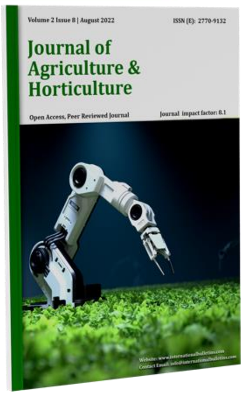

ANALYSIS OF THE DEGRADATION OF SOILS IN DESERT PASTURES USING REMOTE SENSING DATA

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Abstract. This article presents the results of a study on the analysis of the state of soil degradation distributed on desert pastures based on remote sensing data. The article also emphasizes the importance of remote sensing of soil cover in determining the relationship of soil properties and vegetation with the natural and climatic conditions of the study area. In turn, the use of vegetation indices characterizing the vegetation cover using GIS technologies in monitoring the state of pasture degradation is of great practical importance.

Keywords: desert pastures, vegetation cover, cartographic data, natural and climatic conditions of the territory, annual precipitation, sandy desert soils, degradation processes, GIS technologies.

Introduction. In the world's desert pastures, efforts are being made to assess the intensity of degradation, desertification, and drought processes; evaluate and predict changes in pasture conditions under the influence of natural and anthropogenic factors; restore degraded pasture soils; enhance pasture productivity and biodiversity; and implement effective methods for the sustainable use of pasture lands. Therefore, scientifically grounded management of the effective use of desert pasture soils is essential to improve the efficiency of cultivating fodder crops in arid regions, preserve and sustainably develop these ecosystems, ensure food security, identify lands at risk of degradation, and protect them. These are among the most pressing tasks of our time.

Currently, in our republic, comprehensive measures are being implemented to protect pastures, ensure their rational use, and widely apply resource-saving technologies for the effective utilization of pastures. These efforts also aim to prevent and combat pasture degradation processes and organize geobotanical research on pasture lands, achieving significant results. Specifically, the Development Strategy of New Uzbekistan for 2022–2026 identifies key strategic tasks, such as "...reclaiming 464,000 hectares of new and abandoned land and improving agro-services based on science and innovation."

In light of these objectives, conducting scientific research to improve the mechanisms for the effective use of pasture lands holds significant importance.

Degree of Study of the Problem: It is well known that, in the current conditions of increasing water scarcity, the rational and scientifically based use of existing desert pastures, their protection, enrichment of plant species, study of the unique characteristics of desert soils, and monitoring of pasture conditions are of great importance.

Extensive scientific research in this field has been conducted by international scientists such as G.A. Balyan, R.D. Harrison, B.L. Waldron, T.A. Monaco, M. Gamoun, B. Hanchi, M. Neffati, B.J. Esmagulova, and N.A. Tkachenko. Among Uzbek scientists, significant contributions have been made by E.V. Lobova, N.V. Kimberg, G.A. Sergeyeva, L.A. Pankov, I. Turopov, M. Mahmudov, R. Qoziyev, R. Qurvontoyev, L.A. Gafurova, G.M. Nabiyeva, M.I. Ruzmetov, N.Ch. Namozov, O.O. Davronov, and X.N. Rasulov, among others.

However, scientific studies analyzing the degradation of desert pastures using index maps, particularly in the case of the Qizilcha massif of the Nurota district, have not been sufficiently conducted.

Research Object and Methods. The research object consists of sandy-desert soils distributed in the desert pastures of the Nurota district, Navoi region. During the study, remote sensing data will be processed using specialized GIS technology tools, such as ArcGIS 10.8.1, SAS Planet, and Global Mapper. Additionally, the ENVI software will be utilized for pixel classification.

Research Results and Discussion

Today, as in all fields, we can observe the rapid development of digital technologies in agriculture. In such times, geoinformation technologies (GIS) serve as a system that aids millions of researchers worldwide across various fields. GIS can be applied in diverse areas, including the study of global issues and solving practical problems based on the analysis of results [4, 10, 11].

In recent years, observing the phenomena occurring in nature reveals that the natural and climatic conditions of our country's territory create the potential for various negative processes to emerge in the types and subtypes of soils present here. Such occurrences are often the result of irrational and purposeless use of land and water resources, as well as the failure to comply with the requirements for protecting soil cover and plant life.

Therefore, before planning soil conservation measures, it is essential to identify and assess the areas requiring such interventions. In this regard, remote sensing data, along with aerial and satellite information, which reflect the factors indicating the severity of degradation processes in different soil regions, play a critical role. These data provide scientific solutions for addressing such issues, developing and implementing various soil conservation measures, and maintaining the fertility of degraded soils.

The essence of remote soil cover studies lies in identifying the interrelationships between soil properties, vegetation cover, and the natural-climatic conditions of the studied area. It is known that the surface of the soil cover is almost always partially covered with vegetation during every season of the year. Therefore, the structure and composition of vegetation distributed in the area primarily influence the characteristics of the photovisual data obtained through remote sensing.

