicate degradation or urbanization.

2. Average level (0 – 0.1). The maximum was recorded in 2020 (261,990.09 ha). In 2021-2023, this indicator was kept within 172 000 – 213 000 ha. In 2024, there will be a sharp decrease to 46,042.92 hectares, which also confirms the increase in urbanized areas.

3. High level (> 0.1). In 2020-2023, this indicator ranged from 145 000 – 153 000 ha.

In 2024, its area increased almost 3 times to 424,461.33 hectares, indicating a significant increase in urbanized areas.

Table 4 –Dynamics of changes antropogenic impacts

Level of anthropogenic impact	NDBI values	Area by years, ha					
		2020	2021	2022	2023	2024	Average
Low	Lower than 0	79631.19	175961.79	135263.25	135845.73	22670.28	109874.45
Middle	0-0.1	261990.09	172865.97	213215.13	204367.86	46042.92	179696.39
High	More than 0.1	152296.56	145022.76	145414.71	153470.7	424461.33	204133.21

In 2020-2023, yellow and red zones prevailed, indicating a significant anthropogenic impact. In 2024, the dark green color dominates the maps, reflecting the growth of anthropogenic zones (an increase in urbanized or disturbed areas).

The data indicate a significant expansion of urbanized areas and anthropogenic influence in 2024. This may be due to active construction, an increase in the area of paved areas, a reduction in natural ecosystems, or changes in the methodology of data analysis.

This trend highlights the need for spatial regulation and strict land-use zoning, especially in core conservation zones. The integration of NDBI monitoring into local planning processes can help limit further urban sprawl and guide sustainable infrastructure development.

Soil quality analysis. BSI was calculated using (9) formula. The maps (figure 10 and 11) show the change in the values of the Bare Soil Index (BSI) from 2020 to 2024. The color scale reflects different levels of BSI: from low (light shades) to high values (dark shades).

1. In 2020, low and medium BSI values prevail, indicating relatively stable soil coverage.

2. In 2021, there is a significant increase in the area with high BDI values, which indicates an increase in areas with bare soil.

3. In 2022, the trend of increasing BSI values continues, which may be due to deforestation or changes in land use.

4. In 2023, the situation will relatively stabilize, but the area of sites with high BSI remains significant.

5. In 2024, there is a serious increase in zones with high BDI values, which indicates intensive degradation of vegetation cover and an increase in the area of bare soil.