In this regard, using remote sensing data processed with GIS technologies and mapping their results is an effective method for studying the condition of pasture lands. This approach provides valuable insights into pasture productivity and analyzes the negative impact of external factors on pasture lands [1, 6, 12].

In our research, we utilized vegetation indices such as RAINFALL, NDVI, MSAVI, and VCI, which are widely applicable, considering their significant role in identifying and assessing the intensity of negative processes occurring in the soil cover of various regions. Our studies involved decoding multi-year (2013, 2018, 2023) and seasonal (spring, summer, autumn, winter) satellite images of these indices to evaluate trends in vegetation cover changes within the study area.

It is well known that there is a close relationship between the amount of precipitation in a region and its vegetation cover. Precipitation, such as rain and snow, serves as the primary source of moisture for the natural growth and development of plants. In turn, vegetation cover affects soil regimes and contributes to positive changes in soil properties. In this regard, precipitation-related indicators can be analyzed using the RAINFALL index.

According to the results, the region can be classified as having low precipitation availability during the 2013–2023 period. Furthermore, the use of vegetation indices, which characterize vegetation cover, in conjunction with GIS technologies, holds significant practical importance in monitoring pasture degradation. The unsatisfactory condition of vegetation cover, in turn, indicates a gradual decline in the productivity of desert pastures.

During the research, the indicative role of vegetation in the development of degradation processes in the region was also studied. The study of vegetation revealed that the extreme fluctuations in the climate characteristics of desert regions—such as excessively high air temperatures and increased evaporation rates—lead to the degradation of land resources and vegetation cover, ultimately causing drought. In this context, the NDVI (Normalized Difference Vegetation Index) is the most widely used and common vegetation index.

In the course of the research, multi-year (2013, 2018, 2023) satellite images corresponding to the NDVI index were obtained from the Landsat 8 satellite to evaluate trends in vegetation cover changes. However, NDVI calculations are often based on a series of multi-temporal (multi-seasonal) images with specific temporal resolutions. This approach enables dynamic visualizations of processes such as boundary and characteristic shifts, as well as changes in various types of vegetation (monthly, seasonal, and annual variations).

The NDVI is designed to measure the ecological and climatic characteristics of vegetation, but at the same time, it can show significant correlations with certain parameters of entirely different regions, such as productivity (temporal variations), biomass, soil moisture and mineral (organic) saturation, evapotranspiration, precipitation levels, and the strength and properties of snow cover [3, 5].

The primary advantage of NDVI is its ease of acquisition: no additional data or specialized equipment is required to calculate the index, aside from the parameters obtained from satellite research.

Focusing on the data obtained during the study, we can observe that, according to the NDVI gradation, the vegetation-covered areas in the studied region exhibit the following fluctuation indicators: in spring: from -1–0 to 0.2–0.4, in summer: from -1–0 to 0.4–0.6, in autumn: from -1–0 to 0.2–0.4, in winter: from -1–0 to 0.1–0.2.

From the above analysis, it can be concluded that the highest NDVI values for the study area were recorded in 2013. The most negative indicators were noted in 2023, during which the vegetation-covered area in the studied region showed the following fluctuation indicators according to NDVI gradation: in spring and summer: from -1–0 to 0.2–0.4, in autumn: from -1–0 to 0.1–0.2, in winter: from -1–0 to 0–0.1.

This situation can be directly linked to the region's annual average precipitation levels. According to the Rainfall Index map reflecting the annual precipitation in the area, the recorded precipitation was 190.316 mm in 2013, 164.744 mm in 2018, and 116.413 mm in 2023. This highlights that soil moisture is one of the most critical factors for plant growth. If sufficient moisture is available, it acts as a reserve for the next growing season; otherwise, plant growth slows down, and the vegetation may perish.

In this regard, it is important to emphasize that the optimal NDVI values depend on numerous external factors, including weather conditions and climate change. Clearly, NDVI is influenced by the reflective properties of low-density vegetation or bare soil underneath. The MSAVI index addresses this issue by adjusting for the optical effects of soil.

Analyzing the MSAVI index for the Qizilcha massif in 2013, it can be observed that during the spring season, 104,411.34 hectares of the total study area, accounting for 87.17% of the total land, were non-vegetated areas (bare soil), while 15,370.20 hectares, or 12.83% of the total study area, consisted of areas with very sparse vegetation cover.

Overall, the MSAVI is designed to minimize the influence of soil brightness on vegetation index values, which is particularly important in cases where vegetation cover is poorly developed or soil is visible between sparse vegetation. Another advantage of the MSAVI index is its ability to provide a more accurate assessment of vegetation conditions compared to the NDVI index, especially in areas where vegetation is poorly developed or the soil surface is not fully covered by plants [1].