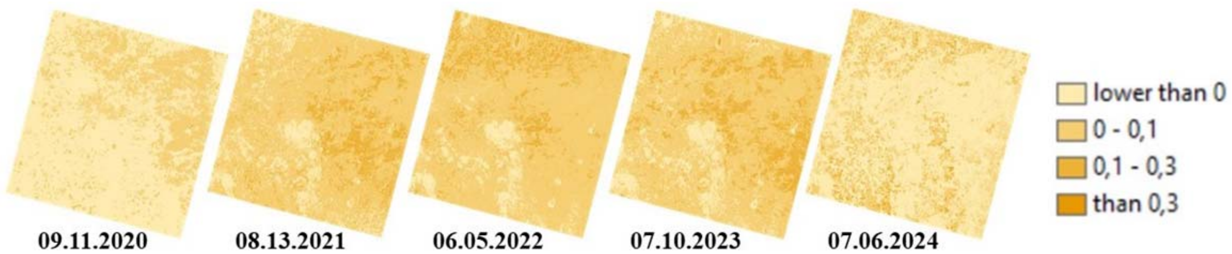

Figure 10 –Results of identification of bare soil areas from satellite images

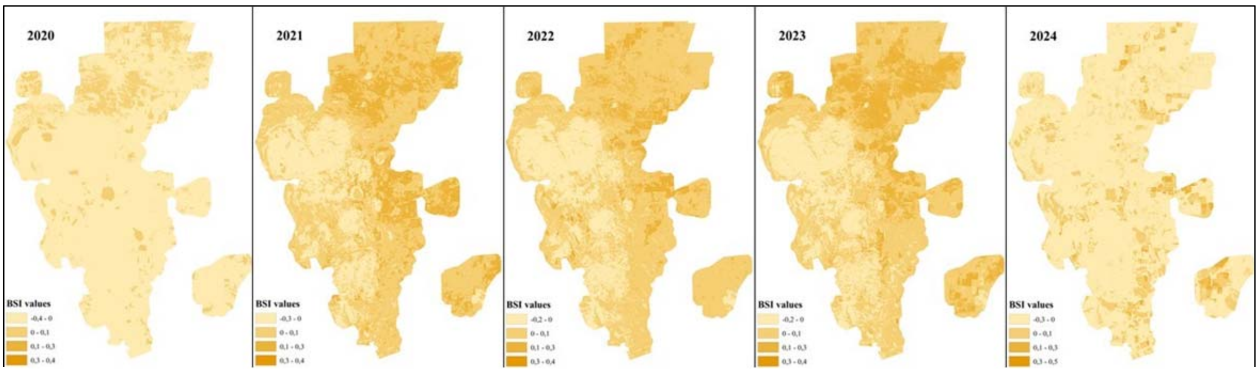

Figure 11 –Monitoring of bare soil areas

Data on the dynamics of the area of plots with different levels of BSI (low, medium, high) confirm visual observations (table 5).

Low BSI values: In 2020-2023, they range from 93 000 to 94 000 hectares, but in 2024 there is a sharp decrease to 12 331.98 hectares. This may indicate a significant decrease in areas with relatively stable soil cover.

Average BSI values: The dynamics shows a sharp increase from 70,334.82 hectares in 2020 to 314 514.36 hectares in 2022, followed by a slight decrease, but in 2024 the area falls again to 88 574.4 hectares.

High BSI values: In 2020, the area of high values was the maximum (323 581.85 ha), but then decreased to 120 669.84 ha in 2021. However, by 2024, there is again a sharp jump to 392 939.28 hectares, which confirms a serious deterioration in the vegetation cover.

Table 5 –Dynamics of changes bare soil areas

Bare soil values	Area by years, ha					
	2020	2021	2022	2023	2024	Average
Low	93000.17	93652.47	53661.15	94549.68	12331.98	69439.09
Average	70334.82	279488.07	314514.36	270280.44	88574.4	204638.42
High	323581.85	120669.84	125725.77	129087.72	392939.28	218400.89

An increase in BSI values indicates an increase in the area of degraded lands and bare soil, which may be the result of anthropogenic activities (deforestation, agriculture, construction) or climatic factors. In 2024, maximum soil degradation is recorded, which can be seen both on maps and in tabular data: the area of plots with high BSI values has increased almost 3 times compared to 2023.

A sharp decrease in low BSI values and an increase in high values indicates a deterioration in the environmental situation in the study area. For further analysis, it is worth investigating possible causes of the deterioration, such as changes in precipitation, surface temperature, the impact of human activity, and possible measures to restore soil cover.

Overlay analysis and conducting an assessment zoning. The overlay analysis was conducted using a formula (10) that integrates multiple environmental indicators:

1. NDVI (Normalized Difference Vegetation Index) – represents vegetation health;
2. NDWI (Normalized Difference Water Index) – indicates water presence;
3. LST (Land Surface Temperature) – measures surface heat levels
4. NDBI (Normalized Difference Built-up Index) – detects urbanization and built-up areas;
5. BSI (Bare Soil Index) – assesses soil exposure and land degradation;

By combining these indices, a comprehensive assessment of environmental conditions was performed. The resulting maps (figure 12) depict the spatial distribution of d egraded zones based on varying levels of environmental stress.

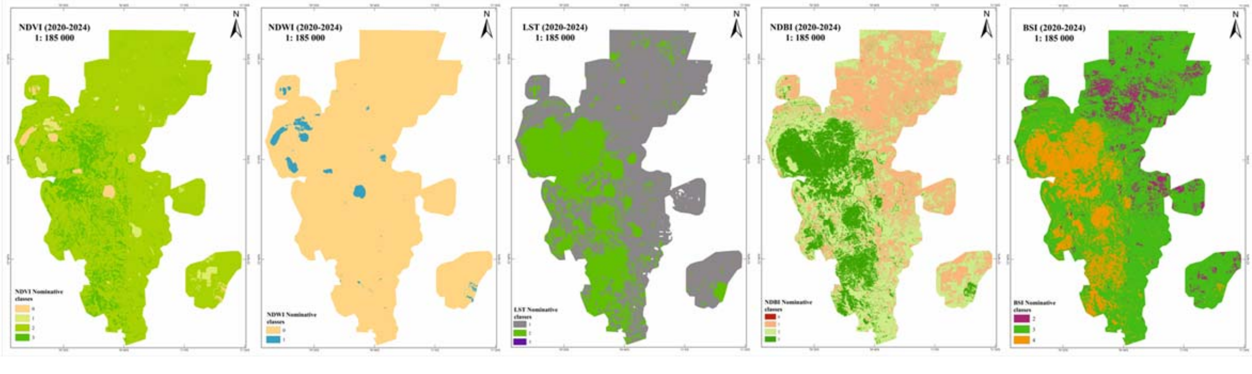

Figure 12 –Comprehensive analysis and Overlay NDVI, NDWI, LST, NDBI and BSI data

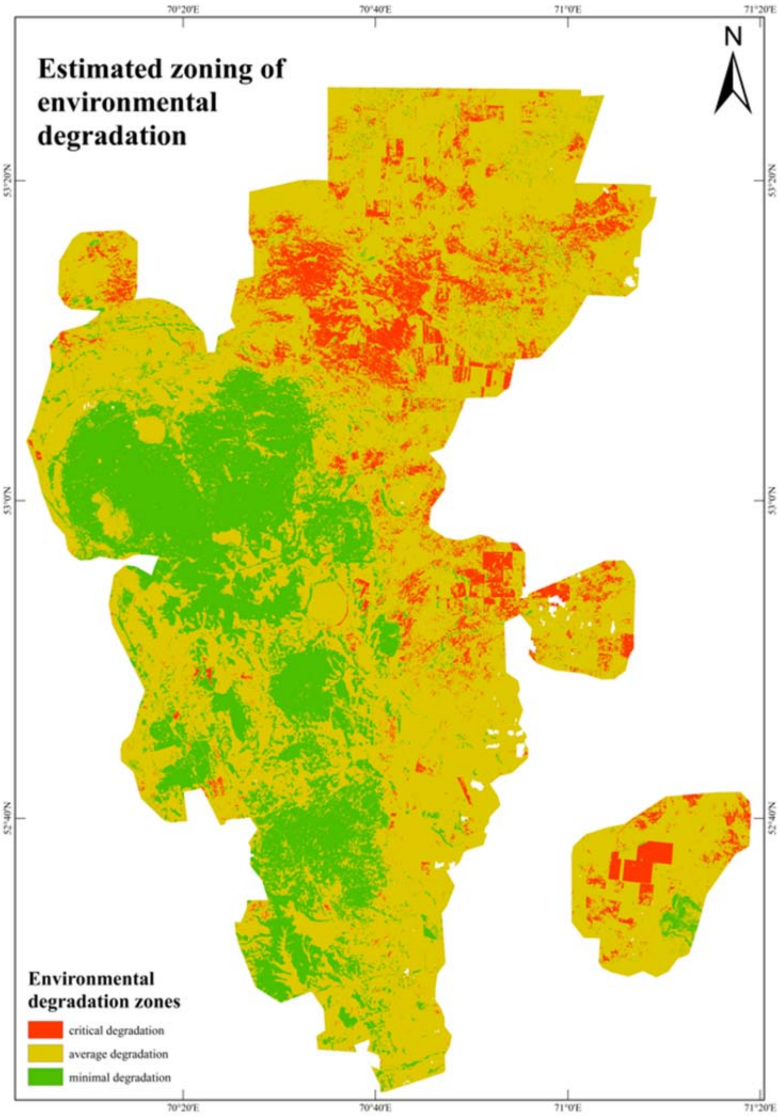

Figure 13 – Estimated zoning of environmental degradation

Figure 13 classifies the study area into three degradation levels:

1. Highly degraded areas (46 296.72 ha): These regions show severe environmental stress, likely due to excessive land use, deforestation, high surface temperatures, and loss of vegetation. The combination of high BSI and NDBI with low NDVI and NDWI suggests significant ecological damage.

2. Moderately degraded areas (334 418.67 ha): These areas exhibit noticeable but not extreme degradation. They may still support some vegetation but are experiencing increasing land degradation pressures.