Focusing on the data obtained during the research and comparing the analyzed years, the relatively optimal values of the MSAVI index correspond to 2018. According to the MSAVI index gradation, the fluctuation indicators of vegetation-covered areas in the studied region were as follows: in spring: from -1–0 to 0–0.2, in summer: from -1–0 to 0.4–0.6, in autumn: from -1–0 to 0.2–0.4, in winter: within the range of -1–0.

The most negative indicators were recorded in the summer, autumn, and winter seasons of 2023. During this period, the fluctuation indicators of vegetation-covered areas in the studied region, based on the MSAVI index gradation, were as follows: in spring: from -1–0 to 0.4–0.6, with large areas exhibiting very sparse and moderate vegetation cover.

In summer, autumn, and winter: within the range of -1–0 to 0–0.2. It is noteworthy that during these seasons, almost 99–100% of the region's area was classified as vegetation-free, indicating that vegetation was largely absent.

According to numerous literature sources, the VCI index can be used to identify drought periods, as plants typically experience stress and deteriorate in condition during droughts [2, 7, 8]. The VCI index values range between 0 and 100, reflecting such conditions. The concept of the VCI was developed by Kogan FN in the 1980s. This index, based on NDVI data, aids in drought monitoring as part of products developed by NOAA (National Oceanic and Atmospheric Administration) [9].

In turn, NDVI, MSAVI, RAINFALL, and CLAY indices serve as complementary parameters to the VCI index. Therefore, their combined use allows for a comprehensive understanding of the negative changes occurring in the research area. The VCI index, in particular, enables long-term vegetation analysis.

During our research, we analyzed the VCI index values for the Qizilcha massif for the years 2013–2023, broken down by seasons (Figure 1).

Analyzing the average values over the 10-year period, it can be observed that 28,018.82 hectares, or 23.37% of the research area, consisted of severely drought-affected lands; 85,676.10 hectares, or 71.47%, were moderately drought-affected lands; 6,056.96 hectares, or 5.05%, were minimally drought-affected lands; and only 131.70 hectares, or 0.11%, were lands unaffected by drought.

When analyzed on a yearly basis:

In 2013, only 12.67 hectares, or 0.01% of the area, were highly drought-affected lands, while 56,015.06 hectares, or 46.72%, were moderately drought-affected lands, and 1.39% were drought-free lands.

In 2018, only 2,493.16 hectares, or 2.08%, of the area were drought-free lands, whereas the largest portion, 61,989.56 hectares, or 51.71%, were drought-affected lands. Drought-free lands accounted for just 2.08% of the area.

In 2023, the largest portion of the area, 90,519.37 hectares, consisted of moderately drought-affected lands, while the smallest portion, 38.53 hectares, was highly drought-affected. Lands in very good condition (drought-free) accounted for only 1.09% of the area.

It is worth noting that throughout the observed years, the relatively largest area of land in very good condition (drought-free) was recorded in 2017, amounting to 4,779.31 hectares, or nearly 4% of the total study area.