3. Slightly degraded areas (111 599.19 ha): These zones maintain relatively good environmental conditions, with stable vegetation cover and lower urban or soil exposure impacts.

The majority of the area falls under medium degradation, indicating widespread but not critical land stress. Highly degraded areas require urgent intervention to prevent further environmental deterioration. Slightly degraded zones could serve as ecological buffers and conservation areas to mitigate further degradation. This analysis highlights priority areas for environmental restoration, conservation efforts, and sustainable land management strategies to reduce degradation trends.

The results of remote sensing monitoring for the period 2020–2024 in Burabay National Park reveal dynamic environmental changes that directly correlate with anthropogenic pressure and tourist activity. Indicators such as NDVI, NDWI, LST, NDBI, and BSI show both degradation and recovery trends, which can serve as a foundation for evidence-based management of tourism flows.

Discussion. Remote sensing monitoring from 2020 to 2024 revealed dynamic environmental changes in Burabay National Park closely linked to anthropogenic pressure and tourism intensity. The combined analysis of NDVI, NDWI, LST, NDBI, and BSI indices demonstrates both degradation and recovery phases, confirming that ecological processes in the park are directly influenced by fluctuations in visitor activity.

*Environmental Stress and Tourism Pressure.*The NDVI and BSI indices show a notable decline in vegetation cover and soil quality in 2021–2022, coinciding with periods of peak tourist activity. The increase in barren soil areas and higher LST values indicate thermal and physical stress on ecosystems caused by trampling, unregulated recreation, and infrastructure expansion. These findings are consistent with patterns observed in other protected areas of Kazakhstan, such as Katon-Karagay National Park, where uncontrolled tourism contributed to vegetation loss and soil erosion [19].

Management Measures Based on Zoning and Carrying Capacity. Environmental fluctuations recorded between 2020 and 2024 highlight the necessity of establishing a visitor management framework based on ecological zoning and carrying capacity assessment. Evidence from Altynemel National Park suggests that a multi-zone approach – combining restricted, controlled, and buffer zones – helps maintain ecological integrity while ensuring sustainable tourism revenues [20].

Based on spatial analysis of Burabay data:

• Highly degraded areas (46,296.72 ha): should be designated as restricted-access with seasonal closures and rehabilitation programs.

• Moderately degraded areas (334,418.67 ha): suitable for controlled ecotourism with regulated trails, eco-friendly infrastructure, and waste management.

• Slightly degraded areas (111,599.19 ha): appropriate for educational and low-impact tourism serving as ecological buffers.

This framework is consistent with UNWTO (2023) recommendations on adaptive visitor management in protected areas [21].

Integration of Remote Sensing into Decision-Making. Remote sensing data provide a reliable scientific basis for monitoring ecological carrying capacity, identifying illegal land use, and forecasting degradation risks. Integrating NDVI–NDBI–BSI datasets enables managers to:

• Adjust visitor limits according to vegetation health and land degradation indicators;

• Prioritize reforestation in zones with NDVI decline;

• Use NDWI and LST indices to detect drought and overheating zones.

Such approaches reflect international best practices in GIS- and RS-based environmental governance [19, 20].

Soil Degradation and Climate Adaptation. The growth of BSI values in 2024 indicates intensified soil degradation due to recreational overuse and infrastructure expansion. To counter these effects, combined measures– revegetation with native species, creation of green corridors, and restrictions on motorized tourism – are recommended [21]. These strategies not only prevent further degradation but also strengthen the park's resilience to climate variability.

Conclusion. The environmental monitoring of Burabay National Park from 2020 to 2024 has revealed significant fluctuations in vegetation cover, water resources, land surface temperature, anthropogenic impact, and soil quality. A decline in vegetation density and water resources was observed from 2021 to 2023, coinciding with increased surface temperatures and urban expansion, indicating ecosystem stress due to overtourism. However, 2024 marked a partial environmental recovery, with higher NDVI values, reduced LST, and an increase in water bodies. Despite these improvements, the increase in anthropogenic influence and soil degradation in 2024 raises concerns about sustainable land management. The overlay analysis classified the park into different degradation zones, emphasizing the need for immediate conservation efforts in highly degraded areas. These findings underscore the necessity for implementing long-term environmental protection measures, stricter regulations on tourism activities, and ecological restoration projects to ensure the sustainable development of Burabay National Park.

The study's methodology demonstrates the effectiveness of remote sensing in monitoring environmental changes, providing a valuable tool for policymakers and conservationists in managing protected areas impacted by overtourism. The study demonstrates the high potential of remote sensing and

GIS integration in supporting evidence-based management of protected areas. The proposed framework of adaptive management – combining zoning, visitor quotas, and restoration measures – aligns with UNWTO guidelines and global best practices.

This research provides one of the first comprehensive RS-based assessments of Burabay's environmental dynamics and offers practical recommendations for balancing ecological protection and tourism development. The results can serve as a model for other national parks in Kazakhstan and Central Asia facing similar challenges of overtourism and environmental stress.

REFERENCES

[1] Eagles, P. F. J., McCool, S. F., Haynes, C. D. Sustainable Tourism in Protected Areas: Guidelines for Planning and Management. – Best Practice Protected Area Guidelines Series. No. 8. – Gland : IUCN, The World Conservation Union, 2002. – 183 p.

[2] Manning, R. E., Anderson, L. E., Pettengill, P. Managing Outdoor Recreation: Case Studies in the National Parks. – Wallingford: CABI, 2017. – 340 p.

[3] Gross, J. E., Goetz, S. J., Cihlar, J. Application of Remote Sensing to Parks and Protected Area Monitoring: Introduction to the Special Issue // Remote Sensing of Environment. – 2009. – Vol. 113. – P. 1343-1345.

[4] Goodwin, H. Overtourism: Causes, Symptoms and Treatment. – April 2019. – P. 110-114.

[5] Eagles, P. F. J., McCool, S. F., Haynes, C. D. Sustainable Tourism in Protected Areas: Guidelines for Planning and Management. – Best Practice Protected Area Guidelines Series. No. 8. – Gland: IUCN, The World Conservation Union, 2002. – 183 p.

[6] Gretzel, U. Technological Solutions to Overtourism: Potential and Limits // In: Mandić, A., Petrić, L. (eds.) Mediterranean Protected Areas in the Era of Overtourism: Challenges and Solutions. – Cham: Springer Nature, 2021. – P. 221-240.

[7] Manning, R. et al. Defining, Measuring, Monitoring, and Managing the Sustainability of Parks for Outdoor Recreation // Journal of Park and Recreation Administration. – 2011. – Vol. 29, No. 3.

[8] Burabay Biosphere Reserve // Kazakhstan National Committee of the UNESCO Program «Man and the Biosphere» (MAB). https://www.kazmab.kz/index.php/biosfernye-rezervaty1/natsionalnaya-set/burabaj/opisanie (accessed: 12.02.2025).

[9] Gandhi, M., Parthiban, S., Thummalu, A., Christy. NDVI: Vegetation Change Detection Using Remote Sensing and GIS – A Case Study of Vellore District // Procedia Computer Science. – 2015. – Vol. 57. – P. 1199-1210. – ISSN 1877-0509.

[10] Chen, X., Wang, Y., Chen, Y., Fu, S., Zhou, N. NDVI-Based Assessment of Land Degradation Trends in Balochistan, Pakistan, and Analysis of the Drivers // Remote Sensing. – 2023. – Vol. 15, No. 9. – P. 2388.

[11] Özyavuz, M., Bilgili, C., Salıcı, A. Determination of Vegetation Changes with NDVI Method // Journal of Environmental Protection and Ecology. – 2015. – Vol. 16. – P. 264-273.

[12] Robinson, N. P., Allred, B. W., Jones, M. O., Moreno, A., Kimball, J. S., Naugle, D. E., Erickson, T. A., Richardson, A. D. A Dynamic Landsat Derived Normalized Difference Vegetation Index (NDVI) Product for the Conterminous United States // Remote Sensing. – 2017. – Vol. 9, No. 8. – P. 863.

[13] McFeeters, S. K. Using the Normalized Difference Water Index (NDWI) within a Geographic Information System to Detect Swimming Pools for Mosquito Abatement: A Practical Approach // Remote Sensing. – 2013. – Vol. 5, No. 7. – P. 3544-3561.