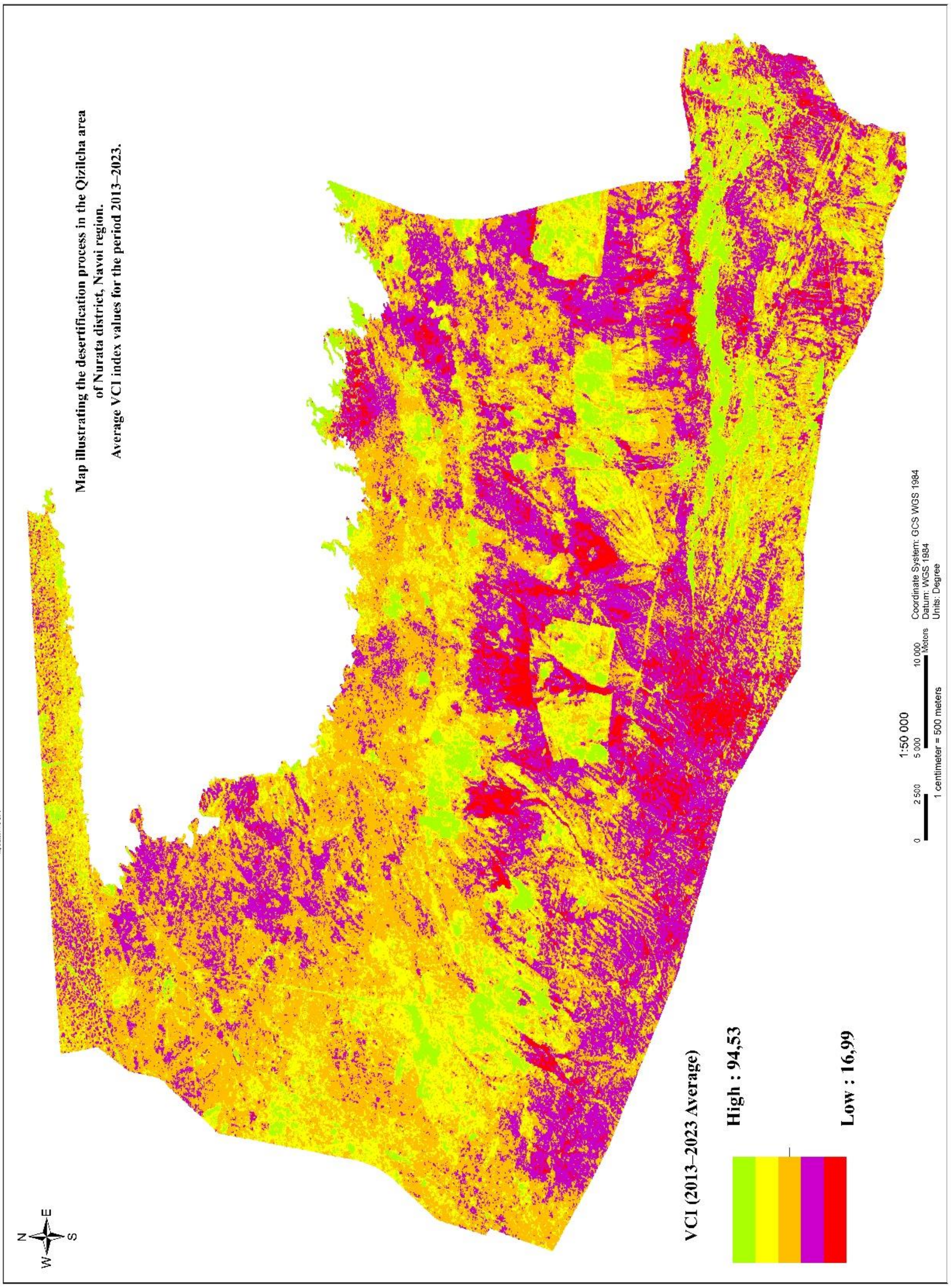

Figure 1. Average Monitoring of Vegetation Cover in the Studied Area Based on the VCI Index (2013–2023)

Conversely, the area experiencing severe stress, i.e., highly drought-affected lands, was recorded in 2018, accounting for 6,670.36 hectares or 5.56% of the total research area. To explain this, we refer to the factors influencing the VCI index, particularly the RAINFALL index, which reflects the amount of precipitation in the area. According to the data, the average annual precipitation in 2017 was 200.77 mm, while in 2018, it was 164.74 mm. Such a sharp difference in precipitation between consecutive years significantly impacted the values of the VCI index, along with NDVI and MSAVI indices.

Conclusion:

The highest values of the NDVI index for the study area were observed in 2013. The most negative values were recorded in 2023, during which the NDVI index gradation indicated that the vegetation-covered area's fluctuation ranged as follows: Spring and summer: -1–0 to 0.2–0.4, Autumn: -1–0 to 0.1–0.2, Winter: -1–0 to 0–0.1.

This situation is directly related to the average annual precipitation in the area. According to the RAINFALL index map, the annual precipitation in 2013 was 190.316 mm, decreasing to 164.744 mm in 2018, and dropping further to 116.413 mm in 2023.

The MSAVI index showed relatively optimal values in 2018. During this time, the fluctuation indicators of vegetation-covered areas ranged as follows: Spring: -1–0 to 0–0.2, Summer: -1–0 to 0.4–0.6, Autumn: -1–0 to 0.2–0.4, Winter: within -1–0.

The most negative MSAVI values were recorded during the summer, autumn, and winter seasons of 2023, during which the fluctuation indicators ranged as follows:

Spring: -1–0 to 0.4–0.6, with large areas having sparse and moderate vegetation cover. Summer, autumn, and winter: -1–0 to 0–0.2. During these periods, approximately 99–100% of the study area was classified as vegetation-free.

For the VCI index between 2013–2023, the largest area of land in excellent condition, i.e., free from drought, was recorded in 2017, amounting to 4,779.31 hectares or nearly 4% of the total study area. Conversely, the largest area under severe stress, i.e., highly drought-affected lands, was observed in 2018, amounting to 6,670.36 hectares or 5.56% of the total area. This aligns with the RAINFALL index values, where the average annual precipitation in 2017 was 200.77 mm, decreasing to 164.74 mm in 2018. Such drastic differences in precipitation between consecutive years had a significant impact on the VCI index values, along with the NDVI and MSAVI indices.

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