[14] Moharir, K., Pande, C., Gautam, V., Dash, S., Mishra, A., Yadav, K., Darwish, H., Pramanik, M., Elsahabi, M. Estimation of Land Surface Temperature and LULC Changes Impact on Groundwater Resources in the Semi-Arid Region of Madhya Pradesh, India // Advances in Space Research. – 2024. – Vol. 75. – DOI: 10.1016/j.asr.2024.09.025.

[15] Abir, F. A., Ahmmed, S., Sarker, S. H., Fahim, A. U. Thermal and Ecological Assessment Based on Land Surface Temperature and Quantifying Multivariate Controlling Factors in Bogura, Bangladesh // Heliyon. – 2021. – Vol. 7, Issue 9. – e08012. – ISSN 2405-8440.

[16] Salas, E. A. L., Kumaran, S. S. Hyperspectral Bare Soil Index (HBSI): Mapping Soil Using an Ensemble of Spectral Indices in Machine Learning Environment // Land. – 2023. – Vol. 12, No. 7. – P. 1375.

[17] Nguyen, T. C., Chidthaisong, A., Kieu, D. P., Huo, L.-Z. A Modified Bare Soil Index to Identify Bare Land Features during Agricultural Fallow-Period in Southeast Asia Using Landsat 8 // Land. – 2021. – Vol. 10. – DOI: 10.3390/land10030231.

[18] Understanding NDWI – Exploring the Range and Values for Effective Water Resource Management. Farmonaut. https://farmonaut.com/remote-sensing/understanding-ndwi-exploring-the-range-and-values-for-effective-water-resource-management/ (accessed: 25.04.2025).

[19] MDPI. Sustainable Tourism Development in National Parks: Balancing Conservation and Visitor Management // Sustainability. – 2023. – Vol. 15, No. 22. – P. 15989.

[20] MDPI. Sustainable Development of Ecotourism in "Altynemel" National Park, Kazakhstan: Assessment through the Perception of Residents // Sustainability. – 2023. – Vol. 15, No. 11. – P. 8496.

[21] UNWTO. Overtourism? Understanding and Managing Urban Tourism Growth beyond Perceptions. – Madrid : World Tourism Organization, 2018. – 120 p.

А. Ш. Шәкен[1], Қ. Т. Қырғызбай*[2], А. Н. Әбубәкір[3]

[1] PhD, доцент міндетін атқарушы (Әл-Фараби атындағы Қазақ ұлттық университеті, Алматы, Қазақстан; *shakenaiman1982@gmail.com*)

[2] *PhD, аға оқытушы (Әл-Фараби атындағы Қазақ ұлттық университеті, Алматы, Қазақстан; ***kyrgyzbay.kudaibergen@gmail.com***)

[3] Магистрант (Әл-Фараби атындағы Қазақ ұлттық университеті,Алматы, Қазақстан; *aruzhana379@gmail.com*)

ҚАШЫҚТЫҚТАН ЗОНДТАУ ДЕРЕКТЕРІН ҚОЛДАНА ОТЫРЫП БУРАБАЙ МҰТП АНТРОПОГЕНДІК ЖҮКТЕМЕСІНІҢ ЭКОЛОГИЯЛЫҚ САЛДАРЫН КЕШЕНДІ БАҚЫЛАУ

Аннотация. Овертуризм көптеген ерекше қорғалатын табиғи аумақтарда өзекті мәселеге айналып, қоршаған ортаның айтарлықтай нашарлауына әкелуде. Берілген зерттеу 2020-2024 жылдар аралығындағы қашықтықтан зондтау деректерін пайдалана отырып, Бурабай Мемлекеттік Ұлттық табиғи паркіндегі овертуризмнің экологиялық салдарын талдауға арналған. Зерттеуде өсімдік жамылғысы, су ресурстары, жер бетінің температурасы, урбанизация және топырақтың деградациясының өзгеруін бағалау үшін NDVI, NDWI, LST, NDBI және BSI индекстерін пайдаланатын кешенді талдау қолданылады. Ғарыштық түсірістер экологиялық жағдайды дәл бақылауды қамтамасыз ету үшін ең аз бұлттылық және жоғары туристік ағын кезеңдерін ескере отырып таңдалды. Нәтижелер 2021-2022 жылдары NDVI мәндерінің уақытша төмендеуімен өсімдік жамылғысының айтарлықтай ауытқуын көрсетіп, 2023-2024 жылдары айтарлықтай қалпына келгендігін тіркейді. NDWI талдауы 2024 жылы ішінара қалпына келу белгілерімен су объектілерінің 2023 жылға дейін қысқарғанын көрсетеді. LST тербелістері жердің деградациясының әсерін дәлелдейді, берілген өлшемшарттар 2021-2023 жылдардағы жер бетіндегі температураның жоғарылауын көрсетеді. NDBI көрсеткішінің өсуі урбанизацияланған аумақтарды және антропогендік әсердің артқандығын айқындайды. BSI тенденциялары топырақтың деградациясының жоғарылауын көрсетеді. Талдау нәтижесінде Мемлекеттік Ұлттық табиғи паркінің аумағы жоғары, орта және аз деградация деңгейі бойынша 3-ке бөлініп, қорғаудың шұғыл шараларын қажет ететіндігін дәлелдеді. Нәтижелер Бурабай Ұлттық паркіндегі туризм мен қоршаған ортаны сақтауды теңестіретін тұрақты басқару және азайту стратегиялары туралы құнды ақпарат береді.

Түйін сөздер: қашықтықтан зондтау, Landsat 8, қоршаған ортаның деградациясы, овертуризм, мониторинг, ГАЖ.

А. Ш. Шакен[1], Қ. Т. Киргизбай*[2], А. Н. Абубакир[3]

КОМПЛЕКСНЫЙ МОНИТОРИНГ ЭКОЛОГИЧЕСКИХ ПОСЛЕДСТВИЙ ОВЕРТУРИЗМА В ГНПП «БУРАБАЙ» С ПРИМЕНЕНИЕМ ДАННЫХ ДИСТАНЦИОННОГО ЗОНДИРОВАНИЯ

[1] PhD, исполняющий обязанности доцента (Казахский национальный университет им. аль-Фараби, Алматы, Казахстан; *shakenaiman1982@gmail.com*)

[2] *PhD, старший преподаватель (Казахский национальный университет им. аль-Фараби, Алматы, Казахстан; ***kyrgyzbay.kudaibergen@gmail.com***)

[3] Магистрант (Казахский национальный университет им. аль-Фараби, Алматы, Казахстан; *aruzhana379@gmail.com*)

Аннотация. Овертуризм становится актуальной проблемой во многих охраняемых природных территориях, вызывая значительное ухудшение состояния окружающей среды. Данное исследование посвящено экологическим последствиям чрезмерного туризма в национальном парке «Бурабай» с использованием данных дистанционного зондирования с 2020 по 2024 год. В исследовании применяется многокритериальный подход с использованием индексов NDVI, NDWI, LST, NDBI и BSI для оценки изменений в растительности, водных ресурсах, температуре поверхности земли, урбанизации и деградации почв. Спутниковые снимки были отобраны с учетом минимальной облачности и периодов пикового туристического потока, чтобы обеспечить точный мониторинг экологической обстановки. Полученные данные свидетельствуют о существенных колебаниях растительного покрова с временным снижением значений NDVI в 2021-2022 годах, за которым последовало заметное восстановление в 2023-2024 годах. Анализ NDWI показывает сокращение водных объектов до 2023 года с признаками частичного восстановления в 2024 году. Колебания LST подтверждают влияние деградации земель, показывая повышение температуры поверхности в 2021-2023 годах, которая затем снизилась по мере улучшения растительного покрова. Расширение урбанизированных территорий, отраженное в росте NDBI, свидетельствует об усилении антропогенного воздействия. Тенденции BSI указывают на усиление деградации почв, особенно в 2024 году. В результате анализа национальный парк был разделен на три уровня деградации, выделив области, требующие срочных природоохранных мер. Результаты исследования дают ценную информацию об устойчивом управлении и стратегиях смягчения последствий, позволяющих сбалансировать туризм и сохранить окружающую среду в национальном парке Бурабай.

Ключевые слова: дистанционное зондирование, Landsat 8, деградация окружающей среды, овертуризм, мониторинг, ГИС.